The Industrial Revolution
Course Guidebook
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This course, The Industrial Revolution, covers the emergence of the Industrial Revolution in 18th-century Britain and the spread of its inventions and ideas to the fledgling United States, seeking to show how and why this great modern transformation occurred. From the steam engine to the horseless carriage, the rise of the factory to the role of immigrant labor, the course provides insight not only into the historical period but also into the birth of modern life and work as we know it.
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The Industrial Revolution

Scope:

Throughout most of world history, nearly everyone has been poor, life expectancy has been short, and famine has been a frequent visitor. Today, many parts of the world are so wealthy that they regard poverty not as normal but as a special problem that ought to be eliminated. The single great cause of this increase in wealth has been industrialization. We know now beyond question that industrial societies generate wealth, which eventually spreads widely to benefit all their people, even though inequalities increase and even though the early stages of industrialization are often dirty, exploitative, and painful. No other way out of collective poverty has yet been discovered.

Britain was the first country to undertake industrialization. It began in the mid-18th century, by which time Britain had achieved political stability, acquired a colonial and commercial empire, founded banks and insurance systems, and discovered ways to increase its food output so that fewer farmers could feed more people than ever before. First in the cotton textile industry, then with improvements in coal mining, pottery manufacture, and iron smelting, new methods began to catch on, including the application of water and steam power to machinery, the concentration of large work forces in factories and mines, and the division of labor. When the economist Adam Smith wrote his classic work *An Inquiry into the Causes of the Wealth of Nations* (1776), all these processes were just getting underway. Part of Smith’s genius was to recognize that they were not of merely local significance but had potentially world-changing implications.

Industrialization also required good transport and good communications. In the late 18th century, British entrepreneurs began to build a canal system to link up the country’s navigable rivers and to connect all its major cities so that bulk goods could be carried economically between them. No sooner was the canal network complete, by about 1830, than a newer and faster technology, railways, began to displace it. Trains exploited improvements
in steam-engine technology, which had been undertaken a century earlier to pump water out of flooded coal mines; when miniaturized, this technology proved adaptable to locomotives that could achieve high speeds running on smooth metal rails.

This course of 36 lectures asks why Britain was the first country to industrialize, why the United States and many parts of Europe caught up in the 19th century, and how these changes affected the course of world history. The initiative had shifted to the United States by the later decades of the 19th century. Carnegie in steel and Rockefeller in oil built near-monopoly corporations of unprecedented size as they came to dominate entire industries. Henry Ford, borrowing from the bicycle and meat-packing industries, worked out how to mass-produce motor cars on a moving assembly line from fully interchangeable component parts. Orville and Wilbur Wright then achieved what had been regarded throughout most of world history as the impossible—they made machines capable of controlled and sustained flight.

Industrialization victimized some people even as it benefited others. This course will examine the lives of early industrial workers who suffered terrible working conditions in horribly polluted cities, frequent industrial accidents, reduced life expectancy, and the shattering of traditional ways of life. These were the conditions in which socialism drew the interest of such intellectuals as Karl Marx, who could simultaneously admire industry and deplore capitalism, the economic system to which it was linked. Industrial societies specialize in constant innovation, which can also mean constant insecurity for people trapped in its coils. Among the themes we will cover is the way industry changed the distribution of political power both within nations and between them. Warfare, once mechanized and industrialized, became more destructive and hideous than ever before, as the two world wars attested in the first half of the 20th century.

The course ends with a survey of the globalization of industry; the Asian Tigers are now catching up with their Western rivals. One lecture late in the course considers the computer revolution and the phenomenal increase in knowledge-related technologies, all of which have been accompanied by great feats of miniaturization. Another considers the environmental costs of
the Industrial Revolution. By the end of this series, you will be better placed to understand the processes that have enabled you to anticipate a long life of unprecedented comfort, surrounded by convenient devices, user-friendly technologies, and the prospect that more such conveniences will arise to help you and your descendants in the coming decades.
The Industrial Revolution, which transformed the world over the past two and a half centuries, was the most profound and beneficial event in human history since the Neolithic Revolution—the discovery some 12,000 years ago that plants and animals could be domesticated. Industrialization has created, on balance, a much safer world and one that supports larger populations with greater life expectancy than ever before. Over the course of these 36 lectures, we’ll explore how humanity has learned to make and distribute devices of increasing complexity, whose collective effect has been to make life longer, richer, safer, and more varied for us than for nearly all our predecessors on the planet.

An Anti-Traditional Phenomenon

- Beginning in the 1700s, in central England, an ingenious group of men began experimenting with the business of making things and discovered that traditional methods could be improved, accelerated, and made more efficient. Their advances began in woolen and cotton textiles but soon spread to pottery, coal mining, iron making, and transport.

- The basic insight that it was possible to make things more quickly and efficiently led to new methods of transportation and new ways those items might be sold and traded. Those insights, in turn, led to new ideas about how a society involved in such manufacturing and trading should be reorganized. The result was a new distribution of status and wealth.

- A new era of critical thinking began. Industrialization depends on the idea that tradition should not always constrain us and that careful thought can enable us to do what our ancestors never even attempted. In this sense, industrialization has immense anti-traditional implications.
By now, industrialization has been institutionalized to such a degree that we expect to see new inventions and methods introduced every year and to watch old ones fall into obsolescence. Although the process is benign overall, that doesn’t mean that everyone profits from it. The nature of social change is that it produces winners and losers. Each time a technology is made obsolete, some people may lose their livelihoods or drop out of the workforce altogether.

Still, although industrialization has caused constant upheavals and dislocations, in the long run, it has created a higher standard of living for more people than ever before, greater longevity, and greater opportunities.

The overall effect of industrialization has been liberating; in fact, democracy correlates closely with industrialization, as does the presence of mass literacy, widespread higher education, and respect for human rights.
Connotations of *Industry*

- The word *industry* tends to conjure negative associations, perhaps in part because of certain odd characteristics that we nearly all share. First, humans are capable of an incredible depth of ingratitude. Most of us never think about the debt we owe to our industrial predecessors—except when the things they gave us are suddenly taken away.
  - Think about electrical power. We’re so familiar with electricity that we never think about it when it’s working; we think about it only when it suddenly stops working. Of course, most people in world history have had to manage without electricity. We have it as part of the legacy of the Industrial Revolution.
  - The great iron and steel manufacturer Andrew Carnegie once said that capitalism was all about turning luxuries into necessities. In other words, new inventions that once caused a sensation gradually become familiar and feel normal, until we reach the point of wondering how we ever got along without them. Then, we forget how useful they are until we’re forced to do without them again.

- In addition, most of us think more about the future than the past. We take what the world gives us as our starting point.
  - The gifts of the past are present all around us and are too familiar to induce a sense of awe and wonder. The future, by contrast, is a zone of speculation where we can imagine marvelous improvements over our current condition.
  - If we do think about the past, it’s often nostalgically; we’re likely to daydream about either the simple contentment of the “good old days” or the pageantry of aristocratic life we see in costume dramas. Factories and commerce seem like intruders into that world, rather than sources of improvement.

- The third reason the Industrial Revolution has negative associations is that there is much to dislike about it. The people who brought it about were trying to make themselves rich and were rarely
motivated by a sense of benevolence toward others. Many of them were ruthless employers; the successful ones made themselves rich while leaving their employees poor.

- A long moral and literary tradition has condemned rather than celebrated the industrialist. The great novelist Charles Dickens lived in the midst of the Industrial Revolution and was unsparing in describing its ugliness, squalor, and human cost.

- In real life, John D. Rockefeller, the pioneer of the modern American oil industry, who made himself one of the richest men in the world, was widely hated as a grasping, unscrupulous monopolist who destroyed other people’s livelihoods and drove his workers hard and mercilessly.

- Industry has also caused many of the environmental problems we face today. The Industrial Revolution began by burning coal in massive quantities, then went on to burn oil in even greater amounts. As we know, extracting fossil fuels from the earth is dangerous and dirty, and burning them causes pollution.

- Finally, the Industrial Revolution made warfare much more horrific, with mass killing by means of machine guns, high-explosive bombs, and industrial gas. Worse still, it brought us nuclear weapons, the ultimate indiscriminate killing machine, capable of destroying everything.

**Embracing the Paradox**

- It might seem paradoxical to celebrate a process that shattered traditional ways of life, increased economic inequality, exploited workers, fouled the atmosphere, and exponentially increased the horrors of war. Nevertheless, the basic principle of this course is that we should embrace the paradox and be grateful for the Industrial Revolution.

- Most people in traditional societies are powerless, and the accident of birth decides irrevocably what they will do in life. These are ways of life that tend to be short, oppressive, and exhausting. To
be a hunter-gatherer or a peasant—the fate of tens of millions throughout world history—is to live a life of constant drudgery, completely devoid of choice.

• Although the inequality of industrial societies is real, it’s an inequality where the poorest are far less poor than their ancestors. It’s true that the gap between the richest and the poorest often increases with industrialization, but it’s also true that the poorest people in advanced industrial societies are in many ways richer than the richest people in a traditional society.

• It would be pointless to deny that the exploitation of industrial workers has been severe at many times and places throughout the Industrial Revolution.
  ○ The Marxists, who presented the most powerful challenge to industrial capitalism from the mid-1800s to the late 1900s, regarded exploitation as inseparable from capitalism and aimed to destroy it.
  ○ Karl Marx himself believed that as the rich got richer, the poor would get poorer until, finally, they would rise up in rebellion against the wealthy minority. What Marx was seeking was industrialization without exploitation—that is, industrialization without capitalism.
  ○ But what actually happened in the early 20th century is that the rich realized they could continue getting richer only by making the poor richer. They recognized that their capacity to make things had outstripped their pool of consumers; thus, it was necessary to turn the makers into consumers, too.
  ○ The first employer to apply this principle in a significant way was Henry Ford, who overnight raised the average worker’s pay at his auto assembly line factories from about $1.50 per day to $5. The raise kept the workers on the job and had the effect of turning them into buyers and drivers of Ford cars.
○ Some economic historians believe that one of the reasons for the severity of the Great Depression was that wages, although they had been rising rapidly in the last 20 to 30 years, had not risen fast enough to keep up with increases in output during the 1920s. In other words, wages needed to be higher still.

○ There were also widespread fears during World War II that as soon as the demand created by the war ended, depression conditions would return. With the scarcity of labor during the war, however, wages rose sharply, creating the enlarged buying power that could sustain the economy when the fighting ended.

- Environmentally, the early stages of the Industrial Revolution were filthy, with appalling levels of smog and smoke. Marx’s colleague Friedrich Engels wrote that rivers in certain parts of England were open sewers, full of human waste and industrial effluent. As late as the 1960s, American rivers were often contaminated with high levels of detergent, phosphorous compounds, oil sludge, and other effluent.

○ That’s not true today, however; the rivers of Britain and America are incomparably cleaner now than they were half a century ago, even though productivity has continued to rise. The environmental movement mobilized citizens to protest against pollution, at which point democratic governments passed legislation to restrict it and to clean up the long legacy of industrial pollution. Environmental remediation became a new entrepreneurial opportunity, and inventors hastened to supply the demand.

○ Ironically, the way to correct a problem caused by industrialization was with more industrialization. Historians recognize that there’s a close correlation between a society’s wealth and its ability to clean up the environment.

- The horribly destructive weapons made possible through industrialization remain with us. Even here, however, there are
a few offsetting factors to consider. The maturing of industrial societies has led to a steady fall in violence.

- Psychologist Steven Pinker has demonstrated convincingly that war and violence are far less common than they used to be.

- Three principal reasons for this, he says, are the rise of international commerce; the rise of the nation-state, which has advanced legal systems and a monopoly of force; and the rise of mass education, which encourages people to be more reasonable and restrained—in other words, industrial society.

- It seems reasonable, then, to claim that industrialization has created, on balance, a much safer world. It’s certainly one that supports larger populations with greater life expectancy than ever before.

**Suggested Reading**

Dickens, *Hard Times*.


**Questions to Consider**

1. Why do you think the functioning of democracy correlates so closely with industrialization?

2. Do you agree or disagree with the claim that industrialization has created a safer world?
Why Was Britain First?
Lecture 2

For a century, historians have debated what factors in British life enabled Britain to begin industrialization earlier than any other nation. In this lecture, we’ll discuss those factors, which include the growth of political stability, the development of sophisticated financial institutions, a surplus population available to work, the habits of hard work and self-discipline on which industrial life depends, intellectual notions of “human capital,” a flexible social system, and an aggressive colonial policy.

Growth of Political Stability

- Industrialization—the building and running of factories—required the investment of large sums of money over long periods of time. In Britain, the development of political stability after 1689 made investors willing to risk their money on industrial ventures.

- In the 17th century, Britain was riven by civil war, revolution, and regicide. In 1642, after an escalating series of confrontations related to where ultimate political power lay, King Charles I declared war against Parliament. Over the next four years, the royalist army and the army of Parliament clashed in a succession of sieges and pitched battles. The outcome was a victory for Parliament and defeat for the king.

- Charles I was eventually captured, tried, and executed for treason. In 1653, one of the leaders of Parliament, Oliver Cromwell became the lord protector of England and governed the nation until his death in 1658. At that time, the English aristocracy brought the former king’s son back from exile and crowned him Charles II.

- Charles II’s brother and successor, James II, antagonized the people whose support he needed and was forced to flee from England in 1688. Parliament did not repeat the mistake of attempting to govern
without a king, but it did make clear that from then on, Parliament was supreme and the king ruled on its sufferance.

- These events of 1688–1689, known as the Glorious Revolution, created conditions of political stability that have endured right up to the present, making the constitutional monarchy of Britain one of the most durable in the world.

**Emergence of Financial Institutions**

- Industrial investment was also facilitated by the development of sophisticated banking and insurance institutions. The Bank of England, established by an act of Parliament in 1694, stabilized the nation’s finances.

- The Bank of England was a joint-stock venture, capitalized at £1.2 million, that acted as banker to the government. It was able to lend at the comparatively low interest rate of eight percent. The act creating it also raised a tax on beer, ale, and vinegar, the first £100,000 of which was earmarked each year for interest payment on the national debt.

- Banknotes were introduced as the equivalent of money, and the trustworthiness of the bank enabled paper money to become serviceable in business transactions. “As safe as the Bank of England” soon became a byword, and it began to attract investment from abroad. In the 18th century, lawyers also worked out techniques to limit investors’ liability so that the risk of loss was confined to the amount they had invested—a great stimulus to economic growth.

- Economic theorists began to see the national debt as an asset, as well as a liability. Britain’s wealthiest merchants, by buying government bonds, were also investing in the future of the state and its ability to keep paying them interest and, eventually, of returning their capital. Insurance supplemented joint-stock ventures, enabling investors to hedge risks.
The stock market also began in the 1690s, in Jonathan’s Coffee House in London. Colonial ventures in sugar, tobacco, slaves, spices, and other high-value commodities all generated surplus wealth that sought reinvestment. Industrialization presupposes great concentrations of capital, and British colonial trade ventures generated it.

○ In the 1500s, British privateers, such as Francis Drake, preyed on Spanish treasure fleets. After the defeat of the Spanish Armada in 1588, Britain got involved in colonizing the Americas. Following establishment of the colonies, Britain began to participate in the slave trade—a high-risk, high-return business.

○ There was a similarly risky but profitable trade in India in high-value silks, spices, and tea. The East India Company, founded in 1600, had a monopoly on British trade beyond the Cape of Good Hope. The East India Company gradually became the key political player in India. Britain moved steadily to dominate the whole subcontinent and, eventually, to unify and rule it.

**Surplus Population**

○ Industrialization would not have been possible in Britain without a surplus population able to work in mills, mines, and factories and to create a swelling domestic market for more goods. Population rose rapidly between the mid-18th and mid-19th centuries. The population of Britain was about 5 million in 1700 and only half a million more by 1750. Then it took off; there were 8.3 million people by 1801 and 16.8 million by 1851.

○ Ironically, in 1798, Thomas Malthus cautioned that population growth always outstrips the capacity of the land to feed the people and that the result is bound to be misery, malnutrition, and vice. Malthus reasoned that population increases geometrically, whereas the food supply could only increase arithmetically. That had been true for generations, but Britain was now discovering ways to break out of this vicious circle.
• Since the late 18th century, incredible gains in population have been achieved in the industrial nations, yet people are better fed than ever before. This is one of the most astonishing achievements of the last 250 years.

• Improvements in agriculture and a climatic warming trend both helped. Nutrition improved, as did longevity. In the 1790s, Edward Jenner developed the smallpox inoculation. In the same era, bubonic plague, one of the great killers in the 14th to 17th centuries, began to disappear.

• Britain was first to experience demographic transition, which is characteristic of industrial societies. The term refers to a period of high birth and death rates, followed by a lower death rate and rapid population growth, in turn followed by a lower birth rate. The rate of increase begins to decline toward a new and much higher equilibrium point.

Work Ethic and Self-Discipline
• Industrialization was characterized by certain attitudes toward work and self-discipline, many of which had been nurtured by the Protestant Reformation.

• According to the Weber-Tawney thesis, developed in the early 20th century, the Protestant theory of predestination encouraged stern self-monitoring and a search for clues that one was among God’s chosen. The Calvinist idea of predestination led not to fatalism but to intense seriousness, sobriety, and punctuality. The idea of a calling, which was familiar in Protestant life, was the secular equivalent of the old Catholic vocation to the religious life.

• These attitudes partially replaced the older Christian idea that accumulating wealth is sinful with the idea that sober, continuous, and successful hard work is a way of doing the Lord’s work. The rise of these attitudes corresponded to industrial development in Britain, the Netherlands, northern Germany, and the United States.
• The Weber-Tawney theory that there is a connection between religion and the rise of capitalism remains controversial, partly because Protestant Scotland was much slower to industrialize than England and partly because Catholic Belgium industrialized earlier than Protestant Holland. The theory isn’t a perfect fit, but it remains noteworthy.

• A strikingly large number of the great industrial entrepreneurs of the late 18th century were Nonconformists (Quakers, Presbyterians, Congregationalists, Baptists, and Unitarians). That is, they refused to conform to the state Church of England and insisted on remaining outside it, despite civil penalties. Nonconformists were excluded from the old universities and could not be army officers or magistrates, but they were not barred from any economic activity.

“Human Capital” and Flexibility in Social Systems

• Industrialization also presupposes the existence of “human capital”; an interest in science, technology, and innovation; a willingness to experiment; and a belief that the future might be different from, and better than, the past.
  ○ Fatalism has been an incredibly powerful source of inertia throughout human history. Industrialization defied the idea that the future

Wind and water power had been used for centuries, but after 1800, they began to be operated in new and more effective ways to speed up the processes of manufacturing.
is bound to be the same as the past and insisted that it can be different and better.

- Generations of intellectual innovators, such as Robert Boyle, John Locke, and Isaac Newton, along with the Royal Society (founded in 1660), led to increasing secularization of scientific knowledge. In the 17th and early 18th centuries, there was a sharp split between science, considered a gentleman’s activity, and technology, the province of mechanics and tinkerers. After 1800, these two disciplines came together, ensuring that the secularization of science would continue.

- Flexibility among the elite and political sympathy for economic growth were also essential to the rise of industrialism.
  - In 18th-century Britain, members of the aristocracy were already interested in coal mining on their lands and in agricultural improvement. By contrast, many of the European aristocracies regarded work as dishonorable or were far more preoccupied with war and disdained economic activity.
  - Although British aristocrats tended to look down on commercial activities, when they saw a great opportunity or when the burden of their debts embarrassed them, they did, in fact, seize the opportunity to restore their estates.

Aggressive Colonial Policy
- In the 18th century, the British government also supported an aggressive colonial policy. Britain conducted five immense wars during this period and emerged on the winning side in four of them, losing only the American Revolutionary War. British success led to overwhelming naval dominance.

- The Royal Navy actively supported merchant navy and colonial trade ventures. That, in turn, created the ideal support for British manufacturers, especially of textiles, to sell abroad, capturing foreign markets and expanding them rapidly. British mercantile policy also made sure that Britain’s colonies served British interests.
- The Navigation Acts, which would later be a grievance to American colonists, specified that all trade with Britain and its colonies must be in British ships and that all colonial imports and exports must pass through Britain en route to their ultimate destinations. These laws played a significant role in nurturing an unparalleled British merchant marine.

### Suggested Reading

Deane, *The First Industrial Revolution*.


Lane, *The Industrial Revolution*.


### Questions to Consider

1. How did Britain’s vigorous colonial and commercial policies contribute to its eventual industrialization?

2. What factors contributed to Britain’s extraordinary political stability after the Glorious Revolution?
The Agricultural Revolution
Lecture 3

British agriculture became increasingly productive in the century after 1700, freeing up thousands of people to leave the land and move into manufacturing work. A combination of factors made these improvements possible, including new forms of land tenure and use, enhanced crops, improvements in animal breeding, and innovations in farm machinery. Some historians call these processes, collectively, the Agricultural Revolution. Population was growing rapidly after 1750, but food production more than kept pace, so that the ancient specter of famine receded ever farther into the distance.

The Shift to Enclosure

- The shift from the traditional open-field system to enclosure was a necessary first step for the Agricultural Revolution in Britain. Traditionally, open fields had been broken into strips, on which different farmers grew their own crops side by side. The system was inefficient because each farmer’s strips of land were scattered. Diligent farmers were at the mercy of lazy ones whose land sprouted weeds. The unfenced common land in the village was open to all, for wood gathering and the grazing of sheep, pigs, cows, and geese.

- Enclosure was the consolidation of these strips into single fields that could then be fenced. Enclosure had begun in the Tudor era, continued through the 17\textsuperscript{th} century, and accelerated in the 18\textsuperscript{th} century.

- The usual method was for the major local landowners to introduce a bill into Parliament for enclosure of the village. Lands would be surveyed and then shared out in consolidated parcels to all who had legal title to them. Wealthier farmers gained from this process, whereas landless men, denied their ancient commons rights, were the losers.
• Holders of traditional rights to graze or collect firewood on common land or to live in cottages on the common often found that if they could not document these traditions, they would be excluded. At that point, they either left the land completely, becoming part of the first generation of industrial workers, or became landless farm laborers.

Increases in Cultivated Land
• The enclosure and farming of previously common land increased the total volume of land under cultivation, while the average size of farms also grew. Average farm size increased from about 65 acres of scattered land in 1700 to a concentrated farm area of about 150 acres in certain counties.

• The total amount of land under cultivation went up from 21 million acres in 1700 to about 29 million in 1800. Wasteland was cleared and seeded, often for the first time. Swamplands were drained to create fertile new farmland.

• A common pattern by 1800 was that tenant farmers rented from large landowners, while themselves hiring landless farm laborers—a three-tiered rural population. Increasingly, rural laborers were men as the number of women and children doing farm work declined.

• Farming gradually shifted from subsistence to a market orientation. As growing numbers of British people made their living from nonfarm activities, farmers concentrated on looking for profitable ways to grow the food needed by others.

• In the 1720s, Daniel Defoe noted the beginning of what we now call sales in farm produce futures. Although Defoe suspected that farmers were being defrauded, this development suggests the maturation of a business model that offered farmers cash or credit at times other than once a year when the harvest went to market.

Enhancements in Crop Yields
• New crops and new forms of rotation led to increases in productivity. Ever since the discovery of America, new food crops
had become available to supplement the traditional wheat, oats, barley, and vegetables of the English diet.

- Potatoes were among the most important of these new crops. Potatoes provide three or four times as much nutrition per acre as cereal crops, as well as vitamin C. They were vital to the Irish food supply (where population was growing quickly) but less so in England, where they were regarded as poor people’s food.

- The introduction of root crops, such as turnips, rutabagas, and field beets, and of clover increased the food supply for people and animals and had a beneficial nitrogen-fixing effect. A system of growing clover and turnips instead of leaving fields fallow was introduced from the Netherlands in the mid-1600s and caught on throughout much of England. Clover, in particular, was highly effective in maintaining nitrogen levels in the soil.

- “Turnip” Townshend (1674–1738), a politician and aristocrat interested in agricultural improvements, was a pioneer of this method. He established the four-year crop rotation in this sequence: wheat, turnips, barley, clover. The clover and turnips were used as animal fodder, which increased the farm’s production of manure that could itself be used on the fields to improve fertility.

- At this time, farmers were also learning to set aside grains from the strongest and most disease-resistant plants as seeds for the following year—an early form of selective farming that led to yield increases.

**Improvements in Animal Breeding**

- Fencing facilitated improvements in animal breeding. Although we take fences, walls, and hedges entirely for granted, they had important effects by demarcating land, keeping animals off cropland, and making selective breeding effective. Breeders began to cultivate animals for specific characteristics—notably, sheep for wool and meat and cows for milk, leather, and meat.
The best of the breeders was Robert Bakewell (1725–1795), who created the New Leicester sheep breed, which was made to grow rapidly, producing tasty mutton. Bakewell also joined up with Robert Fowler to produce a fast-growing cow that was ideal for beef production. Another sheep breeder, John Ellman, bred the Southdown sheep, which produced wool that was easy to card and spin.

By 1850, British cows and sheep were completely different—stronger and more useful than their predecessors of the 1700s. Farmers replaced oxen with bigger, stronger, and faster horses as their principal draft animals.

**Innovations in Farm Machinery**

Early mechanization of farming also increased productivity. Seed drills improved the regularity of plant distribution in fields. The traditional method was *broadcasting*, but it was deficient in even distribution and depth and vulnerable to birds and other scavengers.

Darwin's arguments concerning natural selection were based in part on the process of domestic selection, that is, the modification of animals to better meet human needs.
• The seed drill was invented by an eccentric farmer and theorist, Jethro Tull (1674–1741), a contemporary of “Turnip” Townshend. Tull’s seed drill, invented in 1701, was an important advance. It ensured even distribution of seeds and depth of planting and reduced losses to scavengers.

• Better plows, made from more durable iron and steel, also enhanced productivity. First was the Rotherham plow, introduced from Holland, that had a hard metallic plowshare that remained sharp with frequent use.

Rural Leaders

• A group of prominent rural leaders undertook systematic improvement of their estates, demonstrated the economic benefits that could ensue, and enjoyed the favorable notice of influential writers.

• Thomas William Coke of Holkham (1754–1842), a British politician, owned large and prosperous estates and ran a model farm, experimenting with best practices and encouraging information sharing. For about 40 consecutive years, he invited farmers from all over the country to his estates—in effect, introducing the world’s first agricultural show. He also determined that differences in soil in selected areas would affect the usefulness of innovations.

• Arthur Young (1741–1820) was a farmer and regular writer on farming, producing 25 books on the topic during his life, beginning in late 1760s. His well-written works were widely translated and admired across Enlightenment Europe.
   ○ Young hated wastefulness and believed that far better use could be made out of land than was currently the case. He also voiced the Enlightenment notion that God or divine providence had created a universal abundance that just needed human energy to be realized.
   ○ Young understood the absolute centrality of security of tenure. One of his proposed reforms was to make farmers more
confident that the land they rented would remain theirs or, ideally, that they’d be in a position to buy it.

- He published *The Farmer’s Kalendar* in 1770, a month-by-month account of jobs the diligent farmer needed to do to prosper. He founded the *Annals of Agriculture* in 1784, which eventually ran to 46 annual volumes.


  - William Marshall (1745–1818) was Young’s greatest critic. While Young toured the country and chatted with locals to get a sense of farm conditions, Marshall believed one had to farm an area for a few years before being able to discuss it with any authority. Marshall worked as a farm manager in several British regions and wrote a 12-volume account of British agriculture, published in 1798.

  - Historians still find both Marshall and Young useful as they struggle to piece together the state of farming life in the late 1700s and early 1800s and to determine why farming became so much more productive at the time.

**The Irish Experience**

- The English experience diverged sharply from that of Ireland in the 18th and 19th centuries. England had developed a widely diversified agricultural sector. By the early 1800s, farmers were capitalists, eager to maximize profit from their lands, interacting with a large urban population, and able, in ordinary years, to meet demand even though population was rising.

- Ireland, by contrast, concentrated on one crop, potatoes, and thus, was caught in the catastrophe of the 1846 famine, which may have
led to as many as a million deaths and resulted in the emigration of another million people.

- After some hard harvest years in the 1760s and a very bad year in 1816, England never again suffered from famine. In the long run, ironically, England did not continue to feed itself, coming in the late 19th century to rely increasingly on food imports. That strategy was acceptable most of the time, but it also had a perilous side, as the blockades of the two world wars made clear.

**Suggested Reading**

Kerridge, *The Agricultural Revolution*.

Mingay, *Arthur Young and His Times*.

Overton, *Agricultural Revolution in England*.


**Questions to Consider**

1. How did the development of scientific ideas contribute to improvements in British farming?

2. Which was more important to increases in British farm output: climate change, crop rotations, or new forms of land tenure?
By 1700, Britain already possessed a large urban population—not only in London, by far the single largest city, but also in several provincial towns. Britain was more urbanized than France and was rivaled only by the Netherlands and parts of urban northern Italy. Small-scale manufacturing of textiles, metal goods, and glassware; carpentry; and thriving brewing and distilling businesses had built up strong and distinctive trade traditions.

London

- It is no coincidence that nearly all major cities are coastal or on navigable rivers. At a time when water was the best means of transport, major cities historically were centered on route centers and ports.

- London, a city since the Roman era, was already a magnet to people from the English countryside. In the early 1700s, it was home to about 750,000 people—perhaps 15 percent of the entire population of Britain. Its sheer size made it an immense market, transforming the lands around it into farms to feed the townspeople and stimulating enterprise in the city to fulfill their needs.

- London was dangerous in many ways, however. With the city’s many wooden structures, fire was a constant danger, especially given that heating, lighting, and cooking all depended on open flames. The Great Fire of London, in 1666, was one of the most notorious catastrophes in British history, destroying 13,200 houses and 87 churches.

- Rebuilding was itself an immense job and a tremendous economic stimulus. Christopher Wren’s St. Paul’s Cathedral is probably the best remembered post-fire structure. Following the fire, the London government began to regulate the width of streets, the use of brick
or stone in construction rather than wood, and roofing with tiles instead of thatch.

- Other dangers included poor diet, adulterated food, and contaminated water. Indeed, in the late 17th and early 18th centuries, more people died in London than were born there. Although the city was economically attractive, it was the perfect breeding ground for epidemics. Plague was less common after the 1660s, but the city was still swept regularly by smallpox and typhus. In the early 19th century, cholera would add a new horror.

**A Center of Trade**

- Along with these drawbacks, London had many assets. The royal court was centered there, and around the court developed the *London season*. Wealthy gentry and aristocracy spent the winter
and spring in London. Their presence stimulated luxury goods trades, such as watchmaking, jewelry making, stationers, coach making, cabinetry, and dressmaking. The aspiring middle classes, too, become urban consumers. London was a magnet to immigrants fleeing persecution abroad, such as the French Huguenots, many of whom brought their skills to the city, chiefly in the silk industry.

- Work in London was traditionally controlled by the old guilds, many dating back to the medieval era. But as the city grew rapidly outward and as new kinds of work arose, it became increasingly difficult for the guilds to keep a grip. They had grown out of an era of relative economic stability rather than sustained growth. New forms of work now arose. In a list from 1747, 215 different occupations were noted, but 50 years later, the list had expanded to 492, most of which were not regulated by guilds.

- London was also the center of colonial trade and colonial-related trades, such as tobacco processing and sugar refining. It was the headquarters of the monopoly companies that dominated Britain’s empire: the Merchant-Adventurers, which held a monopoly on English textile trade in Europe; the Levant Company, with monopoly rights to the Ottoman Empire; the East India Company, the exclusive European trader in India; and Muscovy Company, trading with Russia.

- London dockyards thrived, with wharves on both banks of the Thames below London Bridge. Ships brought wares from around the country and around the world. The Navigation Acts specified that anything made in one of Britain’s colonies had to be shipped to Britain first, then re-exported. These regulations were a source of grievance to the American colonies but a great stimulus to shipbuilding and ancillary trades in London.

**Provincial Towns**

- In early-18th-century Britain, no other provincial town or city had even 50,000 people. The next largest rank of towns included Bristol, Edinburgh, Norwich, York, Exeter, and Newcastle. All were either
ports or administrative centers with a smaller farming hinterland. Bristol, Liverpool, and Glasgow were port cities facing the Atlantic that grew prosperous through colonial trade in slaves, tea, tobacco, and sugar.

- Next in size were such towns as Birmingham in the Midlands. Birmingham produced metal goods, such as nails, buckles, buttons, knives, saddlers’ ironmongery, and brassware. These goods were called “toys,” and Birmingham was nicknamed “the toyshop of Europe.” It was also the center of gun making.

- There was a distinctive attitude to business evident in the towns and cities. When young William Hutton first went to Birmingham in 1741, he was instantly aware of the difference between this thriving provincial manufacturing town (with a population of about 20,000) and the countryside where he had grown up. Hutton wrote: “I was surprised at the place, but more at the people. … They possessed a vivacity I had never beheld.”

- Provincial towns were usually built around a central marketplace. On designated market days, farmers and craftspeople would gather in the town marketplace to sell their goods. The marketplace also served a labor exchange function.

- The 18th century also witnessed the growth of shops in provincial towns. Shops, which we take for granted, were once a novelty—places where particular goods were sold away from the places where they were made. Quaker shopkeepers pioneered the idea of having fixed shop prices instead of the tradition of haggling.

- Observers also noticed new towns springing up around one particular type of business. For example, Sheffield specialized in the cutlery trade, Burton-on-Trent specialized in beer, and St. Helens specialized in glass. Specialization was possible only when a town intended to supply a wider area—such as London—beyond the immediate market.
- Although the transport system was poor—and the Industrial Revolution would be greatly stimulated by its improvement—already in the early 1700s, goods were moving in large quantities not only by sea and river but also by wagon and packhorse.

**The Guild System**
- The guild system in many provincial towns regulated access to most of the important trades, many of which restricted membership to families that had been in a particular business for generations. The guilds also fixed prices and regulated quality control.

- Under the guild system, a young man would become an apprentice, often going to live in the household of a master craftsman. Often, the young apprentice’s family would have to pay the master craftsman to take him on. Like female live-in servants, an apprentice was forbidden to marry. The system was subject to abuse, and apprentices could find themselves working as unpaid servants with no rights.

- When his apprenticeship was complete, the apprentice became a journeyman. The word is derived from the French *journée*, meaning “day.” Journeymen were paid by the day.

- Journeymen could hope to accumulate enough experience and funds to become master craftsmen in their own right. This was a realistic expectation for blacksmiths, weavers, pin makers, wheelwrights, thatchers, glaziers, and coopers. However, there were other industries already growing too large in scale for that to be a common path, such as shipbuilders, breweries, and tanneries.

**The 18th-Century Workplace**
- A common pattern in the provincial towns was for businesses to be grouped together by type—for example, all the wheelwrights on the same street, all the butchers, all the candle makers, and so on. Work was regulated as much by daylight as by the clock, with craftsmen expecting to work longer hours in summer than in winter.
• In many workplaces, alcohol flowed freely, especially when safe drinking water was difficult or impossible to find. Beer making was already a big business, not least because it was actually less harmful to one’s health in many areas to drink beer than to drink water. Urban water supplies were especially dangerous because wells were often contaminated by their proximity to cesspools. Rivers were also dumps for tanneries, dye works, and other polluting trades.

• Also common in the 18th century was the distilling of gin. However, gin contributed to poor health and premature death, and it was hard to regulate, often contaminated with turpentine. Generations of working people drank away their pay rather than struggle to get ahead.

• This was the fabric of social life that the first industrialists had to combat: trying to find ways to get people to work regular hours, by the clock and not the seasons, and to be sober throughout the working day. London businessmen were the first to push employees to work beyond daylight hours. A 1747 book called *London Tradesmen* describes workshops lit by lamps and candles, with work continuing after dark, especially in winter.

**Combating Fatalism**

• The first industrialists also had to overcome the workers’ ancient sense of fatalism and instill the idea of progress and economic growth. They were materialists who needed others to share their sense that it was possible and desirable to gain wealth.

• Nevertheless, there was a constant drumbeat of criticism, not only from workers, who preferred the older, slower pace, but also from church leaders, who feared cities as centers of vice, luxury, and atheism. For example, in 1777, the bishop of Chester preached that a recent earthquake was God’s warning to the cities of Manchester and Macclesfield.

• When we look back at the late 18th century, we’re so impressed with the increased pace of economic activity that it’s difficult to remember that it took place in the face of widespread skepticism that
such improvement was possible. The changes required a radically new idea about the possibility of progress and of transforming the world as it was into something different and better.

• On the other hand, in those decades, fatalism, great though it was in Britain, was less prevalent there than almost anywhere else—a fact that helps explain the great transformation to the Industrial Revolution.

Suggested Reading

Borsay, *The English Urban Renaissance*.


Questions to Consider

1. How does the sheer proximity of large groups of people stimulate innovation and inventiveness?

2. Why were all of Britain’s important preindustrial cities also ports?
The Royal Shipyards
Lecture 5

Shipbuilding was one of the first industries to bring together large numbers of men to undertake complicated precision work. When we look at ships from the 1600s—such as the *Mayflower*—and those from the early 1700s, we’re astonished that something so small could cross the Atlantic Ocean. But for their time, these ships were amazingly large and complex; in essence, they were floating towns that could keep several hundred people alive for months at a time away from land. Making, maintaining, and running them stimulated many new manufacturing methods. Historians point out that ships at sea anticipated what factories would be later and that many of the techniques of industrial discipline can be found first in nautical discipline.

**Anticipating Industrialization**

- Many of the methods of organizing work and many of the logistical principles that would become common in the factories of the 1700s were pioneered in shipbuilding, especially for the Royal Navy, starting in the late 1600s.

- The shipyards of the Royal Navy created the large-scale organization of work, materials, logistics, and complex construction that would be characteristic of later factory-era industrialization and pioneered many of these methods in a nation still using techniques that were slow, labor intensive, tradition bound, and based on organic materials.

- What is so striking to us now is that the shipyards were successful in an era of poor internal communications and preindustrial work traditions. By later standards, the Royal Navy shipyards were nightmarishly inefficient, but by the standards of their own time, they made crucial organizational advances.

- Already before 1700, the Chatham naval shipyards near London employed more than 800 people, at a time when most manufacturing
was done in the workshop system or by a master craftsman with one or two journeymen and apprentices.

- Shipyards pioneered the bulk ordering of raw materials (wood, rope, barrel hoops and staves, and cannons) and refined logistics and materials flow. The industry also gave rise to ancillary businesses, an arrangement that would later be common in industrial towns.

- The only group with sufficient capital to maintain operations on this scale was the government, which ran the yards and was reluctant to contract out to private companies. Historians know much about the shipbuilding industry because the Royal Navy kept good records and because we have such valuable documents as Samuel Pepys’s diary from the 1660s and 1670s.
  - Pepys became chief clerk of the Navy Board after the Restoration of 1660 and rose to be chief secretary to the Admiralty in the 1670s.
  - Pepys doubted that the Royal Navy dockyards were being run as efficiently as they could be. He was discouraged by indifference over quality control, was eager to create systematic methods, and deplored slavish reliance on tradition.

The Process of Shipbuilding

- The Company of Shipwrights, one of the guilds that restricted entry into the shipyards, was founded in 1605. Its apprenticeship system limited who got jobs, often a privilege that descended through families. These jobs were highly coveted because they were secure and paid well. The guild listed 26 distinct jobs—many of them eccentric—including rat killer, keeper of the clock, keeper of the plugs, scavelmen, and treenail mooters.

- The only power source available in the shipyards was provided by draft animals, mainly horses, but most of the work was simply done by men using muscle power. Jobs that are easy today with power tools were painfully slow. Sawing through pieces of oak, for example, required a two-man saw and the use of a saw pit.
• Ships of the line required enormous quantities of materials and were tremendously expensive. They had to be strong enough to bear the weight of their cannons and to endure the recoil of a broadside but also streamlined enough to make good progress in pursuit of other ships or in fleet movements. They had to be stable enough so that a quantity of guns could be placed well above the waterline for more versatility and to obviate flooding danger.

• When a ship was being made, paper plans were first drawn up at the scale of 1 to 48. Once the plans were agreed upon, full-size templates of the various components were made out of thin and relatively light fir wood. They would then be copied in oak by the ship’s carpenters. A first-rate ship of the line would use the timber from 100 acres of land, about 4,000 mature trees.
  ○ English oaks grow very slowly, reaching full maturity only after more than 100 years. Previous deforestation of Britain meant that much of the timber for ships had to come from abroad, especially from the Baltic lands.
  ○ One of the many benefits of developing colonies in America was that wood for masts could come from New Hampshire and Maine instead. Builders were delighted by the high quality of American wood.

• Certain parts of a ship’s frame had to be made from oak trees whose trunk had divided into massive limbs along certain angles. These were the angled pieces that attached keel to sternpost and ribs to deck beams. The grain of the wood had to flow properly to ensure the strength of the frame.

• Careful forestry over the centuries had taught people how to make trees split at certain angles and certain heights or how not to. Even so, those who cut trees for the Royal Navy were aware of 65 possible defects that could make wood unsuitable.

• Oak cut in winter had a reputation of being less liable to rot than that cut in summer, but all wood had to be seasoned for a few years
before actually being used in construction. Seasoning prevented warping and helped make ships strong enough to absorb enemy broadsides and to be able to stay at sea for months.

- The Royal Navy sent out surveyors to identify ideal trees and reserve them with distinctive marks: the broad arrow. By the late 1600s, this was a slow, tedious business, and master builders had to scrounge wood from all over the country. There were severe penalties for cutting a tree with the broad arrow marked on it.

- A first-rate ship of the line could take 10 years to complete. The danger was that it would begin to rot even before completion.

A Complex Operation
- The head of the shipbuilding operation was a master shipwright, who relied on drawings, models, tradition, and rule of thumb. The shipwright chose the essential pieces of wood for the keel and ribs of the ship.

- Also important were the block makers, who created the blocks through which ropes were drawn to raise and lower sails. Caulkers, pitch heaters, oakum boys, smiths, joiners, carpenters, wheelwrights, plumbers, bricklayers, sail makers, and even gilders, who decorated the stern and the cabin, all worked in the same place.

There was relatively little change in ship design from the early 1600s through the early 1800s, although sizes increased, as did the number of ships.
• Shipyards would have a mast house, often more than 100 feet long, where the masts, made of several pieces of fir wood, could be assembled before fitting to ships. The logs were kept in mast ponds, underwater, until assembled, to prevent them from drying and splitting.

• Sail makers also required a great deal of space where the canvas could be laid out, cut to size, and stitched. Canvas was used for sails, boat covers, tarpaulins, and even sailors’ clothes.

• Even larger were the rope houses, which were up to 1,000 feet long so that rope could be made indoors, protected from the rain.
  ○ To make rope, hemp was imported in bulk, mainly from the Baltic. Hemp fibers were dragged across spiked boards to disentangle the fibers. Spinners would then attach the ends to a turning wheel and walk along the rope house, carrying bundles of the fibers and twisting them into yarn. Then, a bundle of 400 yarns would be tarred for weatherproofing. Tar was imported at first from the Baltic and, later, from the Carolinas.
  ○ After drying, the yarns would then be woven together into thick rope. Depending on its intended use, rope could be up to 24 inches thick. Making an anchor cable of 24-inch diameter rope would require the labor of 200 people.
  ○ A first-rate ship of the line required huge quantities of rope for many uses—often more than 100,000 feet in all. Rope needed to be replaced frequently, as did the sails.
  ○ The smithery, or dockyard blacksmith’s shop, made anchors, the single biggest preindustrial metal objects, often weighing two tons or more. Smitheries also made links of anchor chain, bolts for main timbers of the ship, and iron bands to hold mast sections together. Guns were made from bronze, an alloy of copper and tin, or from iron.
Preindustrial Methods and Materials

- One of the clearest ways we can describe this process of shipbuilding is preindustrial. The materials used were primarily organic—wood for the timbers of the ship and flax for the rope and canvas sails. These materials were produced by slow rural processes, with long periods of growing and seasoning.
  - Not only was wood hard to find by the 1700s, but it was also difficult to transport over long distances, when roads were poor and there were no canals or railways.
  - Further, everything was susceptible to rot and decay, and there was the chronic problem of boring creatures damaging hulls and seaweed and crustaceans attaching to hulls and slowing the ships down.
  - Historians have shown that even with good maintenance and major refits, a fighting ship could rarely be kept going longer than 20 years; replacement was required not because the design was obsolete but because the ship was made of organic materials that were decaying.
  - In 1761 came the first experiment with copper sheathing of hulls. This method was successful and became universal in the Royal Navy fleet in the early 1780s. Use of copper sheathing meant that ships could stay at sea for two years instead of the previous four months before coming in to dry dock for hull repairs.

- Although there were constant laments from Pepys about corruption, waste, pilfering, and incompetence, in fact, Royal Navy ships usually held their own in long blockade service and in battle. In the great sea battles of the 1700s and early 1800s, English ships, though they burned or were dismasted by enemy fire, hardly ever sank. French ships had the edge in grace of design and were slightly more innovative, but British ships had superior solidity and durability under fire.
• The Royal Navy shipyards created the large-scale organization of work, materials, logistics, and complex construction that would be characteristic of later factory-era industrialization. Even more impressive, the shipyards pioneered many of these methods in a nation still using techniques that were slow, labor-intensive, tradition-bound, and dependent on organic materials.

Suggested Reading

Coad, *Historic Architecture of the Royal Navy.*

———, *The Royal Dockyards, 1690–1850.*

Coote, *Samuel Pepys.*

Dodds and Moore, *Building the Wooden Fighting Ship.*

Questions to Consider

1. In what ways were the Royal Navy shipyards like an industrial enterprise and in what ways were they still preindustrial?

2. How successfully did the navy balance the various requirements of making effective fighting ships?
For centuries, Britain had a thriving domestic and export trade in woolen cloth. In the late 18th century, a group of entrepreneurs invented machines to spin thread and weave cotton cloth, then built some of the world’s first factories to house them. The invention of the cotton gin in 1793 enabled American planters to grow cotton in bulk, most of which was shipped to Liverpool. Key advancements realized by the textile industry included the gathering of workers into the same place to work under close supervision; the invention of machines that could work faster and more consistently than hand workers; the application of power sources to those machines; and the development of huge domestic and foreign markets.

The Early Textile Trade

- For centuries, the clothing trade in wool in Britain had been a small-scale domestic industry, often practiced by farming families. Clothiers took raw wool to families and collected their finished cloth at the end of each week. Women usually carded the raw wool and spun thread, while men wove cloth on hand looms.

- Surplus broadcloth, the kind of woolen cloth that was being made, was exported to Antwerp in the Netherlands by the Merchant Adventurers’ Company. This was a steadily expanding trade, and it was open to competition after 1690.

- The county of Lancashire in the northwest and the regions around Liverpool and Manchester became cotton-producing areas, using imported cotton from India and the West Indies. The clothiers were small-scale capitalists long before the first textile machines arrived, and the area had a fund of workers who were familiar with carding, spinning, and weaving.

- Cotton cloth being imported from India was called *calico*. Women liked the cloth because it was light, it could be printed in bright
colors, and it enabled them to adopt new fashions, but domestic textile manufacturers persuaded Parliament to ban calico in 1700, fearing that the competition would undermine their livelihoods. The ban on cotton imports wasn’t repealed until 1774.

- In the early 1700s, certain experiments raised the possibility that textile manufacturing might be centralized and mechanized. The Lombe brothers’ silk mill in Derby is often regarded as the world’s first water-powered factory. It profitably employed 300 workers, making silk thread for weavers.

- Silk was a luxury item, however; mass production would take off in cotton and wool manufacturing, where demand was potentially much greater.

**Weaving and Spinning Machines**

- An early attempt to make a weaving machine was John Kay’s *flying shuttle*, developed in 1733. It worked at twice the speed of a conventional loom.

- Weaving became far faster than spinning, which remained the bottleneck in the production process. The first practical spinning machine was James Hargreaves’s *spinning jenny*. Hargreaves saw a way to increase the output of the spinning wheel from one spindle at a time to six or eight. His device was patented in 1764.

- Richard Arkwright improved on the spinning jenny and created the *water frame*, which could spin strong cotton yarn. Arkwright built a factory at Cromford, in Derbyshire, where the fast-flowing Derwent River could turn waterwheels linked to the spinning machines. He installed overshot waterwheels, which were far more efficient than the traditional undershot wheel.

- Although hand spinners could make about 20 hanks to the pound, Arkwright’s factory could produce 60 hanks to the pound—much finer yarn to make smoother and thinner fabric. Arkwright
also mechanized other stages of the process—cleaning, carding, drawing, and roving—that preceded spinning.

- Inventor Samuel Crompton created a hybrid machine called the *mule* in the late 1770s that could produce 300 hanks to the pound—incomparably finer than any yarn seen before and strong, as well. One mule could contain 1,000 spindles; watched by just two or three people, this device could do the same work that previously required dozens or even hundreds of people at spinning wheels. Mules remained the basic spinning machines into the 20th century.

**Growing Demand for Textiles**

- The overpowering superiority of machine spinning rapidly drove hand spinners out of business. Early manufacturers encountered severe resistance from local people, who were afraid that machines would destroy traditional ways of life and work. Modern economists are familiar with the concept of economic growth and rising productivity, but at this time, workers believed that a machine five times as efficient would put four out of every five workers out of a job.

- A rash of machine-breaking riots took place in 1779. Parliament investigated machine-breakers’ complaints but concluded that a lucrative new industry was springing up with far more benefits than harm and that traditional ways would have to yield. Former cottage workers must now move to factory jobs. The nation was beginning to adapt to the concept of government support for economic growth.

- As it turned out, the demand would continue to grow, absorbing labor that had been threatened by mechanization. From the late 18th century to the late 19th century, Britain exported a huge percentage of its cotton textiles to Europe, the United States, and more often, to captive colonial markets in Africa, India, and the West Indies. In this era, productivity rose rapidly, quality improved equally rapidly, and prices continued to decrease. By the 1820s, half of all Britain’s exports, by value, were cotton goods.
New technologies were complemented by American Eli Whitney’s invention of the cotton gin in 1793, which facilitated the massive growth of plantation cotton. The American cotton crop increased from 2 million pounds in 1791 to 182 million in 1821.

The Fortunes of Hand-Loom Weavers

- Between 1770 and 1810, as spinning technology improved, there was a heightened demand for hand-loom weavers. They were often gathered together in workshops but continued to work individually—a halfway stage to the integrated factory.

- In the 1790s, William Radcliffe employed about 1,000 hand-loom weavers and was always on the lookout for more. These years would be remembered later as the golden age of the hand-loom weavers.

- Once weaving technology caught up in the 1810s, however, the hand-loom weavers’ trade went into a long decline. A famous example is the family of Andrew Carnegie, who left Scotland, penniless, to try their luck in America. Hand-loom weavers lacked the capital to shift over to the far more expensive power looms.

Employment Conditions

- The cotton spinners were pioneers of factories as social systems, as well as production centers. They struggled to assemble and keep a workforce, a problem that persisted for the first half-century of cotton factory production.

- Arkwright found that to lure people to Cromford, he had to hire entire families, offer them houses, and create a cohesive community, complete with a pub. Even when paying higher wages than those available to farm laborers or domestic manufacturers, these early entrepreneurs struggled to keep a steady workforce.

- The textiles industry was vulnerable to shifts in fashion and to intermittent booms and busts, making employment unpredictable. When Friedrich Engels wrote about the condition of the English
working class in 1844, he said that the mental stress and uncertainty about work from day to day was even worse than the slum conditions, poor housing, and bad food the workers were forced to endure.

- Engels also made a point noted by other observers at the time: As steam power displaced waterwheels after about 1825, manufacturers showed a preference for women and children as workers. The machines did the hard work, and “operatives” or “hands” were needed mainly to watch or to repair broken threads. Children’s small hands and ability to get into tight spaces and women’s dexterity were assets. Owners also knew that women and children could be paid less and were less likely to strike.

**Rapid Advancements in Methods**

- Historians have long debated whether the Industrial Revolution, beginning in cotton, actually impoverished the workers or whether—despite the undeniable miseries—they were better off than their rural predecessors, who could also experience severe poverty. Certainly, the textile revolution created far more affordable, popular clothing than British people had ever had access to before.
• Methods developed for cotton manufacture were later adapted for linen, wool, and worsted. Other textile processes advanced rapidly, as well. For example, in 1750, bleaching a piece of fabric using sour milk (lactic acid) could take several months. Experiments with the manufacture of sulfuric acid brought the time down to about one month, and by 1800, the perfection of bleaching powder (lime chloride) reduced the time scale to one or two days.

• Similar advances were made in the printing of fabric. The old method, still in use in the late 1700s, was to have a master printer carefully ink wooden blocks and apply them to the fabric. Inventor Joseph Bell’s printing rollers created far greater regularity in pattern on large pieces of cloth and worked 100 times as quickly.

• The industry continued to grow. In 1813, there were 2,400 power looms in Britain; in 1829, 55,000; and in 1850, 224,000. The British textile industry never rose to near-monopoly status, however. Even by the mid-19th century, most companies were medium sized and specialized in a particular fabric or process.

Factories as Model Communities

• Conditions in many of the factories were regimented, and the work was unpredictable. Manchester manufacturers championed the idea of laissez-faire; they resisted government regulation and wanted to be free to run their factories in their own way. In contrast, some employers tried to create model communities in which the residents would be happier, healthier, and organically unified.

• Robert Owen was among the first of such employers. He was Welsh by birth but ran textile mills in Scotland. On first entering the business, he was horrified by the squalor of workers’ homes, widespread drunkenness, mass illiteracy, and appalling work conditions.

• Owen strove to create a humane working environment, with shorter hours, rudimentary education for children in the mill, and improved housing. Utilitarian philosopher Jeremy Bentham invested in the
mill and accepted a lower rate of return than if profit had been the only consideration.

- In the 1850s, Titus Salt created a community called Saltaire for the manufacture of alpaca worsted. It was a state-of-the-art factory designed to carry out all phases of manufacture. Salt built a workers’ village next door, with a chapel, almshouse, bathhouse, a hospital, and a library. The sign over the entrance arch read: “Abandon beer, all ye who enter here.”

Suggested Reading


Fitton, *The Strutts and the Arkwrights, 1758-1830.*

Lemire, *Cotton.*

Mathias, *The First Industrial Nation.*

Questions to Consider

1. Why did the textile industry start out in remote rural districts but later move to such cities as Manchester?

2. What were the most important technical and social challenges faced by early textile entrepreneurs, such as Arkwright?
The Industrial Revolution ran on coal. Immense coalfields underlie parts of Britain, and coal had been mined and quarried to a small extent ever since pre-Roman times. Improvements in mining technology in the 18th century, however, along with rising demand, transformed coal mining into a large-scale capitalist enterprise. Coal fueled the steam engines that turned the textile machines, and it powered the furnaces that created large-scale iron and steel manufacturing.

**Dangerous and Dirty Work**

- Since ancient times, inhabitants of Britain burned coal from geological outcrops, but weathering made it poor fuel. Already by the time of the Romans, the British understood the need to dig into the ground to recover coal that would burn better.

- Coal is fossilized carbon—the compressed remnant of plants that grew millions of years ago. Mining it has always been, and still is, among the most dangerous jobs in the world. Mines are subject to subsidence, with tunnels suddenly caving in to crush miners or to trap and suffocate them behind a rockfall.

- The activity of coal mining releases poisonous gases, such as carbon monoxide, trapped in the coal seams. Other gases, especially methane, can explode. Miners breathe in coal dust and are susceptible to lung diseases, including silicosis and pneumoconiosis “black lung.” In addition to all this, the work is backbreaking and carried on in near-total darkness.

- The traditional coal mine had a shaft about eight feet in diameter. This shaft was dug straight down into the earth until it met the coal seams, and the lateral tunnels were dug out from the bottom of the shaft to dig up the coal itself.
Coal was hauled up in baskets made of woven sticks by a team of horses turning a windlass. Underground, the miners at first used a system in which they cut out part of the coal but left large pillars of it standing to hold up the roof. An alternative method was the longwall system, which shored up the area already dug out, leaving just a narrow passage.

**The Expansion of Mines**

- By 1700, coal mines were becoming larger and deeper. These large mines were susceptible to flooding, which could be severe, especially near the coast, such as the huge mining area around Newcastle. If a mine was on high ground, it was sometimes possible to build a tunnel from which floodwater would drain away. But better methods were urgently needed by 1700.

- A second problem was that of transport. Coal is high in bulk and relatively low in value. In fact, Newcastle developed partly because of its proximity to the river Tyne and the North Sea, which allowed...
transport by water to London. If a mine was further inland, the cost of getting the coal to the coast for shipment was simply too high.

- Ventilation was also a serious problem; it was difficult to get circulating air into the mines. There was a constant hazard of “choke damp” and “firedamp,” poisonous gases. In the Tyne area, shallow mines had a flooding problem; although this problem lessened with greater depth, the flammable gas problem worsened. As mines went deeper, owners’ investment increased, making accidents and cave-ins financial as well as human disasters.

- Lesser but also significant problems included lack of illumination, difficulty of access, underground transportation, and subsidence. When coal faces were no longer in production, often the weight of the rock strata above an area would gradually press down on pillars of coal, leading to subsidence above.

An Early Steam Engine

- Responses to all these problems began to increase in the 1700s. One of the first was Thomas Savery’s atmosphere engine, patented in 1698. It was the first steam engine in history, and it was designed to pump flooded mines. But it could raise water only about 80 feet and had to be sited inside the mine itself. Miners believed it increased the likelihood of fires or explosions.

- Thomas Newcomen, an ironmonger from Devonshire, greatly improved Savery’s design. The new engine could operate at only two or three strokes per minute at first and depended on the creation of a vacuum in a steam-filled cylinder. The first one was used at a Staffordshire colliery in 1712 and caught on quickly; some engines stayed in use throughout the 18th and 19th centuries.

- Newcomen installed 78 engines during the 20 years of his patent. When the patent expired, others got into the business, installing 300 more in the next 40 years—nearly always as mine-pumping engines but occasionally to lift water into high ponds that fed waterwheels for rotary motion.
Improved Transport

- Tramways—the world’s first railways—were a response to the coal transport problem. Tramways were wooden, low-friction tracks, easing the way for horses to draw coal wagons down to wharves at the river. The world’s first railway bridge, Causey Arch, built in 1726, carried a mine tramway down to Tyneside from a mine seven or eight miles from Newcastle. At the time, it was the highest and longest single-span bridge in England.

- In Northumberland, the normal pattern was for railways to run mainly downhill to the riverside. Wagons rolled under own weight, with a brakeman riding them and a horse hitched behind. After the wagon was emptied, the horse would drag it back up the hill to the mine.

- At the river, coal was dumped in covered sheds to keep it dry until boats arrived to take it to London. Coal was tipped from overhanging spouts into keelboats rowed by four men. They transported the coal downstream (working with the tide) to ships in the Tyne River estuary and loaded it by hand into ships, which carried it to London.

- After 1800, mine owners tested stationary steam engines on the railways in winding houses, using them to lower coal wagons down to the waterside and haul them up. A stationary steam engine at that point was more suitable than a locomotive and, in fact, remained so on steep gradients, because a direct pull is better than a locomotive-powered railway on steep ground.

- As mines went deeper, owners experimented with sending tunnels out farther and equipping them with underground tramways. After about 1750, horses were taken underground to pull baskets of coal. That meant making the tunnels higher and wider, but it added much-needed power.

- To draw coal out of the mine, innovations with waterwheels turning windlasses demonstrated a great increase in speed and reliability over the horse-drawn method.
Safety Lamps

- The next issue to address was the need for improved lighting. Following a terrible accident in 1812, when 92 men and boys were killed in a gas explosion during a shift change, philanthropists became interested in the idea of finding ways to improve safety.

- The challenge was to find a way to carry a light into the mine that would not cause fires and explosions when it encountered gas. Two similar designs were proposed, one by a practical mine engineer, George Stephenson (later, the great pioneering railway builder), and the other by an upper-class scientist, Sir Humphrey Davy. Both were effective in preventing explosions of firedamp.

- Safety lamps had both economic and safety consequences; they enabled many “fiery” mines to be reopened and the most dangerous areas of working pits to be fully exploited. However, miners were slow to adapt to safety lamps or exposed themselves to danger by taking their covers off in the mine. Late in the 19th century, candles were still being used in many mines.

Improved Ventilation

- Increased ventilation was another important mining improvement. Miners realized that it was better to have two mine shafts than one; especially if a draft could be drawn through to keep air circulating. Miners learned how to set a fire at the top of one shaft to draw air through from the other, a process called “coursing the air.” They also learned that it was essential to guide air through all the workings—even those not currently in use—to prevent the concentration of flammable or poisonous gases.

- Mine owners installed doors to guide airflow while keeping underground communications as direct as possible. One shocking example of child labor was to have children serve as trappers, sitting alone and in total darkness next to trapdoors to open and close them when coal was being dragged to the pithead. The trappers made sure that fresh air got to the areas where miners were currently at work.
• Even when hazards had been known for centuries and remedies had been available for decades, not all mine owners showed a concern for safety. In 1862, at Hartley Colliery, 204 men and boys were killed in an accident that blended bad management with bad design and bad luck. The accident led to such a public outcry that Parliament passed design regulations in response.

Women and Children in the Mines
• As mining developed, owners sought a more efficient method of sorting out coal at the surface.

• From about 1760, mine owners utilized inclined planes with screens of metal bars, so that the small coal (less valuable) would fall through the screens, while larger pieces of round coal were preserved. Another typical children’s job was as a coal picker, sorting rock from coal on conveyor belts below the screens.

• By the Victorian era, a literary protest against women and children in the mines was gaining momentum, however. Such labor would soon be prohibited by law.

The Importance of Coal in Industrialization
• Coal was involved in every aspect of the British Industrial Revolution:
  ○ Coal fueled steam engines, which made mine drainage possible and then made manufacturing independent of wind or water mills.

  ○ Coal fueled railways.

  ○ Coal released the iron industry from dependence on charcoal.

  ○ Coal provided a cheap, reliable fuel for domestic heating and for nearly all industries that required some form of heating: brewing, salt making, glassmaking, papermaking, and so on.
The statistics demonstrate that coal, industrialization, and economic growth are inextricably linked. In 1700, 3 million tons of coal were produced; in 1750, 5 million tons; in 1830, 30 million tons; and in 1870, 128 million tons.

Economic historian Michael Flinn estimated that the rate of increase of coal use accelerated about one percent per year in the early 18th century; two percent per year in the late 18th century; and three percent per year after 1830.

By the 1850s, many economists were anxious that Britain’s coal reserves would be exhausted, bringing the economy to a grinding halt. There are, in fact, still hundreds of years’ worth of coal reserves, but the fear bears witness to the centrality of coal in the Industrial Revolution.

Suggested Reading

Atkinson, *The Great Northern Coalfield, 1700–1900*.

Galloway, *A History of Coal Mining in Great Britain*.


Lewis, *Coal Mining in the 18th and 19th Centuries*.

Questions to Consider

1. Were most of the dangers associated with coal mining unavoidable in the early stage of the Industrial Revolution?

2. Why did the problem of mine drainage have such far-reaching consequences for other areas of British industrial development?
Throughout most of world history, metals were very scarce and expensive. Until the late 18th century, use of iron was confined mainly to horseshoes, nails, knives, weapons, and cooking pots. The availability of inexpensive ferrous metals (iron and steel) was one of the necessary conditions for the Industrial Revolution. Iron is much more durable than wood; a wooden industrial machine would be vibrated or pounded to pieces after a year’s work, but one made of iron would last for decades. Like coal mining, the iron industry has origins stretching back well before 1750, and its transformation took place in gradual stages.

**Ironworking**

- Initial evidence of ironworking from around 1500 B.C. has been found in the Middle East. To have metal objects of any kind in the ancient world was a sign of wealth and status. Bronze and gold were valued because of their appearance; iron, because of its hardness. The first evidence of ironworking in Britain appeared around 500 B.C.

- Making iron requires crushed iron ore, limestone (a catalyst of the reaction), and a fuel that burns hot enough to melt the iron out of the rock. A temperature of about 2,550° F is needed. To make iron, the fuel, ore, and limestone were fed in at the top of a blast furnace, and the fire was made hotter by high-pressure air blown in from below.

- Early blast furnaces in England were usually sited near iron ore mines and beside fast-flowing streams so that a waterwheel could power the bellows and supply the vital air stream. Once a furnace was in operation, it would be kept going in a continuous *campaign*, sometimes for a year or more.

- At the bottom of the blast furnace, liquid iron flows out and into a long trough (the *sow*); it then flows into molds, which are placed at right angles to the sow (*pigs*).
• The standard fuel for blast furnaces was charcoal. A great deal of woodland—about 10 acres of forest—was required to produce one ton of iron in the 1500s and 1600s.
  ○ The heavy population of Britain over the centuries meant that wood was being used far more quickly than it could regrow. Wood was the main material for building houses, barns, and fences and the main source of fuel in areas away from coal mining districts. As we saw in Lecture 5, shipbuilders also needed it in large quantities.
  ○ Britain was so severely deforested by the early 1700s that ironmasters feared their business would soon come to a stop—an irony given that it was poised to take off. But for the moment, the lack of charcoal seemed like an insuperable obstacle.

• Many manufacturers of iron goods imported iron from Russia or Sweden rather than make it from scratch. Import of the metal meant that the price of metal goods was high. Imports remained high throughout most of the 1700s; thus, Britain had both a strategic and a commercial interest in generating more home production.

• The major types of iron were cast iron, which is hard but brittle, and the more costly wrought iron, which is more flexible and malleable. The first stage of the process, drawing the metal out of the ore, produced pig iron. The second stage was forging, or remelting the pigs and beating them to drive out the impurities, especially sulfur and carbon compounds.
  ○ That made the iron workable for wire drawing, pin and nail making, locks, horseshoes, and much later, for railway tracks and machine tools. Making wrought iron was more labor intensive and required specially trained workers; hence, the end product was more costly.
  ○ Some iron was also used for the still more difficult steel-making process. Steel contains more carbon than wrought iron but less than cast iron. Steel was used only in fine goods in the 18th century, such as watch and clock springs. Working it was
an intricate and small-scale craft, again, ironically, in light of what would happen later.

Abraham Darby I

- An important breakthrough was made in the early 18th century by Abraham Darby I (1678–1717), a Quaker ironmaster and the first in a great dynasty of ironmasters. In 1709, he worked out how to smelt iron by burning coke.

- Coke is coal that has been heated to drive off sulfur and silicon impurities, leaving it nearly pure carbon. In the 1640s, English brewers had experimented with it for beer making because ordinary coal gave an off-taste to the beer. Glassmakers, ceramics makers, and manufacturers of copper and brass all experimented with different types of coal to determine the uses for which they were best suited. Because Britain was well stocked with coalfields, this advance improved the industry’s prospects.

- Abraham Darby made cast iron pots and pans, kettles, water pipes, boilers, and metal ovens. He also pioneered making molds out of sand. Darby’s cast iron wares sold widely; they were cheaper than wrought iron wares because there was no need for skilled workers to make them. Darby also made a deal to supply parts to John Newcomen, the pioneer of early steam engines, to supply cast iron parts for the engines.

- Darby was already making iron as a capitalist—that is, as a master with a large wage-earning workforce. Like mining and shipbuilding, the iron industry was becoming too capital intensive for an ordinary person to break into.

Use of Coke to Smelt Iron

- The coke method of smelting caught on slowly at first, but it gradually became standard after the 1750s, as charcoal became scarcer and British manufacturers looked for ways to make good-quality iron at home rather than import it.
There were even discussions in the 1730s and 1740s about exporting the first stage of the process to the American colonies, where the wood and charcoal supply was thought to be endless, then concentrating on forge work in Britain. The success of the coke process made that unnecessary, however.

Britain’s constant wars against France throughout the 18th century created a steady demand for metal weapons. In fact, most improvements in ironworking technology were in response to military demand.

In 1779, Abraham Darby III, grandson of the coke innovator, built the world’s first bridge of iron, a high single span over the Severn River. Coalbrookdale, where Darby worked, was also the scene of a famous painting, *Coalbrookdale by Night*, by Philip James de Loutherbourg. It shows a blast furnace at work, with great leaping flames of red and yellow lighting up the district and casting lurid shadows over the people and horses toiling in the foreground. It is a dramatic image of the power and vitality of industrialization.
Once the coke process became standard in the late 18th century, the iron industry migrated away from remote country valleys, where it had sought out woods and water power, onto the coalfields. An area near Birmingham became known as the “Black Country” because it was home to so many dirty, smoky metal workshops.

**Cort’s Puddling Process**

- The industry was still bedeviled by the problem of impurities that made much of the coke-produced iron unsuitable for wrought iron work. Henry Cort’s *puddling* process, patented in 1783, helped solve that problem.

- Puddling was the process of stirring and agitating molten iron, releasing more of the sulfur and carbon impurities. Puddling was done in what was called a *reverberatory furnace*, in which the iron did not come into contact with the fuel of the fire but was melted by extremely hot air passing over and around it.

- In Cort’s process, the iron was brought out of the furnace, hammered, and then shaped into bars or rods by passing it through rollers, which also removed more of the impurities. It enabled forges to increase weekly output by several hundred percent in comparison to traditional methods.

- Cort was a contractor to the Royal Navy, looking for a way to displace reliance on Swedish iron imports by making high-quality iron locally at competitive prices. Unfortunately, he profited little from his vital discovery because his partner had embezzled money from the Royal Navy. Cort’s patents were seized, forcing Cort into bankruptcy.

- Even so, the importance of the method was recognized at the time. In fact, Lord Sheffield said that Cort’s method, along with James Watt’s steam engine, were two technologies that more than compensated for Britain’s loss of America in the Revolutionary War.

- Cort’s puddling method caught on quickly. The Royal Navy used the less-brittle wrought iron for anchors, metal fittings for decks
and rigging, and barrel hoops. After 1791, it would offer contracts only to iron makers who used Cort’s puddling process.

“Iron-Mad” Wilkinson

- Another central figure in the ironworking industry was John “Iron-Mad” Wilkinson, who regarded iron as a miracle product. He made the first metal boat, understanding Archimedes’s principle that it would float so long as the volume of water displaced weighed more than the combined weight of the boat’s metal hull and the air it contained. Skeptics believed it would sink; Wilkinson proved otherwise.

- Wilkinson patented a method of boring extremely accurate cannons for the army. James Watt hired him to make cylinders of the same accuracy for his greatly improved steam engines. Watt’s steam engines were a huge stimulus to the industry after 1775. They replaced water power as a source for blowing high-pressure air into blast furnaces.

- Wilkinson made and was, in the end, buried in an iron coffin. As he and others learned how to make iron in volume, it became available for even more uses—for example, as a substitute for wood in industrial machines, for precision instruments and machine tools, and later, for bridges and railroad tracks.

Rapid Increases in Production

- Iron manufacturing caught on rapidly in the late 18th century, supplying a growing number of other industries. The quality kept rising and the price kept falling—one of the recurrent features of industrial capitalism. By the 19th century, iron was the obvious material for such vital innovations as railway locomotives and metal ships (which could be made far larger than traditional wooden ones).

- Again, statistics tell the story. In 1700, Britain produced 12,000 tons of iron; in 1750, 18,000 tons (a modest gain despite early innovations); in 1790, 90,000 tons; and in 1820, 400,000 tons.
The iron industry continued to expand throughout the 19th century and was given an immense boost by the invention of railways. It also came to be the standard structural material for a wide variety of machines and tools.

Suggested Reading

Ashton, *Iron and Steel in the Industrial Revolution*.

Evans and Ryden, eds., *The Industrial Revolution in Iron*.

Harris, *The British Iron Industry, 1700–1850*.

Hyde, *Technological Change in the British Iron Industry, 1700–1870*.

Questions to Consider

1. Why was the switch from charcoal to coke so vital to the development of British iron making in the 18th century?

2. What characteristics of iron made it the basic raw material of so many other industries?
Wedgwood and the Pottery Business

Lecture 9

In the late 18th century, a group of pioneers, led by Josiah Wedgwood, abandoned the traditional English method of making pottery, put it on a scientific footing, and greatly expanded the accuracy, variety, and scale of manufacture. Wedgwood, whose products are still available and highly valued today, also exploited many new avenues of marketing, which was sometimes as important to the spread of industrialization as improvements in manufacturing techniques.

Josiah Wedgwood

- Wedgwood pottery is among the most famous in the world. Josiah Wedgwood (1730–1795), the man who turned his family’s traditional cottage industry into an immense, lucrative, and up-to-date manufacturing concern, was a contemporary of Arkwright and Abraham Darby III.

- Wedgwood accomplished for pottery what Arkwright did for textiles and Darby did for iron making: He expanded the scale of manufacture, perfected techniques, rationalized the business, and found innovative ways to improve quality while cutting costs.

- He also befriended many of the leading business innovators, intellectuals, and scientists of his era, including Matthew Boulton, business partner of James Watt, and Joseph Priestley, the man who first isolated oxygen. He was the grandfather of Charles Darwin.

- Wedgwood was the son, grandson, and great-grandson of potters and was born in an area still called “The Potteries.”
  - The area was close to a coalfield for fuel, was close to Derbyshire for lead glazes, and was well supplied with clay. Around 1700, it was discovered that ground-up flint made the area’s reddish clay whiter.
However, the area was plagued by poor communications because it was not on any of the navigable rivers. It was very difficult to bring in supplies or ship out finished goods. The roads were poor, and transport depended on heavy wagons and packhorses.

- Wedgwood received a basic education and was then apprenticed to his brother. An attack of smallpox in 1747 nearly killed him. Because of his illness, he suffered for years in his right knee and ultimately had his leg amputated in 1768. He became an expert workman, especially in delicate branches, such as spouts and jug handles, because he could not use the treadle of the potter’s wheel. He went into business on his own in 1759.

- A profitable element of the business was repairing high-quality china that was chipped, cracked, or smashed. Wedgwood studied Chinese designs, as well as Meissen from Germany and Sèvres from France. Grateful customers spread word of his skill, including local gentry, whose patronage he sought. An early patron was Sir William Meredith, Member of Parliament from Liverpool.

- Wedgwood’s company had a great breakthrough in 1765, when it received an order from King George III’s wife, Queen Charlotte, for a creamware set. Creamware is a cream-colored pottery, stronger than Chinese porcelain but still pale and delicate. Wedgwood appealed to the queen successfully for permission to rename the style “queensware,” and it became a key part of his marketing efforts.

- Wedgwood’s letterhead and bills now carried the header “Josiah Wedgwood, Potter to Her Majesty.” This is what is known in Britain as a “royal warrant”—a superb marketing point in a monarchy.

**Systems and Innovation**
- Potters in Wedgwood’s era found it difficult to make two batches of pottery quite the same. Color or glaze quality varied, and many pots were still lost in kiln firing.
Wedge Wood carried out systematic experiments with clay, glazes, colors, and kiln temperatures, keeping meticulous notebooks that were written in code to discourage industrial espionage. He was more interested in the science of his materials than most of his contemporaries, trying to discover relevant principles in application of glazes, behavior of clay, and firing techniques.

- He invented a high-temperature thermometer for kilns to eliminate as much guesswork as possible. In addition, he created a stronger and more consistent creamware, duplicating color and thickness in repeated batches. Willing to innovate, Wedgwood adapted a lathe originally designed for woodworking to the process of finishing and decorating pottery.

**Wedgwood Factories**

- The Wedgwood factory was characterized by a strict division of labor, with different people doing mixing, firing, painting, and glazing. Wedgwood abandoned the traditional system consisting of the apprentice, journeyman, and master and substituted intense specialization.

- Wedgwood studied bottlenecks in production and tried to establish rates of work in each operation so that materials flowed evenly through the factory from start to finish. He battled constantly against traditional laborers, who were not used to factory hours and
Wedgwood also recognized the advantage of taking on children to learn his new methods, as opposed to converting older workers already set in their ways.

- In 1769, Wedgwood founded a factory and workers’ model village at Etruria. Etruria was named after Etruscan ware, one of the styles of pottery that made Wedgwood famous. This was the era of the excavation of Herculaneum; Wedgwood had the early books translated and sought images of the excavated pottery to copy.

- A distinguished-looking factory, with a cupola and Georgian façade, Etruria became the standard model of pottery factories for more than a century. Every room had a different function. Each room even had a separate entrance in order to segregate workers at each stage of the process, so that no one would learn all the processes and carry the secret off to a rival. This was an early example of what historians call the “deskilling” of labor.

- Wedgwood was the first pottery master to buy a James Watt steam engine; he used it to turn potters’ wheels at uniform speeds and to grind colors and flint.

- On opening day at Etruria, Wedgwood and his business partner, Thomas Bentley, made six vases in the Etruscan style. On them were painted classical figures and the legend: “One of the first day’s productions at Etruria in Staffordshire by Wedgwood and Bentley.” Also on the vases was the Latin phrase *Artes Etruriae Renascunter* (“the Etruscan arts are reborn”).

- Wedgwood biographer Robin Reilly noted: “It was not only the products of the Etruria factory that were innovative; the layout of the factory and the management techniques employed there were exceptionally advanced … From 1772, it was Wedgwood’s policy to mark everything made at Etruria. He was the first earthenware potter consistently to mark his goods and the first ever to use his own name, which was impressed in the clay.”
• Wedgwood’s only patent was in 1769, for a method of imitating Greek vases. These were made of red clay covered in a black glaze and then carved through the black. Knowing that patents were hard to enforce and could often enrich lawyers more than patent holders, when Wedgwood invented jasperware (the characteristic blue and green matte-finish pottery with white decoration), he relied on secrecy rather than patenting.

A Marketing Pioneer
• A marketing pioneer, Wedgwood opened a London showroom in Soho, designed to draw in wealthy customers. He offered a wide inventory, frequent novelties, and free delivery. He issued his first catalog in 1773 to enable customers to see and order the full range of his offerings.

• Winning a large order from Catherine the Great of Russia was another coup. In 1773, she ordered a 952-piece tea set of creamware, all with the same frog motif but each with a different landscape painted on it.

• Filling the order required an immense effort for more than a year, including hiring first-class landscape painters. The price was £3000 (more than £1 million today), and Wedgwood was terrified that Catherine might die before it was delivered and he wouldn’t be paid. She did pay, however, and he put the whole thing on display in London before sending it off to Russia—a marketing sensation.

Investment in Better Transport
• As the Wedgwood pottery business expanded, effective communications with Liverpool and London became essential. Getting clay for queensware was quite difficult; the clay was quarried in Cornwall, brought by ship to Liverpool, carried by boat up the Mersey and Weaver rivers, and put on a wagon. Wedgwood joined schemes for building an improved turnpike road.

• Understanding the importance of canals for bulk transport, Wedgwood also became an investor in the Trent and Mersey
Canal, which linked Liverpool and Manchester with the Midlands. He supported it, bought shares, urged family members and other pottery owners to invest, and became its unpaid treasurer.

- The canal, which opened in 1771, went right past the front of the Etruria factory—resulting in vastly improved communications and a reduction in transport costs.

**A Distinguished Intellectual and Scientist**

- Wedgwood was a member of the Lunar Society, a group of distinguished businessmen and intellectuals who met regularly to exchange ideas. They sometimes called themselves “the lunarticks” but were, in fact, the opposite: enlightened, empirical, sensible, and dedicated to the idea of human improvement in every way.

- Members of the Lunar Society were strongly sympathetic to the American cause in the Revolution, and many were antislavery advocates, as well. Wedgwood had deplored British tax policy for many years and anticipated a political rift. But he was discreet, knowing that he could not afford to offend his customers, and would share his real views only with close friends and Lunar Society associates.

- In 1783, Wedgwood presented papers to the Royal Society on his “pyrometer” and on the scientific analysis of different clay samples. The scientific exactitude he practiced soon caught on when it became clear that it enabled the manufacture of a more dependable, durable product and one that could be turned out reliably on a large scale.

**Suggested Reading**


Mokyr, *The Enlightened Economy*.
1. Why was marketing as important as production for Wedgwood?

2. What challenges did Wedgwood face in his factories, and how well did he address them?
Canals facilitated nearly every aspect of industrialization. Britain’s first commercial canal opened in 1761 and at once showed itself superior to all other methods of transport. A horse pulling a floating barge could draw almost 50 times as much weight as it could with a wagon. Canals made it possible to carry bulk solids, such as coal, iron ore, bricks, timber, clay, and grain, over long distances at relatively low cost. Building canals, especially across hilly country, proved an immense technical challenge but inspired some highly innovative technologies. Canals, which accelerated bulk transport across Britain, caught on rapidly between 1770 and the 1830s, when they were eclipsed by the faster and more efficient railways.

Improving River Transport

- Before the Industrial Revolution, roads in Britain were poor, even after the building of turnpikes. Periodic attempts to improve Britain’s navigable rivers—the Thames, Severn, Mersey and Weaver, Humber and Trent—had been made for centuries. Strategies to improve the rivers included straightening curves, dredging shallow areas to deepen them, shoring up banks, and building towpaths and locks to make them navigable higher up.

- Because rivers are flowing, they shift their banks over the years, and their currents can make progress upstream difficult for draft horses, whereas canals are still-water environments.

- Sankey Brook in Lancashire was extensively broadened and deepened for coal transport from St. Helens to the Mersey River and began to carry in 1757. However, this consisted mainly of an improvement of a preexisting stream.
Britain’s First Canal

- The first wholly artificial canal was projected by the 24-year-old duke of Bridgewater, the owner of coal mines at Worsley, who was looking for a method of economically shipping coal to Manchester.
  - He hired James Brindley (1716–1772) to design and build the canal. Brindley joined up with the duke and his agent, John Gilbert, and together, they confronted the vast array of new problems in making a working canal, often inventing techniques to overcome unforeseen difficulties.

  - Brindley favored the method of contouring to keep earth moving to a minimum. This meant he would take an indirect route to cut down on the number of cuttings through hills and embankments across low places—all work that had to be done by hand and was painstakingly slow. Brindley’s method of *clay puddling* was key to making the bed of the canal watertight so that the area did not just become a swamp.

- The single most spectacular feature of the Bridgewater Canal was the Barton Aqueduct, a structure built over the valley of the Irwell River. People flocked to the aqueduct to see the sheer strangeness of boats sailing over a bridge, high above a river. Embankments leading to the aqueduct were equally impressive as engineering feats. Intense lateral pressure exerted by the water above ground level made the banks susceptible to breaking. Brindley foresaw the

The opening of Britain’s first canal was such a success that two passenger boats were built, offering day tours along the canal.
possibility and worked out a method for isolating sections in the event of a breach so that the entire canal would not drain away.

- Opening of the canal halved the price of coal in Manchester and proved immensely profitable to Bridgewater. He recouped all his expenses in less than 10 years and went on to become enormously wealthy. At Worsley, the canal doubled as mine drainage, and because an ever-growing network of underground canals was built inside the mines, coal could be loaded onto barges almost at the coal face.

- Over the next 15 years, there were 52 acts of Parliament related to canal building. Parliament would authorize routes and eminent domains and specify tolls to be charged at the locks on different items carried.

**Trent and Mersey Canal**

- Brindley was next commissioned to build the Trent and Mersey Canal. For that, he needed a change in elevation, which meant building locks. Criticisms came from mill owners who feared that they would lose water power, from river navigation companies now facing competition and forced to cut prices, and from gentry who didn’t want canals crossing their lands.

- The key to the creation of the canal was the locks. A lock is a pair of gates that can be opened and closed to control changes in water level. The system presupposes a reliable water supply at the high point, because water will not flow uphill.

- As completed, the Trent and Mersey Canal rose through 35 locks and a 3,000-yard tunnel, the Harecastle Tunnel, and four shorter tunnels. The Harecastle Tunnel took 11 years to build and was completed in 1777.

**The Canal Scheme**

- Canal tunnels were too small for horses, which had to be led over hilltops, while crew members “legged” the boat through the
tunnel—that is, they lay on their backs and walked upside down, with the friction of their feet on the walls and their backs on the deck keeping the boat going. Some later tunnels had groups of full-time professional “leggers” waiting in huts at either end.

- The canals were built by workers with picks and shovels. At first, the builders relied on local subcontractors, who hired farm laborers during the off season, but in the 1790s, these were replaced by migratory teams of full-time builders.

- Creating lock bottoms required “clay puddling,” or compressing a mixture of clay and sand into place to stop seepage into the surrounding ground. A towpath of ash and cinders for pulling horses was built beside the canal.

“Canal Mania”

- The years 1793 and 1794 were a time of “canal mania,” in which 38 acts of Parliament were passed for new canal schemes. It was also a period of exaggerated enthusiasm by investors, as some routes were never destined to be profitable.

- The pros and cons of the canal system were aired in pamphlet wars. One argument in favor was that canals, by bringing prices down, promised cheaper food and, therefore, a healthier, happier population. Also, because a horse could pull 50 times as much freight by barge as by wagon, fewer horses were needed for the same amount of trade, creating savings in acreage needed for horses’ fodder.

- Brindley’s great successors were John Rennie, Benjamin Outram, William Jessop, and Thomas Telford. These builders were increasingly daring, creating longer and higher bridges, deeper cuttings, and straighter and more direct canals.

Thomas Telford

- Thomas Telford (1757–1834) was probably the greatest of the canal builders after Brindley. The son of a Scottish shepherd and
apprenticed to a stonemason, Telford became a road surveyor, architect, and general engineer. In the 1790s, he began to specialize in canals.

- Telford recognized the benefits of iron for aqueducts. Iron aqueducts could be prefabricated offsite and weighed far less than solid stone structures. Their only drawback was that they would eventually rust, requiring sections to be replaced.

- Telford’s greatest achievement was the Pontcysyllte Aqueduct in north Wales, which was 1,000 feet long and 120 feet high. Although the original plan had stepped locks down one side of the valley and up the other, with a low stone aqueduct, Telford urged investors to let him build a high iron structure instead.

- The structure was made of cast iron. Stone piers rose from the valley, but the trough was cast iron, bolted to plates on the masonry. Brass bands and cannon fire celebrated its opening, followed by a procession of barges. Sir Walter Scott said that the aqueduct was the most impressive work of art he had ever seen.

**Funding the Canal System**

- Canals authorized in the 1790s often struggled with inflation. A sudden demand for supplies and labor relevant to canals caused prices to rise. This was the era of the Napoleonic Wars, which also stimulated demand and contributed to rising prices.

- Acts of Parliament often specified how much money canal companies were allowed to raise. When the funds ran out because of inflation, investors suspected corruption or negligence. Many projects had repeated stops and starts as they cast around for more money.

**Important Canal Routes**

- The most significant canal routes were the Forth and Clyde Canal (finished in 1790), which linked the west and east coasts of Scotland, and the Leeds and Liverpool Canal (finished in 1816),
which linked industrial Yorkshire and Lancashire—including an amazing crossing of the Pennines. The Kennet and Avon Canal linked Bristol and the Severn estuary with the Thames Valley.

- One of the most impressive features of the Leeds and Liverpool Canal was the Bingley Five Rise, a set of five locks in a “flight,” in which the lower gate of one served as the upper gate of the next. The set of locks raised the canal 60 feet.

- As canals became larger after 1790 and crossed more high ground, the problem of keeping them full of water intensified. Dams had to be built across high streams to store enough water through the year so that it could be fed into the canals.

- Telford also worked with Jessop on the Caledonian Canal, designed to cut across Scotland from southwest to northeast, linking up the lochs. This canal route greatly shortened the stormy sea route around the north of Scotland and gave access to large ships, not just narrow barges.

- Poet Robert Southey, a friend of Telford, found the scene of a successive locks, nicknamed “Neptune’s Staircase”—the longest staircase lock in Britain—particularly impressive. He wrote, “The pyramids would appear insignificant in such a situation.”

- By 1830, there were 3,900 miles of canals in Britain and a new category of employment: bargemen. Bargemen led a healthier life than many of those working in the new industrial jobs. There was also a new work category of lockkeeper, who opened the gates, collected tolls, and ensured that embankments were watertight.

- Working on the canals became a way of life for hundreds of people for more than a century, only falling into decline when railways could do the work of transportation faster and more efficiently. When railway building began, however, the expertise and cumulative experience of the canal builders would be put to good use.
Suggested Reading

Burton, *The Canal Builders*.
Corble, *James Brindley*.
Hanson, *Canal People*.

Questions to Consider

1. Why was the transportation of bulk solids so vital to industrial progress?
2. What were the greatest strengths and weaknesses of canals as a transport system?
Steam Technology and the First Railways

Lecture 11

The year 1830 was one of the great turning points in the history of transport—and, thereby, of industrialization itself. The Liverpool and Manchester Railway, which opened in 1830, was the first railway run entirely by steam-powered locomotives. Based on a long series of incremental technological improvements over the previous half-century, it brought together high-pressure steam engines, high-quality iron manufacture, and successful experiments in using rails for horse-drawn or cable-drawn haulage. Over the next 20 years, a nationwide railway system spread across Britain, privately financed and operated, immensely lucrative, and providing a stimulus for the entire British economy.

Early Steam Engines

- Steam engines went through nearly a century of improvements before being mounted on vehicles. The first steam engines, developed by Thomas Savery and Thomas Newcomen, were used mainly for mine pumping and were slow and inefficient.

- In the Newcomen engine, steam from a boiler pushed a piston up inside a cylinder. The steam valve closed, and then a jet of cold water was shot into the cylinder. It caused the steam to condense, creating a vacuum, which drew down the piston. Then, the cycle was repeated. The up-and-down motion was transmitted by a beam to a simple pump, drawing water out of the mine. Another name for an engine of this kind is a “beam engine.”

- James Watt improved the speed and efficiency of Newcomen engines. Watt realized that Newcomen engines were inefficient because the cylinder had to be heated and cooled during every stroke. Most of the energy from the fuel was devoted to heating the cylinder, rather than working the engine itself. In 1764, Watt substituted a separate condenser, enabling the main cylinder to remain hot all the time and achieving far higher fuel efficiency.
• Watt, in partnership with Matthew Boulton, created a highly profitable enterprise: a factory to build steam engines. They employed John “Iron-Mad” Wilkinson to bore cylinders in a method developed for military cannons.

Precision and Innovation
• All early industrialists were plagued by poor-quality machine tools, lack of standardized parts, and lack of precision craftsmanship. Watt, Boulton, and Wilkinson all specialized in precision. Boulton and Watt sold ready-made engines or helped owners of Newcomen engines convert them, for huge savings in coal costs.

• Watt also patented the “sun and planet” motion in 1781, which converted the reciprocating stroke of a beam engine into rotary motion. That made it applicable to turning factory machinery, including at cotton mills, and increased his business.

• Watt’s patent restricted other entrants into the steam engine business until 1800. After that, steam engines caught on in a huge array of businesses, speeding them up and creating new possibilities for large-scale production.

Richard Trevithick
• Horse-drawn railways, especially in coal-mining districts, were already in operation throughout the 18th century. The low-friction environment of smooth wheels on smooth rails enabled horses to pull greater weights than they could have done on roads.

• In mining areas, gravity carried full wagons down to the wharf, and then a horse or a stationary steam engine attached to a cable dragged them back up, empty. These early mine railways were usually wooden, but the engineers at the Coalbrookdale ironworks substituted iron rails as early as 1767. Iron rails proved vastly superior and caught on at other ironworks and collieries; they were not subject to rot and could carry greater weights more easily.
In the early 19th century, mining engineers began to experiment with steam-driven locomotives. In 1801, Richard Trevithick, a Cornish engineer, created a steam-powered carriage that he nicknamed the “Puffing Devil” and ran it on the road. It worked, but the roads were very poor, and it often broke down.

Trevithick patented the high-pressure steam engine in 1802 and made a working railway locomotive in 1804. Its weight was so great that it broke the rails. Still, he had made a crucial breakthrough by bringing together a high-pressure steam engine mounted on a trolley and running it on iron rails. This innovation would change the world.

George Stephenson

Stephenson was probably the single most important person in the history of railways, one whose work brought together all the necessary inventions and insights, improved them, and turned them into recognizable working railways. He and his son, Robert, built the first commercially successful railways in the 1820s.

Stephenson was a mining engineer whose job was to look after the pumping engines at the mine. He was aware of Trevithick’s experiments and began to tinker with making his own locomotive.

In 1810, Stephenson realized the importance of the “steam blast” system—a necessary advance in making workable locomotives. Directing the exhaust steam from the cylinders into the chimney created suction to draw air into the locomotive’s fire (like a bellows effect), causing it to burn hotter and more efficiently.

Stephenson also showed skeptics that metal wheels on metal rails did provide enough friction to give traction, so long as the gradients were shallow—therefore, a rack-and-pinion system would not be necessary.

Stephenson was commissioned to build the Stockton and Darlington Railway, partly using stationary steam engines with cables and
partly using moving locomotives. The railways was 25 miles long and opened for business in 1825.

- Horses pulled the passenger trains, which looked just like stagecoaches, except they were on rails. Stephenson worked out a system called the “dandy cart.” When the rail gradient was uphill, the horse would pull, but when it was downhill, the horse would climb onto a cart at the back, where hay was waiting, and ride as gravity carried the train down the slope.

- The locomotive engine, however, could pull a long freight train, occasionally reaching 15 miles per hour. It led to a halving of the price of coal in Darlington.

**Liverpool and Manchester Railway**

- Stephenson followed up by engineering and building the Liverpool and Manchester Railway, which opened in 1830. It was faster and relied entirely on moving locomotives.

- The Liverpool and Manchester Railway was financed by Lancashire industrialists impatient at the high cost and slow speeds of the canal system. Among the advantages of a railway over a canal was that it would not freeze in winter and was not susceptible to drought; further, one train could make many back-and-forth trips in the time a canal boat could make only one. It was also easier to increase the volume of traffic on a railway.

- The Stephensons defied skeptics by working out a way to cross the Chat Moss swamp, pouring in thousands of tons of rock ballast to create a firm surface.

**Rainhill Trials**

- In 1829, as the Liverpool and Manchester Railway was nearing completion, the board held a competition, the Rainhill Trials, to determine whether stationary steam engines or moving locomotives would be used to pull the trains. The best locomotive maker would receive £500 and the contract for the new line.
Huge crowds gathered, seated in grandstands alongside the track. Locomotives had to go up and down the selected length of track 20 times, for a total of 60 miles, pulling three times their own weight.

An early favorite was the *Novelty*, which limbered up with a solo run and astonished the onlookers by going nearly 30 miles per hour. But it was finicky and accident prone, whereas the Stephensons’ locomotive, the *Rocket*, was hardy, durable, and dependable.

The *Rocket* was the clear winner, traveling 70 miles fully laden and even going at 12 miles per hour up a gradient (much faster than the fixed-engine system could have managed).

The *Rocket* embodied another important technical breakthrough—the tubular boiler. Rather than have a fire heating one large tank of water, water was forced through 25 copper tubes surrounded by superheated air, which boiled it and turned it to high-pressure steam far more quickly.

The method of heating water with a tubular boiler used in George Stephenson’s *Rocket* was retained in the building of steam locomotives in Britain into the 1950s.
The First Railway Casualty

- The opening of the Liverpool and Manchester Railway was a momentous occasion, drawing national celebrities, including the prime minister. A procession of eight trains set off, pausing along the route to exhibit the railway’s most spectacular achievements, such as the crossing of Chat Moss and the Sankey viaduct.

- At one point, William Huskisson, Liverpool Member of Parliament and president of the Board of Trade, who had been one of the great enthusiasts for the railway throughout its construction, walked in front of the *Rocket* as it was coming down an adjacent track. People then had no conception of how quickly a vehicle traveling at 20 miles per hour would reach them. Despite shouted warnings, the locomotive hit and seriously injured Huskisson.

- Wounded, he was put on board another of the trains, the *Northumbrian*, driven by George Stephenson himself, which set off at top speed to Manchester and the nearest hospital. The hospital couldn’t save Huskisson’s life, but bystanders were astonished at the train’s speed in covering the ground—36 miles per hour (which shows how rapid progress had been since the Rainhill Trials of the previous year).

A Significant Leap in Industrialization

- Early railway promoters had expected the railways to thrive entirely on freight, but they discovered an unanticipated demand from passengers, as well. Ten times as many people rode the train in the first year as expected, and for the first decade, passenger transport was the most lucrative part of the whole business.

- It was clear by the early 1830s that the railway was going to upstage the canals, even though canals had been such a dramatic improvement over earlier transport. This is an excellent example of the way industrialization began to speed up traditional methods.

- It was not long after that Stephenson and many of his rivals were commissioned to build major railways between such distant centers
as London, Birmingham, and Edinburgh. And already at the Rainhill Trials, representatives from the first American railroads had been in attendance to see whether the locomotives actually worked and were impressed by the outcome.

- In the next lecture, we will see how the Stephensons and many other eminent engineers set about building a great nationwide railway network, much of which is still in operation today.

**Suggested Reading**

Burton, *The Railway Builders*.

Dickinson, *James Watt and the Industrial Revolution*.

Rolt, *George and Robert Stephenson*.

Simmons and Biddle, eds., *The Oxford Companion to British Railway History from 1603 to the 1990s*.

**Questions to Consider**

1. How did Watt’s improvements to the Newcomen engine make steam-powered railways possible?

2. What qualities enabled George Stephenson to succeed as a pioneer railway builder?
The Railway Revolution
Lecture 12

The advent of the railways marked one of the most decisive shifts in British history. The technical and commercial success of the Liverpool and Manchester Railway set off a boom in railway building throughout the 1830s and 1840s. Trunk lines were built between major cities, linking previously remote parts of Britain and making the transport of bulk items—and people—far quicker and cheaper than ever before. Although the railways displaced long-distance stagecoaches and threatened the canals’ monopoly on inland bulk transport, they stimulated urban growth. They also created a high demand for further development in the metal industries, significantly stimulated the economy, and provided employment for tens of thousands of people.

A National Effort

- In Britain, each new railway line required an act of Parliament. The acts provided limited liability and created the right of eminent domain. Because Britain was already a densely settled country, the siting of lines meant cutting across lands owned by hundreds of individuals. Bribery of Members of Parliament, who owned estates the railways would cross, was widespread and contributed to the high cost of British railway building.

- Landowners who lacked political influence were often resentful of these forced purchases. There was also widespread opposition from people who had made their fortunes in turnpikes, stagecoaches, and canals—technologies that now faced the threat of a faster and more efficient rival.

- In the 1820s and early 1830s, financing was usually local (local mine owners and merchants), but it became national as the success of the Liverpool and Manchester line showed the immense possibilities of the technology.
Isambard Kingdom Brunel

- The Stephensons continued as major railway builders in the 1830s and 1840s, with the son, Robert, gradually displacing his father, George. Robert was a formidable witness before Parliamentary committees and had a brilliant grasp of detail in both locomotive building (the *Rocket* and many superior successors) and line planning.

- Robert Stephenson also understood the need to develop good subcontractors to build sections of the line, people who were able to handle tough gangs of unruly workers, master complicated tasks in building cuttings and embankments, drive tunnels, and handle money.

- Other major figures came on the scene, many of whom had been apprentices under George Stephenson. The greatest of these newcomers was Isambard Kingdom Brunel, chief engineer of the Great Western Railway.

- Brunel used a seven-foot railway gauge for greater comfort and luxury. (Gauge defines the spacing of the rails on a railway track.) However, a seven-foot gauge made the line more costly to build, enforced shallower curves, and prevented interchangeability of rolling stock.

London and Birmingham Railway

- Robert Stephenson built the London and Birmingham Railway at the usual gauge of four feet, eight and a half inches, which became the standard for most of the world (mainly because British contractors built many of the first railways in other countries).

- Before the work even started, the company spent £32,000 on legal expenses to maneuver the bill through Parliament and £750,000 on land purchases (the equivalent of several billion pounds today). On the first presentation of the bill, the House of Lords rejected it, reflecting a greater skepticism about railways in the south of England than in the north. But the bill passed in 1833, and work began on this 112-mile line, the longest ever attempted.
Robert Stephenson was only 29 when the work began, but he was a daunting personality with unrivalled experience. Stephenson divided the whole length into sections of about six miles and contracted them out. All sections were built simultaneously. To have 20,000 people working on one project simultaneously was a new jump in scale over the kind of organization the factories, mines, and foundries had achieved in the previous decades.

The London and Birmingham Railway was laid out to exacting standards and was extremely flat, with no sharp curves; thus, it has remained usable as a high-speed line even today, without much reengineering. It opened in 1838, having a cost £5.5 million—more than double the anticipated amount.

**A Stimulus to Economic Growth**

- English railway architecture shows the Victorian spirit at its most euphoric, and some of the finest structures in Britain are related to railways. The London and Birmingham Railway and others boasted elegant stone stations, triumphal arches, and classical tunnel facades.

- Some stations, built in the Gothic Revival style, were designed to look like medieval cathedrals. These buildings, while overdone, still conveyed the general sense of excitement and pride generated by railways.

- Railways stimulated economic growth both directly and indirectly. Communication between cities was quicker and easier than ever before, as was bulk transport of low-value items, such as coal, iron ore, and cotton.

- Railways under construction were a major stimulus to the iron and steel business, contractors, brickworks, and mining. By 1850, all the largest companies on the London stock exchange were railways, and they were far more highly capitalized than even the biggest manufacturers.
A Major Employer

- Railways also became major employers in their own right. The actual building of the lines was done by tens of thousands of migratory workers, with the basic tools of pick, shovel, and wheelbarrow. The workers were called “navvies”—a holdover term from when these kinds of teams worked on the canals, or “navigations.” In the late 1840s, 300,000 were at work building railways, and 60,000 more worked on the completed lines.

- Railway workers transformed the landscape with cuttings, embankments, bridges, and tunnels of a kind and scope never previously seen. By 1850, there were 6,000 miles of track in operation, with main line average speeds of 40 miles per hour.

- By 1873, railways had 275,000 permanent employees, making them a central component of the economy. Several new towns, such as Crewe, Swindon, Middlesbrough, and Wolverton, grew up solely as railway building and repair centers.

St. Pancras Station in London was completed in 1868; with its adjoining hotel, it resembles a medieval castle.
Cheaper and Faster Postal Service

- In 1840, Rowland Hill’s innovation, the “penny post,” was made possible by the railways. Hill was an inventor and social reformer who wrote an influential study of the postal system in 1837, urging reform of waste, slowness, inefficiency, and high cost.

- Until then, delivery of letters had been expensive and slow, and payment was made on delivery (the recipient could look at the letter and decide not to take it). Costs varied according to distance and were high. The General Post Office accepted Hill’s proposals. Making mail delivery cheap and prepaid by the sender was a calculated risk that paid off; business and personal communication became far easier and cheaper, and the move contributed to economic growth and business security.

- The General Post Office delivered 76 million letters per year in 1839 and 863 million per year by 1870. Next-day delivery was available anywhere in the United Kingdom. Easy communication by rail combined with cheap post was another milestone in the history of industrialization and economic growth.

New Management Challenges

- Stagecoach lines’ fears that railways would displace them were well founded, but the demand for short term horse-drawn transport actually accelerated, and the number of horses and carriages in Britain continued to rise as cities grew and citizens’ wealth increased.

- Railways created a new class of managers, remote from their employers, who had to take responsibility for the safe working of the railways. Most industries until then operated all in one place, under the supervision of the owner or overseer, but railways, by their nature, were dispersed. Managers had to show the right blend of subordination and initiative to prevent crashes and to keep the system running smoothly and according to schedule.
• Companies also recognized the need for long-term worker loyalty and tried to make working for the railway a lifetime proposition with security and dignity. Railways built by private enterprise meant owners did not have to contend with bureaucratic national planning, wasteful duplication, nonstandardization, and unprofitable lines.

• More railway lines were projected than were ever built, and some lasted only a few years before falling into bankruptcy. After the astonishing success of the Liverpool and Manchester Railway, a great surge of enthusiasm in 1836–1837 led to a bubble, with some unwise overinvestment in railways by people who lacked the necessary detailed knowledge.

• The diversity of private ventures also led to the building of 13 separate London termini but no general exchange, which created severe transshipment problems and remained a weakness of the system into the 20th century.

**Limited Government Involvement**

• While government largely kept a hands-off attitude, an 1844 act of Parliament established minimum safety standards for trains, brakes, and signals. It also specified that every line should run at least one cheap passenger train per day (the “parliamentary trains”) to enable ordinary people to ride.

• Parliament reserved to government the right to take over private lines after they had been in operation for 21 years (although when it came to that point, in the 1860s, government did not—until 1947). The threat of takeover was important in discouraging abuse of a natural monopoly position and probably helped keep prices down for shippers and passengers.

• A period of consolidation reduced the number of companies, all of which agreed in 1892 to move to standard gauge. Steam locomotives ran on British rails for 140 years, the last ones being withdrawn in 1968. The railway system, much of it, is still present,
with the original track beds laid out by Stephenson, Brunel, and others still in use.

- In the next lecture, we’ll study more closely one of the great railway builders, Isambard Kingdom Brunel. After distinguishing himself as chief engineer of the Great Western Railway, he went on to pioneer another of the significant new industrial technologies: oceangoing steamships.

### Suggested Reading

Barman, *Early British Railways.*


Kirby, *The Origins of Railway Enterprise.*


### Questions to Consider

1. What were the benefits and drawbacks of leaving railway development in private hands rather than instituting a government planning policy?

2. In what ways were railways clearly superior to canals as bulk transportation devices?
Historians enjoy arguing about which is more important, great individuals or broad social and economic forces. Of course, both are significant influences, but it can be helpful for historians to single out particular figures who epitomize historical trends—for example, Arkwright’s work in textiles, Wedgwood in potteries, Brindley in canal building, and the Stephensons in railways. Once we get to Isambard Kingdom Brunel, the temptation to emphasize the life and work of a particular individual becomes impossible to resist. He was a Promethean figure, intellectually and technologically daring, who pushed new possibilities further than any of his contemporaries.

A Talented Father

- Isambard Kingdom Brunel (1806–1859) was a notable figure in the Industrial Revolution, effecting key innovations in oceangoing, steam-powered, iron-hulled ships. The son of an engineer, Brunel learned much of his trade from his talented father, Marc Brunel. Marc Brunel was a royalist officer in the French navy, who fled to the United States during the French Revolution and worked for five years as chief engineer to the city of New York.

- Back in Britain by 1799, Marc Brunel pioneered the mass production of rigging blocks for the Royal Navy and won a contract to mass-produce boots for the Duke of Wellington’s army, which won the Battle of Waterloo in 1815 against Napoléon.

- Young Isambard Brunel helped his father build the first tunnel under the Thames River. Two earlier attempts had failed, one nearly drowning the railway pioneer Richard Trevithick. The tunnel was finally finished in 1842, and Marc Brunel was knighted by Queen Victoria.
Great Western Railway
- In 1833, at age 27, Isambard Kingdom Brunel was appointed chief engineer of the Great Western Railway and built it to a higher level of quality and comfort than any rival line.

- After riding on the Liverpool and Manchester Railway, Brunel decided it was uncomfortable and instead built the Great Western Railway to seven-foot gauge. That meant that curves had to be shallower, the right-of-way broader, tunnels wider, and all locomotives and rolling stock larger. He planned the line as flat and straight as possible—with minimal gradients. He fought an intense battle to get parliamentary approval that cost nearly £90,000 in legal and other fees.

- There were constant problems with the project because no one had worked with seven-foot gauge before. The most difficult section was from Bath to Chippenham, where huge embankments, cuttings, and a long tunnel were needed. The tunnel had to be blasted through hard rock, using a ton of gunpowder per week for three years.

- The entire line of the Great Western Railway opened in 1841. Brunel’s biggest mistake was ordering locomotives that were too small and underpowered. He was forced to admit his error and subsequently bought superior ones from George and Robert Stephenson.

“Battle of the Gauges”
- The Great Western Railway also hired a brilliant 21-year-old, Daniel Gooch, who had been apprenticed under Stephenson. Gooch soon began custom building far better locomotives, well fitted to the Great Western Railway.

- Gooch was quiet, businesslike, and puritanical—the personal opposite of Brunel, who was characterized by his Byronic swagger. But Brunel, who knew Gooch had been right about the locomotives, came to trust the young man implicitly.
The years 1845–1846 saw the “battle of the gauges,” in which most of the other railway companies tried to get parliamentary approval of the railway gauge of four feet, eight and a half inches, as the national standard. Although Brunel’s locomotives could run faster, there were already more than 2,000 miles of standard-gauge track, as opposed to 240 miles of seven-foot gauge. In 1892, the Great Western Railway gave up and converted to standard gauge.

The Atmospheric Engine

When Brunel was asked to extend the line down into Devon, he made another mistake, overreaching by trying a daring new technology—the “atmospheric engine.” Instead of having a heavy locomotive pulling coaches, a stationary steam engine would create a vacuum in a pipe laid along the track. A piston attached to the train would fit snugly in the pipe, and the vacuum would suck the train along. The train would be quiet, and the system would achieve significant fuel economy.

Brunel had worked out that a large percentage of the energy used by a locomotive at high speed was consumed in moving itself against wind resistance; thus, if the engine was stationary, there would be a significant savings in fuel.

Although the system was sound in theory, it didn’t work well in practice; such a system depended on a tight, permanent seal, which proved impossible to create. The system dried out in summer, froze in winter, and needed so many workers to maintain it that it cost more than conventional locomotives. Brunel realized in 1848, after just one year of operation, that the atmospheric engine was a flop.

The Royal Albert Bridge and Paddington Station

Another great achievement by Brunel was the Royal Albert Bridge over the Tamar River. For this structure, two massive wrought iron trusses were placed on the piers when they were just above the waterline. These trusses were then jacked up a bit at a time as the brickwork of the piers was built under them until the whole
bridge was high enough to satisfy Royal Navy requirements of 100-foot clearance.

- At first, the least interesting station of the Great Western Railway was Paddington, its London terminus. It was utilitarian because of the directors’ bottom-line concerns.
  - Brunel, who served on the design committee for the 1851 Great Exhibition, was delighted by Joseph Paxton’s design for the Crystal Palace, constructed of iron framing and plate glass.
  - Inspired, Brunel used the same idea for Paddington Station, using prefabricated sections, which were strong and light and enabled rapid construction.

**S.S. Great Western**

- Brunel’s next monumental achievement was to transform shipbuilding. In the early days of the Great Western Railway, Brunel had suggested to its directors that passengers could eventually take a Great Western train from London to Bristol, then get on a ship of the same name and sail it all the way to New York. The directors took Brunel seriously, and he collaborated with several experienced marine engineers to create the S.S. *Great Western*, a steamship that could cross the ocean.

- The current theory was that such a machine would take up all available space with coal, leaving none for passengers and cargo. Brunel disagreed, realizing that bigger ships would have far larger cargo space and room for cabins. Brunel also recognized that the limiting factor for ships’ speed is their length; thus, a longer ship would be faster.

- At 236 feet, the S.S. *Great Western* was the longest ship ever built up to that time. Launched in 1838, it used a combination of sails and steam-powered paddle wheels. Brunel hoped it would be the first steamship to cross the Atlantic Ocean.
• However, a rival ship, the *Sirius*, set off first. The *Great Western* then suffered a fire in its engine room, which delayed departure. Even so, the crossing was a success. Although the *Great Western* narrowly lost to the *Sirius*, it used far less coal and crossed in a shorter time (15.5 days). In fact, the *Sirius* had run out of coal and had to burn some of its cargo to complete the voyage. The *Great Western* became the first regular trans-Atlantic passenger steamer.

**S.S. Great Britain**

• Brunel’s second great achievement in marine technology came with the S.S. *Great Britain*. Ever since John “Iron-Mad” Wilkinson’s iron barge, the possibility of metal ships had been accepted, but Brunel built his on an incomparably grander scale. The largest to date was 500 tons; Brunel’s was 3,000.

• When the hull was half built, Brunel decided to switch to the new propeller technology, instead of paddle wheels. That offered cleaner lines, more fuel efficiency, and greater speed. The *Great Britain* finally set off on her maiden voyage in 1845 and knocked another 36 hours off the crossing time to New York (now just 14 days).

• The ship went aground a year later off the Irish coast, and the owners were afraid it would have to be abandoned. Brunel finally found a way to lift it off the reef on a high tide in 1847 and bring it back to Liverpool for repairs. It spent the next 24 years carrying emigrants from Britain to Australia.

**Transforming Shipbuilding**

• Brunel’s third ship, the S.S. *Great Eastern*, begun in 1854, was still more innovative. It was large enough to travel nonstop to Australia, powered with propellers, paddle wheels, and sails. Six times the volume of any current ship, it needed only a small crew. It was designed with many new features, including uniform metal plates and a double hull and bulkheads for strength and watertightness.

• The ship was nearly impossible to launch. The river was not wide enough, which meant that the ship had to be built for sideways
By the time the *Great Eastern* was launched, Brunel was on his deathbed. The ship finally sailed the Atlantic in the summer of 1860 and was acclaimed in New York. It hit a reef in 1862, but it did not sink because of the double hull. Sold in 1865, it was used to lay trans-Atlantic cable in 1866—facilitating almost instantaneous transoceanic communication.

- The Stephensons, Brunel, and the other great Victorian engineers were able to build accurate, efficient locomotives and steamships because they had access to something none of their predecessors had enjoyed—high-quality machine tools. Late-18th-century and early-19th-century craftsmen learned how to make more accurate and more durable lathes, stamps, taps, dies, and all the other devices essential for turning out precision machinery. These machine-tool innovators will be the subject of the next lecture.
Suggested Reading

Bagust, *The Greater Genius?*

Brindle, *Brunel.*

Christopher, *Brunel’s Kingdom.*

Vaughan, *Isambard Kingdom Brunel.*

Questions to Consider

1. When did Brunel’s fearless individuality hinder rather than help his projects?

2. What were the benefits of steam-powered, iron-hulled ships in comparison with the wooden, sail-powered alternative?
When we study spectacular innovations, such as steam locomotives and oceangoing ships, it is essential to remember that their makers required a wide array of special tools and materials. This lecture is a history of the pioneer tool makers who improved precision, accuracy, strength, and uniformity in the treatment of metals, on which all subsequent technologies depended. The higher standard of machine-tool making they established enabled engineers to build high-pressure steam engines to minute tolerances. It also laid the groundwork for the mass production of identical parts, which would be crucial for a later stage of the Industrial Revolution.

John “Longitude” Harrison

- A long tradition of skilled craftsmanship in metals contributed to the development of high-quality machinery. Among the preindustrial craftsmen, clock makers and watchmakers were the most skilled. The quest for accurate marine chronometers challenged a generation of clock makers, of whom the most distinguished was John “Longitude” Harrison (1693–1776).

- Sailors in Columbus’s day could already compute latitude accurately with readings from the stars and sun, but longitude was much more difficult. An extremely accurate clock could help: If you knew the time in London and knew your latitude, you could work out your longitude.

In developing his marine chronometer, John Harrison worked out methods to compensate for the motion of ships, humidity, and variations in temperature.
The challenge of making a clock that accurate took most of Harrison’s lifetime. Harrison aimed to win a prize of £20,000, offered by the Admiralty in 1714. The prize was offered in the wake of a disaster at sea, in which an English fleet whose navigators had miscalculated their longitude foundered on the rocks; 2,000 men were lost.

Harrison set out to compete for the prize while still a young clock maker. His first model, H1, went on a navy expedition to Portugal in 1736 and proved far more accurate than the ad hoc methods used by the ship’s captain. Harrison worked out processes to compensate for the ship’s rocking, humidity, and unevenness in temperature.

In a 1761 trial of an improved model, the longitude estimated was accurate to within one nautical mile. Although squabbles at the Navy Board held up the prize, Parliament gave Harrison £8,750 in 1773, when he was 80. His clocks used diamonds, improved steel, bimetallic strips, and other materials enhanced over the course of the century.

Captain James Cook loved the Harrison chronometer. Cook was the British mariner, explorer, and cartographer who circumnavigated the globe, located and mapped a large part of the Australian coast, charted the two islands of New Zealand, mapped much of the Alaskan coast, and discovered Hawaii. If anyone needed a good chronometer, it was Cook; thus, his endorsement was extremely persuasive.

**Joseph Bramah**

- Another important group of innovators were the locksmiths, who developed intricate and powerful mechanisms and advanced the possibilities of craftsmanship in metals.

- Joseph Bramah (1748–1814) was the most illustrious of these. The son of a Yorkshire farmer, he was apprenticed to a cabinetmaker. In 1778, he received a patent for a toilet-flushing system with a
ball and flapper—essentially the same system we still use today. In 1784, he obtained the first lock patent.

- In 1801, Bramah built a lock so complicated that he promised a reward to whoever could pick it. It had 470 million possible combinations and was finally broken only in 1851, at the Great Exhibition, by an American locksmith, who took 51 hours to pick the lock.

**Henry Maudslay**

- The next of these great precision tool makers was a man who worked for Bramah, Henry Maudslay (1771–1831), who greatly increased accuracy in instrument making.

- Maudslay grew up as a “powder monkey,” assembling explosives at an arsenal, then moved on to work as a blacksmith, where he showed a gift for detail work. He perfected metal lathes, making it possible for one precision tool to duplicate itself and to make other devices to exact specifications. Although earlier lathes had been made mainly of wood, Maudslay made his entirely of iron, for greater stability and durability.

- Maudslay linked his lathes to a steam engine to get a regular rotation rate. He adapted and improved a variety of earlier devices to hold the tool against the wood or metal being worked—in effect, serving as mechanical hands. He and his successors made these mechanical hands increasingly sophisticated, guided by fine screw threads, in ways that could be duplicated to make standardized items.

- Maudslay’s employer, Bramah, patented the device in 1794 and enjoyed many of the benefits. It was now possible to make lock parts by machine rather than (slowly and laboriously) by hand.

- In 1797, Bramah refused to give Maudslay a pay raise, prompting him to strike out on his own in business—an act of mean-spiritedness Bramah came to regret. Maudslay prospered and eventually employed 80 men in his own workshops.
Precision and Uniformity

- Maudslay spent much of his later career making steam engines for ships, including the first ones to be installed in ships of the Royal Navy, presaging the end of its long sailing tradition.

- Maudslay improved micrometers to an accuracy of almost $\frac{1}{10,000}$ of an inch. An invention of James Watt’s in the 1760s also depended on improvements of fine screw threads.

- Nearly all the prominent engineers and tool makers of the next generation worked for a time as Maudslay’s apprentices or assistants. One was Joseph Clement, who later built Charles Babbage’s calculating machine, which is now regarded as the world’s first computer.

- Maudslay perfected the making of screws, nuts, and bolts with uniform pitch (the angle at which the thread is set)—a vital improvement for high-pressure engines. The principles had been understood since Leonardo da Vinci’s day, but production was only possible on Maudslay’s precision lathes. Until then, each individual nut and bolt had had to be marked as partners in disassembly. Maudslay created sets, along with the taps and dies for cutting them to standard sizes.

James Nasmyth

- Maudslay’s last assistant was James Nasmyth (1808–1890), who shared his mentor’s perfectionism and went on to develop new machines, including the steam hammer. The son of an artist in Edinburgh, Nasmyth loved tinkering and building moving models.

- He realized early on that the key to high-quality engines is accurate machine tools. In a trip to London, Nasmyth showed Maudslay a working model of a high-pressure steam engine that impressed Maudslay so much, he took on Nasmyth as his assistant.

- In the 1830s, Nasmyth built and ran a factory halfway between Liverpool and Manchester, adjacent to the Liverpool and
Manchester Railway and to the Bridgewater Canal. (That location is surely as good a candidate as any for the symbolic center of the Industrial Revolution.)

- Nasmyth found high-quality machines much more reliable than many of his workers and wrote of his machines that they “never got drunk, their hands never shook from excess, they were never absent from work; they did not strike for wages, they were unfailing in their accuracy and regularity.”

- Nasmyth developed the steam hammer to help Brunel build the S.S. Great Britain’s massive drive shafts.
  - The steam hammer operator could control the force of the hammer descending on an object or could rock an entire building with a power-reinforced fall.
  - The steam hammer was the central instrument for making forgings (shaped iron and steel) from then on. In 1843, Nasmyth also developed and patented the pile driver—a closely related device that was vital for metal bridge building then going on across Britain.

- Nasmyth wrote an excellent autobiography, in which he emphasized the importance of hands-on work for aspiring engineers, enabling them to get a feel for the metals, machines, and techniques. He also believed that workers involuntarily responded to the energy that they witnessed when machinery was working properly.

**Joseph Whitworth**
- Joseph Whitworth (1803–1887) was the most famous of Maudslay’s assistants. Plane technology was vital for accuracy and was developed by several of Maudslay’s assistants and a few independent engineers before Whitworth. These included James Fox, who began as a butler to a country clergyman but who went on to build high-quality looms for Arkwright and Strutt textile mills, and Richard Roberts, the son of a shoemaker who ended up in Maudslay’s workshops.
Whitworth, a fanatic for improving quality, took the achievement of absolute flatness about as far as it could go before the development of microtechnology in the late 20th century.

Beginning in 1841, Whitworth campaigned successfully for all British manufacturers to standardize screw and bolt sizes, thread pitch, and depth. Prior to that, every manufacturer had different standards, which led to waste and complexity when repairing machines. Whitworth created the British Standard Whitworth (BSW) system, which persisted for the next century.

Whitworth also rejected the tradition of decorative frames and casings for his machine tools, in favor of massive functional designs, as heavy and stable as possible. And, unlike his predecessors, Whitworth specialized in making and selling machine tools—they were the heart and center of his business, rather than incidental to creating other tools.

High-quality machine tools furthered the goals of the Industrial Revolution and allowed for the development of production engineering and mass production. The next time you have to replace a nut on a bolt you already possess, or the next time you need a standardized part for your car, give a moment’s thought to Bramah, Maudslay, Nasmyth, and Whitworth, whose ingenious and innovative work laid the foundations for accurate, standardized, rapid machine manufacture.

**Suggested Reading**

Musson and Robinson, *Science and Technology in the Industrial Revolution*.

Sobel, *Longitude*.


Questions to Consider

1. Why was precision so essential to industrial progress?

2. What are the advantages of standardization?
For more than 200 years, journalists, politicians, sociologists, and other interested observers have debated the effect of industrialization on the English working class. Important questions include whether wages actually fell for the men and women drawn into the new factories, forges, and coal mines and whether the working class was growing steadily poorer or their lives were actually better than the rural poverty from which they came. Economic historians have concluded that there was a slight fall in real wages from the 1760s to about 1820, followed by a steady rise thereafter into the era of mid-Victorian prosperity. These are, however, just trends, which conceal the particular realities of individual families’ experiences.

The “De-Skilling” of Workers

- The shift to industrial work often entailed “de-skilling” of workers. The traditional sequence of apprentice, to journeyman, to master was displaced by a situation in which employees performed a single job. Many of these jobs, in mining, shipbuilding, and iron and steel working, required great physical strength, which gave advantage to younger men. Miners and shipyard workers sometimes worked in gangs of different ages, partly as a way of protecting their older members.

- As strength and eyesight deteriorated, older workers were often forced into lower-paying situations. In the industrial era, older workers were extremely vulnerable; there was no vestige of a welfare state until the early 20th century and certainly no state-supported pension schemes to care for elderly workers.

- While employers sought control over their workers, working people in many trades struggled to retain some sense of autonomy. Mine workers owned their own picks and shovels, for example, and paid to have them kept sharp by the blacksmith. Shoemakers had their own tools, as did coopers (barrel makers).
Swings in the Business Cycle

- An odious tradition was paying workers in “truck”—that is, not with real money but with tokens that could be redeemed only at a store owned by the employer. Prices were often higher than in other shops, and food was sometimes adulterated by unscrupulous owners. Its American equivalent, a little later, was the company store.

- Even workers paid in money usually had to patronize shops where they were generally charged high prices. They were too poor to buy anything in bulk and could never enjoy economies of scale. Those who worked a six-day week were often unable to shop until Saturday night, and late-night markets became a feature of industrial towns. Saturday night markets had a social function, as well.

- When work was available, most trades’ workers maintained a fragile solvency; however, seasonal unemployment and underemployment were widespread. Textile markets would sometimes be glutted, leading to layoffs. Swings of the business cycle could lead to years of accelerated work, followed by months of idleness, confronting working people with crisis conditions.

- Traditionally, there had been a clear connection between willingness to work and prosperity. By the early 1800s, it was becoming obvious that the business cycle took no account of individual decency. Before the Industrial Revolution, people went hungry when harvests failed. Now, some were hungry in the midst of what otherwise looked like prosperity—a baffling new reality.

Separation of Work from Home Life

- The New Poor Law of 1834 was a harsh measure to minimize social welfare. Those who had no work and no family to care for them were forced to go to the workhouse. This system also made it more difficult to travel to areas where work was available, because this relief was available only in the parish where one was registered as living.
• Workers shared the middle-class ideal that the man should work and his wife should stay at home to look after the children. On farms, women had traditionally worked as long and as hard as their husbands, but after migration to the towns, the separation of work from home created a new ideal.

• The reality of low wages often made fulfilling the ideal impossible, forcing married women into the workforce, where they were vulnerable to pay discrimination. Some industries excluded women from all but the lowest-paid and least-skilled work.

• Cities had always been unhealthy places, and they remained so—or deteriorated—as industry caused their immense growth—often with no planning for adequate sanitation or water supply and with no minimum standards embodied in building codes.

Friedrich Engels

• Friedrich Engels’s *The Condition of the Working Class in England* is one of the classic accounts of working conditions. In 1842, as a young man, Engels came from Germany to manage his father’s textile factory in Manchester. He traveled widely and wrote a searing account of the wretchedness of workers’ lives. He combined his personal observations with those of journalists, magistrates, and reformers.
Engels noted that workers’ houses in Manchester were built so shoddily and carelessly that they were never warm or dry and began to fall to pieces as soon as they were inhabited, yet landlords charged exorbitant rents. The homes were overcrowded, often with two or three families to a house, all sharing the same rooms. There was no running water, only communal wells and communal latrines.

Such areas were centers of the periodic outbreaks of cholera that terrified everyone after 1830. They were also chronic sources of intestinal and respiratory diseases. Photographs of the towns confirm written descriptions that these cities were full of choking smoke, smog, and sometimes acidic fog.

Engels also noted in the 1840s that a bad situation was being made worse by the arrival of numerous Irish immigrants.

He seems to have shared a widespread prejudice against the Irish, seeing them as prone to drunkenness and recklessness and having such low living standards that they would force down wages for everyone else.

On the other hand, Engels said that the Irish were more fiery than the phlegmatic English, and he speculated that they might provide the spark for revolutionary class consciousness that would lead to reform.

Engels’s book came out in Germany and impressed Karl Marx, who became his lifelong friend and collaborator. They anticipated that conditions would continue to worsen and that the workers would finally be goaded into collective revolutionary action.

Equally horrified was the French liberal Alexis de Tocqueville, who after seeing Manchester, famously remarked: “Civilization works its miracles and civilized man is turned back almost into a savage.” An American writer for the Whig Review of 1849 noted, “Every day I live I thank heaven that I am not a poor man with a family in England.”
Workers’ Protections

- An obvious way for the workers to react to poor wages, job insecurity, and dangerous working conditions was by creating trade unions—strength in unity. However, fear of the French Revolution prompted Parliament to pass the Combination Acts of 1799 and 1800, making it illegal for workers to conspire in this way.

- Only “friendly societies” were allowed, in which workers paid weekly sums with the promise of sick pay or a decent burial if they died in a work accident.

- Workers’ legal protections were also weakening. Since the late Middle Ages, Parliament had legislated minimum wages and fixed prices for many crafts and trades. After 1800, it began to repeal these laws in response to manufacturers’ lobbying and a new attitude toward economic growth and changing technology.

- Workers who had earlier been protected by these laws now found themselves more vulnerable. Courts had previously upheld workers’ complaints against innovations but now generally sided with the employers instead.
  - One response was intimidation of employers by workers. Another response was Luddism, a violent, destructive protest against labor-saving machinery. Luddites were named for “Ned Ludd,” a semi-mythical figure, comparable to Robin Hood, who stood up for the poor by attacking symbols of their oppression. Luddism began during the economic crisis conditions of 1811–1812 in Nottinghamshire.

  - Hosiery employers were using new looms and unskilled labor; the Nottingham workers responded by smashing the machines. Luddism then spread to northern areas, where hand workers were threatened with displacement by machinery. This panicked the government, which devoted huge resources to stamping out Luddism. Eventually, the movement was repressed.
Methodism

- A significant force in moderating radicalism was the influence of Methodism. Growing since the mid-18th century, the religion of Methodism caught on widely among working-class people who were alienated from the Church of England. The religion, which emphasized decency, restraint, temperance, moderation, and respectability, was particularly influential in Welsh mining villages and Lancashire textile towns.

- E. P. Thompson, in his 1963 book *The Making of the English Working Class*, suggests that the widespread adoption of Methodism in Britain, which had no counterpart in France, accounts partly for the orderliness of British industrial life in comparison with the repeated revolutionary upheavals in France. That moderation, as opposed to the tradition of riots and machine breaking, contributed to the later English trade unions’ emphasis on dignity and restraint.

- Thompson also emphasized that one of the consequences of industrialization was the recognition by the people who worked in these new mines, factories, and workshops that they all had something in common. He wrote, “In the years between 1780 and 1832, most English working people came to feel an identity of interests as between themselves, and as against their rulers and employers.” Consider his title, “the making” of the working class—created partly by pressures on them, partly by their reaction to those pressures.

- Thompson pointed out that these were real people, faced with difficult and often dangerous situations as they struggled to come to terms with a new reality. They were never passive but contributed to this new world—sometimes through protest and violence.
Suggested Reading

Belchem, *Industrialization and the Working Class*.


Hobsbawm, *Industry and Empire*.

Thompson, *The Making of the English Working Class*.

Questions to Consider

1. Why were urban conditions so squalid in the first industrial cities, and why was government slow to remedy the situation?

2. How did old traditions of work persist into the new industrial environment and with what consequences?
Industrialization changed the appearance of the world and its social organization. It had tremendous intellectual implications, as well, affecting political and economic thought, poetry, fiction, painting, and aesthetics. This lecture is a look at how poets and novelists responded to industrialization, whether praising it for its material achievements; condemning it for its noise, ugliness, and pollution; or puzzling over the vast disparities it generated between rich and poor. Industrialization is an inexhaustible topic for literature. Although it is not literally true, literature is—figuratively and symbolically—more emotionally intense than economic, technical, or political writing on the same topics.

A Human Enhancement of Nature

- For more than a century, critics have emphasized literary condemnations of industrialization, but there was actually a great deal of excitement and admiration for the new technologies and the changes they inspired.

- In a 1754 poem, John Dalton described the Thomas Savery steam engine, then in use to keep mines from being flooded. Impressed by its combination of fire, steam, iron, great wooden beams, and ability to pump water, he celebrated this machine as better than anything the Romans had built.

- Equally impressed with steam power was Erasmus Darwin (grandfather of Charles Darwin), who anticipated the wonders it would achieve in a lengthy 1792 poem called The Economy of Vegetation. Already before the invention of first steam train, Darwin glimpsed the possibility of powered flight and aerial warfare.

- Steam engines fascinated poets and novelists because machines never grew tired or discouraged and could do so much more work than individual people. Ebenezer Elliott, around 1830, pointed out
that Watt’s steam engine, though very powerful, was constructive, whereas tyrants’ powers were all destructive.

- Wordsworth makes a similar point in the poem “Steamboats, Viaducts, and Railways,” from 1833. Although Wordsworth was critical of the misuse of industrial power and was horrified when a railway line was built in the beautiful mountains of the Lake District, he also admitted that steam engines were a superb achievement, a kind of human enhancement of what nature had offered.

**Dark Satanic Mills**

- One response to industrialization was the belief that, as different parts of the world were brought closer together through railways and steamships, the bad old days of war would cease and universal peace would take its place. Charles Mackay was a newspaper writer and editor (the London *Times’s* reporter in New York during the American Civil War), who in “Railways, 1846,” voiced the hope that railways would bring peace and harmony.

- When we look at a steam locomotive, we see something old, something deserving of preservation. To 19th-century writers, however, locomotives were brand new. The temptation for artists was to compare them to something older, such as horses, which they were replacing.

- One of the most common reactions, especially among poets, was to criticize industrialization for making England uglier than it used to be and making nostalgic comparisons of past and present. In the 1868 poem “The Earthly Paradise,” William Morris, socialist and craftsman, condemns contemporary England for its ugliness, in favor of a happier, cleaner, imaginary past.

- For some artists, this comparison took on a philosophical or religious undertone.
  - For example, William Blake detested Newton and Locke; he saw them as attempting to unravel the delightful mystery of life and to put in its place barren mechanisms.
Blake’s poem “Jerusalem,” written in 1808, speculates that Jesus once came to Britain and contrasts a glorious religious utopia in the past with the contemporary industrial horror. He asks, “And was Jerusalem builded here / Among these dark Satanic Mills?” In fact, “dark satanic mills” entered English from this poem as a standard phrase condemning the ugliness of industrialization.

**A New Utopia or Hell on Earth?**

- The idea of factories as fiery pits of hell is another common image from the literary critics of industrialization. The poet Ernest Jones, in “The Factory Town,” from 1855, argued that people were being tortured in factories, just as they were once tortured on the rack by the Spanish Inquisition.

- Many writers had a special indignation about child labor. Frances Trollope suspected that middle-class people didn’t know, and didn’t want to know, what was actually going on around them; Trollope believed that literature was the medium for exposing evils.

- Depending on whom you read, you could conclude that industrialization was either building a new utopia or creating a hell on earth. Skillful writers were able to imply both ideas at once.

**Charles Dickens**

- One of the great ages of British fiction coincided with the Industrial Revolution. In 1854, Charles Dickens drew a deeply unflattering picture of the new industrialists in *Hard Times*.
  - Mr. Thomas Gradgrind is the pitiless representative of the industrial system, who has made a fortune in the hardware business and tries to bring up his children according to strict utilitarian principles. He spends his time tabulating data on people as though they were just pieces of machinery.

  - The representative working man in the book is Stephen Blackpool. Hardworking and honest, he refuses to join a trade union because he rejects the concept of class conflict. In the
Dickens implies that both sides of the industrial system corrupt and degrade people.

- Dickens himself as a child had been taken out of school and forced to work in a factory at the age of 12. The place swarmed with rats, and his job, for 10 hours a day, was to stick labels on bottles of boot polish. His father was in debtors’ prison at the time, which meant that Charles’s education had come to an abrupt end.

- Dickens was always a searing critic of child labor and of the feeling of monotony and helplessness characteristic of long hours of factory labor.

Elizabeth Gaskell

- Elizabeth Gaskell depicted sympathetic industrial characters in *Mary Barton*, but her version of their employers was much less satirical. Her husband was a Unitarian minister in Manchester who actually met many of the central figures and knew firsthand what was happening.

- A famous passage in *Mary Barton*, from 1848, contrasts the households of the poor and rich. The poor workers’ house has hardly any furniture, is infested with vermin, and smells terrible. In the gloom are “three or four little children rolling on the damp, nay wet, brick floor, through which the stagnant, filthy moisture of the street oozed up.” By contrast, the house of the local factory owner has a roaring fire, plenty of food for everyone, fine carpets, and even cut flowers.
Gaskell’s *North and South*, published in 1855, went further in arguing both sides of the great industrial question.

- Margaret, a 19-year-old girl, leaves the rural south of England with her parents and goes to work in a textile mill. She befriends a working-class family, whose father is a militant worker, preparing to lead a strike. At first, Margaret sympathizes openly with the workers and despises the factory owner, Mr. Thornton. She chides him for not looking after the workers better and, by calling them “the hands,” dehumanizes them.

- He responds that the workers put in their hours at the factory and are then free to do whatever they want; he refuses to become a paternalist. Thornton also points out to Margaret that in order to compete with his rival manufacturers, he cannot pay wages as high as he might like, or else will go out of business.

- The ending shows Margaret accepting Mr. Thornton’s offer of marriage. By then, the militant factory worker has come to recognize that on crucial questions, he and his employer agree: Their common foe is dishonesty, laziness, and backward-looking obstructionism. Margaret, too, has come to share this view and to reject the idea that there is an essential antagonism of interests between capital and labor.

**Industrialization Overlooked**

- Perhaps equally striking, however, is how many of the Victorian novelists said little or nothing about industrialization. Anthony Trollope’s dozens of immense novels take place in London and all over the English provinces, but there is never so much as a mention of industrialization. Only the fact that his characters travel by train demonstrates that the world has recently changed.

- George Eliot just once, in *Felix Holt*, created a politically engaged working man, whereas William Thackeray had none. That’s a reminder that large areas of Britain—particularly in the south—remained relatively unaffected by the industrial transformation.
• Of course, industry is always present in the background, creating fortunes for some, making others poor, and both sharpening and challenging class distinctions.

D. H. Lawrence
• In the late 19th and early 20th centuries, a new generation of novelists with working-class backgrounds achieved success, especially Arnold Bennett and D. H. Lawrence.

• Bennett’s novels are all set in the “five towns,” the potteries district where Josiah Wedgwood created the first modern pottery factories.

• D. H. Lawrence came from the Nottinghamshire coal fields. His autobiographical novel *Sons and Lovers*, from 1913, describes his early life growing up as a coal miner’s son. The father is a tyrannical, hard-drinking man made coarse and desperate by life underground, and the hero’s mother, who has come to hate her husband, is determined that her son shall not suffer the same fate.

Suggested Reading


Gallagher, *The Industrial Reformation of English Fiction*.

Warburg, *The Industrial Muse*.

Webb, *From Custom to Capital*.

Questions to Consider

1. How did authors’ social class position affect their literary interpretation of the Industrial Revolution?

2. Why do the acceleration of industrial life and the growing gulf between rich and poor make such compelling themes for fiction and poetry?
Britain has always had social classes, but they were never as rigid or impermeable as those of Spain and Prussia, for example. Aristocrats were sometimes willing to involve themselves in industrial affairs. This flexibility in social structure meant that, as the first generation of industrialists became wealthy in the late 1700s and early 1800s, they were able to gain political power and influence national policy.

**Political Representation for Industrialists**

- Ever since the English civil wars of the 1600s, Parliament had been the center of power; but the king still remained influential. He could often buy the compliance of important figures with patronage.

- The political system in the late 1700s and early 1800s gave the strongest representation to the aristocracy and landed gentry, whose income came from the sale of crops and the rental of farmland. They had a strong presence in the House of Commons and an even stronger one in the House of Lords.

- The industrialists’ first objective was to get political representation for the new industrial cities they had built. Manchester, Liverpool, and Birmingham had no seats in Parliament, and by end of the Napoleonic Wars in 1815, when these cities housed tens of thousands of people, there was no correlation between population and seats in Parliament.

- There was also no regular process of redistricting; thus, only an act of Parliament could effect change. The landed classes had an obvious incentive to discourage redistricting, fearing that it would lessen their influence.
A Corrupt System

- One nickname for the traditional political system was “Old Corruption,” given by an influential journalist named William Cobbett. He meant that it was an elaborate system of special privilege, bribery, and the artful exclusion of the majority—a system that could not possibly be defended on principle.

- Britain had a representative government, but it was not a democracy. Less than five percent of the men could vote. In constituencies where there was a genuine choice, candidates had to bribe voters with dinners, gin, and straight offers of money, making a campaign expensive and highly uncertain.

- Many places whose population had been in decline for centuries still had seats in Parliament—the so-called “rotten boroughs.” Others were “pocket boroughs,” in which the local landowner was able to choose whom he wanted as the Member of Parliament, with no possibility of a challenge.

- One possible response to this system was for manufacturers to buy landed estates and join the traditional upper class. Men who became rich enough through trade or business could buy access to pocket boroughs.

A Wave of Reform

- One response to the corrupt political system was to provoke public discussion of the inequities of the current system and agitate for reform. At end of the Napoleonic Wars, a wave of reform agitation, strikes, and food riots swept through Britain, especially in the manufacturing areas. The end of the war had created a recession and widespread unemployment.

- The government responded with repression, notoriously, the Peterloo Massacre of 1819, when a massive demonstration in favor of political reform was attacked by soldiers, killing 15 demonstrators and injuring nearly 500.
• The situation reached a crisis point in 1832. The Reform Act of 1832 passed the House of Commons but was rejected by the House of Lords, who stood to lose by the changes. That led to rioting in the major cities, even an attack on the home of the duke of Wellington, hero of Waterloo. Finally, the legislation passed.

• The clutter of anomalous methods was now replaced by uniform rules for voting in every constituency. There was new representation of industrial towns, with 50 or 60 new seats. Successful factory owners began to campaign for seats and to represent their own interests in Parliament.

Free-Trade Movement
• The industrialists, once they had more access, wanted British economic policy oriented in their interest rather than in the interest of the landowners. The main issues were free trade and political regulation of industry.

• First, industrialists wanted a reduction in tariffs. They believed in free trade—the idea that they should be able to import raw materials cheaply, without paying import duty, and export finished goods cheaply, without paying export duty. Reduced tariffs would enable them to sell their goods all over the world, expanding their markets and stimulating productivity at home.

• The industrialists also believed that free trade would generate peace—that is, everyone involved in trade arrangements would have an incentive to keep them going and to solve disagreements.
peacefully. They depicted themselves as men of peace, as opposed to the traditional aristocrats, for whom war was a way of life.

- Another benefit of free trade, from the employers’ point of view, was that if food imports came in cheaply, they would be able to pay lower wages to their employees and, thus, enhance profits. The argument was self-interested, but its advocates were confident that workers’ standard of living would also improve from sustained economic growth.

- Landowners, by contrast, wanted high tariffs on imported food because it enabled them to sell food at a higher price than if they had to compete with cheap imports. They had secured passage of the Corn Laws in 1815 to guarantee this principle.

The Anti-Corn Law League

- Once the manufacturing interest became more prominent in Parliament, the case for free trade grew stronger. Two Members of Parliament, Richard Cobden and John Bright, founded the Anti-Corn Law League in 1839 to campaign for free trade.

- The league held mass meetings, arguing that free trade was equally good for manufacturers and working people, bringing prosperity to all. It built Free Trade Hall in 1842, on the site of the Peterloo Massacre, which had become hallowed ground in Manchester.

- In 1842, the Tory government responded with many reductions of tariffs.

- Finally, the crisis of the Irish famine in 1846 prompted repeal of the Corn Laws. From then on, cheap food could enter Britain. Tariffs on most other goods were also ratcheted down to create a condition of near free trade.

Regulation of Industry

- A second issue was the political regulation of industry. Manufacturers argued that regulation should be left to individuals.
All men had the right to enter into contracts or not to enter into them, as they saw fit. This was the most fundamental freedom of all, and to legislate it was to limit freedom.

- Advocates of regulation argued that contracts were not being made by equally powerful people; thus, workers were at a disadvantage. They had to take what work they could get, even at near-starvation wages, and lack of political support exposed them to exploitation.

- Widespread use of women and children in the workforce strengthened the argument for intervention. Parliamentary commissions encountered dismaying cases of overwork, brutalization in the workplace, industrial disease, accidents, and premature death.

- This ushered in an era of growing statistical studies, sociological research, and public health campaigns. The argument was made on utilitarian grounds that regulation benefits even the employers by creating a healthier and less turbulent workforce.

- The outcome of these debates was a succession of factory acts and mine acts regulating the number of hours women and children could work and establishing baseline conditions for work.
  - The first of these was the Cotton Mills Act of 1819, prohibiting the employment of children in textile factories. It was strengthened in 1833 by the creation of factory inspectors and by specifying that children under 13 should be given some elementary schooling.

  - In 1842, after sensational revelations in public hearings, the Mines and Collieries Act banned the employment of women and girls in coal mines. In 1845, the first safety legislation regulating fencing of dangerous machinery was passed.

**Trade Unions**

- Industrial workers did not benefit from the Reform Act 1832. Only property owners could vote, and most workers owned no property.
• Some responded by joining movements for political reform in the 1830s and 1840s—notably the Chartists, who favored an extension of the franchise to all adult men. They wrote the “People’s Charter,” whose six points were designed to make it possible for ordinary working men to participate in politics.

• Other workers began to create trade unions. Although the Combination Acts were repealed in 1824, unions were still prohibited from picketing and intimidation and were still vulnerable to prosecution for conspiracy.

• Unions became steadily more powerful, especially among skilled workers, in the mid-19th century. Unions emphasized respectability, decency, and middle-class values as a way of allaying old fears but insisted on their right to participate in the benefits of industrialization.

• The Trades Union Congress (TUC), founded in 1868, debated common concerns. In the late 19th century, it began to explore the possibility of establishing a political party of its own—plans that eventually resulted in the creation of the Labour Party in Britain.

Karl Marx

• Meanwhile, a small minority of workers was attracted to the theories of Karl Marx. In Marx’s view, industrialization was desirable but not so long as it was organized on capitalist principles. In his view, capitalism was always exploitative.

• Marx favored collective ownership of the means of production and believed that socialist revolution was inevitable. As the working class grew larger and the bourgeoisie grew smaller, there would be a transformation of quantity into quality, and the proletariat would become revolutionary and overthrow the capitalists.

• Marx expected the revolution to happen first in England, the United States, and Germany as those countries became industrial leaders—
but certainly not Russia, which was still overwhelmingly a peasant society.

- Industrialists were, of course, aware of the existence of Marxism and of the appeal it might have for disgruntled workers. One of the arguments for paying better wages and for permitting political regulation of industry later in the 19th century was to forestall the danger that Marxist prophecies might come true.

### Suggested Reading


Royle, *Chartism*.

Rubinstein, *Britain’s Century*.

Schonhardt-Bailey, *From the Corn Laws to Free Trade*.

### Questions to Consider

1. Why was the political conflict between industrialists and landowners so sharp in the early 19th century?

2. Which was more useful from the perspective of working men in the 1830s and 1840s: the vote or better working conditions and wages?
Economics as a discipline came of age along with industrialization as intellectuals struggled to understand why Britain had become so dynamic, why it was so quickly growing richer, and why its political social structure was changing. Now, a system was beginning to develop in which great rewards went to people who broke with tradition and tried something new. By the early 1800s, the continuous improvement of machinery, the growing scale of factories, the increased movement of people into factories, and the social dislocations that went with these changes helped give rise to the discipline of economics.

Mercantilism

- In the 18th century, the prevailing economic theory was mercantilism, based on the idea of a zero-sum game: One nation’s gain must be another nation’s loss. Therefore, according to the theory, a nation must bring in more gold and silver than it exported and try to keep as much trade as possible for itself.

- This theory motivated the acquisition and jealous preservation of colonies by Britain and other European powers. It justified high tariffs, to make it difficult for other nations’ goods to sell in Britain. It inspired the notorious Navigation Acts, which mandated that all of Britain’s colonial trade must come via England and must be in British or British colonial ships.

- Mercantilism presupposed that a nation’s strength required close political regulation of economic activities—a claim that the theorists of the industrial age were about to challenge.

Adam Smith

- Adam Smith’s *The Wealth of Nations*, published in 1776, is often regarded as the first modern study of economics. A philosopher and
moralist during the Scottish Enlightenment, Smith was a professor at Glasgow University.

- In the book, Smith offered a sequence of fascinating and influential ideas, one of which was that self-interest can have positive social outcomes. In other words, a baker provides bread not because he is concerned about the welfare of others, but because he is concerned about his own welfare.

- Smith believed that wealth was based on labor, not on the possession of money. Nations were wealthy to the degree that they improved their efficiency in employing labor.

- An important point Smith made is that the division of labor increases efficiency to an astonishing degree. Therefore, three factors become important: workers’ dexterity, their ability not to waste time, and the invention of machines to do specialized work even faster. Smith realized that there was an immense amount of cooperation and division of labor already.

- Smith argued that the “invisible hand” of the market was extremely good at organizing economic affairs. Individuals respond to a new demand by providing the required goods or services. Government does not need to specify that someone should do it—and is likely to make mistakes in trying. This attitude was in strict contradiction to the position of the mercantilists.

- Smith also argued that there is a human propensity to trade. This was itself related to the division of labor—because it makes it reasonable for individuals not to try to do everything for themselves but to exchange parts of their labor in trade.

- Importantly, Smith reasoned that economic growth is real—not a zero-sum game. As people get wealthier, they are not necessarily taking wealth away from someone else. What’s more, consumers will benefit as producers compete to provide better-quality goods at lower cost. As successful businesspeople accumulate money, they
will reinvest it in new factories, creating new employment for more people.

**David Ricardo**

- Smith’s ideas were refined by David Ricardo in his 1817 book, *Principles of Political Economy and Taxation*. Ricardo, the son of a Jewish banker who had emigrated to England from Holland, was respected in Parliament for his understanding of complex economic issues.

- Ricardo witnessed the conflict between two groups of the wealthy—the landowners and the rising industrialists. Landowners wanted food to be expensive; industrialists wanted it to be cheap. Landowners were dominant in Parliament well into the 19th century and were eager to preserve their situation.

- Ricardo argued that as industrial progress continues, more workers are needed, and thus, wages will rise. Because workers have to be fed, food production increases. More and more marginal land will be used, and overall food prices will rise. Workers may get more money, but they are no better off because they have to pay more for food.

- The losers in the situation are the capitalists because they are forced to pay higher wages to keep their workforce. Landowners come out on top because they can charge high rent for land and get high prices for food.

- Ricardo became a great advocate of abolishing protectionist laws and allowing cheap imports of food into the country. He was more generally in favor of free trade to prevent unproductive landlords from profiting.

**The Business Cycle**

- Thomas Malthus, like Ricardo, assumed that even as national wealth increased, the poor would remain poor, because the ability to reproduce was so much greater than the ability to increase food
production. Only voluntary self-restraint could reduce population—Malthus favored delaying marriage or not marrying at all as a way of reducing the size of the population.

- The next generation of economists took up the question of the business cycle. Malthus had glimpsed it but had never developed it fully.

- By the early 1800s, it was clear that booms and busts alternated in the business cycle. For example, individual manufacturers hear of rising demand for a product. That gives them a logical reason for trying to meet the demand. Many enter the trade until the demand is satisfied. Now, so many are in the trade that they create a glut. Demand and, therefore, prices fall; workers are laid off; and some businesses go bankrupt.

- This pattern was first theorized systematically by Swiss historian and economist Jean Charles Léonard de Sismondi in 1819 in his *New Principles of Political Economy*. Although Ricardo had doubted that cycles and crises could happen, Sismondi saw the evidence. He observed that employers don’t have perfect knowledge of what’s happening, and everyone is acting in the dark. He favored government intervention to support the unemployed.

- Sismondi also observed the tendency of capitalists to pay excessively low wages, which led to periodic phases of overproduction and under-consumption. This idea was later picked up by Karl Marx, who predicted that crises would become ever more catastrophic and eventually provoke revolution.

**Robert Owen**

- Economists also involved themselves in the question of social justice. They asked whether exploitation was central to industrial capitalism or whether workers and employers have a shared set of concerns and goals.
The utopian socialists denied that class conflict was inevitable. For example, Robert Owen, who ran textile mills outside Glasgow, was a benevolent employer, who provided decent workers’ housing, fair wages, and a school for the children, yet his business was still profitable.

Owen’s 1813 book, *A New View of Society*, advanced an environmental theory of human development. He favored a kind of humane social engineering to create suitable industrial-era people. He argued that the factory was a social system, as well as a place of production, and could be run so as to create a form of cooperative sharing socialism.

**John Stuart Mill**

- Ricardo and Malthus were also friends of Jeremy Bentham and James Mill, the utilitarians. They brought philosophy down to earth, insisting that the greatest good for the greatest number, rather than some religious principle, should guide human conduct.

- John Stuart Mill, James’s son, tried to apply the utilitarian principle to economics. His *Principles of Political Economy*, published in 1848, became the great textbook of 19th-century economics and was widely read, translated, and reprinted.

- Mill pointed out that the laws relating to production that Smith and Ricardo had discovered were not matched by the laws of distribution; here, moral principles and community decisions must apply. He argued that if the community favored principles of equality, it could arrange distribution along those lines. No system of distribution was actually “natural” at all.
Mill was not a socialist, but many socialists and trade unionists found him sympathetic for such insights. He knew that in contemporary Britain, the lowest incomes went to the people who labored the most and the highest incomes went to those who did almost nothing. Abandonment or transformation of such a system was not necessarily unjust.

Mill believed in the value of private property and hard work. Mill also tried to turn economics into a rigorous academic discipline, modeled on the physical sciences. But he realized that prediction is always uncertain and that the complexity of human life makes accurate anticipation of the future impossible.

**Shift to Mathematical Economics**

- Already by the mid-19th century, some economists wondered whether the fundamental basis on which the Industrial Revolution was built would keep it going. William Stanley Jevons, a brilliant mathematical economist, wrote *The Coal Question* in 1865, arguing that Britain would soon run out of coal and the Industrial Revolution would end.

- The book also introduced the “Jevons paradox,” which argued that as fuel use increases in efficiency, we don’t use less of it but more. For example, after Watt improved Newcomen steam engines by making them more efficient, the number in use and total coal consumption went sharply up, not down.

- Jevons’s work also demonstrated a shift to mathematical economics, which has been a trend ever since. Although Adam Smith was purely descriptive, by the late 19th century, statistics and equations were becoming all the more important as economics became more detailed and precise.
Heilbroner, *The Worldly Philosophers*.

Schumpeter and Schumpeter, *History of Economic Analysis*.


Strathern, *A Brief History of Economic Genius*.

### Questions to Consider

1. What was so revolutionary about Adam Smith’s ideas, and what made them so difficult to grasp among his contemporaries?

2. Was John Stuart Mill justified in his claim that questions of distribution are not governed by natural laws and should be disconnected from questions of production?
The American Revolution coincided with the beginning of the Industrial Revolution in Britain, but there were important differences between the two countries. Where Britain had little land and a large population, America had an immense quantity of land and a comparatively small population. Some of the Founding Fathers, including Thomas Jefferson, wanted to prevent America from following the British path because he thought of cities as centers of vice and moral decay. Others, notably Alexander Hamilton, believed that America must industrialize. Hamilton persuaded President Washington in the early 1790s to encourage a policy of promoting industry, which would make the nation rich and powerful and end its dependence on foreign imported manufactures.

**Hamilton’s Views on the Economy**
- Alexander Hamilton published three significant reports in 1790–1791.
  - Hamilton’s *First Report on the Public Credit* stipulated that the U.S. government should take over the debts of all the states to give confidence to investors and to establish the principle of federal supremacy. This would help create political and financial stability, vital for industrial success.
  - A second report called for the creation of a Bank of the United States, modeled on the Bank of England. It stipulated that the richest citizens would invest in the bank, which would give them a direct material stake in the survival of the republic.
  - Hamilton’s *Report on Manufactures* stipulated that government would promote industry, with subsidies to get companies started until they could compete with foreign rivals.
- Hamilton supported creation of the Society for Establishing Useful Manufactures, giving the society a 10-year tax exemption as an
Although the company proved inadequate at running cotton mills, it leased land and water-power rights to private companies and later became a steel-making center.

The Entrepreneurial Americans

- What actually happened in the U.S. economy over the next 30 years was part Jeffersonian and part Hamiltonian. America not only began manufacturing but, according to Jefferson’s wishes, also became a farmers’ republic.

- In 1815, when the Napoleonic Wars ended, 95 percent of Americans made their living in farming or agriculture-related pursuits, whereas in Britain, that number had already fallen to about 30 percent. At the same time, however, an enterprising minority of Americans had begun to establish industries, especially in the northern states.

- The important difference between rural dwellers in Europe and America was that the Americans had a highly entrepreneurial outlook, were receptive to innovation, were politically active (nearly all white men had the vote by the 1820s), and thought of their farms in terms of businesses rather than subsistence.

- America had no feudal past and no peasants—these were middle-class citizens who were familiar with the idea of taking risks to make gains. Unlike the British, they were also highly mobile, willing to move for opportunities. Most had at least some education and were probably the most literate people in the world at that time.

Samuel Slater

- One approach to American industrialization was to bring British experts to the United States. Throughout the 18th century, Britain had passed laws to prevent emigration of skilled craftsmen and technology. Hamilton actively supported industrial espionage and the acquisition of skilled workers from Britain. Jefferson was skeptical of the idea and called these workers “ephemeral pseudo-citizens.”
The most famous of these transplants was Samuel Slater, who built the first commercially successful powered spinning mills in the United States and became a millionaire industrialist. In England, he was nicknamed “Slater the Traitor,” but in the United States, he is known as the father of the American Industrial Revolution.

Slater came from Derbyshire and was apprenticed to a British textile manufacturer, Jedediah Strutt, where he learned how to run and maintain Arkwright water frames for cotton spinning. He emigrated to the United States in 1789, at age 21, bringing an excellent memory for details of the machinery.

He set up his factory in Pawtucket in partnership with two Rhode Island merchants, using copies of Arkwright machinery. He was able to adapt the Arkwright system to American conditions and run the first successful water-powered cotton mill in American history.

Slater created a workers’ village modeled on the one in Derbyshire and employed entire families in the mill. He adopted the superior spinning mule in 1804, staying abreast of new English technology, and was one of the first American manufacturers to adapt steam power to the textile industry.

**Other Early American Industrialists**

A home-grown textile pioneer was Francis Cabot Lowell, from Boston. He visited British factories in 1810, memorized their main principles of design and machinery, and was able to build copies in a partnership called the Boston Manufacturing Company.

- Lowell died in 1817, but his partners built on his achievement and created a textile town named after him: Lowell, Massachusetts.

- Lowell integrated spinning and weaving at the same site, powered by fast-flowing water at the great bend of the Merrimack River.
• Machine maker Paul Moody, already an expert hand-loom weaver, created viable power looms at Waltham, Massachusetts. He created a planned worker town in order to avoid the horrors of Manchester—which Lowell had also observed.
  ○ The company employed young farm women on annual contracts. The idea was to give them a few years’ work experience before they returned to the farm to marry, instead of creating an English-style permanent degraded proletariat. The women were offered good working conditions and relatively high wages.

  ○ At first, women came to work enthusiastically at the model community and regarded the chance to work and earn their own money as liberating. However, work in the 1820s was still long and hard, and facing wage cuts and rent increases in the 1830s, the women struck twice.

  ○ Women created a trade union in 1845, hoping to improve pay and conditions. Textiles became an increasingly competitive business, and prices fell, putting a downward pressure on wages. Although the workforce later shifted increasingly to Irish immigrant women, the factory still competed successfully against British weavers.

**Eli Whitney**

• Eli Whitney is probably the most famous innovator in American manufacturing history. He is best known for his invention of the cotton gin, in 1793. The cotton gin was a simple device to separate cotton fibers from seeds in short-staple cotton—previously a time-intensive job.

• The innovation would have immense implications. In a sense, it affirmed the Jeffersonian view, by making America a rural supplier of raw materials to industrial England. It facilitated vast expansion of plantation slavery across the American South in the ensuing years and created a close connection between the South and English factories.
• Before the gin, slavery was potentially in decline as tobacco lands played out, but now, it received a new impetus and thrived from the 1790s to 1860s, when the Civil War finally ended it.

• Whitney and his partner wanted to be paid with an extortionate 40 percent of the cotton they ginned, and potential customers responded by copying the machine and building their own. Whitney spent years vainly trying to secure his patent rights and came close to bankruptcy.

• At that point, Whitney turned in desperation to another form of manufacturing that made him semi-legendary—as one of the early pioneers of mass production. He claimed he could make identical muskets for the U.S. army and signed a contract promising to provide the federal government with 4,000 muskets within 15 months and another 6,000 a year after that.

• A French gunsmith, Honoré Blanc, had tried to make muskets with interchangeable parts, and Jefferson had witnessed a demonstration of his guns’ being assembled from different parts in 1785 while U.S. ambassador to France. He wrote an excited letter to the secretary of war on the possibilities of this method and described it to George Washington.

• Even 20 years later, Whitney was not able to deliver the guns at the promised rate. However, getting the contract got him an advance of $5,000 and spared him the mortification of bankruptcy.
The American System

- Still, Whitney had the idea that it might be possible to make components sufficiently identical so that any set could be assembled into one working musket. This was the crucial insight of mass production, though Whitney lacked the skill, quality of machinery, and quality of workforce to make it happen.

- In his factories, fitters to tinker, file, and adjust were essential. Whitney hoped eventually to be able to dispense with skilled armormers so that cheap, unskilled labor could preside over work done by precision machines.

- A manufacturing approach called the armory practice (because it was first developed in American armories) relied on interchangeability of parts and mechanization to produce those parts. This method of production was later known as the American System.

- What’s more, among the weapons used by American soldiers in the War of 1812–1815 were Whitney muskets, which performed quite well.

Rift between North and South

- As soon as the War of 1812–1815 ended, cheap British imports began to flow into the United States. That prompted passage of the first tariffs (30 percent on iron, 25 percent on textiles) to help domestic manufacturers. These were the first of many tariffs over the coming decades, whose collective effect would be to stimulate American manufacturing to rival England’s.

- These tariffs also contributed to worsening political tensions in the new nation. The divide between North and South developed into a split between an industrializing sector that benefited from high tariffs and a raw-material sector that benefited from low tariffs. This situation demonstrated that different parts of the nation had drastically different conceptions of how government should direct its energies.
• In the next lecture, we’ll continue the story of American industrialization, showing how the United States first matched Britain’s achievements, then exceeded them.

Suggested Reading

Hounshell, *From the American System to Mass Production*.
Lind, *Land of Promise*.
Mirsky and Nevins, *The World of Eli Whitney*.
Morris, *The Dawn of Innovation*.

Questions to Consider

1. How did American conditions differ from British, and did they make the challenge of industrialization more difficult or easier?

2. Which was more realistic, Jefferson’s or Hamilton’s view of the American future, and why?
The application of steam power to long-distance travel was as vital to industrialization in America as it was in Britain. Once again, a combination of imported British ideas and local American developments proved decisive in meeting and eventually exceeding British achievements. The scale of the United States, its imperative need for labor-saving devices, and its enterprising population all contributed to making America the industrial nation par excellence by the post–Civil War decades.

**Fulton and Livingston**

- Although Robert Fulton is the most famous name associated with steamboats, he was not the first to manufacture them. American John Fitch created a steam-powered boat with an engine attached to rows of oars and demonstrated it in 1787 to Constitutional Convention members on the Delaware River in Philadelphia. He also designed and built a model steam locomotive.

- Robert Fulton (1765–1815), an ambitious farmer’s son from Pennsylvania, visited France, where he spent much of the 1790s tinkering with the idea of a working submarine. He finally got one built, and it sailed below the surface of the Seine River for 17 minutes. The French navy briefly showed an interest, but at that point, the practical applications seemed highly dubious, and it never went into service.

- The American ambassador to France, Robert R. Livingston, was impressed by Fulton, and the two created a partnership to make economically viable steamships. In 1803, Fulton built one and tested it on the Seine.

- Livingston was one of the richest Americans of his generation and a signer of the Declaration of Independence, with a great deal of
political influence; he was able to get exclusive rights to steam navigation on the Hudson River from the state legislature.

- Back in America, Fulton and Livingston capitalized on their French experiments and created a boat, later called the *Clermont*, which ran the first commercial service, beginning in August 1807, on the Hudson River from New York to Albany.

- Fulton and Livingston ordered two more ships, both of which also turned a profit—demonstrating to skeptics that this was a viable method of travel, superior to sailing ships, which even on a broad river, had to tack against the wind.

**Steamboats on the Mississippi**

- Fulton built the first Mississippi steamer in 1811. It sailed successfully from Pittsburgh to New Orleans. Briefly, Fulton and Livingston had monopoly rights on the Mississippi, but the fury of the westerners, plus legal challenges, overthrew their exclusive claims and opened up the river trade to competition.

- That led to rapid improvement in the boats, a rapid decline in cost to passengers and freight shippers, and economic expansion.

- Steamboat travel on the Mississippi was hazardous, however. Early hopes for huge profitability proved ill founded, and it became a highly competitive business. Both insurance and fuel costs were high.

**The Erie Canal**

- Canals and railways were vital to British industrial growth, and they were equally important on the American side of the Atlantic. The Erie Canal was the first great canal in America. Begun in 1817 and opened in 1825, it ran for 360 miles across upstate New York, linking the Hudson River at Albany with Lake Erie.

- To appreciate the importance of the Erie Canal, we need to understand the extent to which the Appalachian Mountains had been a barrier until the canal opened. The chain separated the East
Coast from the Midwest. Transport across them was extremely costly. But once the canal opened, there was a continuous circle from the East Coast to the Great Lakes, the Mississippi Valley, and the Gulf of Mexico. Steam power made it possible to travel all parts of it in both directions.

**Railway Fever**

- The next step in the American Industrial Revolution—building American railroads—was not a smooth transition because railroads needed so much capital. The first working railways on a significant scale were the Charleston and Hamburg in South Carolina and the Baltimore and Ohio Railroad, designed to run from Baltimore over the Appalachians to the Ohio River.

- A key figure here was Peter Cooper, a carriage maker who built *Tom Thumb*, a locomotive light enough not to break the rails (a common early problem) and short enough to negotiate steep curves.

- Railway fever caught on quickly as speed and reliability improved; however, most lines before the Civil War were still relatively short, from one town to another nearby.

- The first of the great trunk lines was the Erie Railroad, from New York City to Lake Erie. Begun in 1835, it took 16 years to build; the company frequently went bankrupt, and there were endless difficulties acquiring land, keeping laborers, and making equipment work.

- Early railroad travel proved hazardous. When trains crashed in the winter, for example, the wooden carriages often splintered, and coal from the stoves set fire to the debris. Death by fire was common for railway riders throughout the 19th century, until wood coaches were replaced with metal ones in the 1890s.

**Farming with Machines**

- In the 1830s, the rate of American inventions accelerated. *Putnam's* magazine declared, “The genius of this new country is necessarily
mechanical. Our greatest thinkers are not in the library, nor the capitol, but in the machine shop.”

- Consider the McCormick reaper, developed by Cyrus McCormick in 1834, and the steel plow, developed by John Deere in 1837. These two inventions had the effect of enabling individual farm families to farm large acreage.

- The Homestead Act of 1862 opened up the Great Plains to settlement, and tens of thousands went there after the Civil War. A farm of 160 acres could be plowed with a Deere plow and harvested with McCormick reapers.

Samuel Morse
- On the face of it, Samuel Morse was an unlikely inventor of a great technology. Morse was a painter, who spent years living in Paris and copying the European masterpieces at the Louvre and was later an art history professor.

- In France, Morse had witnessed the semaphore system that brought news to Paris from the ports when ships came in. It worked fine in good weather but was hopeless in mist and rain. He asked himself whether it might be possible to create an electrical equivalent. Morse had learned of electrical experiments being carried out by others, including Joseph Henry, who had worked out how to send a current down a wire to ring a bell a mile away.

- Morse’s distinctive contribution was to create a version of the alphabet in short and long electric pulses, or dots and dashes, Combined with trains and a rapidly modernized post office (as in England), Samuel Morse’s telegraph accelerated the transfer of information on both sides of the Atlantic.
that could travel over the wire and be quickly translated back into English. He successfully demonstrated his system at a congressional hearing in 1838. In 1844, he succeeded in sending a message from the Supreme Court to Baltimore, about 35 miles away: “What hath God wrought.”

- Rapidly accelerating the transfer of information, the telegraph caught on quickly on both sides of the Atlantic. England and France were joined by telegraph in 1851. Britain and America were joined by 1858 (although the first cable soon failed and couldn’t be replaced until after the Civil War, in 1866).

**The Colt Revolver**
- Firearms remained an area ripe for innovation in America. Samuel Colt was an emblematic figure in the history of American business. He went much further than Eli Whitney had in mass-producing firearms.

- Colt was the first to figure out how to make a revolver work without all the chambers igniting at once (a great hazard with early models). The Colt revolver was an ideal close-combat weapon because it was short and manageable.

- Texans were enthusiastic about Colt revolvers in the Mexican-American War of 1846–1848. The huge western migration that followed the California Gold Rush also led to a surge in sales; Colt sold 325,000 pocket pistols of an 1849 design.

- High-quality machine tools meant that the gun parts were nearly interchangeable; however, fitters at the end of the process still had to file and adjust the finished guns.

**Rapid Improvements in American Technology**
- The rapid rate of improvement in American technology caught English rivals by surprise. Americans swept most of the machinery medals at the 1851 Great Exhibition in London; winners included Colt and McCormick. McCormick also won the *Légion d’honneur*
in France, “having done more for the cause of agriculture than any other living man.”

- The English machine-tool maker Joseph Whitworth, who standardized screw threads, led a British delegation to America to see how Colt and others were perfecting machine-standardized manufacturing. Colt built a factory in London in 1853, which was much admired for its high degree of standardization of machine-made parts.

**Industrial Capacity and National Power**

- The era of the Industrial Revolution was indeed a time of buoyant optimism; however, looming over it was the question of slavery. In many ways, slavery and industrialization were direct opposites—forced labor rather than free—but in another sense, they were linked. For example, cotton grown by slaves fed the textile factories of Britain and America.

- In the early 1860s, these two systems were put to the test in the American Civil War. Industrialization of the North proved decisive. Far more railroad mileage meant greater ability to move troops, better armories and weapons, and improved manufacturing capacity. European onlookers concluded from the Civil War that national power and industrial capacity were becoming synonymous.

- The United States was not the only nation to follow Britain’s industrial lead. As the 19th century dawned, France, Germany, and the Netherlands also recognized the advantages of the Industrial Revolution and began to adopt the new technologies. European industrialization will be the topic of the next two lectures.
Suggested Reading

Douglas, *All Aboard*.

Morgan, *Robert Fulton*.

Morris, *The Dawn of Innovation*.

Staiti, *Samuel F. B. Morse*.

Questions to Consider

1. How did American social conditions create an environment receptive to new inventions in transportation and farming?

2. What was the connection among slavery, industry, and the Civil War, and how did industrialization influence the outcome of the war?
In this lecture, we will explore the Industrial Revolution in Europe and look at how industrial processes took hold there in the 19th century. Before about 1830, Europe lacked several of the characteristics that helped Britain pioneer the Industrial Revolution. First, it was swept by constant warfare. Second, it was politically fragmented, especially in Germany and Italy. Third, European banking and insurance systems were less well developed than those in Britain, prohibiting the growth of innovation and invention.

**Constant Warfare**

- Europe had been swept by almost constant warfare from the 17th century into the 19th. The Thirty Years’ War (1618–1648) devastated Germany and was followed by a long sequence of 18th-century power struggles, many of which took place on German soil, discouraging investment.

- German states were headed by warrior-aristocrats who lived to fight. The Prussian Junkers were landowners whose peasants lived in conditions close to serfdom. Junkers would become soldiers but not entrepreneurs; Prussian society had no social mobility and maintained rigid class demarcations.

- Then, in the late 18th and early 19th centuries came the great upheaval of the Napoleonic Wars. All of Europe was convulsed, whereas Britain enjoyed prolonged political stability. For France, the years from 1793 to 1815 were ones of almost constant war against Britain, during which Britain imposed a naval blockade, defeated the French navy, and seized many of its colonies.

- In those crucial two decades, British industrialism roared ahead, and its overseas markets grew steadily larger, while French trade was bottled up. Even after the defeat of Napoleon in 1815, political
instability persisted. France experienced revolutions in 1830, 1848, 1851, and 1870. In Germany, the struggles of the late 1860s culminated in the German unification of 1871.

- The end of the Napoleonic Wars brought renewal of cheap British goods, which drove many French and German competitors out of business.

**Political Fragmentation**

- During this same time, Europe was also politically fragmented, especially in Germany. Italy was not unified until the 1860s, and Spain still had strong regional differences, traditions, and even languages.

- There were more than 300 governments in Germany before the Napoleonic Wars and still more than 30 afterward—each with its own laws, traditions, guilds, and strong local principles. Energy that might otherwise have gone into industrial development was devoted to running dozens of small state governments.
  - Customs and tariff barriers discouraged easy trade within Europe. Sometimes there were tariff barriers even within states.

  - The multiplicity of governments also precluded mobility of labor, preventing large numbers of people from making the switch from farming to industrial work.

- In France, peasant farmers became landowners during the Revolution, when feudal restrictions were abolished. However, they had little incentive to leave the land in the 19th century, population growth was moderate, and farmers were protected by high tariffs against imports of cheap food from abroad. The incentives that had driven English and American industrialization were absent.

- Britain had developed a worldwide colonial empire that created concentrations of capital of a kind that the continental European powers could not match. British naval power had gradually pushed the earlier colonial powers onto the defensive, while Spain
in particular had never developed the traditions of individual enterprise that facilitated industrialization.

**Lack of Innovation**

- European banking and insurance systems were less well developed than those in Britain. The Italian city-states had led the world in banking at the time of the Renaissance, but the area had been wracked by war and petty politics. The system lacked the scale and stability to maintain its advantages in comparison with Britain after the Glorious Revolution in 1688.

- The European systems were not conducive to obtaining patents. Although several important inventions were made in 18th-century Europe, such as the silk loom, chlorine bleaching, and advances in steel manufacture, they were isolated rather than part of a self-sustaining culture of innovation and progress.

- Britain, in contrast, had large centers of innovation and invention, such as Manchester and Birmingham, where constant improvements in technology and technique improved efficiency.

**The Industrial Revolution in Belgium**

- It slowly became clear to Europeans that industrialization and power went together. Industrialization was a way for enterprising and daring innovators to become rich.

- The first European country to emulate Britain was Belgium in the early 1800s. It had a long tradition of cloth manufacture and a population familiar with textiles, as well as rich coal fields for basic fuel. An iron and steel industry developed in Liège.

- Interested Belgian businesspeople began to visit Britain to see how industrialization was being accomplished, then began to lure experienced workers from Britain (as the United States had done with such British textile experts as Slater).
• William Cockerill, born in 1759, was a Lancashire blacksmith who became a mechanical engineer. In 1799, he moved to Liège and began to manufacture spinning and weaving machines based on British ones he’d seen in Manchester. Napoleon awarded him the Legion d’honneur, and Cockerill became a Belgian citizen.

• War blockades meant no supplies could come in from England; thus, Cockerill was able to corner the market on his machines, exporting many to France and becoming immensely rich. For a time, Cockerill’s factory was the single largest in the world.

French Ironworks
• The end of the Napoleonic Wars gave European powers the chance to begin catching up. Under Napoleon, France abolished internal tariffs and the traditional guilds, making it easier for labor to move to new businesses and adopt new technologies.

• French ironmasters began to visit England to learn about and eventually set up English-style integrated forges. One ironmaster, François de Wendel from Lorraine, visited England and Wales and persuaded many British workers to come back with him to set up a puddling forge. His plan was to get the immigrants to teach a generation of French apprentices, who could then take over the work at a lower rate.

• French ironmasters often found it difficult to get the same productivity from French workers, but by the mid-1830s, the British workers were disappearing, and new generations of French ironmasters and workers were taking over without the need for external aid.

Railway Building in Germany
• The German Zollverein of 1834 facilitated internal trade; it constituted a large free-trade area of German states, including much of what are now Poland and the Baltic states.
Railway building in France and Germany began in the 1830s and was a significant stimulus to other industries. In fact, railway building led the way in French and German industrialization in the same way textiles had in Britain. The first German line opened in 1835 (the year after the Zollverein); although just six kilometers long, it was profitable.

There was a great surge of railway building in the 1840s in Germany, with 6,000 miles of railway opened. The government alone had sufficient authority to build them, and government dominated railway building in this era. Traditions of entrepreneurship were still weak, and only the government had the required capital.

In Britain, the railways were a response to the existence of a nationwide market, as coal mine owners and manufacturers tried to break up the monopoly of the canals. In Germany and France, by contrast, the railways led the way and created a nationwide market, prompting other industries to develop.

There was an enormous drop in the cost of bulk transportation in Germany—somewhere between 80 and 90 percent. Now, it was possible to move coal long distances fairly economically. This was a stimulus to the growth of industrial districts around the Ruhr and Berlin.

**Railway Building in France**

- In France, railways were joint ventures between government and private enterprise. The government appropriated the land and built bridges and tunnels, while private companies laid the track. In the 1840s, private companies were given 36-year leases from the government to run railways, rather than permanent property rights. The government regulated the rates charged and insisted that all government shipments travel at below-market rates.

- France was already politically centralized and bureaucratic. Profound fears of foreign encirclement led to an early preoccupation with making railways part of a strategic system. For example,
the French government specified building railways along the German border as a defensive precaution—railways that were unlikely to be profitable and would not have been undertaken by private enterprise.

- Bureaucracy centered in Paris created a railway system that radiated from Paris to the different provincial areas but neglected to create links from one region to the next. Sometimes, it was possible to ship goods to a town 100 kilometers away only by sending them 500 kilometers to Paris on one line and another 500 kilometers back on another.

- There was widespread expectation that the French government would eventually nationalize the system, but in the 1850s, Napoleon III extended leases to 99 years. Railways were nationalized in Italy in 1905, in Germany in the 1920s, in France in the 1930s, and in Britain, in the 1940s.

**Tariff Barriers against Britain**

- Railways were the perfect incentive for ironworks because of the demand for iron rails, locomotives, and carriages. The boom in building railways made it worthwhile to invest in expensive blast furnaces and rolling mills.

- Despite the pioneering ironworks in France, which imported British workers, many parts of the French iron industry carried on using charcoal and wood for nearly a century after Britain had switched to coke. France, more heavily forested, had a lower incentive to change. Similarly, Sweden, nearly all forested, had still lower incentive and remained a producer of charcoal-smelted steel.

- European governments also created tariff barriers against imports of British consumer goods as they tried to help their own fledgling industries capture domestic markets.

- In the next lecture, we’ll explore more of the European Industrial Revolution, especially as it developed metallurgical industries,
culminating in the work of one of the great engineers of history, Gustave Eiffel, whose Eiffel Tower in Paris is probably the most recognized metal structure on the planet.

**Suggested Reading**


Evans and Ryden, eds., *The Industrial Revolution in Iron*.

Kitchen, *A History of Modern Germany, 1800 to the Present*.


**Questions to Consider**

1. Did Belgium, France, and Germany benefit or suffer from the fact that they had to catch up with Britain in the early 19th century?

2. Were the social or the political obstacles to industrialization in Europe more difficult to overcome?
In this lecture, we’ll take a further look at the Industrial Revolution in Europe. We’ll focus on Germany’s achievements in ironworks and metallurgy; its sophisticated educational system, emphasizing the sciences; and its achievements in electrical engineering and shipbuilding. We’ll also look at innovative builders in France, such as Ferdinand de Lesseps, who built the Suez Canal, and Gustave Eiffel, who constructed the Eiffel Tower.

**Beginnings of German Industrialization**

- German unification was a gradual process, led by Prussia under Otto von Bismarck and culminating in 1871. Bismarck declared King Wilhelm I of Prussia the new Kaiser, or emperor of Germany. After that, Germany industrialized rapidly.

- Bismarck intended to dominate Europe, and industrialization was clearly indispensable to that goal. The Ruhr district of northwestern Germany became the heartland of German industry. It had large coal deposits and iron ore mines.

- One of the first leading entrepreneurs in Germany was an Irish immigrant, William Thomas Mulvany, who moved to Düsseldorf in 1855. He brought in a group of British entrepreneurs and investors to open the Hibernia Mine. In 1866, Mulvany founded a local consortium, the Prussian Mining and Metallurgical Corporation, which was soon emulated by German-born mining experts and ironmasters.

**Alfred Krupp**

- Essen was home to the Krupp family, which had been among the town’s many small-scale metal workers for generations. Alfred Krupp (1812–1887) inherited a workshop with five employees and
turned it into an industrial empire that employed 20,000 in Essen and another 55,000 at other sites by the time of his death.

- Krupp was a great Anglophile; he visited Britain in 1838 to study metallurgical techniques. Krupp was in England for the Great Exhibition of 1851, where he presented a flawless block of steel weighing two tons—then the largest ever—and a cannon cast from steel. Superior to wrought iron, harder and more durable, steel was clearly the metal of the future for railways, weapons, and other uses.

- By 1900, Krupp’s was the single biggest industrial company in the world, concentrating on munitions and selling weapons to 46 different countries. He built the first steel breach-loading cannons, which proved their superiority over French muzzle-loaders (the traditional method) in the Franco-Prussian War of 1870.

A Center of Science

- Germany developed a sophisticated educational system that was the envy of the world in the 19th century, particularly in science. In fact, all serious Americans aspiring to scientific careers went to study there in the mid- and late 19th century.

- Germany led in industries that required advanced scientific knowledge, such as chemicals. For example, Germany pioneered synthetic dyes for the fabric industry—colors that were true and less costly than natural ones. A British inventor, William Henry Perkin, invented the first purple dye that didn’t bleed or fade, but German companies developed it.

- Aniline dyes also turned out to be painkillers, leading to German pharmaceutical developments, as well. German companies began to dominate in this area. Germany also led in advances in surgical instruments, watches, cameras, clocks, and electricity—one of the great new technologies of the late 1800s.
Werner von Siemens

- A representative figure for Germany’s achievements in electrical engineering was Werner von Siemens, who specialized in improving on technologies that others had invented. In 1847, he founded an electrical works that made telegraph equipment.

- Siemens also experimented with a method of telegraphy in which a needle pointed to a letter on a display to spell out words, an alternative to Morse code. His company grew rapidly after 1880 with Alexander Graham Bell’s invention of the telephone and electrical power transmission.

- Siemens built the world’s first electrically powered elevator. He contributed to the development of X-rays, dynamos, and loudspeakers, and he bought the rights to develop Edison’s inventions in Germany. Siemens also encouraged the creation of high-quality technical schools in Germany for training new generations of technologists.

Increasing Industrial Output in Germany

- As in Britain, in Germany, industrialization created a property-less working class, the proletariat. Overall living standards rose steadily through the late 19th century, starvation became almost unknown, infant mortality rates declined, and working people ate better diets with more meat.

- One of the founders of the Social Democratic Party of Germany, August Bebel, was a Prussian carpenter and doorknob maker, a skilled craftsman, who felt threatened by mechanization and capitalism.

- Bebel was convinced from reading the works of Karl Marx that capitalism was based on exploitation and that, although industry was a positive force, capitalism was not and must be displaced. Bismarck put Bebel on trial for treason. His prosecution failed for lack of evidence, but Bebel was then jailed for two years for making seditious speeches.
While Bismarck was acutely conscious of the challenge of socialism, he was also aware of the social stress caused by industrialization in Britain. He dealt with these issues by creating a welfare state to give working people a greater sense of security. Life expectancy in Germany climbed steeply between 1870 and 1914, partly because of this aid and partly because of rising real wages and overall better conditions.

Between 1870 and 1900, Germany’s percentage of the world’s industrial output rose from 16 percent to 19 percent, while Britain’s fell from 32 percent to 18 percent. By World War I, Germany and the United States had both overtaken Britain. In 1870, the biggest British companies were still larger than the biggest German ones, but by 1900, the situation was reversed.

**Ferdinand de Lesseps**

- France, in contrast, saw a much slower development of industrialization. Leading figures of the late 19th century in France included Ferdinand de Lesseps, who projected and built the Suez Canal—a project of considerable daring and imagination.

- De Lesseps was not a technologist but a career diplomat who had spent time in Egypt, read about various earlier canal projects, and eventually put together a scheme, drawing on the expertise of other engineers. He did not believe the rumor that the sea level was different at the two ends.

- His company arranged with the Ottoman Empire in 1858 to create the canal, which would be 118 miles long and 26 feet deep. Egypt provided the forced labor—1.5 million Egyptian workers. There was a continuous narrow channel by 1867 and an official opening of the wider canal in November 1869.

- Then, de Lesseps moved on to the Panama Canal project of 1882–1889. Unfortunately, the project was defeated by malaria and yellow fever, an inhospitable climate, constant landslides, jungle terrain, and labor shortages.
Gustave Eiffel

- Another leading French figure in the 19th century was Gustave Eiffel. Trained at one of the elite French schools, he was first a railway bridge builder employed by the government. His first significant bridge, the St. Jean railway bridge in Bordeaux, built at age 26, is still in use today.

- Eiffel had boundless faith in technical progress—he was the embodiment of Jules Verne’s idea that the engineer or scientist is the real hero of the modern world.

- Eiffel experimented constantly with better construction techniques and new materials, such as cast iron tubing for load-bearing parts. In the 1870s, he worked on making high-quality prefabricated parts that could be shipped to a site and assembled quickly. In the 1880s, he developed the concept of temporary portable bridges that could be assembled from prefabricated parts but later moved.

The Eiffel Tower

- Momentously, Eiffel was commissioned to build the ceremonial centerpiece for the Paris Universal Exposition of 1889, held to commemorate the 100th anniversary of the French Revolution. He overcame initial doubts by telling organizers that it would be the tallest building in the world (almost 1,000 feet) and that the French Tricolor would fly from the top. The Eiffel Tower remained the tallest building in the world from 1889 to 1930, until the Chrysler Building was built in New York City.
Eiffel made the revolutionary decision not to cloak the tower but, rather, to emphasize the fact that it was a great metal skeleton, with all of its structural functions clearly visible. Eiffel had previously designed and built the internal skeleton of the Statue of Liberty for the sculptor Bartholdi.

He also carefully worked out the wind stresses beforehand. Most of the parts were prefabricated, and logistics were extremely well coordinated.

The tower was his last major structure, and he spent the last years of his life fighting to prevent it from being dismantled. The original plan had been for a temporary structure for the exhibition. He argued that it would be useful for meteorology and even as an anchor for airships. He succeeded in getting it preserved, and it soon became useful for radio signal transmission.

**Industrialization Elsewhere in Europe**

Even by 1900, industrialization was far from universal in Europe. Italy, unified in 1870, had a rapidly developing north but a backward rural south. Russia and southeast Europe were still overwhelmingly agricultural.

In 1900, the Russian finance minister recognized that without industrialization, Russia could never be politically significant. He understood that if Russia did not undertake industrialization, it was going to be left behind or even colonized by the more advanced industrial powers of Western Europe.

Industrialization in Russia began in the decade and a half before the Russian Revolution. Lenin also regarded industrialization as the most essential job for building communism. Interestingly, Marx had never thought communism was likely in Russia; his point was that it comes with advanced industrialization and, therefore, would start in Britain, America, or Germany.
Suggested Reading

James, *Krupp*.

Jonnes, *Eiffel’s Tower and the World’s Fair*.

McCullough, *The Path between the Seas*.

Sylla, ed., *Patterns of European Industrialization*.

Questions to Consider

1. How did outstanding individuals, such as de Lesseps and Eiffel, advance the legitimacy of industrialization in Europe?

2. Did Bismarck’s use of the state to advance German industry contradict the economic principles developed by Adam Smith and his successors, or was it the right thing to do under the circumstances?
Oil is central to the world’s industrial economies today; it is the most lucrative of all commodities and one that determines the allocation of power and even the fate of nations. Any country that has oil reserves is likely to be able to make itself wealthy, whereas any country that lacks them labors at an immense disadvantage. In this lecture, we’ll examine the beginnings of the oil industry in America; study the successes of John D. Rockefeller, a gifted businessman who vastly expanded and dominated the oil industry and created Standard Oil; and explore the development of new technologies that subsequently increased demand for oil.

A Substitute for Whale Oil

- Like coal, its predecessor as the fuel for the Industrial Revolution, oil is fossilized organic material, subjected to geological forces over millions of years. Until very recently, the earth’s vast oil reserves lay untouched and almost unknown. Only since the late 1850s has oil been used as a fuel.

- Oil from the earth was known in the ancient world. Bitumen seeps in the Middle East were used for mortar and for waterproofing. In 19th-century America, oil seeped to the surface in western Pennsylvania and was blended with opium and used as a patent medicine. Its future potential was still not recognized.

- The chief source of oil before 1859 was from whales, and its main use was as lamp fuel. By the early 1800s, whaling fleets from England, Holland, Norway, and America were scouring the remote oceans in search of whales; in fact, whalers discovered many of the islands of the Pacific and Indian oceans in their quest for the elusive leviathan.

- Overhunting by the 1850s had pushed some whale species to the brink of extinction, had driven up oil prices, and was leading to
the search for a substitute. The spread of industry, with its need for lamp fuel and lubricants, intensified this quest.

The “Earth Oil” Boom

- The “earth oil” boom began in western Pennsylvania in 1859. George Bissell and Benjamin Silliman persuaded a consortium of New Haven bankers to finance its development. Bissell hired Edwin Drake, a salt driller, to dig for oil.

- The team struck the world’s first oil well, 70 feet under Titusville, Pennsylvania, in 1859. They were able to pump 35 barrels a day, which sold for about $20 per barrel. An “oil rush” ensued, comparable to the California Gold Rush of 1849.

- Soon after the first oil strikes, John D. Rockefeller arrived from nearby Cleveland. He quickly realized that the most lucrative part of the business lay not in getting oil out of the ground but in refining and marketing it.

- Refining meant heating oil to separate it into different layers. Kerosene was the first valuable layer; then came gasoline and natural gas. An early challenge was to move it from the oil fields, where it came to the surface, to the refineries in Cleveland. The rapid rise in production led to a rapid decline in price for crude oil, from $20 a barrel in 1859 to $0.10 by 1861.
Ruthless and Highly Successful

• Rockefeller achieved a near-monopoly position in the refining business in the 1870s. However, when overabundant supply pushed prices down to impractical levels, Rockefeller saw the need to control the whole industry and restrict output into the market.

• In the 1870s, he offered to buy out competitors, then kept on their owners as managers. He ruthlessly fought price wars; he would cut his prices and let the whole business run at a loss for a while, confident that he had the ability to outlast his rivals and force them into bankruptcy. As soon as they surrendered or went out of business, he would again raise prices to resume profitable operation—now with one less competitor.

• Rockefeller strove to ensure control of the oil transportation system. By shipping in large volume, he was able to demand preferential rates from railroad companies. He bought into early experiments in pipeline manufacture. In 1882, he established the Standard Oil Trust, a near-monopoly.

Standard Oil

• Standard Oil offered a high-quality product, guaranteed against impurities and against the danger of explosions, which were common in early kerosene lamps. Rockefeller pioneered in creating a nationwide marketing network and by advertising Standard’s distinctive red branding everywhere.

• Oil was shipped by train to localities, then taken in horse-drawn red wagons from street to street. Consumers would bring their own red “Standard” cans to the street to have them filled from the wagon tanker. Standard Oil’s reputation for quality and safety made the product popular with consumers.

• Rockefeller was a pioneer of vertical, as well as horizontal integration. He acquired forests so that he could make his own barrels; he bought boats in New York to keep the export business in his own hands.
• Rockefeller’s business methods provoked increased criticism. Henry Demarest Lloyd wrote editorials in the *Chicago Tribune* against Rockefeller’s monopoly practices, undercutting of competition, and demand for rebates from railroad companies that carried the oil. Lloyd’s lengthy article in *The Atlantic Monthly* in 1881 summarized the case against Rockefeller and lost the industrialist much of his good reputation.

**The Richest Man in the World**

• In 1882, Rockefeller and his partners created the first modern “trust,” a way of sidestepping literal monopoly by creating a series of branches of the company and having a board of trustees oversee everything.

• By then, Rockefeller always had enough cash on hand. He was able to sail through economic hard times, using them to his advantage to buy other assets cheap and strengthen his grip. He was fanatical about increasing quality, cutting costs, maintaining efficiency, and expanding the company.

• By 1890, Rockefeller was probably the richest man in the world. He eventually became a large-scale philanthropist. He founded and donated millions to the University of Chicago, yet he refused to have any of its buildings named after him.

**Discovery of New Oil Fields**

• No one knew how much oil was available in the Pennsylvania fields. Geological knowledge was very limited, and many feared the oil reserves would soon be depleted. In 1885, the state geologist of Pennsylvania said that people living at the time would witness the end of oil.

• A few early strikes in California were of poor quality and deep, which made drilling much more expensive. However, in 1892, a driller named Lyman Stewart hit a high-pressure well, producing more than 1,500 barrels per day. By then, a field on the Ohio-
Indiana border had also opened up, leading to another plunge in crude oil prices.

- Rockefeller, changing course, decided to buy actual oil wells, partly so that he could store the oil rather than sell it too cheap on a glutted market. In the 1890s, discoveries were made in 11 other states, notably in Texas and Oklahoma.

- The most dramatic oil well was at Spindletop, Texas, discovered in 1901. Much deeper than previous wells, at 1,000 feet, it sent a gusher 175 feet into the air and roared like a volcano. Once contained, it produced 100,000 barrels per day. By then, dozens of other drillers had gushers of their own, and the price fell to $0.03 a barrel (less than drinking water at the same site).

- Although the industry faced overproduction from wells, a series of new technologies guaranteed the future of oil, eliminating the oversupply problem. The first motor vehicles, invented in the late 1880s, used gasoline. What’s more, railroads began to look for ways to switch to oil once it was clear that a plentiful supply would be available. Ships, including navy ships, switched from coal to oil.

Trust-Busting

- By now, the political situation of the trusts was changing. Congress had passed the Sherman Antitrust Act in 1890, but it was relatively toothless at first.

- Ida Tarbell, one of the first “muckraking” journalists, published a history of Standard Oil in 1904. It went into detail about Standard’s industrial espionage, bribery of state legislatures, and use of intimidation and price ways to beat rival companies into submission. Tarbell came from Titusville, where the oil boom had begun and where her father had been one of the competitors swallowed up by Standard Oil.

- Theodore Roosevelt, president from 1901 to 1909, decided to use the power of the federal government to intervene against abusive
trusts. His justice department launched a prosecution of Standard Oil in 1906, saying that its directors were “the biggest criminals in the country.” It was an immensely complex case that took three years to resolve. The outcome was a court order to dissolve Standard Oil.

- The Supreme Court upheld the verdict. Standard Oil was broken up into several companies: Esso (which later became Exxon), Chevron, Mobil, Amoco, Conoco, and ARCO. Because they did not compete vigorously against one another, the public benefit of the breakup was marginal. Shareholders who held on to their holdings, including Rockefeller, soon found that they were richer than ever before.

**Growth of the Automobile and Demand for Gasoline**

- The rapid growth of automobile use at exactly this time led to an immense increase in demand for gasoline, which had hitherto been an incidental product of refining.

- William Burton, a chemist trained at Johns Hopkins, working for Standard of Indiana, devised a technique for getting more gasoline out of crude oil, through the process of thermal cracking. Standard of Indiana (later Amoco) patented the process and sold the right to use it to the other former Standard Oil branches—making itself for a while the most successful of the spin-off companies.

- The rising automobile industry needed not only a dependable fuel supply but also a reliable supply of steel for frames, chassis, and engines. It came from the American steel industry, which grew to immense proportions in the same years as Standard Oil. We’ll explore the steel industry in the next lecture, paying special attention to the larger-than-life man who dominated it, Andrew Carnegie.
Suggested Reading

Chernow, *Titan.*

Walker, Rienstra, and Stiles, *Giant under the Hill.*

Weinberg, *Taking on the Trust.*

Yergin, *The Prize.*

Questions to Consider

1. What were Rockefeller’s greatest worries, and were they justifiable?

2. Is it possible that the public benefited from Standard Oil’s achievement of a near-monopoly position in the oil industry?
Steel and oil are the two fundamental raw materials of the industrial world—even today—and John D. Rockefeller and Andrew Carnegie did more than anyone else to establish successful business empires around them. In the last lecture, we saw how Rockefeller created one of the first modern corporations and brought a new product, oil, to the center of industrial society. In this lecture, we’ll examine how a much older industry, iron making, was revolutionized in the mid-19th century by Andrew Carnegie, one of Rockefeller’s contemporaries. Like Rockefeller, Carnegie was a fanatic for business discipline, efficiency, and technological modernization. By the end of the 19th century, Carnegie came to dominate the steel industry.

Increases in Iron Use

- Iron use increased steadily in the early American republic, rising from 30,000 tons in 1776, to 200,000 tons in 1830, to 820,000 tons in 1860. Demand came from the increased number of steam engines in use and, after 1830, from the rise of railways, which needed iron rails.

- British techniques, such as coking coal and puddling, for wrought iron were adopted in the early 1800s, though the abundance of wood in America meant that coal remained the standard fuel for much longer than it did in England. The iron industry was centered in Pennsylvania, where supplies of iron ore and coal could be brought together.

- Steel was then only a tiny part of the industry, used for special goods, such as swords and knife blades. Steel was difficult to manufacture, needing a precise combination of carbon (between 0.15 and 0.25 percent) and iron.
Improved Steelmaking Processes

• Henry Bessemer, a businessman and inventor in England, devised and patented a better method of making steel in the 1850s. Another Englishman, Robert Mushet, perfected the technique, working out how to create exactly the right mix of iron and carbon and blow high-pressure air into it. The method could make steel as cheaply as wrought iron and in volumes of up to 1 ton per minute.

• In the early 1870s, an American company, the Pneumatic Steel Association, gained patent rights to the Bessemer and Mushet inventions and licensed other American companies to use them.

• The Bessemer process was soon challenged by a second innovation in production, the Siemens-Martin, or open-hearth, process, which created a higher-quality steel containing less nitrogen.

Andrew Carnegie

• In this environment of innovative developments in steelmaking, Andrew Carnegie began to take an interest in steel manufacture. The Carnegie family had left their home in Scotland and come to America when Andrew was 13. Andrew worked first in an American textile factory, then as a Morse code telegrapher, and then for the railroads.

• He served as an assistant on the Pennsylvania Railroad in the 1850s while still in his 20s. There, he learned sophisticated business management techniques—dealing with distributed assets, levels of trustworthiness, strict accountability, unforeseen problems, and

Carnegie was never a steelworker and, like Rockefeller, is important chiefly as the creator of a great, semi-monopolistic corporation.
cost-effectiveness. He showed a great talent for buying successful stocks, taking advantage of what we now call insider trading, which was then legal.

- Carnegie’s experiences with the railroads convinced him that wooden bridges were vulnerable and should be replaced with stronger, more durable, and fireproof iron bridges. He invested heavily in the Keystone Bridge Company and when the Civil War ended in 1865, he resigned from railroad management to devote himself full-time to speculation, first in bridges, then in iron and steel.

**Surge in Railway Building**

- After the Civil War, there was a surge of postwar railway building. Between late 1865 and mid-1869, the first transcontinental railroad was completed, and other lines soon followed. Demand for materials rose steadily from year to year.

- Carnegie became majority owner of the Union Iron Mills and struggled to get its tradition-bound managers to think more rationally about iron production. He had gambled on the idea that others would know the business and that he would simply provide the capital, the customers, and the vision for the future.

- Until 1872, Carnegie made money mainly as a speculator, but an uneasy conscience nagged at him. He thought that amassing money was idolatrous, and now that he had a massive quantity of it, he switched once and for all into manufacturing instead of speculation.

- Steel was becoming increasingly necessary as the trains themselves were getting heavier and faster, causing significant wear and tear on iron rails. Carnegie planned to integrate all phases of the manufacture in one place and to generate massive economies of scale, while introducing much more rigorous bookkeeping at every phase, to know exactly where profits were greatest and losses most severe.
Edgar Thomson Steel Works

- Carnegie’s new factory, called the Edgar Thomson Steel Works, specialized in making high-quality steel rails at lower cost and higher quality than all competitors. It was sited near Pittsburgh, where two railways and a river were available to bring in supplies and carry away finished products.

- Carnegie’s company was part of the Bessemer pool, a group of steel companies that enjoyed the right to manufacture according to the Bessemer process and kept the price of rails high by excluding potential competitors.

- Carnegie consistently undercut his competitors, while steadily improving quality. He proved that steel rails were more durable and needed to be replaced less often than iron. Edgar Thomson Steel Works made a profit of $11,000 in its very first month of operation.

- The scale of production began to ramp up as blast furnaces grew larger and employees worked constantly to increase productivity. By 1900, Carnegie’s factory alone was manufacturing more steel than the whole of Britain.

“Continuous Flow”

- In 1890, after Carnegie bought a nearby plant, he achieved “continuous flow,” meaning that from the time the raw materials of coal, iron ore, and limestone came into the factory, they went through every process without cooling and reheating. Iron ore went in; finished steel rails or girders went out.

- One key part of the expansion was getting a reliable supply of coked coal; Carnegie wrangled with coke entrepreneur Henry Clay Frick in the 1880s over the price of coal. They solved the dispute by merging the companies, so that now one part of the company simply transferred the coal to another part.

- Carnegie bought out rivals whenever possible and eventually came to dominate the entire industry in the Pittsburgh area, though rival
companies dominated the Chicago area, Maryland, Alabama, and other regions.

The Homestead Strike

- Henry Clay Frick, Carnegie’s former competitor and a tough anti-union man, became his deputy. Carnegie claimed publicly to be pro-union, but he was impatient that the union members, skilled workers in the Amalgamated Association of Iron and Steel Workers, were reluctant to accept all his innovations in production. He felt they were impeding the progress of the company and should be excluded from his factories.

- Carnegie authorized Frick to provoke a crisis in 1892 at the Homestead Steel Works by refusing to negotiate a new union contract, then locking the workers out when they refused to accept a pay cut.

- Frick then built guardhouses around the factory, strung barbed wire, and set up searchlights, preparing for a standoff. The union workers also readied for a fight. Eventually, the state militia arrived, summoned by Frick and fighting on behalf of the company. Its firepower was enough to defeat the union. The outcome was a severe defeat for the union, not only at Homestead but also in other steel factories in the area.

- The Homestead Strike is remembered as one of the great traumatic events in the history of American trade unionism. The steel industry remained nonunionized until the Great Depression era of the 1930s.

Growing Demand for Steel

- Meanwhile, Carnegie was diversifying his product. He foresaw that when the national railway network was largely built, demand would diminish (although replacement rails would continue to make it a good market). He prepared for the day by developing steel girders and frames—for new skyscrapers, elevated railways, the superstructure of the Brooklyn Bridge, and more.
• Another enormous source of demand after the Civil War was shipbuilding, especially on the Great Lakes. The incentive here was partly the discovery of immense iron ore fields in Minnesota from the Mesabi Iron Range. Mesabi ore was high in phosphorus, which was not suitable for Bessemer converters.

• That prompted Carnegie to shift more of his production to the open-hearth method. Despite the expense, he would always upgrade equipment in light of shifts in demand and the nature of raw materials.

• The oil industry also became a major customer for steel goods; it required steel for tanks, tanker cars on railways, storage tanks at wells, and pipelines.

Massive Merger of U.S. Steel Companies
• In 1901, a massive merger brought the nation’s principal steel manufacturers together in one giant company, U.S. Steel, the first corporation in the world to be valued at more than $1 billion ($1.4 billion in assets). The deal was brokered by Charles Schwab, who worked for Carnegie, and Elbert Gary, president of Federal Steel.

• U.S. Steel brought together Carnegie Company, Federal Steel, American Steel and Wire, the National Tube Company, the American Tin Plate Company, the American Steel Hoop Company, and the American Sheet Steel Company. It soon added the American Bridge Company and Lake Superior Consolidated Iron Mines.

• At that point, Carnegie retired to devote himself to philanthropy and pacifism. He made a famous failed attempt to broker an end to World War I in 1915 and donated libraries and church organs throughout the English-speaking world. He also founded the Carnegie Foundation and Carnegie-Mellon University.

• In the next lecture, we’ll turn to the American labor movement, to understand how workers in these new industries managed new developments in the labor market.
Suggested Reading

Rogers, *An Economic History of the American Steel Industry*.
Standiford, *Meet You in Hell*.

Questions to Consider

1. Which was more important for success at the corporate scale in late-19th-century America: skill in production or skill in management?

2. Why was it possible for Carnegie to reduce prices while increasing the quality of his steel goods?
Sharp contrasts between the American and British labor movements continue to intrigue historians. Where the British trade unions became extremely powerful, created a political party of their own, and rose to play a central role in 20th-century British politics, the American unions remained smaller, weaker, and less political. On the other hand, American workers earned, on average, better wages than their British counterparts and enjoyed higher rates of social and professional mobility. In this lecture, we examine the contrasts between the British and American labor movements and offer some explanations for these differences.

Social and Professional Mobility

- As the scale of workplaces increased during the Industrial Revolution, face-to-face relationships declined, and workers often simply became a factor of production. Efficiency-obsessed factory owners, such as Carnegie and Rockefeller, wanted to be sure that every person worked as long and as hard as possible.

- In Britain, the tradition of staying in one place meant that workforces tended to know one another, be related, and have a sense that being workers was their permanent destiny. In America, strong traditions of social and professional mobility made workforces less homogeneous.

- In one basic respect, conditions favored workers in America over those in Britain. In America, land was plentiful and the population was comparatively low. Anyone who lived in America or who could get to America had the possibility of becoming a landowner—an option that tens of thousands followed in the post–Civil War years as Homestead Act farmers.

The Impact of Immigration

- Immigration intensified the heterogeneity of the workforce. Workers came from all over Europe or, in California, from Asia. At
Carnegie plants in 1901, when U.S. Steel was created, of the 14,000 workers employed, 11,000 were from southern and eastern Europe.

- Many came to America with the idea of upward mobility. They looked on their working-class condition as temporary, not permanent, and therefore did not want to harness themselves to their fellow workers permanently. Employers often played different ethnic groups in the workforce against each other in a deliberate attempt to hinder unionization.

- English workers lured to America often commented on the fact that America made a bracing contrast with England because the managers did not give themselves airs of superiority but accepted the American ideas of equality of opportunity and would fraternize with workers as equals.

- Shrewd employers simultaneously despised and exploited immigrant workers. They often had to teach immigrants newly off the boat how to read the clock, learn a few English phrases, get used to a six-day work week, and develop a sense of industrial discipline.

- It was difficult with such diverse groups for union leaders to build a sense of trust and cooperation. The International Ladies’ Garment Workers’ Union, representing clothing workers in New York City, had to hold meetings in English, Italian, Yiddish, Polish, and German, and language problems dogged many other working-class unions.

- Some immigrants looked on America solely as a place to make money before they returned home; thus, they were reluctant to get involved in industrial disputes, especially if the wages seemed to them relatively high. In fact, 44 of every 100 workers from southern and eastern Europe in the decade before World War I returned to their homelands rather than staying permanently in the United States.

**Union Radicalism**

- American radicalism was also largely influenced by immigrants, and this was another source of suspicion between them and older
ethnic groups of workers. Marxism had caught on much more strongly in Europe than in America.

- For example, during the Homestead Steel Works strike of 1892, an anarchist, Alexander Berkman, shot Henry Clay Frick. Berkman had nothing to do with the factories or the strike, but his act contributed to a swing in public relations against the workers. (Incidentally, his gun was so feeble that Frick survived.)

- Even 30 years before the Russian Revolution, there was intense fear against socialists and radicals, especially if they were atheists. Eugene V. Debs, American Railway Union leader and later leader of the Socialist Party, emphasized that his was a Christian socialism and that Jesus was a working carpenter with a bag of tools.

- This perspective was different from the employers’ view that workers were simply one of the costs of production. Employers tended to be powerfully influenced by social Darwinism, believing that it was natural for an employer to dominate his workforce. There was also a Calvinist tradition, very strong among American white Protestants, that encouraged a culture of hard work and stern self-discipline and that regarded poverty or unemployment as sinful, rather than as an aspect of reality in the world of the business cycle.

- These were the conditions in which unions in the United States struggled to develop. One early example was the Knights of Labor. It quickly grew very large, but it could not sustain itself.

**Great Railroad Strike of 1877**

- A series of strikes in the late 19\textsuperscript{th} century demonstrated the escalating sense of crisis as the scale of industry increased and as workers exposed to the business cycle felt themselves ever-more vulnerable.

- The first was the Great Railroad Strike of 1877, part of the fallout from a business recession that began in 1873. The strike originated in Martinsburg, West Virginia, when workers who had suffered
two successive pay cuts refused to work and brought trains to a standstill. The governor sent in the state militia, but its members sympathized with the strikers and refused to harm them.

- News spread along the railway system, leading to much more violent outbreaks in Pittsburgh, Baltimore, Philadelphia, and later, St. Louis. The worst fighting and destruction occurred in Pittsburgh, where the militia fortified themselves inside a roundhouse, only to have it burned down around them. They fought their way out, shooting more than 20 strikers.

- Most of the strikers were not unionized, and they were ultimately forced back to work. But the strike created a legacy of mistrust and resentment between labor and management that would worsen between then and the decade of the 1910s.

**Haymarket Square Riot**

- Another significant strike was the 1886 Haymarket Square riot. Unions from all over the country had been appealing for an eight-hour workday, and workers from the McCormick Harvesting Machine Company in Chicago were on strike.

- They held a large rally in Haymarket Square and made peaceful speeches, but then someone threw a bomb, killing seven policemen and four bystanders and injuring many others.

- Eight anarchists were rounded up and put on trial. All were convicted, and seven were sentenced to death, despite extremely flimsy evidence that they were the actual perpetrators of the crime. Four were executed the next year, and a fifth committed suicide in his cell.

**Pullman Strike and Eugene V. Debs**

- The Homestead Steel Works Strike, discussed in the previous lecture, gravely weakened the union movement in the steel industry. Another significant strike was the Pullman Strike of 1894. This was a strike against a pay cut for industrialist George Pullman’s
employees, many of whom lived in company houses whose rent was not cut correspondingly.

- Pullman cars were luxurious carriages, including sleeping cars, attached to long-distance trains. The American Railway Union tried to persuade rail workers nationwide to boycott trains pulling Pullman cars to force the employer to negotiate.

- Eugene Debs led the American Railway Union, and the strike probably would have succeeded had he not ignored a government injunction against impeding trains carrying the U.S. mail. Debs was imprisoned for contempt, and without his leadership, the strike unraveled and the workers returned to work.

- In labor union strikes, the role of government was often decisive. Historian Herbert Gutman has demonstrated that if the local community and local government sympathized with the strikers,
they would often prevail. But if employers could get government on their side, strikers would generally lose.

**Ludlow Massacre of 1914**

- During the Ludlow Massacre of 1914, miners were facing desperate conditions in a Colorado mining camp owned by a Rockefeller affiliate, the Colorado Fuel and Iron Company. The miners faced an extreme winter climate, long hours of work, low pay, and a high accident rate in dangerous mines subject to subsidence and explosion.

- The miners were also forced to use an overpriced company store for supplies—a common abuse of the era. The strike, which was organized by the United Mine Workers of America, lasted from September 1913 to the spring of 1914.

- The strike involved a succession of gun battles, sabotage, and atrocities. In the single worst incident at Ludlow, troops fired into the strikers and set fire to the tent colony in which they were living after being forced to leave company housing. The overall death rate in the area during the strike approached 100, making it the deadliest event in the whole of American labor history.

**Change in Response to Crises**

- After a public outcry about events in Ludlow, President Wilson sent in federal troops, who arrested many on both sides while trying to disarm and pacify the region. Wilson called for a congressional investigation.

- Rockefeller, aware that this was a public relations disaster, improved conditions in the area and created a system whereby workers were represented on committees relating to safety and work conditions. The defeated union later bought the site and built a monument to honor the dead miners and their families.

- The American counterpart of the British Trades Unions Congress was the American Federation of Labor, led by Samuel Gompers. He and his fellow leaders generally emphasized bread-and-butter
issues—better pay, workplace safety, shorter hours, and payment in money, not scrip. Gompers wasn’t as political as many of his British counterparts.

- Changes in labor conditions most often came in response to crises rather than as a result of a real shift in the balance of power, as was true in Britain. For example, a congressional investigation after the Ludlow Massacre led to legislation against child labor and in support of an eight-hour workday.

- By the early 20th century, Britain and America were heading in very different directions in terms of their labor situations. By then, America had already surpassed Britain as the leading manufacturer and had a reputation for innovation and ingenuity that Britain was beginning to lose.

Suggested Reading

Greene, *The Slavic Community on Strike*.

Gutman, *Work, Culture and Society in Industrializing America*.

Livesay, *Samuel Gompers and Organized Labor in America*.

Salvatore, *Eugene Debs*.

Questions to Consider

1. Why did the United States never develop a political party based on labor unions?

2. Were industrial conditions relatively better for working men and women in the United States by comparison with those in Europe?
For more than a century, historians have struggled with the question of why Britain, after pioneering the Industrial Revolution, eventually lost its competitive edge to America. In this lecture, we explore possible explanations, including the phenomenal industrial growth of America after the Civil War, Britain’s failure to exploit new technologies in the oil and chemical industries, a decline in the quality of British goods, the high status and esteem awarded American industrialists and the value of hard work, the emphasis on science in American schooling, and British reliance on protectionism and constraints on free trade.

Phenomenal Growth after the Civil War

- American growth, absolute and relative, after the Civil War, was phenomenal. For example, coal production rose from a small base in 1865 to 212 million tons in 1900 and 455 million tons in 1914.

- Americans switched early and effectively to machine cutting at the coal face, while Britain remained content with the hammer and pickax. German and American coal mines were installing underground electric tramways, but the British still used mine horses. Because British miners were paid less than American ones, mine managers had lower incentive to introduce expensive machinery.

- Similarly, with steel, U.S. production rose from almost nothing in 1860 to 10 million tons in 1900 and 50 million tons in 1914. By the time Carnegie sold out to U.S. Steel in 1901, his factories alone produced more steel than the whole of Europe.

- In textiles, whose innovations had been crucial to kick-starting the Industrial Revolution, British productivity and exports actually went down. British companies failed to adapt to an improved technique, ring spinning, whereas America successfully switched
over. Ironically, British companies made ring-spinning machinery, but they could not interest local buyers and, therefore, exported the equipment.

**British Investments in America**

- One possible answer to the conundrum of why Britain started to fall behind America might be found in the disparity in the size of the two countries.
  - Once America began building railroads and factories, the sheer magnitude of the United States and the vast internal market it provided made its eventually outstripping of Britain perhaps inevitable.

  - But this answer bumps up against the fact that there is no close correlation between land area and prosperity. For example, the Netherlands at the time was already becoming quite wealthy despite its small size, whereas Brazil remained poor. Clearly, many other factors were involved, as well.

- Another possible answer to the question is that Britain had had to experiment nearly every step of the way and often went down blind alleys, whereas the later-arriving nations, America and Germany, could take advantage of acquired experience and advance more rapidly, adopting rational schemes and state-of-the-art technology from the outset.

- We have also seen that Britain exported much of its accumulated experience to America—for example, textile operatives attracted to New England mills and British specialists lending their expertise in railway machinery and know-how.

- Also, British capital was heavily invested in American railroads, land, and industrialization throughout the 19th century for high returns. In fact, much of the financing for the Erie Canal came from British investors.
• Into the late 19th century, Britain remained very strong as a banking, financial, and insurance center and remained strong in shipping, as well. Much capital was diverted into these areas of the economy rather than into industry and manufacturing.

**Failure to Exploit New Technologies**

• Britain certainly remained a world power but seemed to lose some of its pioneering energy after about 1870. It failed to keep up with American advances of scale—as innovated by Rockefeller and Carnegie—and was content to have many small- or medium-sized firms making the same goods. Few companies went public, most staying in the hands of the families that had founded them. These firms were satisfied to make small, steady profits rather than growing and seizing larger shares of the market.

• America, meanwhile, pioneered the creation of semi-monopolistic corporations. Even more strikingly, Britain failed to get involved in the essential new industrial developments of the late 19th century, especially in the oil and chemical industries.

• Trade unions also played a role. Although the British Labour Party dedicated itself to socialism, in practice, unions tended to have a deterrent effect on industrial progress. Union members could not imagine the possibility that innovation would open up new employment opportunities, although in fact it did just that in America and Germany.

• Faced with the hazard of a strike, employers were more tempted to carry on in the same traditional way rather than innovate—and willing to accept smaller profits rather than fight. In other words, management had a conservatism of its own to match the conservatism of the workers, and all this took place in an environment in which class antagonisms remained strong.

• Britain was also less abundant in raw materials than America. Although it had most of the materials for the first Industrial Revolution (iron ore and coal), it did not have oil. By the 1870s,
Britain could no longer feed itself and was dependent on food imports from America and Canada.

- Britain was still immensely strong, and it was still the world’s greatest military and imperial power, but it was showing signs of strain.

Decline in Quality of British Goods
- At the same time that the quality of British goods was declining, the Americans became aggressive at improving the quality of their goods and marketing them successfully.

- As an example, in 1883, New Zealand ordered 20 locomotives from Britain, but after 18 months, only two had been delivered. It then canceled the order and gave it to a Philadelphia firm instead, which delivered them in four months and charged £400 less per locomotive.

- Historian Paul Johnson offers another example: In 1887, 24 new British naval gunboats were launched, nearly all of which went awry on trial. In one, three men were killed by an explosion in the boiler room.

Impact of American Imports
- By the 1890s, American inventions were being imported into England, such as sewing machines and typewriters. Innovative American advertising techniques helped sell them to British customers. At this time, Germany also vaulted ahead, exporting more goods to Britain.

- E. E. Williams’s book *Made in Germany*, published in 1896, warned Britain that it was losing or had lost its ability to compete in a growing range of industries, especially metals, chemicals, dyes, mining technology, automobiles, and the growing field of electrical goods.

- When the London Underground railways were built, mainly between 1900 and 1914, the electrical expertise necessary to make
the system workable came from the United States—a complete reversal of what had taken place in the railway technology system 60 or 70 years before.

Rewards and Status

- Another important difference between Britain and America was the system of rewards and status. Industrialists never acquired high social status or popular esteem in Britain, nor did those who were simply “rich” (that is, “vulgar”). The aristocracy, which set the tone for British life, favored a life of conspicuous leisure, not hard work.

- One way of understanding the relative decline of Britain side by side with America is by seeing which Americans wanted to move to Britain, as opposed to which Britons wanted to move to America.
  - Probably the most famous American emigrant to Britain in the late 19th century was the novelist Henry James. In his view, Britain was a far more fertile source for fiction than the United...
States. Britain had ancient traditions, a heritage of feudalism, and far greater nuance and complexity in its class system.

- And James’s novels are explorations of the strange ways Europeans express their sense of class pride. Often, these novels involve naïve Americans bumping up against a kind of civility that they’ve not met before in the straight-ahead, money-matters-most world of America.

- In Britain, men who made fortunes in industry often bought their way into the aristocracy and taught their sons to become gentlemen of leisure rather than factory operators. These young men would go to Eton and Christ Church, Oxford, where they would meet members of the upper classes, absorb their attitudes, share their interests, and shun the idea of becoming factory managers.

- The heirs of early industrialists sometimes used the family factories as sources of money rather than as businesses that needed constant care, steady reinvestment, and upgrades to equipment.

**Lack of Scientific Literacy**

- In Britain, the status of science was very low at the universities, especially if it had a practical or technological application. Yet scientific education was vital to understanding new methods in all the major industries.

- Class stratification also meant that the vast majority of young Britons had no prospect of ever seeing the inside of a university. Elementary schooling for all was only introduced by legislation of the early 1870s and was dogged by disagreements over what religious curriculum should be taught, rather than what might seem more relevant—the need for basic math and scientific literacy.

- As the British Empire grew through the 19th century, imperial service, either military or administrative, was another attractive career, higher in status than industry.
American entrepreneurs, by contrast, passed on businesses from father to son, creating industrial dynasties, such as those of the Rockefellers, Vanderbilts, and Fords. Business and industry remained high-status activities in America, where hard work was esteemed rather than scorned.

British indifference about industry is weaker today than it was 100 years ago, but the tradition still has not completely died out. However, in America, the best and brightest at the universities often go on to business school.

**Tariffs and Protectionism**

- Another reason for the disparity between America and Britain lies in the traditions of the British Empire, which grew rapidly in the Victorian era. Britain had pioneered free trade, but in the later decades of the 19th century, as it began to struggle against foreign rivals, some politicians and businesspeople pointed out that the empire could be closed off to outside business and become a protected market for British goods.

- In the 1890s and 1900s, tariffs returned, which were beneficial in the short run because they created protected markets, but they were destructive in the long run because they permitted Britain to get away with its failure to keep up.

- Protectionism would come back to haunt Britain when the defense of the empire added to its difficulties in the two world wars and when the worldwide revolt against imperialism after World War II eliminated the empire altogether.

- However, it is important that we not overstate British decline. Some historians also note that Britain in 1850 was more like Britain in 1750 than Britain in 1914. That is, although nearly all the conceptual and technological breakthroughs had been made by 1850, they still involved a comparatively small percentage of the population, whereas by 1914, these breakthroughs were almost universal.
Suggested Reading

Burk, *Old World, New World*.


Mathias, *The First Industrial Nation*.


Questions to Consider

1. Was it inevitable that America would outpace Britain in industrialization, and why?

2. What “lessons learned” by the British were Americans able to exploit in their own industrialization efforts?
Thomas Edison, the most famous American inventor of his era, perfected the lightbulb in 1879 and created the first commercially viable electric lighting system in the 1880s and 1890s. George Westinghouse challenged Edison with alternating current, the system that eventually prevailed. To its first observers, electricity had an almost magical quality. Its use caught on quickly, affecting nearly every other industry. Electricity also transformed the landscape, with the building of coal-fired power stations and, later, the damming of rivers for hydroelectricity. It transformed the urban setting, as well, by festooning city streets with transmission wires.

Development of Electrical Technology

- The scientific study of electricity in the 18th and 19th centuries eventually gave rise to electrical technology. Benjamin Franklin had shown that lightning was electrical and that its hazards could be mitigated with lightning conductors.

- The Italian physicist Alessandro Volta invented the first effective battery about 1800. Michael Faraday in England devised the first dynamo (electric generator) about 1830, and others built on this as a more effective way of generating strong current. At first, these dynamos were experimental, but in 1867, Werner von Siemens in Germany and Charles Wheatstone in England created devices that were powerful enough for practical use.

- Samuel Morse experimented with electric telegraphy in the 1830s. He recognized the possibility of an electrical alternative to the semaphore system, which worked only in clear weather and in daylight.
  - Of course, he invented Morse code, turning the alphabet into dots and dashes that could be transmitted electrically. Morse demonstrated that the technology was viable to a congressional committee in 1844.
This was precisely contemporaneous with the development of railways in the United States. Railway companies quickly grasped the value of telegraphy for sending messages over long distances and began to use it from about 1850. The first transcontinental telegraph wire system was established in 1861 as a faster and easier alternative to the Pony Express.

**Arc Lights**

- The first electric lights were arc lamps, in which a brilliant spark jumped across a gap between two rods. Humphry Davy had built one early in the 19th century but struggled with the problem of generating enough current in those early days to make the sparks jump.

- Arc lights were developed further by Charles Brush in America, who lit up the whole town of Wabash, Indiana, in 1879 and mounted a show to light Niagara Falls at night.

- Arc lights flickered and sputtered, and their light was harsh. Lighting public places at night, however, gave citizens a feeling of greater safety.

**Thomas Edison**

- Thomas Edison, a professional inventor, recognized the potential of incandescent lightbulbs to transform illumination, using many small bulbs with a steady light instead of a few massive ones. He was already famous for inventing the phonograph and improving the telegraph earlier in the 1870s.

- Edison’s challenge was to identify a substance that would glow inside a vacuum tube without burning up. He first tried platinum, then carbonized cardboard, and finally, carbonized bamboo fibers in bulbs that could last more than 1,000 hours.

- In England, at almost exactly the same time, Joseph Swan created a similar system. He installed a lamp outside his shop, and crowds gathered every evening to stare at its steady light.
• A large electrical exposition in Paris in 1881 showcased the many European and American versions of electrical lighting. Edison had the biggest display, including the largest dynamo ever built to that point. Weighing around 30 tons, it powered a glittering array of lights and two giant Es. Edison won the gold medal.

Direct Current
• Edison had commercial backers who wanted to profit from the invention, and he was always as much a businessman as an inventor. His bulbs had to be economically practical, as well as durable.

• Edison’s vision was to build a central power station and an effective transmission system: a steam-powered engine turning a dynamo that could be linked to many houses or offices by wires carrying electricity. He opened the first one in Manhattan in 1882, linked to 59 houses, then built several more in other cities.

• A significant limitation of his system was that it was based on direct current (DC), which worked only close to the power station; it could not be carried out to the suburbs.

“War of the Currents”
• Edison’s eminent rival was George Westinghouse, who had already distinguished himself, at age 22, as the inventor of air brakes for railway trains. The brakes facilitated much longer trains and greater safety because they applied brakes simultaneously on every car and were failsafe.

• Westinghouse electricity was based on alternating current (AC), which could be transmitted economically over long distances, using a transformer that stepped up voltage to 3,000 volts. Another transformer, or substation, would bring it down to 100 volts for local domestic users. Westinghouse tested his system successfully on a large scale in Great Barrington, Massachusetts, in 1886.

• During their rivalry in the 1880s, the “war of the currents,” Edison claimed that AC was dangerous. Edison even designed the electric
chair, a gruesome new device to carry out sentences of capital punishment, using AC as a way of suggesting that this could happen to unwary customers. He wanted to use the word “Westinghoused” for prisoners killed in this way.

- In the long run, however, the Westinghouse system prevailed and is now universal in the United States.

**Electric Lighting**

- Electric lighting transformed the appearance of American cities. They became bright at night, in effect prolonging the day. The lack of naked flames made domestic lighting far safer, although there were plenty of electrical fires in the early days.

- Transmission lines and telegraph wires crisscrossed city streets, transforming their appearance for the worse. When numerous rival companies were competing, each would have its own poles and wires—creating a labyrinth.

- Accidents related to live wires led to a reform in New York that required burying the wires instead. However, faulty buried wires sometimes created explosions of leaking gas (also in underground pipes) or electrified the streetcar lines, shocking the horses.

- Despite these problems, domestic electric lighting was superior in every way to its predecessors. Kerosene lamps and gas jets created unpleasant fumes and were fire hazards. Electric light was bright, constant, and clean.

**Electric Streetcars**

- Electricity was applied to transportation, as well as lighting, in the 1880s. Buses had been operating in U.S. cities since the 1820s, pulled by horses. Streetcars using rails gave a smoother ride and lower friction, allowing horses to pull more, and caught on at the same time as railways in the 1830s.
• Electric streetcars helped solve the problems caused by urban horses: They did not create manure, they did not suffer maltreatment, and they never grew weary.

• Streetcars moved by a cable were used on steep streets, such as those in San Francisco. They were introduced in 1873, at first with a steam engine creating the power. They were then operated with electricity in the late 1880s, just a few years after electric lighting became common.

• In flatter environments, overhead power cables brought electricity to motors mounted on buses and trams. The first city to have a fully electrical streetcar system was Richmond, Virginia, in 1888.

Power Stations and Hydroelectric Dams

• Power stations became a new feature on the urban landscape. The large-scale manufacture of electricity was dirty and intrusive, requiring masses of coal to be brought in and ash shipped away. Power stations were generally sited at the waterfront, where coal could arrive by barge and water could be used in the production of steam to turn turbines.

• Power station design pioneered several aspects of industrial building. Designers had to confront the problem of effective flow-through, and they created perpetual-motion hoists to lift coal so that it could be loaded into furnaces by gravity. The stations used reinforced concrete to make the structure strong and fireproof. Concrete also provided a durable and steady foundation for the immense rotating generators.

• At first, power stations created immense clouds of thick black smoke. Later, improvements were made, including more economical combustion methods, such as automated stoking and higher chimneys to create better draft.

• When the coal had been burned to turn the turbines, ash would fall from the bottom of the furnaces and would be conveyed out to
trains that carried it to ash heaps. By 1910, large stations produced 10 tons of ash per hour, emerging at temperatures of more than 1,000° F. The ash was highly acidic and toxic—creating poisonous fumes when sprayed with water to cool—and it could burn through steel and even corrode concrete.

- An alternative to coal-powered stations was hydroelectric power, which used high-pressure water to turn turbines. It was a very effective method, but it required damming rivers and flooding valleys—often valuable farmland. These dams could double for water supply and flood control—especially significant in the arid West.

Other Electric Products and Uses
- Electricity was adapted to dozens of technologies in the early 20th century beyond its initial uses in telegraphy and lighting. It facilitated not only streetcars but also underground railways, such as the New York and London subway systems, which would have been impossible with steam locomotives.

- Electricity was vital in refrigeration, as well; the expansion of refrigeration greatly diminished the incidence of food poisoning and made transcontinental food trains possible. Americans could begin eating

Grand Central Station In New York was completely rebuilt from 1903 to 1913 to accommodate the new electric trains.
a wider variety of foods rather than just whatever was available locally in season.

- New electric appliances came on the market every year after 1900—stoves, vacuum cleaners, shavers, hair dryers and curlers, and even the first electric typewriter in 1902. Many of these new devices were made in a novel way—on moving assembly lines.

- Ever since Eli Whitney’s experiments with the mass production of guns 100 years earlier, American inventors and manufacturers had been struggling to perfect a system of creating identical components that could then be assembled to make duplicates in number. As we will see in the next lecture, it was the bicycle and car manufacturers who successfully ushered in the era of mass production.

**Suggested Reading**

- Freeberg, *The Age of Edison*.
- Israel, *Edison*.
- Nye, *Electrifying America*.
- Stilgoe, *Metropolitan Corridor*.

**Questions to Consider**

1. What combination of scientific, economic, and technological factors ensured the success of electricity?

2. Why did alternating current displace direct current in the early years of domestic electrification?
A series of changes at the very end of the 19th century marked another significant advance in industrialization. This was the full achievement of parts interchangeability and mass production, along with the development of practical motor vehicles. Various industries had come close to interchangeability—most notably, those innovated by Eli Whitney, Samuel Colt, and Isaac Singer. However, these still needed skilled fitters to assemble a set of parts and make them work together precisely. Ultimately, it was the bicycle and car manufacturers who successfully ushered in the era of true mass production.

Precursor to Auto Manufacturing

- The first industry to achieve full interchangeability of parts was bicycle manufacturing. Bicycles were invented in England in the 1870s. The first was the penny-farthing, which had a very large front wheel and a small back wheel. It was awkward to mount and dangerous in accidents.

- Albert Pope was the first American importer of these bicycles, and he later began manufacturing them at a factory in Hartford, Connecticut. The factory was an offshoot of a sewing machine factory, using the same type of machine tools.

- Pope finally achieved full parts interchangeability. His machine tools were accurate enough and his metals durable enough so that any one set of parts could be put together to make a finished and working product. What’s more, spare parts could be distributed nationwide and would reliably fit.

The Safety Bicycle

- The safety bicycle, essentially the same design we use today, was invented in the 1870s by the Englishman Harry Lawson. Marketed successfully for the first time in 1885 in England, it had two wheels...
of the same size and a chain to link central pedals to the back drive. It was safe and, according to the advertising, suitable for women.

- A craze for bicycles ignited in America in the 1890s. Pope exploited the demand, pioneering pneumatic tires in place of solid rubber ones. Pope also devised the segmented market, a pattern that would be adopted by the car industry and persists today.

- Pope founded the League of American Wheeelsmen, partly a club for bike enthusiasts but also a lobbying organization, to ensure that cities permitted bicycles on their streets and to campaign for better roads.

The American Auto Industry
- Car manufacture was based on the mechanical progress bicycles had begun, and many of the first carmakers had tinkered with bikes. The world’s first gasoline-powered road vehicles were bicycles and tricycles made in Germany by Gottlieb Daimler and Karl Benz in 1885. The first recognizable automobile was built in France in 1891 by Émile Levassor.

- France was the first leader of the car industry, partly because it had suitable roads. Napoleon had ordered the building of a good system of roads, and city streets were already cobbled.

- However, European cars were very expensive, often built in small lots or as one of a kind. When the automobile industry took hold in America at the end of the 1890s, the idea was to make large numbers of cars at a low unit cost and on a sizeable scale—the same logic as that of Rockefeller and Carnegie. Hundreds of Americans experimented with making automobiles; early on, Ford and General Motors emerged as leaders.

General Motors
- A key figure in the creation of General Motors was William Durant. He worked as a carriage maker in Detroit but moved early on into cars. He accomplished a great publicity feat in 1908 in England with a demonstration of his mastery of full interchangeability.
• Historian Merrill Denison wrote: “Three stock Cadillac cars were disassembled at the Brooklands racetrack in England, and their parts heaped indiscriminately together. From the pile, mechanics using simple tools put together three vehicles, all of which turned in perfect performances in the 500-mile road test that followed. It was a superb demonstration of the standards attained by American machine methods.”

• From 1895 to 1910, the American auto industry came into existence. In addition to the actual carmakers, numerous related industries were created: those producing gasoline, fashioning tires, making leather for seats, and offering credit and insurance.

**Henry Ford**

• Henry Ford’s automobile factory in Detroit, which opened in 1907, marked a significant advance over all its predecessors.

• Ford was born in Dearborn, Michigan, and raised on a farm. From an early age, he loved tinkering, and he became familiar with steam engines and the new technology made possible by electricity. In the early 1890s, he worked for Edison as a generator supervisor; then, in 1896, he built his first car, the Quadricycle.

• Ford built the engine, which used a belt-drive system, by hand. In this first venture, however, he did not think to build in any brakes. Ford’s designs improved quickly.

• Ford decided to build cars that could be used all year round rather than just in the summer. The automobile would be enclosed, sturdy.

**Henry Ford manufactured the Model T between 1908 and 1927, making more than 15 million of them in all.**
enough to deal with poor road conditions, simple enough that owners could repair them, and cheap enough for the average person to own one.

- He told a skeptic, “I am going to democratize the automobile. When I’m through, everybody will be able to afford one, and about everybody will have one.”

The Ford Factories
- Ford built a factory with custom-made machine tools to produce only the Model T. Showing great confidence and entrepreneurial daring, he made an enormous upfront investment during the business recession of 1907. He took advantage of developments in vanadium-alloy steel, which was lighter and stronger, and used pressed-steel parts—also developed in the bicycle industry—instead of much heavier metal castings.

- Sales began in 1908 and almost at once outstripped all rivals in number. Production could not keep pace with demand, and Ford began construction of another factory, at Highland Park. He hired Albert Kahn to build it, the man who had designed the first purpose-built automobile factory for Packard in 1905.

- Highland Park was electrically powered, which meant no more overhead belts and pulleys transmitting mechanical power, as had earlier been standard in factories. Overhead instead were conveyors and craneways to carry materials and partially finished cars easily from point to point.

- Ford and his production engineers worked hard to perfect the flow-through of materials to make sure that every object arrived at the right place at the right time and in the right quantity.

- However, the production process was still static from 1910 to 1913. Because the Model T was the only model Ford produced, the factory invested heavily in machine tools designed just for that one
car. Production in 1910 was double that for 1909, and it doubled again the next year.

**The Assembly Line**

- Ford’s most important innovation was the moving assembly line. In the early manufacture of the Model T, workers assembled parts, then carried them to the next area for another segment of the job.

- In a moving assembly line, the work was broken down into smaller units, workers stayed in one place, and the work progressed far faster. The assembly line also had the effect of speeding up slow workers and slowing down those who were too fast. The overall effect was to make the workers much more efficient. The first car part manufactured in this fashion was made four times as quickly as before.

- Adam Smith had outlined the importance of the division of labor in 1776 when he wrote *The Wealth of Nations*, but now, the subdivision of labor was being taken to extremes. Ford’s assembly line was an example of the “scientific management” principles put forth by Frederick Winslow Taylor in 1910.

- A challenge was to get all processes flowing at compatible speed to prevent the creation of bottlenecks at any point. All processes had to be subdivided, and all initiative taken out of workers’ hands. To some, the work was mortifying and deadening; they became cogs in a machine. They were not allowed to take any initiative; if something broke down, a crew of specialists would come in to fix it.

**Dissemination of Mass Production**

- Ford’s process was spectacularly successful: In 1910, 20,000 cars were manufactured; in 1911, 53,000; in 1912, 82,000; in 1913, 189,000; in 1914, 230,000; in 1915, 394,000; and in 1916, 585,000. What’s more, prices came steadily down—starting at $950 in 1908 and down to just $490 by 1913.
Before long, Ford realized that he was so successful, he might saturate his market. He needed to keep thinking about ways to create more potential buyers. Reducing price was one way to do that. Another was to pay more to workers so that they could afford his cars. He made a dramatic decision to more than double the average wage, from around $1.50 to $5.00 per day and, at the same time, cut the workday from nine hours to eight.

This was the beginning of the insight that a maturing industrial economy must have a highly paid workforce. Otherwise, the goods the factories are producing won’t be sold because there won’t be a large enough market.

Ford’s ideas caught on quickly, both in assembly-line production and in higher pay for workers. Far from being secretive about his methods and success, he welcomed journalists and photographers, even competitors, to see exactly how everything worked, which had the effect of increasing the rate of diffusion to other industries.

Ford’s Model T dominated the market for the next 10 years or more, but in the mid-1920s, it began to lose out to General Motors, which introduced annual model changes. Buyers could compete for the prestige of the newest vehicle, and when the Model T’s market share finally began to decline, Ford switched over to annual models, as well.

Government Road Building

- The Model T could go over rough ground, but automakers realized that unless a better road system was built, the industry would soon reach its limits. A crucial moment came when Carl Fisher, maker of the bright headlight, asked Ford to contribute to the Lincoln Highway, a projected road to run from San Francisco to New York City.

- Ford declined and cautioned against private road building. He argued that carmakers needed to establish the principle that the state or city government should build roads—a massive hidden subsidy
to the auto industry that had not been available to the railroads. As we know, this vision of Ford’s was ultimately realized.

**Suggested Reading**

Denison, *The Power to Go*.

Gelderman, *Henry Ford*.

Hounshell, *From the American System to Mass Production*.

Nevins and Hill, *Ford*.

**Questions to Consider**

1. Why was the achievement of full interchangeability delayed so long beyond the aspiration?

2. Why was it conceptually difficult to imagine paying auto workers $5 a day?
Two bicycle-repair workers from the level-headed town of Dayton, Ohio, applied themselves to the problems of heavier-than-air flight with methodical diligence, worked out how to actually accomplish it, and—using advances in industrialization—turned the age-old dream of flying into a reality. We remember them as the Wright brothers, central figures of the industrial age. Aircraft would be vitally important to the continued advancement of industrial society, creating possibilities of previously unimaginable mobility. The onset of World War I, just a decade after the first flights, created an immense incentive, especially for the combatant nations, to improve design, performance, maneuverability, and maximum output.

Balloons and Gliders

- The first motorized aircraft were aloft less than 20 years after the first motor vehicles took to the road. The same kind of engine served both devices, and earlier experiments in flight, with balloons and gliders, meant that a wealth of experience was already available.

- The first balloon flights were done by the Montgolfier brothers in France in 1783. The balloons were basically containers made of fabric and paper, full of hot air, attached to a basket.

- In 1785, Jean-Pierre Blanchard made a successful crossing of the English Channel in a balloon powered by hand-operated wings. He also experimented with hand-operated propellers to power balloons and took a hydrogen balloon up to 12,500 feet. These devices were the ancestors of the airships.

- From 1804 to 1809, England’s George Cayley built model gliders, known as “flying parachutes.” He designed curved wings of the kind that would be crucial later and recommended that wings be fixed rather than flapping. He made two working gliders, in 1849 and 1852, that could fly a few hundred yards after a running
downhill start. The Wright brothers later praised Cayley for his systematic scientific studies and practical models.

- The technology of gliding was taken further by Otto Lilienthal, a German experimenter, who made a series of working gliders in the 1890s.

- At about the same time, Clement Ader in France experimented with motorized flight. In 1890, he built a steam-powered aircraft, but he hadn’t worked out how to control it in flight.

**Airships**

- Meanwhile, French and German inventors were experimenting with airships, carrying on where the balloon men had left off. A French airship with an electric motor flew in 1884 and 1885. Its lighter-than-air approach seemed intuitively right.

- Ferdinand von Zeppelin in Germany patented the key components of a lighter-than-air ship in 1895 and added American patents in 1899. He used hydrogen, which carried a fire risk but made the whole machine lighter than air. The availability of better motors by 1900, along with strong, lightweight frames, made airships commercially viable. The first flight of the zeppelin over Lake Constance in 1900 was a success.

- The problem of the early zeppelins was susceptibility to storms and high winds because of their enormous surface area. They were also slow and vulnerable to fire.

- Then, airships became the world’s first bomber aircraft in World War I, attacking London and Paris, until improvements in interceptor planes made them too vulnerable.

**The Wright Brothers**

- The search for heavier-than-air controlled flight machines continued. The most famous name in heavier-than-air flight is that of the Wright brothers—and justly so. Their experiments took place
quietly between 1900 and 1905 at Kitty Hawk, North Carolina. In the first three years, they did extensive glider tests. Unlike their European rivals, they lacked government sponsorship.

- The planes of the Wright brothers looked like bikes—open and spindly, as well as very lightweight. Although neither brother had been to college, they were not mere tinkerers; they read systematically on the history of aviation up to that point and studied fluid dynamics to understand airflow.

- Like Edison, the Wright brothers worked systematically and through trial and error, experimenting with a wide variety of wing shapes and craft designs. Their most important early invention was a set of controls to keep the plane level and to enable it to rise, fall, and turn in a controlled and correctable way.

First Flights
- On December 17, 1903, the Wright brothers achieved their first successful flight. The plane consisted of a lightweight gasoline engine turning twin propellers mounted at the back of the wings. The first few flights were made into a strong wind at 10 or 15 miles per hour and lifted just a few feet up but traveled several hundred feet.

- The Wright brothers’ first major public display did not take place until five years later. In 1908, Wilbur flew in Paris, and Orville flew in Washington, DC. They were demonstrating their planes to secure government contracts, which required a successful controlled circular flight. Wilbur astonished the French, who until then had doubted rumors about the flights.

- Suddenly, the Wright brothers were the most famous people in the world. Wilbur made a triumphant tour of Europe, demonstrating the plane’s ability. Orville met the president, William Howard Taft, in 1909 and made a demonstration flight up and down the Hudson River and around the Statue of Liberty.
But the Wright brothers remained reluctant to put on shows unless they had secured contracts and patent protection. They declined the chance to win a prestigious prize offered by an English newspaper owner for the first cross-channel powered flight. Louis Blériot, a French pioneer who had seen and admired the Wrights’ plane, won it instead on July 25, 1909.

European Aviation

French aviators and plane builders dominated the next five years, up to the outbreak of World War I. They repeatedly broke records for duration, speed, and altitude. Blériot himself became one of the first large-scale manufacturers of airplanes, selling hundreds of copies of his record-breaking machine.

The Gnome company in France pioneered high-quality lightweight engines in the years leading up to the war. However, French companies, and comparable ones in Britain and Germany, showed none of the obsession with mass production that Ford had in his automobile factories.

Governments looked on with interest. This was the era of the great naval race between Britain and Germany and a time during which there were constant rumors of an imminent great war. The governments of Germany and Russia began to invest heavily in aircraft research and development.

Glenn Curtiss

The Wright brothers were producing planes at the rate of only two per month in their first year of production, 1910. Manufacture was a slow process, especially the shaping of wings out of carefully made wooden sections covered with fabric. Building biplanes, the main early models, was a skilled and laborious process.

In America, Glenn Curtiss entered the field of aviation and became the only American manufacturer to rival the Wright brothers. The Wright brothers never became effective large-scale producers,
selling only 26 planes to the government in the next eight years; Curtiss, however, sold about 250.

- Just as Henry Ford had made his reputation as a car racer, then switched to manufacturing, so did Curtiss, who had been a bicycle and motorbike racer. Alexander Graham Bell, impressed by the high quality of Curtiss’s engines and his personal daring and ability, drew him into the Aerial Experiment Association.

- In 1910, Curtiss gave demonstrations to the U.S. military, proving that it was possible to fire guns at ground targets from a plane and that planes could be used to drop bombs. Also in 1910, an aviator flew a Curtiss plane off a warship to a nearby land airstrip, establishing the possibilities of naval aviation, as well.

- Curtiss next demonstrated that it was possible to build a working flying boat and made his fortune manufacturing them for the U.S. Navy from 1912 onward. His innovations made possible great advances in aviation as a weapon and as a point of access to otherwise obscure areas—for example, the exploration of Alaska.

- Curtiss also led the switch among American makers from “pusher” propellers, mounted behind, to “tractor” propellers, that is, propellers mounted in front and pulling the plane along through the air.

**Planes as Weapons**

- Governments became the principal buyer of aircraft in the years leading up to World War I—seeking ways to make planes effective as weapons when they were still too small to be useful for transport and too dangerous for passenger service.

- The first planes to go to war were part of the Italian campaign to conquer Libya in 1911. Planes were used to observe enemy locations and movements and to take photographs, while airships were used to drop bombs. Both worked effectively.
Another important breakthrough came just before the First World War began, with the experiments of a Russian designer named Igor Sikorsky, who proved that it was possible to build a multi-engine aircraft and one that was far larger than had been thought possible until that time.

When World War I began, France, Russia, and Germany each had more than 200 aircraft ready for use. At first, they were used mainly for observation, but from those early models, designers developed the light fighter plane and the heavier multi-engine bombers.

Once fighter planes with forward-firing guns had been created by mid-1915, aviators—who had been heroic daredevil figures before the war—became the focus of national pride for their single combats in the sky. Roland Garros in France and Manfred von Richthofen in Germany were like medieval knights, duelists whose skill and daring enabled them to score victories.

World War I

During World War I, the combatant nations accelerated their production of aircraft dramatically and began incorporating mass-production techniques. There was a strong continuity from car to aircraft manufacture, enabling automakers to adapt to the new business.

Technology improved so rapidly under the stress of war that planes could arrive at the front as state of the art but be obsolete in a few months as the enemy came up with something better. Mobilizing factories to mass-produce planes was inefficient if the production lines then abruptly had to be re-created for a new model. All combatants occasionally made the mistake of continuing to produce obsolete aircraft, which could be lethal for their crews.

Once the Americans entered the war in 1917, and began arriving in large numbers in early 1918, the sheer numbers of aircraft mobilized by the Allies began to shift the balance of the war in their favor.
During the course of World War I, Britain went from an insignificant manufacturer to a mass producer of such aircraft as the Sopwith Camel.

- Sadly, the utopian hopes invested by some writers in the possibility that aviation would bring world peace were shattered. Instead, aircraft became just one more weapon, adding to the dangers and horrors of the worst war in world history to that point. In the long run, nevertheless, they were vitally important to the continued advancement of industrial society, creating possibilities of previously unimaginable mobility—not just for elites but for growing numbers of ordinary citizens.

Suggested Reading

Bilstein, *Flight in America*.

Tise, *Conquering the Sky*. 
Questions to Consider

1. What was the psychological impact in Britain of the first cross-channel flight?

2. In what ways have aircraft contributed to the continued advancement of industrial society since their invention?
Industrial Warfare, 1914–1918
Lecture 30

In 1914, for the first time, several of the world’s great industrial powers confronted each other with mechanized armies and high-powered, well-manufactured long-range weapons, inaugurating a world war more lethal than any in the long annals of human conflict. The horrifying possibilities of industrialized warfare had been glimpsed in the American Civil War of the 1860s and the Franco-Prussian War of 1870. The appalling carnage of World War I demonstrated the power of industrialization for immense destruction, as well as creative production.

Organization for War

- Aircraft, poison gas, machine guns, long-range artillery, metal fighting ships, tanks, and barbed wire were all industrial products; were all subject to mass production; and had all proved lethal. The buildup to World War I was the clearest possible demonstration of the price of industrialization.

- It was widely thought that the building of railways and motor vehicles over the preceding decades would make war more mobile than ever before and would reward the fastest. But in fact, the superiority of defensive over offensive weapons quickly brought the early mobile phase of the war to an end.

- The building of trench lines across Europe bore witness to the stalemate that ensued. The war became one of attrition, in which the capacity to supply soldiers and munitions was decisive.

- Politicians on all sides realized that they must organize industry in support of the war effort, underwrite the cost of new weapon development, and ensure that their citizens were used as efficiently as possible if they were to win.
Germany’s Advantages

• Germany had several short-term advantages. For example, it already had a large standing army with a tradition of victories in the campaigns that had led to German unification in the mid-19th century.

• Germany’s Industrial Revolution was more recent than that of Britain, and its rate of growth in the 30 years before the war was much higher. It was well supplied with coal and iron ore. Its government had supervised German industrialization, whereas Britain followed a strong laissez-faire policy and was slower to adapt to central direction.

• Germany’s chemical industry was much more advanced than that of Britain or France, which gave it an edge in weapon production. Among the worst of the new weapons was poison gas, which remained a fearsome psychological threat throughout the war.

Naval Warfare

• In the long run, Germany, having failed to win an early decisive victory, faced disadvantages, some strategic, some industrial: It was fighting a war on two fronts, and it was unable to trade with America—already the world’s most productive industrial nation.

• British naval blockades prevented American ships from reaching Germany. President Wilson, fearing a recession, allowed American businesses to continue trading with Britain and France. The blockade also prevented imported fertilizers from reaching Germany, which led to a sharp fall in food production. Germany eventually retaliated with unrestricted submarine warfare, which in turn brought the United States into the war in 1917.

• At the start of the war, Britain found itself vulnerable. As a successful trading nation, it had early on learned to specialize and to rely on other countries for many vital supplies. German submarines disrupted imports and made those goods that did arrive more expensive. Britain also depended heavily on exporting, which
became more difficult, as well. Increasing military demand meant that everything became scarce and was susceptible to inflation.

**Workers on the Home Front**

- In the first months of the war, hundreds of thousands of British workers had enlisted from jobs that were vital to the war effort, such as coal mining and production of explosives, iron, and steel. To ensure that workers were available to meet vital job requirements, the British government established a system called the “reserved occupations,” whose workers were expected not to enlist. Germany established a similar system.

- Another significant issue in the war effort was the power of the trade unions, which had gained a central place in British industrial life. The unions feared losing the tenuous power they had achieved over the preceding half-century.

- The government was eager to get more people to work, especially women, but the unions were extremely reluctant to let women take over “skilled” positions. Labor-saving machinery invented in recent decades meant that women could do many jobs previously requiring strength or specialized skills, but unions weren’t willing to give those jobs away.

- In Britain, bargains with unions for temporary “dilution” of skill levels enabled women to enter the industrial workforce in large numbers. This experience was replicated in Germany, which employed 5.2 million women for the first time, including in heavy industrial work.

- It was widely recognized in Britain that if the working classes didn’t cooperate, the war would be lost, a situation that increased the power of the Labour Party. Indeed, the war was the decisive moment when Labour displaced the Liberal Party as the second major party in British political life.
• German workers also realized that their cooperation was essential. If they felt their employers were profiting excessively or exploiting them, they would slow down, strike without warning, or pilfer supplies.

• The Second International, a loose confederation of socialist groups and unions, had believed that what they saw as a capitalist war could be prevented if the workingmen of Europe simply refused to fight. But when war came, even those who were sincere about their socialism turned out to be even more sincere about their patriotism. The hopes that the war couldn’t take place if the workers refused to fight were dashed.

Government Intervention in Industry

• In Britain, Asquith’s government fell in 1915, largely because of reports that not enough explosive shells were reaching the British front lines. He had been too dilatory in reorienting the entire economy to wartime conditions.

• A Ministry of Munitions was established, headed by David Lloyd George, that authorized direct government takeover of munitions factories, compulsory arbitration of grievances, and limitations on profits to owners. Lloyd George established an “inventions panel” so that ideas about how to defeat the enemy could be gathered and evaluated.

• In many other economic areas, government intervention and direction became far stronger than ever before. The government realized that Britain, by failing to maintain its industrial lead, had made itself vulnerable. However, under wartime conditions, it was able to catch up.

• For example, the rate of productivity in aircraft rose during the war from 50 planes per month to 2,000. Britain, even though it had lost its industrial lead, had a century-long accumulation of industrial experience and a population familiar with machinery, gadgets, factory life, precision, and work discipline.
• It was industry that now ran the new military-industrial-political system. Businessmen were often given positions of responsibility because they were already familiar with the relevant industries and because they had more expertise in running large organizations dedicated to producing goods than did bureaucrats.

• There is some evidence that Britain may have handled the issue of economic intervention better than Germany, which relied on a tangled government bureaucracy.

**British Tanks**

• British innovations during World War I included the tank, a logical outgrowth of the car industry. These armored vehicles were versatile enough to cross the swampy no-man’s-land and strong enough to deflect enemy bullets and break through barbed wire entanglements.

• Caterpillar tracks had already been invented in 1908 in England for use on tractors. Their designer had demonstrated them for the army, but it wasn’t interested; thus, the patent was sold to The American Holt Manufacturing Company (later, Caterpillar, Inc.).

• In 1915, research and development on tanks resumed. By then, the British and French armies were using Holt tractors to drag supply trains up to the front lines. Britain finally committed tanks to battle in 1916, but in numbers that were too small. Not until late 1917 did they begin to crack the Western Front deadlock. At Cambrai that November, 400 tanks advanced together, broke through enemy lines, and proceeded for six miles.

• Tanks proved decisive in the Allied offensive in the fall of 1918 that finally broke German resistance and forced the Germans to sign the armistice of November 11, 1918. France was developing tanks at the same time; the Germans had some tanks but hadn’t committed themselves to production in scale. As the war ended, Americans were also in the process of developing effective tanks, but none was yet ready.
American Involvement

- American intervention in World War I gave an immense boost to the Allies’ prospects. Even before America’s intervention, the American economy had been growing extremely quickly because demand for American goods was so high. For example, the U.S. steel industry grew 235 percent between 1913 and 1917.

- Everything America could produce, the Allies would buy. Indeed, President Wilson had permitted American banks to lend money to the Allies so that they could buy American goods.

- Germany had hoped to knock the Americans out with submarine warfare, but the United States and Britain could build ships to replace those lost quicker than Germany could build new submarines. In the last year of the war, German shipbuilding fell to one-fifth of its prewar level; at the same time, American shipbuilding was 14 times its prewar level.

- Soon after joining the war, the United States created a War Industries Board, a centralized agency for buying and ordering war materials. It ordered companies to standardize their equipment, fully understanding the importance of parts interchangeability.

- In 1918, the United States also persuaded Britain and France to join the Interallied Council of War Purchases and Finance. The idea was to coordinate all war-related trade and shipping to prevent duplication and maximize efficiency at the national and even international level.

Treaty of Versailles

- When the fighting finished in November 1918, the victors gathered at Versailles to hammer out the terms of the peace treaty. This is widely regarded by historians as one of the worst treaties ever made—one that set the scene for the even-more-catastrophic World War II two decades later.
• To justify the length and destructiveness of the war, the British and French insisted on vengeful terms, designed to make Germany weak into the indefinite future. John Maynard Keynes (an advisor to the British treasury at the time) recognized that Germany was a central part of the world industrial system and that peace required it to be economically and industrially strong. Keynes rightly predicted that if Germany was weak, its trading partners would be weakened, as well.

• In retrospect, it's likely that if the Allies had joined together to rebuild Germany after the war, its new republican government would have been stronger, its people would have been less embittered, its industrial recovery would have been quicker, and the rise of the Nazis would have been much less likely.

Suggested Reading

Boot, *War Made New.*

Ropp, *War in the Modern World.*

Questions to Consider

1. Contrast Germany’s advantages at the outset of World War I with its disadvantages over the long term.

2. In what economic areas did government intervention and direction become stronger during the war?
After making massive advances during World War I, American industry continued to expand rapidly in the 1920s. Real incomes rose steadily, enabling working-class Americans to become more prosperous than ever before. Inventions devised before the war now became available to many citizens as mass-production methods caught on in new industries. Most urban homes were electrified in the 1920s, and rural electrification followed in the 1930s. Americans suffered less from food poisoning and had an improved diet throughout the year, cleaner home interiors, fewer house fires and deaths from burning, and better health and rising life expectancy. All these benefits were followed by universal primary education and mass literacy.

**Welfare Capitalism**

- Manufacturers in the 1920s experimented with welfare capitalism, trying to make social conditions at work better to diminish union militancy. They had come to the realization that a factory is a social system, as well as a concentration of precision machinery. History had taught them that unions had hindered industrial productivity and innovation in Britain.

- A clearer object lesson was the Russian Revolution of 1917. Karl Marx had predicted that the working class would be ground down to ever-greater poverty and desperation until they rose up to overthrow the bourgeoisie.

- Marx had thought this would happen first in the most industrially advanced capitalist countries, the United Kingdom and the United States. He never dreamed it would occur in Russia, a largely peasant society.

- In the United States, manufacturers worked to ensure that Marx’s expectations were not realized. They achieved this partly through
coercion and partly through high wages and better conditions, to give workers the feeling that they had a stake in the system.

- Governments were also aware of Marx’s predictions and began to create welfare states—especially in Western Europe. Germany pioneered the welfare state; Britain followed in the decade before World War I.

The Russian Revolution
- In fact, the Marxists in Russia won not because the country was convinced by Marxist ideology arguments—most Russians were illiterate, had never heard of Marx, and knew nothing about economics—but because the Bolsheviks were the only political group in 1917 determined to end Russian participation in World War I at any cost.

- Although the czar was overthrown early in 1917, the provisional government that took his place continued the traditional alliance with England and France, fighting against Germany and Austria-Hungary. The Bolsheviks’ determination to end the war at all costs gave them a moment of popularity and enabled them to overthrow the provisional government in October of that year.

- Vladimir Lenin, Leon Trotsky, and the other Bolshevik leaders were themselves sufficiently orthodox Marxists to be puzzled by their own success, which logically presupposed industrial maturity.
They therefore set out to make reality catch up with the theory, by inaugurating an era of emergency industrialization.

“State Capitalism”

- Early attempts at collectivization were failures; defeats in war and revolution had caused chaos and widespread famine. The New Economic Policy, declared in 1921, was a response to this failure. Major industries were nationalized, but smaller ones were granted some individual initiative in the hope that they would speed recovery from the ruinous civil war that followed the revolution itself.

- Lenin called the resulting system “state capitalism” and reasoned that it would be the prelude to full socialism. It worked well in restoring agricultural productivity because the more enterprising peasants had an incentive to produce, which they lacked with collectivization.

- Another objective for Lenin was to catch up with the West in electrification. Hydroelectric dams, such as the Dnieper Dam, were built across the great rivers between 1927 and 1932.

- When Stalin, Lenin’s successor, launched the first Five-Year Plan in 1928, he abandoned the individual incentives but kept the attempt to industrialize as rapidly as possible. Stalin understood the logic of Ford and Taylorism—the idea that scientific management gets the absolute maximum output from workers by deploying them in an organized environment. He also added a high degree of coercion.

- One of the heroic figures of Russian propaganda in those years was the Stakhanovite, the worker-superman so dedicated to industrializing Russia that he would work heroically long shifts. This, too, was an offshoot of Taylorism—the idea that individuals’ productivity can be raised sharply with the right combination of technique, will power, and morale.

- The late 1920s and 1930s was also the period of socialist realism in Soviet literature and cinema, which also idealized the inexhaustible
factory worker and made heroic icons of concrete dams, electrification, and tractors.

- Lenin and Stalin were right that without industrialization, theirs would always be a wretchedly poor country, and they did not shrink from coercion to make it happen. However, reporters in the 1930s described slave labor conditions in Russian factories and the threat of instant dismissal for workers who did not submit to military discipline.

Criticisms of Mass Production
- Mass production brought material wealth to millions, but it was not without its critics because it also brought increased control and surveillance. Mass production had been linked in some way to the coming of World War I, which caused a sense of disillusionment after what, in retrospect, looked like the excesses of Victorian optimism.

- One of the most interesting critics from the interwar years was Aldous Huxley. In his novel *Brave New World*, he points out that industrial capitalism was tending in the same direction as industrial communism—and that both were soulless, materialistic, and controlling. In his view, both also exchanged real freedom for the substitute freedoms of drink, consumer goods, and sex.

- Other sources of criticism for mature capitalism came from a group of English Catholic writers, the distributists, led by G. K. Chesterton and Hilaire Belloc. They argued that the similarities between capitalism and communism were more significant than the differences. Both tended toward concentrations of wealth and ownership. Distributists wanted a vast redistribution of land to ordinary people and a turn away from urban industrial life.

- Their American counterparts were the Southern Agrarians, a group of writers at Vanderbilt who argued against the growing reach of industrial urban life and its tendency to overwhelm older, more traditional ways of life.
The Failure of Marxism in the West

- Meanwhile, Marxists in the West strove to understand why Marx’s own predictions had not come true. Antonio Gramsci, a prominent Italian communist, struggled with this question. He argued that capitalism created not only a powerful new set of material conditions but also new psychological conditions. It pushed its own idea of reality so forcefully onto everyone that most came to accept it as incontrovertibly true.

- In Gramsci’s view, capitalism had even robbed the exploited workers of the sense that they were being exploited and made them quiescent. They supported a state and a nation that was, from the Marxist point of view, exploiting and repressing them.

- His name for this force was “hegemony,” which he used to mean a comprehensive and intimidating vision of the world. The job for Marxists, he said, was to create an alternative vision of reality, a “counter-hegemony.”

Schumpeter and “Creative Destruction”

- Joseph Schumpeter offered an interesting variation on these ideas in his book *Capitalism, Socialism and Democracy*, published in 1942. Schumpeter, who had emigrated from Austria to America, was an enthusiastic supporter of industrial capitalism and especially of entrepreneurs, whom he saw as vital figures in creating economic development.

- Schumpeter coined the phrase “creative destruction” to describe the way in which capitalists make progress by destroying old methods and creating new and more efficient ones through the relentless application of critical thinking.

- Unfortunately, he noted, the critical thinking encouraged by capitalism is eventually turned against the capitalist system itself. He, like the Marxists, believed that capitalism contained the seeds of its own destruction.
• But while Marxists looked forward to that day eagerly, Schumpeter anticipated it with dread. He believed it was already happening as state power, welfare states, and restrictions on entrepreneurs became more onerous.

• Even during the boom era of the 1920s, when productivity was roaring and industrial principles were being applied to ever-more processes, undercurrents of dissatisfaction were rumbling.

The Crash of 1929 and the Great Depression
• The Wall Street Crash of 1929, followed by the Great Depression, gave a new cogency to the critics and created a crisis of confidence for industrial capitalism itself.

• The exact causes of the Great Depression were debated and disputed at the time and have been argued over by historians and economists ever since. The economic weakness of Europe after the Treaty of Versailles and the attempt to force Germany to pay reparations to the victorious allies were almost certainly contributing factors.

• Maldistribution of income in the advanced industrial societies was probably another factor; rising wages should have risen even more to make more people into consumers. Poor decisions by central banks probably contributed, as well.

• The countries worst afflicted were the most industrialized ones: the United States and those in Western Europe. They found themselves with large numbers of unemployed people who wanted work, large numbers of factories that remained closed and silent, and businesses that needed customers but were unable to find them and were forced into bankruptcy.

Supply Outpacing Demand
• Throughout all world history until the Great Depression, one of the greatest human problems had been providing enough material welfare to the population. It had always seemed reasonable to
assume that demand would remain strong as people struggled to find ways to supply it.

- But the incredible rise in productivity of the first 30 years of the 20th century now presented, for the first time, the opposite problem—more supply than demand.

- The logical conclusion was that only by creating richer consumers or some other form of demand would it be possible to restore prosperity and high employment. The system needed high wages to turn workers into buyers, but employers were cutting wages in order to stay in business against competitors who were doing the same thing.

The New Deal

- Until the early 20th century, government had usually tried to prevent monopoly because it cheated customers of the benefits of competition. Now, the National Recovery Administration of the New Deal discouraged what it called “cutthroat competition” and actually encouraged manufacturers, industry by industry, to forego competition.

- This could be done only with a sharp increase in government intervention and monitoring. In fact, this is a further sign that, sooner or later, industrialization expands the role of government. The entire New Deal scheme was based on the premise that only government had sufficient resources to react adequately to a crisis this great and this widespread.

- In retrospect, we see that even the New Deal was unable to jumpstart prosperity. Unemployment remained high throughout the 1930s. Only the approach of a second catastrophic war could create enough demand to get the unemployed millions back to work.
Suggested Reading

Allen, *Only Yesterday*.
Lynd and Lynd, *Middletown*.
Pells, *Radical Visions and American Dreams*.

Questions to Consider

1. What made the Great Depression so difficult to grasp conceptually to the people who experienced it?

2. What were the major criticisms of industrialism in the interwar years, and how cogent were they?
Industrial capacity decided the outcome of World War II. Germany and Japan had gambled at the start of the war that they could compensate for industrial inferiority by strategic daring and military skill. However, the Allies overcame short-term disadvantages and achieved impressive industrial and military superiority in the long run. U.S. industrial production was already the greatest in the world when the war began, and it doubled in output over the next four years. Once the Allies sought American aid, an industrial boom began, employment increased, and wages rose sharply. American entry into the war in 1941 provided an enormous boost to the economy. That is what brought the Great Depression to an end, not the New Deal.

**Attack on France**

- The German advances of 1939 and 1940 showed how well Adolf Hitler had learned the lessons of World War I. He and his generals developed blitzkrieg tactics—using a combination of aircraft and tanks to attack and disorient the enemy.

- During World War I, France had held out against German attacks for four years. This time, it held out scarcely six weeks—one of the most dismaying events of the 20th century and a deep blow to the conventional wisdom that France was a great military power.

- If Hitler had stopped there and consolidated his new empire, he might never have been defeated. But in fact, he made the mistake of attacking the Soviet Union in the summer of 1941, fatally underestimating its strength and determination to fight back.

**Attack on the Soviet Union**

- Hitler believed that industrialization had put the odds in his favor, but in that respect, he was wrong. As we have seen, Soviet industrialization between the wars had been forceful, coercive, and rapid.
The German invasion in the summer of 1941 took Stalin by surprise, and at first, his armies fell back in disarray. They had been weakened by purges of senior officers in the late 1930s and lulled into a false sense of security by the Nazi-Soviet Pact of 1939.

German armies overran most of the productive Russian coalfields. As the German armies advanced, factories everywhere were dismantled by the Russians; the machinery was shipped further east, then reassembled. Nothing was left to fall into the Germans’ hands.

The Soviets organized factory labor on military lines, with long workdays, iron discipline, and meager rations. Much of the richest food-producing land in western Russia had fallen to the Germans.

Having learned from the Americans the importance of mass production, the Soviets concentrated on a few simple designs for tanks and aircraft, then turned them out in huge quantities.

The Soviets’ losses were heavier than those of any other combatant in World War II, but their ability to withstand the sieges was a tribute to their industrial adaptation and resilience.
Lack of Interchangeability, Low Production Volume

- Although Germany had been planning and gearing up for war, it had not followed the American or Soviet path of mass production. Its weapons, aircraft, and trucks were made in smaller numbers.

- Most historians of World War II believe that German weapons were superior to Allied weapons, but they had two crucial weaknesses: Their parts were not interchangeable, and they were subject to insufficient production volume.

- For example, probably the best tanks of the war belonged to Germany. However, too few were made, their range was short, few spare parts were available, and their parts were not interchangeable. If a German tank broke down on the Eastern Front, it had to be shipped back to Germany or wait long periods for spare parts and trained repair crews.

- Similarly, with aircraft, although Germany produced some astonishingly sophisticated designs, including the first jet fighters, very few were manufactured, and they were unreliable.

- What’s more, only a small part of the German army was high tech. Much of it was still dependent on marching infantry, bicycle infantry, and horses.

Need for Fuel

- Germany and Japan were also hamstrung by lack of oil supplies. The biggest production fields were in the United States, the Middle East, southern Russia, and the Far East. Both Axis powers gambled that initial success in the war would enable them to capture crucial oil supplies.

- Although Japan was able to acquire oil supplies with the capture of Burma and Malaya, it was not able to exploit this success because the oil still had to be shipped back to Japan. American command of the seas, with an immense surface fleet and an impressive submarine fleet, sank most of the tankers struggling to get oil to Japan.
Meanwhile, on the Eastern Front, Hitler diverted his armies in Russia to seize the oil fields in the Caucasus. Soviet fighters invaded the barracks at Maykop, where German oil technicians had tried to get production running, and slaughtered them all. Hitler was also unable to seize Middle Eastern oil, which continued to flow to the Allies.

**Allied Advantages**

- As they had in the First World War, the Allies overcame short-term disadvantages and achieved impressive industrial and military superiority in the long run.

- Britain again had command of the high seas with its surface fleet and merchant marine and was able to paralyze Germany’s overseas trade.

- The British government imposed strict regulations on private businesses and, in fact, was able to achieve rapid increases in productivity, quality, and coordination much more effectively than Germany.

- Britain also learned how to mass-produce simple, basic weapons, such as the Sten. This submachine gun was easy to produce, maintain, and repair and could be churned out in huge numbers. It looked like a do-it-yourself item made from bits of metal pipe, but it could be assembled in about an hour.

- Britain also settled on a few effective aircraft designs, then duplicated them endlessly. The Spitfire fighter and the Lancaster bomber, once perfected, were the staple aircraft. Frequently upgraded, the basic designs remained the same, facilitating repair and maintenance.

**American Weapon Production and Shipbuilding**

- American industrial production was already the highest in the world when the war began, and it doubled in output over the next four years. Once the Allies began to seek American aid, a great industrial boom began. Employment increased and wages rose sharply, bringing an end to the Great Depression.
• Two outstanding examples of American mass production were in weapon and ship manufacture. Ford, General Motors, and Chrysler all stopped building cars in early 1942; they now turned their immense productive capacity to manufacturing weapons.

• President Roosevelt toned down his anti-business rhetoric and consulted business leaders to ensure smooth relations among private industry, government, and the armed forces.

• Henry Ford’s aircraft mass production factory at Willow Run, Michigan, was among the most impressive achievements of the era. One of the largest buildings in the world, it used the same techniques as the moving assembly line for cars, despite the vastly greater complexity of aircraft. Opened in 1941, it was producing 10 Liberator bombers per day by 1943 and 20 per day the next year.

• Equally impressive was the American mass production of Liberty ships. These were standard freighters, 422 feet long, and carried 10,000 tons of cargo when fully laden. Henry Kaiser, already famous for building the Hoover Dam, worked out how to prefabricate all the components and assemble them at navy yards—with assembly lines two or three miles long and ending at the water’s edge, where the ships could be launched.

• The first Liberty ship took nearly a year to complete. By 1943, these ships were being completed in just eight days from start to finish. Although German submarines took a great toll on Allied shipping, they could no longer sink ships at a rate approaching the American capacity to replace them.

**The Second Front**

• Stalin, bearing the full brunt of the German attack, was desperate to persuade the British and Americans to invade Western Europe, which would force Hitler to divide his forces. Churchill cautioned Roosevelt not to be too hasty, in part because of the technical difficulty of a sea-borne invasion, but also because in the long run, the Soviet Union was an enemy rather than a friend.
• Still, Hitler had to be defeated, and between Pearl Harbor and D-Day, this was accomplished in two ways. The first was to send mass-produced industrial goods to Russia to help the Soviet armies. Tens of thousands of General Motors and Ford trucks and hundreds of aircraft were ferried to the Soviet armies and played an important role in blunting the German offensives.

• The Western Allies’ other contribution before D-Day was in strategic bombing. The idea was that bombing on a massive scale could destroy the enemy’s industrial capacity and shatter the peoples’ morale. By 1943, the British by night and the Americans by day were running air raids whenever the weather was good enough, in ever-growing fleets of Lancaster bombers and B-17 Flying Fortresses.
  o The evidence suggests that strategic bombing was less effective than its most enthusiastic advocates had hoped. Just as British determination not to surrender had increased in response to the blitz against London and Coventry in 1940, so German morale and productivity increased as the Allied raids against them ramped up.
  o Nevertheless, the bombers did immense damage and greatly slowed German production, whose rate of growth would otherwise have been even higher.

• Germany responded to the massive air raids against cities by dispersing industry into the countryside, which prevented the Germans from concentrating manufacture on any large-scale sites and, in turn, made mass production more unlikely.

• Advocates of strategic bombing before the war had imagined that it would be possible to pinpoint targets, such as factories, railroad yards, or shipyards. The reality was otherwise. Bad weather, high winds, the need to avoid enemy fighters and antiaircraft guns, and the high altitudes at which pilots were flying meant that precision bombing was largely a myth.
The Ultimate Industrial Weapon

- Both sides during World War II worked hard on secret weapons. Many were ingenious, but few were decisive. One secret weapon that was truly revolutionary and changed the course of history was the atomic bomb. It was simultaneously a magnificent achievement and a horrific one—like so much of industrialized warfare.

- Only an extremely sophisticated society could have worked out the combination of scientific and technical problems involved, then manufactured the bombs, then shipped them to the Pacific, and then launched them successfully against the enemy. It was the ultimate vindication of American faith in technology as the path to victory.

- When the fighting ended, the massive redistribution of wealth during the war, with high wages spread widely across the economy, prevented the return of Great Depression conditions. Wages had to be high because demand for workers was so great, and businesses competed with one another to find employees. The postwar boom gave reassuring evidence that peace and industrial maturity were compatible with ever-greater prosperity.

Suggested Reading

Hastings, *Bomber Command*.

Keegan, *The Second World War*.

Milward, *War, Economy, and Society*.

Overy, *Why the Allies Won*.

Questions to Consider

1. Why did Hitler underestimate the long-term significance of industrial potential?

2. Did quantity matter more than quality in the industrial race to win World War II?
Most of the industrial processes we have discussed so far are those that enabled people to perform everyday activities more quickly and easily. For example, textile factories enabled people to manufacture clothing more quickly and cheaply, and railways enabled them to travel with more speed and comfort. Already by the early 19th century, some visionaries were wondering whether it might be possible to find a way to think more effectively—or at least to organize information and accomplish routine intellectual tasks faster. Today, we live with computers of astonishing complexity and phenomenal miniaturization. In this lecture, we’ll examine when these new technologies began, how they developed, and how they have changed our lives in an industrial society.

The Information Revolution

- Today, we have computers that can calculate in one second mathematical problems that would formerly have taken hundreds of lifetimes. Computers have revolutionized the organization of knowledge and ended centuries of mechanical drudgery.

- With the information revolution has come a great change in the structure of the economy itself. In the United States, Western Europe, and Japan, growing numbers of people have found work not in manufacturing industries, which were the staple activities of the first phase of industrial life, but in organizing and producing knowledge. Some sociologists argue that we are now living in a “postindustrial society.”

- From the invention of the first cash registers in the late 19th century up to the modern computer, devices with the power to organize information have transformed our lives. Computer technologists have also made great strides in miniaturization, even as the power of computers has continued to increase.
Charles Babbage

- Charles Babbage was the godfather of the computer revolution. Lucasian Professor of Mathematics at Cambridge and an astronomer, Babbage wanted a quick and reliable way to compute astronomical and logarithmic tables. Further, the British government had asked him to confirm the accuracy of the statistics in its nautical almanac.

- Babbage designed and planned the “difference engine,” a mechanical calculator, and spent 10 years trying to build it. He fell out with his partner, and the device was never finished. In the late 20th century, a group of enthusiasts finally built one using the technologies available to Babbage in his era and proved that it would work. Given that Babbage had to mechanically make all the items that are now electronic, the completed difference engine would have weighed more than 15 tons.

- Babbage’s second version, the “analytical engine,” was even more ambitious. In it, he intended to use the same kind of punched cards that were actually used in computers of the 1960s and 1970s; he had seen the system used in a textile loom to codify fabric patterns.

Ancestors of the Modern Computer

- Another ancestor of the modern computer was the cash register—originally called the “incorruptible cashier” because it was developed to prevent employees from taking money from the till. The inventor was James Ritty of Dayton, Ohio, whose device received a patent in 1883. The National Cash Register Company was formed to exploit the invention and quickly made improvements.

- Also in the 19th century, the search began for better ways of making copies of written documents. Copying was slow, costly, labor intensive, and prone to human error. “Scriveners” were people hired to laboriously copy out documents by hand; in the early years of the Industrial Revolution, thousands toiled at such work.
  - One of the first improvements in copying was the development of carbon paper, which enabled typists to make two or three copies of a document simultaneously. It was developed in the
early 1800s, but it got its initial commercial application after
the invention of the first workable typewriters in 1872.

- The first photocopiers vastly extended the possibilities
  of copying documents automatically. The process of
  photographing a document and duplicating it instantly on plain
  paper was developed by Chester Carlson in 1938. The Haloid
  Company took the device into production, later changing its
  name to Xerox.

Forerunner of the Internet

- Advances in photography, document reproduction, sound
  reproduction, and television all made rapid strides in the 1940s,
  during World War II, and throughout the Cold War, where possible
  military applications brought both
  government agencies
  and corporations
  into research and
development.

- For example, the
  computers at Bletchley
  Park were able to
  crack coded Nazi
  radio communications
during World War
  II. The British
  government continued
to keep them secret after the war in the hope that the Soviet Union
would not know how sophisticated British code-breaking devices
had become.

- One of the people who worked on the Bletchley projects was Alan
  Turing—known as the father of computer science, who had worked
out many of the theoretical principles of computing in the 1930s.
In the late 1940s, the American government began work on the Semi-Automatic Ground Environment (SAGE), a system to organize the information coming in from many different radar stations. The government needed a way to track incoming Soviet bombers accurately so that the United States could rapidly retaliate.

George Valley and Joseph Licklider, two professors from MIT, worked out a technique of automated collaboration between computers that was lightning fast; this was the beginning of computer networking and a distant forerunner of the Internet.

**IBM**

Computers as machines followed the same trajectory as many other devices we have studied in this course. The first ones were massive, expensive, and slow. Bit by bit, they became smaller, cheaper, and faster.

Commercial uses of computers picked up speed in the early 1950s. UNIVAC computers went on sale in 1951 for about $1 million each. Among their earliest customers was the U.S. Bureau of the Census, which had an obvious need for sizeable mechanical computing capacity.

IBM became one of the leading companies in the computer business. It had begun life back in 1911 as the Computing Tabulating Recording (CTR) Company, which manufactured business-related devices. Thomas Watson was its CEO, a superstar of marketing, motivation, and customer service. He changed the company’s name to IBM in 1924 and passed it on as an extremely successful business to his son.

IBM began manufacturing and selling computers with business applications in 1952 for such jobs as inventory, payroll, and billing. Capable of thousands of calculations per second, these computers represented an immense jump in speed and reliability over individuals doing arithmetic.
The invention of transistors in 1947 was a vital step; transistors replaced large, fragile, heated vacuum tubes, or “valves.” Transistors used less electricity, generated less heat, and could be miniaturized. Even better was the invention of the integrated circuit in 1958—what we now call the microchip.

**Apple and Microsoft**

- By 1975, miniaturization and price reduction had accelerated so fast that the first home computer could go on sale, the Altair 8800. In the 1980s, IBM, Apple, and Microsoft became the dominant names in the home computer industry, while the machines themselves rapidly gained in memory, computing power, and user friendliness.
  - Every step of the way in this history was dogged by lawsuits and patent controversies, echoing the experience of earlier innovators, such as James Watt and Eli Whitney.
  - In the 1970s and 1980s, an entire subfield of legal expertise grew up around the computer industry. So many people had contributed to the development of computers and their improvement and the technology was being updated and transformed so regularly that it was almost impossible for all but those who studied it full time to understand the legal intricacies.

- Also in line with earlier trends, computer pioneers became larger-than-life figures. What Andrew Carnegie and John D. Rockefeller were to the late 19th century, Bill Gates of Microsoft and Steve Jobs of Apple were to the late 20th century.
  - Both Gates and Jobs were born in 1955, and both became successes and survivors in the rapidly shifting computer industry. Both became something close to public intellectuals and were assumed to have a special wisdom for their generation—because they had succeeded so brilliantly in it. Both also made fortunes in the billions of dollars and were among the world’s richest men.
  - When Steve Jobs was diagnosed with cancer, he remarked, “Death is very likely the single best invention of life. It
is life’s change agent. It clears out the old to make way for the new.” This sentiment was reminiscent of the insight of Joseph Schumpeter, who developed the concept of creative destruction: In capitalism, progress comes from constantly discarding earlier innovations and ceaselessly looking for better, faster, more robust technologies.

Winners and Losers

• The computer revolution and the knowledge industries it spawned have been phenomenally successful. But they have put stresses and strains on traditional industrial societies, creating clear winners and losers.

• The winners are highly educated people, especially those with technical education and the ability to work with computers. Universities have grown dramatically in the last half-century to supply the demand for highly literate and numerate adults. Incomes now correlate closely with years of education, and in many fields, not just degrees but also postgraduate qualifications have become indispensable.

• Equally clearly, the losers are people who are without higher education and are unable to work with computers. As more manufacturing work is exported to Asia, factories in the United States and Western Europe have closed down. Certain regions, such as northeast England, which were once dynamic centers of the early Industrial Revolution, have suffered high levels of chronic unemployment.

• A broad swath of the United States, now known as the Rust Belt, has suffered in the same way. Many businesses there have been replaced by Asian companies that manufacture both computers and high-quality steel machines, including cars, trains, and container ships.
Postindustrial Society

- The sociologist Daniel Bell popularized the phrase “postindustrial society” in the early 1970s, referring to a society in which the majority of working people are no longer involved in industrial processes.

- There have certainly been seismic shifts in the occupational structure of the developed world. This may seem like something new, but it also has a long industrial pedigree. For two centuries now, the constant process of invention and reinvention has forced millions of people to shift the kind of work they do during their lifetimes, sometimes more than once.

- In the long run, these shifts are usually beneficial overall, but they can be stressful to the particular individuals they affect, especially when workers in middle age suddenly find that the work for which they trained and in which they specialize is either no longer needed or is being done at half the cost elsewhere.

Suggested Reading

Barrett, *The Binary Revolution*.

Bell, *The Coming of Post-Industrial Society*.

Shurkin, *Engines of the Mind*.

Swedin and Ferro, *Computers*.

Questions to Consider

1. How did political affairs affect the development of modern information technology?

2. Is the concept of postindustrial society useful, or does it obscure more than it clarifies?
In the years since World War II, industrialization has accelerated worldwide. In 1947, after independence, India began its long struggle to overcome widespread poverty and famine. China emerged from years of revolutionary turbulence in 1949 to start on the road to economic development. Japan, shattered by World War II, rebuilt its industrial infrastructure at an astonishing rate. Other nations on the Pacific Rim, including the four “Asian Tigers”—Hong Kong, Singapore, South Korea, and Taiwan—all began the industrialization process. Collectively, their achievement has been impressive; however, many of the social dislocations that marred the European and American industrial achievements have been repeated in Asia.

**Industrialization in Japan**

- Latecomers to the process of industrialization can often take advantage of their predecessors’ collective experiences. But latecomers also soon learn that industrialization has never been solely a matter of building factories. It is also a matter of developing a skilled workforce, educating capable managers, building an infrastructure, and creating conditions to facilitate the free exchange of information.

- Japan emulated Western Europe and the United States by starting to industrialize in the late 19th century. At first, it mechanized cotton textile production and then other products based on organic raw materials, such as silk and paper. In the 1890s, Japan shifted to ironworks and steelmaking.

- Japan’s victory over Russia in the naval battle of Tsushima in 1905 demonstrated that it was now a naval power. Over the next 40 years, Japan came to dominate eastern Asia, showing an effective combination of strong military traditions, modern industrial weapons, and penetration into foreign markets with export goods. Japan
also showed that industrialization is not always accompanied by democracy—a point that has been confirmed more recently in China.

- Japan was shattered and humbled by American air and naval power during World War II, but it began to rebuild its industries at once, this time in a politically democratic and avowedly nonmilitaristic environment, under close supervision by the American occupation forces.

- Postwar Japan built a reputation for making dependable, low-priced goods. In the 1960s, it began exporting simple but reliable motorcycles built by Honda and cars built by Toyota and Nissan. Japan also became a prominent shipbuilder and led the world in this industry between the 1960s and 1990s.

**China under Mao Zedong**

- In contrast, China’s industrial rise was delayed until the late 1970s by ideology. When Mao Zedong seized power in China in 1949, after two generations of civil war and foreign occupation, he presided over a vast peasant economy. As a Marxist, he believed in the superiority of industry over agriculture.

- His first effort at mass industrialization failed. Called the Great Leap Forward, it was an attempt to collectivize agriculture and, at the same time, to jumpstart an industrial revolution in the countryside. It was, in fact, an immense leap backward, leading to a famine in which as many as 40 million people died.

- The Great Leap Forward was quietly dropped when Mao eventually came to understand that industrialization cannot come about simply by decree. He then launched the Cultural Revolution, another assault on rational thinking, which further retarded China’s ability to undertake a sensible industrial policy.

- By the late 1960s, it was painfully obvious that Taiwan—the island to which Mao’s defeated foes had retreated in 1949—was much more successful than China. During the same years that China
suffered successive catastrophes, Taiwan enjoyed economic growth rates of more than 10 percent per year. Hong Kong, a British colony since the 19th century, also grew rich, while the People’s Republic of China remained abjectly poor.

**Market Mechanisms in China**

- Chinese leaders gradually realized that they must enter into trading and manufacturing arrangements with the capitalist West. Starting in the late 1970s, China adopted some market mechanisms, which began to pay off at once.

- As soon as peasant farmers were allowed to profit from their own industriousness, their productivity went up sharply. Enterprising small-scale manufacturers and shopkeepers also began to thrive. Although the central government kept a firm grip on political power, it permitted economic initiatives from below. The result was rapid economic growth.

*After a pause in the wake of Tiananmen Square, the economic liberalization of China resumed and has continued up to the present.*
• The government created special economic zones that encouraged investment from abroad. Because manufacturing costs, especially wages, were low in China, foreign capital poured in. By 1990, millions of Chinese workers were making consumer goods for export in factories partly owned by foreign or multinational corporations.

• Chinese pressure for liberalization, coupled with excitement at the collapse of communism in the Soviet Union, led to huge demonstrations in Tiananmen Square in 1989, appealing for democracy and an end to autocratic rule. Unfortunately, the demonstrators were ruthlessly suppressed by massed tank formations. Some of the government liberalizers were discredited and fired, but after a pause, economic liberalization resumed and has continued up to the present.

**Industrialization in India**

• India’s post-independence government, under its first leader, Nehru, wisely decided to follow the path of Western industrialization. Nehru did not adopt Mahatma Gandhi’s extraordinarily unwise suggestion of reverting to subsistence farming and primitive textiles, which in practice would have condemned millions to lives of poverty and famine.

• On the other hand, Nehru was perhaps a little too impressed by the European socialist tradition, whose ideas favored an economy with all the major industries nationalized. Britain tried this experiment between the 1940s and 1970s before Margaret Thatcher finally swept it away. Nehru tried it, too, and found it led to slow economic growth.
  ○ Nehru’s government established some industries, but they were hemmed in by regulations, grew slowly, and were hamstrung by a heavily politicized trade union movement. Nehru hoped that India could become self-sufficient industrially rather than by developing trade links with the more advanced industrial nations, but two centuries
of experience had already shown that this is a poor way of strengthening an economy.

- Nehru also struggled to create a unified secular state out of one that was sharply divided religiously among Hindus and Muslims. In addition, India was ethnically riven by dozens of different groups, many of them with historic antagonisms, and it was linguistically divided so that the only available common tongue was English, which carried the taint of colonialism.

- Finally, India’s tenacious caste system created sharp barriers between members of different social classes. Many castes were associated with particular jobs, and the weight of tradition inhibited the kind of free movement of labor that modern industrialization needs.

- In the late 1960s and 1970s, Indira Gandhi moved further to the left, aligning herself with the communists and nationalizing all the major sectors of the economy. The result was very low rates of economic growth for India until the late 1970s.

- After a financial crisis in 1971, India finally shifted to a more deregulated industrial economy, creating more opportunities for international investment and entrepreneurialism. But India continued to lag behind the best of the Asian Tigers. Its politicians continued to favor the idea of economic autonomy, which in practice retarded growth and permitted inefficient industries to operate without competition.

- Another crisis in 1991 pushed India farther along the road to a free market economy; it began to specialize in telecommunications and service-sector industries.

**India in the World Economy**

- Different Indian states have responded to the improved business climate in different ways, with some faring the best, especially
Maharashtra and Gujarat—the west-central areas inland from Mumbai—and other states, such as Uttar Pradesh, and Bihar, further north and east, remaining very poor.

- India suffers from many fewer food shortages than previously in its history and can now grow enough food to feed itself in most years. Even so, malnutrition is widespread, affecting as many as 43 percent of children, according to one estimate.

- Industrial India today presents a mixed picture. It contains a great deal of entrepreneurial energy, which is more easily able to express itself than in the first four decades after independence simply because the burden of government regulation and obstruction has been reduced.

- India is joining the world economy, which creates a vast potential market and offers high incentives to the most inventive industrialists. Gradually and unevenly, industrialization is enriching the society as a whole and slowly reducing the incidence of desperate, chronic poverty.

- By the early 21st century, the lessons are unmistakable: Nations that industrialize can begin to make their way out of poverty. Those that fail to do so fall ever further behind.

**Improvements Brought by Capitalism and Industry**

- The trajectory of the last 65 years has been the worldwide spread of industry and capitalism. As a result, the world has been able to feed, clothe, and educate an incomparably larger population than ever before while improving the condition of life for millions.

- The world population, around 2 billion at the end of World War II, is now more than 7 billion. Although that increase may be of some concern, the fact that the food-to-population ratio has improved at the same time is also a sign of just how productive an industrial economy can be.
• In his book *The Dragon and the Elephant* (2007), the journalist David Smith writes: “Currently, 200 million people in China and 300 million in India live on less than a dollar a day. But, as the World Bank has pointed out, the economic rise of these countries has been the single most important factor in reducing global poverty over the past two decades.”

• The application of industrial methods to agricultural research and production has led to profound increases in food production, first with the Green Revolution of the 1950s and 1960s, then with genetically modified crops after about 1990. Famines are rare now and occur only at sites of political instability. Where lines of communication are open, food is always available, and developed nations worry more about agricultural overproduction than about inadequate yields.

• Among the great unanswered questions raised by the Industrial Revolution is whether it is sustainable over the long term. The environmental impact of industrialization is the subject of our next lecture.

**Suggested Reading**


Ganguly and Mukherji, *India Since 1980*.

Smith, *The Dragon and the Elephant*.

1. Is there a connection between nations’ political systems and their ability to industrialize?

2. Rapid economic growth increases inequalities of wealth, but might it nevertheless be morally defensible?
Industrialized societies face urban sprawl, depletion of raw materials, a rushed pace of life, and proliferation of environmental carcinogens. However, poverty is still widespread, and the only proven way of diminishing it is industrialization. There has never been a preindustrial society with widespread affluence or economic equality. What’s more, only rich countries show much fervor for environmentalism. In this lecture, we’ll explore the paradox of industrialization: Although it causes environmental problems, the solution is not to eliminate industry but to improve it. The wealthier the world gets, the more concerned it will become with environmental problems and the more likely it will be to find solutions.

Air Pollution

- The coal-driven era of industrialization created pollution; for more than a century, British and American industrial cities were coated in soot. The skies over Manchester, Sheffield, Pittsburgh, Cleveland, Düsseldorf, and Liège were often smoky, sometimes yellowish with sulfur compounds.

- Smoke and smog could sometimes be deadly. Donora, Pennsylvania, near Pittsburgh, was one of the most polluted towns in America in the early and mid-20th century. Wire and zinc factories produced toxic smoke that prevented vegetation from growing on the nearby hillsides. A 1948 smoke inversion episode killed 20 and injured hundreds more with lung ailments. The severity of the event prompted local and state government to consider regulation of what until then had just been regarded as an annoyance.

- In December 1952, London experienced a yellowish-black “pea souper,” in which nothing was visible for more than a few yards ahead. All transportation came to a stop, even ambulances. The “fog” was composed of a concentration of soot and sulfur dioxide.
from factories and power stations, plus vehicle fumes. It killed between 8,000 and 12,000 people and injured about 100,000 more.

- This “killer fog” led to the passage of Britain’s Clean Air Act in 1956 and, eventually, to a ban on the use of coal in the city. Only such crisis events were sufficient to prompt political action because in so many other ways, the smoke-producing fires and factories had benefits.

- Meanwhile, the rise of the chemical industry in the 20th century introduced countless new substances, many of them toxic, to which humanity had inadequate time to adapt. They often had both good and bad consequences.
  - For example, DDT was so effective as a killer of mosquitoes and lice (and, therefore, a suppressant of malaria and typhus) that its inventor, Paul Müller, won the Nobel Prize for medicine in 1948.

  - However, in 1962 Rachel Carson’s *Silent Spring* was outspokenly critical of the indiscriminate use of pesticides and herbicides, with DDT among those central to her case.

**Other Environmental Threats**

- Another problem was water pollution. The most famous incident occurred when the Cuyahoga River in Cleveland caught fire in 1969 and burned for half an hour, damaging railway bridges and scorching waterfront buildings.

  - In another incident, vast algal blooms in Lake Erie used up available oxygen, destroying the lake’s fishing industry and forcing beaches to close.

  - The Santa Barbara oil spill in early 1969 turned California beaches black. In other areas, mysterious massive fish kills were evidence that the rivers were a dumping ground for toxic chemicals.
The 1950s and 1960s gave rise to protests against nuclear fallout. In these Cold War years, tests of nuclear weapons in the atmosphere led to ever-rising levels of background radiation. Both sides were convinced of the value of stopping atmospheric tests, which led to the Limited Test Ban Treaty in 1963. There has been a steady decline in atmospheric radiation since then.

Some were worried that too many people were using up all available resources and would provoke a massive famine. The successes of Western medicine in the wake of the Industrial Revolution had reduced infant mortality and increased life expectancy. Now, gloomy population theorists predicted famines not just in the developing world but for Western Europe and America in the 1970s and 1980s.

There were also fears that industrial overuse of raw materials would lead to a crisis of resource exhaustion, making everything scarce and costly and prompting a much humbler way of life.

Responses to Environmental Concerns

Widespread recognition of the need to respond to all these issues culminated in the first Earth Day (April 22, 1970), when hundreds of thousands of people turned out in cities and on campuses all over America to protest pollution.

The United States created the Environmental Protection Agency and passed a succession of clean air and water acts in the late 1960s and early 1970s.

Some legislation mandated the use of specific technologies, but most created timetables for pollution reduction by whatever methods companies could find. That created a market incentive for pollution-abatement inventions.

America’s anti-pollution achievements in the 40 years since Earth Day have been impressive. The numbers of people and cars have continued to rise, but at the same time, air quality has continued to
improve. Cars are 95 percent cleaner than they were in the 1960s. There has also been a drastic decline in smog in many of the worst areas in the United States, including Los Angeles.

- The environmental movement has given rise to a succession of controversies, including the question: Should we give up on prioritizing economic growth? Doing so would reduce urban sprawl, the use of raw materials, and the fast pace of life, but it would also hinder the fight against poverty.

**Nuclear and Alternative Power**

- In the 1950s and 1960s, nuclear power seemed a promising alternative to producing electricity. Uranium has immense energy potential, mining ore is safer than mining coal, and no smoke or industrial effluent is produced. Many nuclear power stations were built in the United States starting in the late 1950s.

- By the late 1970s, there was growing concern over nuclear power. Building leak-proof containment vessels was difficult; disposing of nuclear fuel rods was challenging; and an undemocratic apparatus of secrecy surrounded power stations.

- In 1979, the Three Mile Island nuclear power plant in Pennsylvania suffered a partial meltdown. Faulty equipment in the control room meant that operators were not sure what was happening and did not know whether to evacuate the neighborhood. No one was killed, but the technology took a significant dive in popularity.

- Far more serious was the disaster at Chernobyl, Ukraine, in 1986, when a reactor exploded, showering radioactive debris over a wide area and sending contamination into the atmosphere. The calamity killed 30 outright and exposed thousands more to high levels of radiation. The accident may have resulted more from Soviet mismanagement than from use of nuclear power itself, but it sent a deeply negative message about the technology.
• Since the 1970s, there have been great hopes for solar and wind power. However, neither works all the time or provides sufficient volume. A vast amount of land is needed for windmills or solar panels for a miserly return of electricity.

• For now, coal, natural gas, and hydroelectric are still principal sources. Continued improvement in emission reduction makes burning coal far less polluting than it was 50 years ago. Natural gas is also viable on a large scale and burns cleaner.

Resource Depletion

• Another controversy is whether we are running out of raw materials. On the face of it, the answer must be yes, but in fact, it is difficult to measure reserves. A more effective approach is to track prices because they show us relative scarcity or plenty. Following raw material prices over the last 200 years, we find that, in real terms, they have come down.

• Business theorist Julian Simon has argued that although there are certainly short-term fluctuations in raw material prices, the long-term trend is toward lower prices because humans become steadily better at inventing substitutions—for example, fiber optic cables made many previous uses of copper unnecessary—and because of greater efficiency and recycling.

• In other words, Simon reasoned, a resource isn’t just “stuff”; it’s stuff plus the human ingenuity to know what to do with it. There has always been plenty of oil in the ground, but it didn’t become a “resource” until someone worked out that it could be refined and used.

• Therefore, some economists have argued that throughout the Industrial Revolution, materials have become steadily more plentiful, and it’s reasonable to think they’ll continue to do so into the indefinite future. We’ve certainly lived long enough since the resource scares of the 1960s and 1970s to see them all disproved.
Global Warming

- Recently, there has been significant controversy over global warming. A monitoring station in Hawaii has been gathering data on carbon dioxide in the atmosphere, showing a steady rise since the 1950s. These have also been years of increasing world temperature. Some scientists have concluded that there is a cause-and-effect relationship here.
  - As carbon dioxide and other greenhouse gases increase, less of the heat that comes to the earth from the sun is able to escape back into space. The atmosphere itself starts to act like a greenhouse, trapping the heat near the earth and warming the planet.
  - If the trend continues, some scientists predict that the polar ice caps will melt, sea levels will rise, and inhabited lands near the equator will become uninhabitable.

Many environmental scientists have predicted that the greenhouse effect will result in the melting of the polar ice caps and rising sea levels, making land near the equator uninhabitable.
Concerns over global warming led to an international treaty in 1997, the Kyoto Protocol, by which the leading industrial nations pledged to reduce their carbon dioxide emissions. However, India and China, industrializing at full speed and major polluters, refused to sign. The United States also refused to sign, partly because other large polluters refused to do so and partly because of serious doubts about the science.

Warming skeptics have argued that earth has a long history of climate fluctuations, most of which cannot have been induced by humans. For example, they argue that warming from 1900 to 1940 was steeper than between the 1980s and 1990s, but that should not have been the case if industrial effluents were the cause. What’s more, in the era from 1950 to 1970, there was an alarm about global cooling.

Global warming is more difficult to deal with politically than pollution because the ostensible harm lies in the future—to others rather than to ourselves. It is also difficult to decide how to allocate importance to different factors: Is it better to use the limited resources we have for hypothetical future benefits or contemporary ones, such as access to clean water in poor countries?

The environmental problems that the world confronts were caused by industrialization, but to remedy them doesn’t mean to eliminate industry. It means to improve industry. The wealthier the world gets, the more concerned it will become with environmental problems, and the more likely it will be to be able to solve them. The solution is more industry, not less, but with regulation to ensure responsibility and cleanliness and to prevent harmful side-effects.
Suggested Reading

Allitt, *A Climate of Crisis*.


Lomborg, *The Skeptical Environmentalist*.


Questions to Consider

1. Why did so many predictions of environmental catastrophe prove to be false alarms?

2. Does increasing industrialization make societies richer, more resilient, and better able to meet their environmental challenges?
The Benign Transformation
Lecture 36

We live in a world full of serious problems—economic, political, social, and environmental. It is also a world replete with extraordinary opportunities. Industrialization, and the frame of mind encouraged by the development of industry, can help us confront our problems with confidence. The Industrial Revolution, although it happened gradually, was one of only two or three of the most significant changes the world has ever seen. In this concluding lecture, we will summarize the main themes of the course and survey the prospects of a world transformed by industrialization.

Defining “Revolution”

- “Revolution” literally means the turning of a wheel, but figuratively, it means a transformation that creates permanent change. Political revolutions happen rapidly, and it is possible to place an exact date on them. Economic and technological revolutions are different. They happen gradually, sometimes to the extent that they are almost imperceptible.

- Some historians question whether the term “revolution” is appropriate to a complex series of processes that began in the 18th century and is still going on today. The phrase “industrial revolution” was used by Friedrich Engels in the 1840s, but the term was not adopted as a standard label by historians until the 1870s.

- The term “revolution” clearly is appropriate because of the magnitude of the changes, considered collectively, and because of their impact on the destiny of the entire world.

Building on the Neolithic Revolution

- The Industrial Revolution built on the achievement of the Neolithic Revolution (the invention of agriculture) by enhancing human wealth, health, security, longevity, and comfort.
• In times so remote we cannot easily date them, ancient societies discovered one by one that plants and animals could be domesticated and bred. There’s nothing natural about farming; it had to be invented.

• This invention facilitated the growth of permanent settlements, cities, and literacy. The great empires of the ancient world were able to create food surpluses, feed armies, trade over long distances, and plan for the future.

• The empires of the ancient world—Greek, Persian, Egyptian, and Roman—were unable to overcome severe technological limits. They never institutionalized the process of constant technical innovation and improvement that we have witnessed in the last two centuries. Even though the Romans had striking accomplishments in building, establishing a substantial network of roads across Europe and creating sophisticated water supply systems, they never learned how to mechanize or mass-produce.

**Beginnings in Britain**

• The Industrial Revolution began in Britain in the mid-18th century with developments in textile manufacturing, iron working, and coal mining.

• Britain was able to lead the way because, by the early 1700s, it had achieved a condition of political stability. It had developed a thriving pattern of overseas commerce and colonization. Its social system was flexible enough to be able to reward the most successful merchants and businessmen, who eventually achieved political influence.

• Various inventions and manufacturing innovations gradually coalesced to promote the growth of industrial cities. Newcomen’s steam engine, Darby’s coke method of smelting iron, and Arkwright’s water frame did not affect many people at first, but by the early 1800s, the acceleration of production and its concentration in new towns had an impact on larger numbers throughout the population, especially in the north.
Britain’s industrialists managed to avoid provoking civil war or massive worker rebellions. They were helped by a repressive government that banned trade unions during the era of the Napoleonic Wars, when industrialism was growing rapidly. Scattered outbreaks of machine breaking by the Luddites, as well as traditionalists’ protests, were offset by most workers’ appreciation that the system would benefit them in the long run.

Although we are appalled at conditions in the early industrial towns, it’s worth remembering that their inhabitants were often refugees from rural poverty and overwhelming squalor.

**Reform and Railways**

- In politics, the Reform Act of 1832 did little to make Britain more democratic. However, it did establish a system by which the rising commercial classes would gain in political influence, capable of shaping policy in their own interest.

- After these reforms, the new political class was able to largely abolish tariffs, creating a free-trade environment in which those engaged in commerce were able to expand their markets around the world.

- These political reforms coincided almost exactly with the beginning of steam railways. The building and operation of a canal system from the 1770s had already provided a stimulus to business. Railways took this stimulus much further, creating conditions in which bulk goods could be transported rapidly, safely, and economically over long distances.

- Railways were a double economic stimulus, supporting all other businesses but also becoming leading employers in their own right, creating a vast array of new jobs and pioneering new techniques of management and work discipline.

**Industrialization in America, France, and Germany**

- In the mid-19th century, America, France, and Germany began to catch up with Britain in the invention and production of new
technologies. Most historians now believe that it was inevitable that Britain would lose its lead when other countries recognized the advantages of industrialization.

- State assistance was important in America and Germany, as were tariff policies to encourage home industry and to exclude foreign competitors. In addition, many of America’s early enterprises were heavily subsidized by the federal government.

- The structure of social rewards tended to take successful Britons out of industry but to keep successful Germans and Americans in it. Britons who made commercial fortunes later had heirs who looked down on business as beneath their dignity. In contrast, in American industrial dynasties, such as those of the Rockefellers, Fords, and Vanderbilts, later generations able to build on their predecessors’ successes.

- Further, there were advantages, as well as disadvantages, to being latecomers; Britain had already gone down various blind alleys that the newcomers could avoid. America, France, Germany, and later, the Asian nations were all able to study the British experience, take what was best from it, and steer away from what did not work.

**Industrialization in the 20th Century**

- The upheavals of the 20th century were closely linked to the industrialization of other parts of the world. World War I, for example, demonstrated that industrially produced weapons were far more deadly than their forerunners and that industrial societies could mobilize vast resources for mutual destruction. For the first time in history, everyone living in the combatant nations became logistically and strategically important.

- World War I led to the Russian Revolution, which in turn, led to the forced industrialization of the Soviet Union. Lenin and Stalin understood that Russia would always be wretchedly poor unless it was industrialized, a process they attempted to achieve in a series of harrowing five-year plans.
Karl Marx, the grand theorist of how industrial capitalism transforms the world, had never dreamed that the revolution would come to Russia. He had imagined that the most industrialized nations, Britain and America, would be the first to inaugurate socialism. To him (as to most of his Western contemporaries), Russia was a byword for autocracy and repression. It was so under the czars, and it remained so under the Bolsheviks—but now with tractors, trains, hydroelectric schemes, and electric generators.

The cost in human suffering was immense, but unexpectedly, forced industrialization enabled Russia to resist the Nazi invasion in World War II. Mass production in Detroit eventually proved an even more powerful force than Hitler’s Wehrmacht.

After World War II, Taiwan and South Korea and, more recently, China and India experienced high rates of industrial growth. Japan also made a phenomenal recovery from the devastation of war. In all these cases, industrialization corresponded closely to higher standards of living and rising life expectancy.

○ Gandhi’s plan for spinning wheels and subsistence farming would have been catastrophic as the basis of India’s post-independence economy.

○ Luckily, Nehru ignored Gandhi’s ideas; his successors have gone further in putting India on the track of rapid economic development.

**Beyond Production and Consumption**

Industrialization has had effects far beyond the immediate issues of production and consumption. For example, industrialization stimulates “demographic transition,” a fall in both birth and death rates, which is reassuring from the point of view of world population.

Two of the great achievements of recent decades have been the Green Revolution and genetic modification of foods. The Green Revolution was the development in the 1950s and 1960s of very high-yield crops. The revolution in genetics since the 1980s has led
to the creation of genetically modified crops, which are even more productive. They can become frost-resistant and even repel pests. Although controversial, these developments suggest that the human capacity to influence the food supply is substantial.

- The poorest parts of the world are, without question, those that still await industrialization. They have the highest incidence of famine, chronic poverty, epidemic disease, and autocratic government.

- Industrialization shapes our world decisively. We are now accustomed to a constant stream of new inventions and technological improvements, an institutionalization of the inventive impulse. Each generation outstrips its predecessors with innovations.
Critiques of Industrialization

- The socialist tradition was generally accepting of industrialization but rejected capitalism because it distributed the benefits so unevenly. The classic statement of this view comes in Marx and Engels’s pamphlet, *The Communist Manifesto*, first published in 1848, which was enthusiastic about industry but looked forward to the imminent overthrow of capitalism.

- More recently, environmentalism has raised the question of whether industrial processes sometimes do more harm than good. Examples of such harm include pollution, overpopulation, resource depletion, environmental carcinogens, and possible global warming.

- Although these are serious problems, they are the problems generated by the success of the Industrial Revolution. They confront us at a time when we have the resilience and resourcefulness to remedy them. For example, Western European and American cities have much cleaner atmospheres than they did 50 years ago because they decided to prioritize pollution abatement.

The Future of Industrialization

- Industrialization does not appear to be declining. On the contrary, it has “gone global” and continues to generate new technologies, such as the recent emergence of computers and the fascinating trend toward miniaturization.

- Technology changes are often accompanied by new social and political arrangements, such as urban decentralization. Growing numbers of people don’t need to be in any particular place to work, and city centers are no longer the industrial hubs they once were.

- Prognostications for the future of industrial society diverge sharply. Can we sustain the levels of innovation we have witnessed over the last 250 years, or was the Industrial Revolution a once-and-for-all process that is now coming to an end? It’s probably reasonable to say that industrialization can go on and will—with overwhelmingly benign consequences for nearly everyone.
Suggested Reading

Allen, The British Industrial Revolution in Global Perspective.


Mokyr, The Enlightened Economy.

Stearns, The Industrial Revolution in World History.

Questions to Consider

1. Has the world ever found any way out of massive collective poverty except for industrialization?

2. Why has the Industrial Revolution constantly encountered practical and moral criticisms?
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destroyed the French effort and how the conquest of those diseases, along with more capital, machinery, and engineering savvy, made the American effort a success.


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