Powering the Revolution
Coal Mining

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 time. 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 *atmospheric 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.
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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.

Steam Technology and the First Railways

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

- George 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 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.