Coal is what can happen to peat after a long time. It is the reduced and compacted remains of forests millions upon millions of years old, forests of club mosses, some 30 meters high, of giant horsetail rushes, of flora in a profusion barely equaled by our most luxuriant jungles today. Its energy density is at the very least triple that of peat.

Oil is what we have left of tiny organisms, phytoplankton, that lived in oceans long, long ago, died and accumulated in oxygen-deficient waters, and then were buried 7,500 to 15,000 feet deep long enough for pressure and heat to transform them into liquid. (Below 15,000 feet the conditions are so extreme that gas, not liquid, is the result.) This liquid then collected beneath impermeable caps of stone to await our pleasure. The energy density of oil is a great deal higher than that of coal and it is liquid and therefore easier to store and transport.

Fossil fuels are the tiny residue of immense quantities of plant matter. An American gallon of gasoline corresponds to about 90 tons of plant matter, the equivalent of 40 acres of wheat—seeds, roots, stalks, and all. Coal, oil, and natural gas are the end products of an immensity of exploitation of sunshine via photosynthesis over periods of time measured by the same calendars used for the tectonic shuffling of continental plates. We are living off a bequest of fossil fuel from epochs before there were humans and even before there were dinosaurs.

4

COAL AND STEAM

And was Jerusalem builded here
    Among these dark Satanic Mills?

—*William Blake, poet (1804)*[1]

The world is now entering upon the mechanical epoch. There is nothing in the future more sure than the great triumphs which that epoch is to achieve. It has already advanced to some glorious conquests. What miracles of invention now crowd upon us! Look abroad, and contemplate the infinite achievements of the steam power.

—*Robert H. Thurston, historian (1878)*[2]

Accident and evolution gifted humanity with culture, which made the species into a sprinter. Humanity had dashed ahead twice before, once in the Upper Paleolithic and again in the Neolithic. In the eighteenth century, humanity sprang out of the blocks the third time. The surge of mechanization that started in England was unprecedented in the speed of its advance and its general influence, but it wasn't all new in its basic physical materials. Wood still sufficed for many purposes; indeed, it still does in our developing nations, especially for cooking and warmth.

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[1] *The Harper Anthology of Poetry*, ed. John F. Nims (New York: Harper & Row, 1981), 244.

[2] Robert H. Thurston, *The History of the Growth of the Steam Engine* (New York: D. Appleton & Co., 1878). Available at http://www.history.rochester.edu/steam/thurston/1878/. (Viewed June 3, 2003.)

Metals—copper, bronze, iron, steel—were expensive but available for tasks requiring special strength, hardness, and durability. The machines of this industrial revolution were new, but their components and basic concepts—wheels, levers, pulleys, screws, and so on—were of ancient lineage.

One of these parts was the wheel, which dates from about 5500 BP. A millennium or so later, Old World peoples had wonderfully useful wheel machines: wagons, chariots, potter's wheels, and others. The proof of their significance is the relative disadvantage of the societies that lacked the wheel, those, for instance, of the high civilizations of America. How often and for how long has a people without the wheel ever subjugated a people with the wheel?

In the first century AD, humans invented a complement to the wheel that became so common that it is hard to imagine life without it: the crank. It is a bar or rod attached to a shaft at a right angle, usually with a handle parallel to the shaft jutting out at the far end for the convenience of anyone who wants to turn or "crank" (the word is a verb as well as a noun) the shaft. With it, members of my grandparents' generation started the engines of Model-T Fords. Today, when I want to sharpen my pencil, I insert it into the pencil sharpener and turn . . . the crank.

The peoples who possessed and fell in love with the wheel and crank—the Chinese and Europeans, for instance—were using them to squeeze more energy out of sunlight long before the eighteenth century by exploiting the movement of water and wind.

The watermill, an ancient prime mover churning away on the Tigris and other Old World streams before Jesus or Mohammed, taps the potential energy stored in water deposited in ponds, lakes, snowpack, and glaciers at high elevations by sun-driven evaporation. The water makes that energy available as it flows back downhill toward the sea.[3] Watermills were at first, and for long after in

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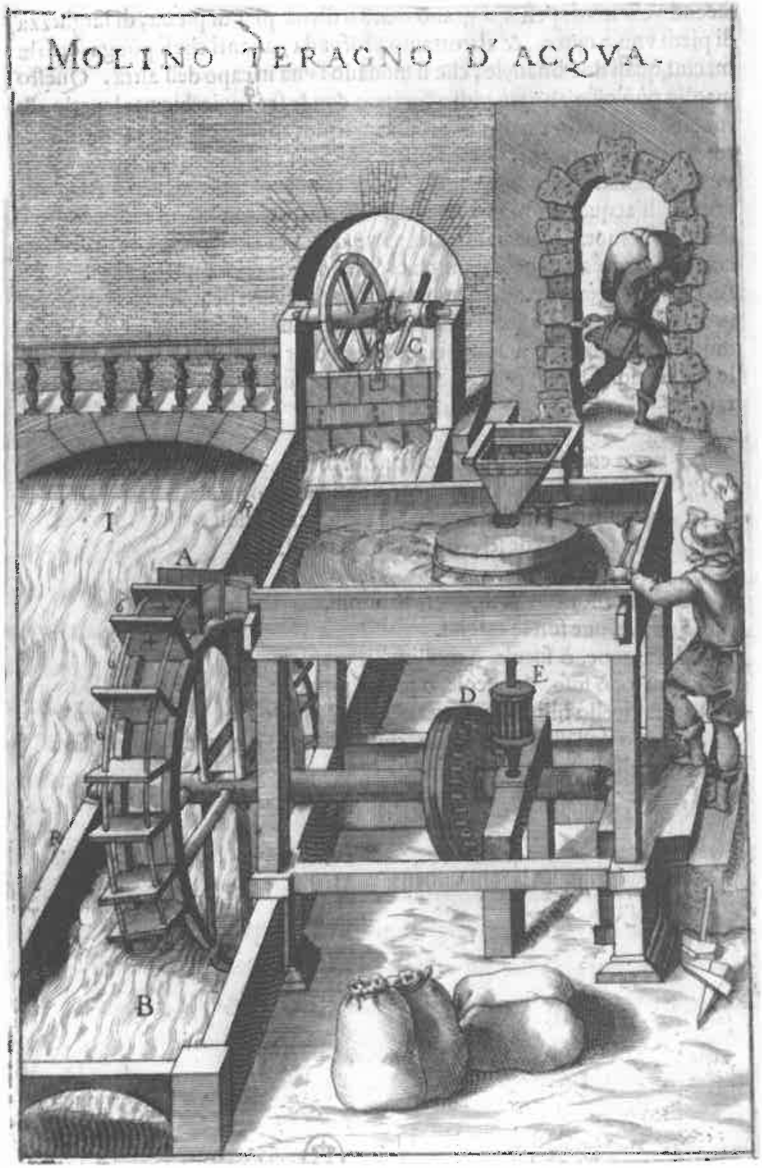
[3] Tidal mills tap lunar, not solar, power; they are omitted for that reason and because they have been of major importance in very few locations.



Mechanism of a watermill, engraving from V. Zonca's *Nova teatro di machine*, 1607.

mid- and eastern Asia, structured with vertical axes—like revolving doors set up in streams. Compared to what followed, they were inefficient because the flowing water pushing the flaps or vanes in one direction was also, unless carefully diverted or otherwise restrained, pushing against the flaps revolving around the axis in the other direction. Some inventive soul—who, when, and where we don't know—shifted the wheel's axis to the horizontal and set up the wheel so as to dip into the moving water from above. The flow pushed the wheel in only one direction. This is the undershot wheel, illustrated on page 65.

It was an improvement, but worked well only on swiftly flowing streams. Then humans built flumes or chutes that brought water from higher elevations to the top of the wheel, where it poured into troughs that were the vanes of this new edition of the old wheel. This tapped the energy not only of water flow but of gravity, the weight and impact of the falling water. A well-built, well-lubricated "overshot wheel," as this kind is called, might produce four or five or even more horsepower. According to Fernand Braudel, the great French historian, an average watermill ground five times as much grain as two men working a hand mill. In the early twelfth century, France alone had twenty thousand watermills grinding wheat, crushing ore, and so on, the energy equivalent of a half million human workers.

In that century waterwheels were common along rivers and lesser streams right across Eurasia and North Africa from the Atlantic to the Pacific. Since then they have been built throughout the rest of the world, where many are still operating, especially in the Third World. If we include in our definition of watermills the giant turbines paired to our dams today that drive dynamos to produce electricity, then this prime mover is as important today as it ever was.

Mills constructed to exploit sun-driven wind—windmills, which first appeared in Persia in the first millennium CE—also started out like revolving doors. That kind were common right up

to our time throughout Asia, where the demand for power exceeded what muscle and water could provide; but someone somewhere, probably in Western Europe in the twelfth century, invented a better windmill. He made a giant vertical fan of the revolving doors, faced it into the wind, and greatly improved the machine's efficiency, bequeathing us what we see in our minds when we think of windmills.

Windmills were and are very useful in windy regions like Southeast Iran, the coasts of China, and, famously, the Netherlands. In the latter in 1650 there were at least eight thousand windmills towering over the sodden countryside pumping water. Well into the second half of the twentieth century windmills were standard equipment in American farms, especially in the semi-arid plains. More and more of them are being raised today because windmills don't pollute.

But flowing water and wind were far from efficient expressions of sun energy. The first froze in winter and sometimes ran low in summer and, anyway, was not available everywhere. The second sometimes blew too hard and sometimes not at all. In the long run, the significance of the mills may be that the people who built and maintained them learned a great deal about levers, axles, cogs, pulleys, screws, and so on. Before the human species could make another quantum jump in exploitation of sun energy, it would have to gain access to much more energy than food or water or wind could supply; it would have to find a better fuel and then invent a more powerful prime mover.

Humanity lusted after concentrated sun energy, of which there were portents. The Byzantines invented Greek fire, a flammable liquid that stuck to everything and could be squirted short distances. Water didn't put it out and so it was very useful in naval battles. The Greeks kept the recipe for Greek fire secret, but it must have included the fossilized sun energy, petroleum, that seeped to the Earth's surface in many places in the Balkans and Middle East. The Chinese invented gunpowder, an extreme kind of fuel. At first it was used as an elixir, then in a sort of flamethrower, then in bombs to unleash a shrapnel of feces and broken crockery among the enemy. Not long after 2000 BP they were using it in guns. The ignition of a fuel—in this case, gunpowder—in a closed container produced enormous push, flinging missiles at velocities so swift that the human eye couldn't follow them. The cannon barrel and cannon ball were prototypes for the piston and cylinder.

Humans did not consider coal a fuel when they first met up with it, but valued it for its peculiar color and even used it in jewelry. In time they learned that it would burn, and a few were using it as a source of heat and light thousands of years ago. But accessible surface outcroppings of the fuel existed in only a few places, and a lot of that coal produced choking, eye-watering smoke. And wood was plentiful, at least to begin with, so there was no need to suffer coal for energy.

There were at least two false or, if you prefer, preliminary starts on revolutionizing industrial production, one in eastern and one in western Eurasia. The ironmongers and miners of China's Song dynasty started an industrial revolution of their own seven or eight hundred years before the Western Europeans got around to theirs. In 1078, China used huge quantities of charcoal to process ore into 125,000 tons of iron, twice as much as Europe (excluding Russia) produced four hundred years later. But then their revolution faltered as they ran into shortages of wood. These ironmongers began to switch to coal, of which China has large deposits in the north and northwest. That solved half their problem; but they did not tap the full sun energy of coal, which would have required inventing a new prime mover. Perhaps that was simply a matter of chance, which plays a more important role in history than many historians like to admit. Perhaps the explanation lies in the disasters that rolled over northern China: barbarian invasions, vicious civil wars, Yellow River floods. China's political and economic center of gravity shifted south and away from its richest coal deposits. Coal was not widely adopted as a substitute fuel for biomass in China until the twentieth century.

In the 1600s, when New York was born as New Amsterdam, and Cape Town and Malacca were also Dutch cities, Holland ran out of harvestable wood and couldn't shift to coal unless it imported it. The Dutch shifted to peat, a fossil fuel of which they had plenty. They warmed their homes, cooked their meals, and processed many of their manufactured products—brewed their beers, refined their sugar, baked their bricks—with peat fires. Rembrandt van Rijn painted his masterpieces as a citizen of the first society primarily powered by fossil fuels, arguably the first modern society. But, like the Chinese, the Dutch did not come up with a revolutionary prime mover. They started down the path that led to fossil fuel civilization, but halted halfway because peat, which fulfilled their immediate needs for fuel, didn't burn hot enough per unit of volume or weight to entice them on to invent a new prime mover.

The birthplace of the lasting, possibly perpetual industrial revolution turned out to be Great Britain. Many explanations have been suggested: a sturdy artisan class, Protestant discipline, an excellent transportation system of rivers and coastal waters, a market freer than most, a relatively dependable currency, relatively honest bankers, and so on, but these were characteristics of Dutch society as well. Whatever the cause or causes of Britain's industrial revolution, the presence of enormous quantities of coal under its soil was an essential ingredient for that revolution. The stimulus for the switch from biomass to coal as the primary source of sun energy was simply that England, Wales, and Scotland, like China and the Netherlands, were running short of forests. The price of firewood in Britain rose 700 percent between 1500 and 1630, much faster than general inflation. In 1608, a census of the number of "tymber trees" in seven of Britain's largest forests set the sum at 232,011. The number in 1783 was down to 51,500. The British imported wood from the Baltics and North America, but their chief solution to their fuel problem was to mine more and more coal.

At the end of the seventeenth century, London was already famous for its smoke. The diarist and gardener John Evelyn, as exasperated as a Los Angeles environmentalist on a bad smog day, complained that London resembled "Mount Aetna, the Court of Vulcan, Stromboli, or the Suburbs of Hell, rather than an Assembly of Rational Creatures, and the Imperial Seat of our incomparable Monarch."[4] Most of the city's coal came by water from Newcastle up the coast, hence the mysterious old saw about the inappropriateness of bringing coals to Newcastle.

Coal was plentiful in the English homeland, but surface outcroppings were used up fast, and by 1700 mine shafts were as deep as 200 feet. There were problems down there with gases and especially with flooding. Dig a 200-foot hole in a countryside with high rainfall, and even if you don't hit springs, the bottom of the hole will fill up with water. The miners tried lining the walls of mine shafts with sheep skins to hold back the water, but that didn't help at all. They dug tunnels to drain the water out of the mines, but this only worked when the shafts were in the side of a hill and gravity could be enlisted to carry the water down into the valleys. Muscle, animal and human, and sometimes watermills and windmills were put to work lifting the water out of the mines, but it was an endless battle that technology circa 1700 could not win. Britain's industrial revolution was drowning *in utero*.

Coal, the Carboniferous legacy of stored sunlight, would solve that problem. Coal would be burned to power the *heat engine*, which my desk encyclopedia defines as "a device that transforms disordered heat activity into ordered, useful, mechanical work."[5] The story of that kind of contrivance, of which today's nuclear reactors are examples, begins with the eighteenth century's steam engines.

Humans had known about the power of steam for as long as they had boiled water and watched the pot lid tremble and lift. In

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[4] Quoted in Barbara Freese, *Coal: A Human History* (Cambridge, MA: Perseus Publishing, 2003), 35.

[5] *The Cambridge Encyclopedia*, ed. David Crystal (Cambridge: Cambridge University Press, 1990), 554.

the first century AD the proto-scientist, Hero of Alexandria, made what we would describe as a sort of lawn sprinkler arrangement powered by steam and watched it spin. Yes, humanity knew that the expansion of steam could provide power, but it was a long walk from that realization to a practical steam engine.

There were enormous difficulties. There were no smiths who made parts in accordance with precise measurements. Metals resistant to high heat and strong enough and light enough to be used for boilers and cylinders, which would contain and restrain steam under pressure, weren't available in quantity. There had never been a useful machine combining piston and cylinder, unless you count the cannon ball and cannon as such. Inventing the first practical steam engine would have to be an event on the far frontier of possibilities.

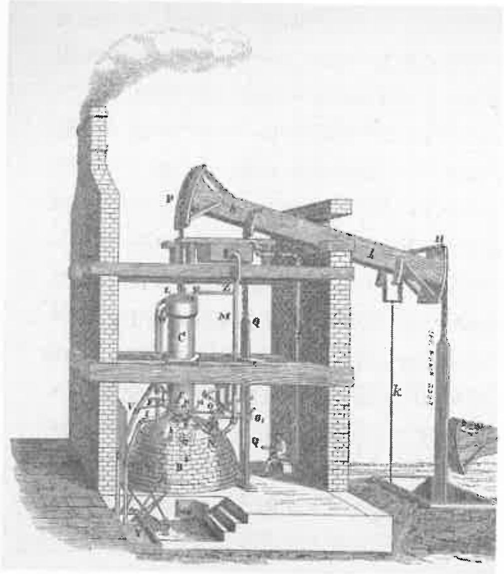
The key concept could not be to use steam to *drive* pistons vigorously and rapidly because machines with such capabilities were barely imaginable. The way around that—to us an odd one—was to use steam to make a vacuum. Classical and medieval Europeans did not believe in vacuum: space existed because there was something in it, even if only air. But halfway through the seventeenth century a German, Otto von Guericke, pumped the air out of a sphere of two carefully fitted halves, and then sixteen horses couldn't pull them apart. In 1680, a Dutchman, Christian Huygens, suggested that exploding gunpowder under a piston in a cylinder would drive out the air and most of its own gases. What would be left would be nearly nothing, at least a partial vacuum. Then atmospheric pressure would push the piston down into the vacuum. Some bright soul might try to harness that motion to do work.

The man who created that engine was an Englishman, Thomas Newcomen, of whom we know very little beyond the dates of his birth and death, 1663 and 1729. We don't even know where he was buried. He was an ironmonger from Dartmouth, one of the robust artisans produced by Western Europe's growing economies. He had little if any formal education (in that he reminds us of Michael Faraday, who figures importantly in the chapter on electricity). Perhaps he had read Huygens and the like, but probably not. He was a Baptist, a Nonconformist in religion like so many of the pioneers of Britain's industrial revolution. His admiring biographers identify him as the "first great mechanical engineer."[6]

Today, it is easier for us to imagine using hydrogen fusion to heat our homes than for Englishmen circa 1700 to imagine using fire to pump water out of mines. You set things on fire to destroy them or for warmth and light, not to push or pull, and Europeans didn't even have good fireplaces or stoves. Those that they had let most of the hot gases rise up the chimney to heat all outdoors. The Franklin (Benjamin Franklin) Stove, which detained the gases and tapped their heat before releasing them, didn't come along for more than a dozen years after Newcomen's death.

We are too accustomed to energy in plenty to comprehend the energy poverty of the world that Newcomen lived in. To illustrate: In 1682 in obedience to the order of Louis XIV, the "Sun King," fourteen waterwheels 12 meters in diameter were built near Versailles to harness the currents of the Seine to pump water to its fountains. They were together called "the eighth wonder of the world," but delivered at the very best 124 and usually not more than 75 horsepower. We scorn automobile engines of such feebleness today; three centuries ago an engine that small and of such power would have been worshipped.

Newcomen, with the help of a plumber named John Cawley or Calley, built a steam machine close by a coal shaft 51 yards deep at Dudley Castle, Staffordshire, in 1712 (see illustration on page 73). He didn't use gunpowder explosions to produce vacuums and move pistons, but steam. The machine's boiler held 673 gallons of water. Its cylinder, vertical, was 21 inches in diameter and 7 feet 10 inches tall. The fit of the piston and cylinder was loose and had to be sealed with a wet leather disk. Steam from the coal-heated boiler admitted into the cylinder lifted the piston up. Then cold water sprayed into the interior of the cylinder. The voluminous steam condensed to a small amount of liquid, producing a vacuum in the cylinder. *Then* came the power stroke, for which all the above was preparatory, as atmospheric pressure drove the piston down into the evacuated cylinder. The piston was attached to a rocker beam, the motion of which could drive a chain of buckets, a bellows, and so on.



Newcomen Engine, as modified by Richard Trevithick at Bullan Garden, Dolcoath, from *Life of Trevithick*, 1775.

Newcomen's first machine made twelve strokes a minute, raising 10 gallons of water with each stroke. Its strength is estimated at 5.5 horsepower, not impressive to us, but the "fire engine," as it was sometimes called, was a sensation in power-starved Britain and Europe. Soon there were scores of Newcomen engines, most nodding at the pitheads of Britain's mines, which now could be dug twice as deep as before. In 1700, Britain produced 2.7 million metric tons of coal; in 1815, 23 million tons. That sum was twenty times in energy equivalent what the existing woodlands of Britain could

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[6] L. T. C. Rolt and J. S. Allen, *The Steam Engine of Thomas Newcomen* (New York: Science History Publications, 1977), 13.

produce in a year. If that quantity of coal were burned in steam engines (a lot of it, of course, went for heat and cooking), the amount of power created would have equaled that of 50 million men.

At least fifteen hundred Newcomen machines were built in the eighteenth century. The rapidity of their spread in an age still, by our standards, more medieval than modern provides a measure of the need they answered. The first Newcomen engine on the continent was constructed at Königsberg in 1722. When Newcomen died in 1729, his engines were operating in Saxony, France, Belgium, and perhaps Spain. The first Newcomen engine in the New World was built in 1753 at the juncture of Belville and Schuyler Avenues in North Arlington, New Jersey. In 1775, John Smeaton built a Newcomen engine to drain Kronstadt's great drydock, which two large windmills were not keeping dry enough. This had a cylinder 5 foot 6 inches in diameter.

Thomas Newcomen's invention was the first machine to provide significantly large amounts of power not derived from muscle, water, or wind. It was a new prime mover. It utilized fire—a natural force—to heat water, to make steam, to do work. It was the first practical machine to use a piston in a cylinder. It worked night and day. If I were to attempt anything so simple-minded as to pick a birthday for the industrial revolution, it would be the first day that Newcomen's engine began operating in 1712.

In the eighteenth century, the Newcomen machine saved Britain's coal industry if not from watery demise then certainly from soggy stagnation, enabling Britain to continue with industrialization. Without increasing supplies of fossilized and concentrated sun energy, Britain's industrial revolution would have fizzled like China's. Without Newcomen's invention there would have been many fewer people in the eighteenth century thinking in terms of heat engines. Without Newcomen's invention James Watt, who for some reason is commonly credited as *the* inventor of the steam engine, actually would have had to invent the first one.

The Newcomen engine was grossly inefficient, as beginnings usually are. It was an impressive prime mover compared to muscle, water-, and windmills, but was wildly wasteful of fuel. It heated water into steam, introduced that into a cylinder, and then sprayed water into the cylinder. An egregious proportion of the fuel's energy was wasted reheating the cold cylinder at every stroke. Most of the Newcomen engines stood at the pitheads of coal mines where coal was cheaper than elsewhere, but even there it was not quite free. Big Newcomen engines consumed coal to the value of £3,000 a year, a hefty sum.

Moreover, as we, with our advantage of hindsight, can proclaim, the Newcomen engine was too big and awkward to be adapted for many tasks. It might possibly do for large ships, but not for land transportation. One at least was built to travel about on a wagon, but it was in the same category as Dr. Johnson's dog that could walk on its hind legs—interesting, but not really practical.

In addition, there was a problem with the kind of motion it supplied. Most of the machines of the budding industrial revolution required rapid, steady, and rotary motion. The Newcomen rocker arm moved slowly, not always evenly, and up and down, not round and round. When smoothly flowing rotary action was required, mill owners used Newcomen engines to raise water to pour down on waterwheels, and then the wheels did the work.

The Newcomen engine was the only practical steam engine for sixty or seventy years. Then a generation of mechanical engineers matured who were familiar with its defects, acquainted with the sciences, and had access to better materials, tools, and more skillful craftsmen than Newcomen had ever had. For instance, after 1774, British engineers who wanted pistons of precise measurements could get them from a new machine for boring cannon barrels.

The first hero of the new generation was James Watt, a Scot, a Presbyterian, a Nonconformist like Newcomen, well educated, and friendly with scientists and venture capitalists. The most important of the latter was Matthew Boulton, who wrote to Watt that he had two motives for investing in his project: their friendship and his "love of a money-getting, ingenious project. . . ." Watt was repairing a model of a Newcomen engine in 1764 when it occurred to him that the engine wasted fuel reheating the cylinder at every stroke. Instead of spraying water into the hot cylinder, why not let the pressure of the steam and the descending piston push the steam into an adjoining and unheated chamber to condense?

A dozen years later he installed two such engines, one to pump water and another to blow air into blast furnaces. They functioned satisfactorily, and by 1790 Watt had joined Boulton in the wealthy elite. By 1800, the Watt engine was producing three times as much power per bushel of coal as even the latest models of the Newcomen engine, and was pumping water out of mines, turning out flour, paper, iron, and so on and on. In the years around the turn of the nineteenth century, after Watt's patent ran out, improvements and applications of his engine came in a rush. The original version consumed too much coal and was too big and heavy to be a practical power source on vehicles or ships. It was also restricted in power and speed by its Newcomen-like dependence on atmospheric pressure to drive the piston into the cylinder as the steam was being expelled. Moreover, the arrangements Watt provided to transform the piston's linear motion to circular motion were more ingenious than effective. Within a few years high-pressure steam engines with pistons driven both back and forth by steam and linked to wheels by cranks and connecting rods were revolutionizing British activities at home and, a few years later, elsewhere.

The magnitude of the influence of the steam engine was clearly apparent in transportation. Primitive locomotives on rails began puffing along early in the nineteenth century. In 1830, one called the *Rocket* pulled a train from Liverpool to Manchester. A decade later, Britain had 1,400 miles of railroad track, continental Europe 1,500 miles, and the United States, sprawled across a continent, 4,600. In 1869, the United States, by then a nation with two populated coasts and a mostly vacant middle, tied the coasts together with the first transcontinental railroad. Elsewhere men with political influence and access to cartloads of capital were thinking about a Cape-to-Cairo railroad, a Trans-Siberian railroad, and other such awesome ventures.

The revolution that steam enacted on the oceans was at least as spectacular. In 1838, the paddle wheelers *Sirius* and *Great Western* raced from British ports to New York City for the honor of being the first vessel to make the westward crossing by steam only. The winner was the *Sirius*, but only because it set sail (an anachronistic verb we still use) ten days before the *Great Western*. The *Sirius* ran out of coal off New Jersey and burned cabin furniture, all the spare yards, and one mast under the boiler of its 320-horsepower steam engine to get to New York four hours before its rival. The *Sirius* made the crossing in eighteen days and ten hours at an average speed of 6.7 knots an hour. The *Great Western* averaged 8 knots an hour and completed the passage in fifteen days. It had four boilers, two engines of the latest design, and arrived in New York with 200 tons of coal in its bunkers. Both ships crossed the Atlantic in about half the time usually taken by ships dependent on wind.

Robert H. Thurston, one of the first historians of the steam engine, opined in 1878 that Watt's hometown, Greenock, originally a fishing village, now "launches upon the water of the Clyde a fleet of steamships whose engines are probably, in the aggregate, far more powerful than were all the engines in the world on the date of Watt's birth, January 19, 1736."[7] But shipping was merely one spectacular manifestation of the impact of Watt's innovation; its influence was greatest in the textile industry, the first to be mechanized. As early as 1800, the steam-driven spinning mule (a machine for spinning cotton thread and winding it on spindles) could produce as much per unit of time as two hundred to three hundred human spinners.

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[7] http://www.history.rochester.edu/steam/thurston/1878/ chapter 3, n.p.

The production of manufactured articles rose exponentially, as did trade, internal and worldwide. Between 1771 and 1775, England imported 5 million pounds of raw cotton; in 1841, 58 million pounds. In 1834, it exported 556 million yards of woven cotton goods. In that year, over 8 million "mules" were at work in England's cotton mills, which employed 220,000 workers. Most of the power in the cotton mills was supplied not by muscle but by the newer prime movers: 11,000 horsepower by waterwheels and 33,000 horsepower by steam engines. The factories of England and, soon after, New England turned out thousands of miles of cotton thread and cloth annually, making more inexpensive and decent clothing available than ever before. The ramifications of this textile explosion were not all positive, however. Plantations in the southern United States shifted to a monoculture of cotton cultivation, a labor-intensive endeavor. And the power there was still supplied by the primitive prime mover of muscle, in the form of slavery, an institution whose slumping status was revived by the profits to be made from the new textile mills.

The industrial (i.e., steam) revolution of the nineteenth century radically altered the global economy and thereby the global balance of power. For instance, the speed and output of England's mills blighted and nearly extinguished the ancient textile industry of India, disrupting the lives of thousands there. During the eighteenth century, India, China, and Europe had accounted for about 70 percent of the world's gross domestic product, each providing roughly (very roughly) one third. By 1900, China's share of the world's manufacturing output was down to 7 percent, India's to 2 percent; Europe's was 60 percent and the United States's 20 percent.

Steam immensely enhanced the speed and dependability of transportation, and spurred migration within countries—from rural to urban, from settled to frontier—often via railroad. Myriads of migrants left Europe for its overseas colonies and the United States: 400,000 people a year from 1850 to 1900, and then 1 million a year from 1900 to 1914. It was as if the shift to steam had pumped

Europe full and it was exploding and flinging fragments of itself over the oceans. In the same decades millions left India and China for the Americas, South and East Africa, Mauritius, the Pacific Islands, and elsewhere to work in plantations, to build docks, roads, and railroads. Many sent their wages back home to their families and eventually rejoined them there; others brought their families to join them overseas, and yet others acquired spouses to found new families in the new lands. Whatever the origins of the migrants, the vast majority crossed the oceans by steamship. The total number of all the ocean-crossing migrants between 1830 and 1914 was an amazing 100 million.

Nothing like this colossal increase in productivity, shifts in global power and reach, alterations in locus of global hegemony, and movement of goods and people had ever happened before. Taking the measure of the steam engine's gravitas, of its historical *mass*, using the word as physicists do, is like trying to judge the significance of the tectonic drift of the continents. Let us consult expert witnesses.

Friedrich Engels was an honest witness of the human costs of the early industrial revolution. He was appalled by the horrors that followed when English factory owners obliged laborers to work to the tempo, mechanical and economic, of the industrial revolution: the illnesses and accidents, the malformations of bones and joints and minds dictated by repetitive labor, the hunger, the insecurity, the general wear and tear that shortened lives. A good proto-sociologist (though occasionally succumbing to the temptation of the exclamation mark and often to that of making prophecies), he collected statistics on England's factory workers circa 1840:

> Of 1,600 operatives employed in several factories in Harpur and Lanark, but 10 were over 45 years of age; of 22,094 operatives in diverse factories in Stockport and Manchester, but 143 were over 45 years old. Of these 143, 16 were retained as a special favour, and one was doing the work of a child. . . . Of

> fifty worked-out spinners in Bolton only two were over 50 and the rest did not average 40 and all were without means of support by reason of old age! . . .
>
> In all directions, whithersoever we may turn, we find want and disease permanent or temporary, and demoralization arising from the condition of the workers; in all directions slow but sure undermining, and final destruction of the human being physically as well as mentally.

Engels predicted that soon the day would come when the proletariat would rise and then "will the war cry resound through the land: 'War to the palaces, peace to the cottages!'—but then it will be too late for the rich to beware."[8]

Charles Dickens was also appalled by the poverty, hunger, disease, and anguish of the peasants who migrated from countryside to city to work in the new factories and, as well, by the ever-thickening coal smoke of the industrializing cities. In his novel *Hard Times*, he provides a description of Coketown, his fictional but accurately representative city of the early industrial revolution:

> It was a town of machinery and tall chimneys, out of which interminable serpents of smoke trailed themselves for ever and ever, and never got uncoiled. It had a black canal in it, and a river that ran purple with ill-smelling dye, and vast piles of buildings full of windows where there was a rattling and a trembling all day long, and where the piston of the steam-engine worked monotonously up and down like the head of an elephant in a state of melancholy madness.[9]

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[8] Friedrich Engels, *The Condition of the Working Class in England* (New York: Viking/Penguin, 1987), 179, 221, 292.

[9] Charles Dickens, *Hard Times* (London: Folio Society, 1994), Book I, chapter V, p. 18.

Dickens also noted, grudgingly and as an afterthought, that the new mills produced "comforts of life which found their way all over the world."[10] He saw both sides of the coin of industrialism, withheld predictions, and contented himself with outrage.

The American statesman and advocate for American industry Daniel Webster was in 1818 much more single-minded than Dickens. He focused on the positive characteristics of the steam engine: its power, adaptability, and promise. To the members of the Boston Mechanics' Institution, he extolled the virtues of the steam engine:

> It rows, it pumps, it excavates, it carries, it draws, it lifts, it hammers, it weaves, it prints. It seems to say to men, at least to the class of artisans: "Leave off your manual labor; give over your bodily toil; bestow your skill and reason to the directing of my power, and I will bear the toil, with no muscle to grow weary, no nerve to relax, no breast to feel faintness." What further improvements may still be made in the use of this astonishing power, it is impossible to know, and it were vain to conjecture.[11]

Power had been about muscle for all of human history, and the most effective way to marshal it had been by assembling serfs and slaves. Now, by golly, the best way was to get yourself a steam engine.

THE NINETEENTH CENTURY is sometimes called the age of coal and steam and ours the age of oil and the internal combustion engine, but the former age continued on into the next century and is still with us. Coal, for instance, is at present the most important fossil fuel for making steam to spin our dynamos and produce our electricity, which the peoples of the richer societies consider as

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[10] Ibid.

[11] *The Works of Daniel Webster*. Vol. 1 (Boston: Charles C. Little & James Brown, 1851), 186.

much their birthright as (ironically) air to breathe. Furthermore, we now have techniques to transform coal into liquid combustibles and other essentials, and there are many nations—China, for instance, and, increasingly, the United States—with a good deal more concentrated energy as coal than as oil under their soils. The hard black fuel has continued and will continue as a crucially important factor in world history. The effects of the first stage of the fossil fuel revolution that appalled and entranced the witnesses quoted above fester and foster today in developing nations, from the grim *maquiladoras* of Mexico's Tijuana to the silky nightclubs of China's Shanghai.

CODA:
NELLIE BLY BEATS PHILEAS FOGG BY EIGHT DAYS

Phileas Fogg, hero of Jules Verne's trendy novel, *Around the World in Eighty Days* (1873), completed his circumnavigation in eleven weeks and three days. Taking the Suez Canal instead of the Cape of Good Hope route saved him weeks, but his greatest advantage was that he traveled by coal and steam, not sail, i.e., by a much more concentrated product of sun energy than wind. (Incidentally, he ran out of coal and had to burn his vessel's superstructure under the boiler of its steam engine to complete the final leg of his voyage—an obvious echo of what happened to the *Sirius* off New Jersey in 1838.)

A decade and a half after the publication of Verne's book, Nellie Bly, a reporter at the *New York World*, suggested to her editor that the newspaper should sponsor her in an attempt to beat Phileas Fogg's record. He tried to dissuade her, saying that it was not a job for a woman, who would have too much luggage and wouldn't have a gentleman to protect her. She answered that if the editor sent a male reporter around the world, "I'll start on the same day for some other newspaper and beat him."

She won that argument and left to go round the world with one bag and no protector on the morning of November 14, 1889. Six

days later she debarked in England. On arriving in France she visited with Jules Verne, and then continued on to Brindisi, Italy, where she caught a ship for Egypt and on to Colombo, Ceylon. She was booked for immediate departure from Colombo for China, but there was a delay of five days. Then she had a piece of luck, a record-setting passage to Hong Kong in spite of headwinds and monsoon storms.

In Hong Kong she saw the American flag at the United States Consulate, the first she had seen since leaving home. "That is the most beautiful flag in the world," she said, "and I am ready to whip anyone who says it isn't." No one spoke. From China she traveled on to "the Land of the Mikado," where she spent 120 hours. Her passage across the Pacific was stormy, but she arrived hale and hearty in San Francisco on January 23, 1890, where she was welcomed enthusiastically. She had completed 21,000 miles in sixty-eight days.

Snows blocked the passes through the Sierra Nevada, so Nellie took the southern route through the Mojave Desert and crossed the continent in four and a half days, reaching Jersey City, her embarkation port, at three-fifteen in the afternoon of January 25.[12] The circulation of the *New York World* was soaring, and she was a media celebrity, one of the very first. There was a popular song entitled "Globe-Trotting Nellie Bly," and soon a Nellie Bly board game that followed square-by-square every day of her circumnavigation. She had circled the world in seventy-two days, six hours, eleven minutes, and fourteen seconds, beating Phileas Fogg's fictional record by more than a week.

One more note about Nellie Bly. She not only proved that you

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[12] I have assumed that all the locomotives and ships involved in this journey burned coal, not wood. I do so because wood was in short supply in many regions and these trains and ships were whenever possible chosen for their speed. Some American locomotives were still burning wood circa 1890, but surely not those that carried Bly across North America in four and a half days.

could go round the world in less than eighty days, but also that speed at a rate of a new society a week often promotes nothing so much as fatigue. She summed up what she had learned in her great adventure thus:

> There is really not much for Americans to see in the foreign lands. We've got the best of everything here; we lack in nothing; then when you go over there you must be robbed, you get nothing fit to eat and you see nothing that America cannot improve on wonderfully.[13]

The revolution instigated by Newcomen and Watt only served to confirm what Bly had already known to be true when she climbed the first gangplank.

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[13] Brooke Kroeger, *Nellie Bly: Daredevil, Reporter, Feminist* (New York: Random House, 1994), 168–69.

5

OIL AND THE ICE
(Internal Combustion Engine)

> For God's sake, be economical with your lamps and candles! Not a gallon you burn, but at least one drop of man's blood was spilled for it.
>
> —*Herman Melville (1851)*[1]

> Oil is probably more important at this moment than anything else. You may have men, munitions, and money, but if you do not have oil, which is today the greatest motive power that you use, all your other advantages would be of comparatively little value.
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> —*Walter Long, House of Commons (October 1917)*[2]

A concern of humanity for millennia and its obsession for the past two centuries has been to find ways to tap energy so as to maximize its availability wherever and whenever it is wanted. The pairing of coal and steam to drive engines was an enormous advance in that search, but the search didn't—couldn't—stop there. Humanity always wants more power in smaller units of volume and weight, of greater portability. Humans want to carry sun-power like six-shooters in a cowboy movie. For that they would need new fuels and new prime movers.

By 1900, locomotive engines were operating at five times the

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[1] Herman Melville, *Moby-Dick; or The Whale* (Harmondsworth, UK: Penguin Books, 1972), 306.

[2] Daniel Yergin, *The Prize: The Epic Quest for Oil, Money, and Power* (New York: Simon & Schuster, 1992), 177.