FROM WATER POWER TO WATT

THE ENERGY REVOLUTION OF THE EIGHTEENTH CENTURY

Jim Andrew

In the seventeenth century, there were no steam engines, no electricity or vehicle fuel from petrol pumps. Power came from human and animal energy, enhanced by wind and water. Changes in water and steam technology in the late-seventeenth and eighteenth centuries contributed to the Industrial Revolution.

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Sarehole Mill. One of the two remaining water mills in the Birmingham area.

Wind power, as now, was limited by variations in the strength of the wind, making water the preferred reliable source of significant power for regular activity. The Romans developed water wheels and used them for a variety of activities but the first definitive survey of water power in England was in the Doomsday Book c.1086. At that time, well over five-thousand mills were identified – most were the Norse design with a vertical shaft and horizontal disc of blades.

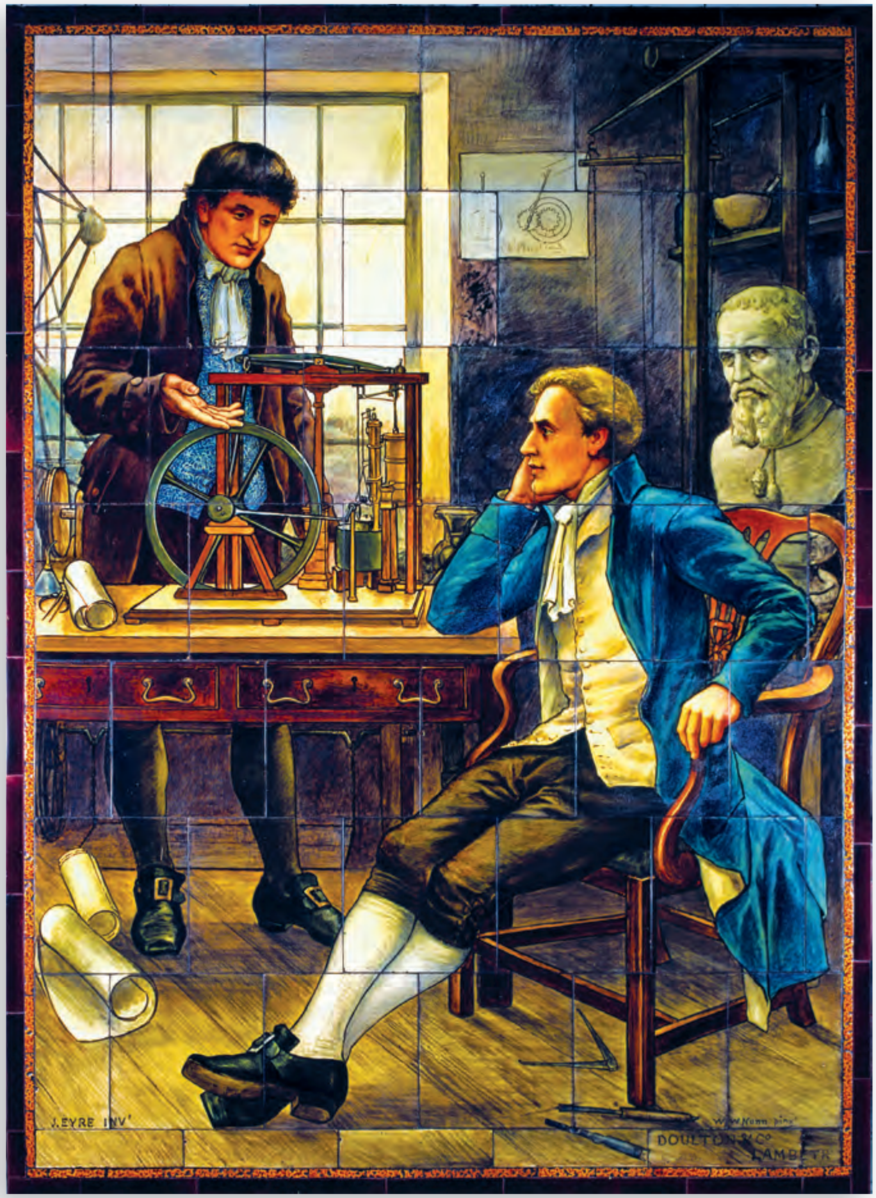
Water-Wheel Technology

Traditional water mills, with vertical wheels on horizontal shafts, were well established by the eighteenth century. Many were underpass designs where the water flowed under a wheel with paddles being pushed round by the flow. Over time, many mills adopted designs which had buckets, filled with water at various levels from quite low to the very top of the wheel. The power was extracted by the falling of the water from its entry point to where it was discharged.

There was little systematic study of the efficiency of mill-wheel design in extracting energy from the water before the eighteenth century. At that time, technical studies were made to compare the power of different designs. Most prominent was the experimental work of the engineer John Smeaton (1724-1792), who brought scientific understanding to bear upon developments.

Smeaton's contribution to water-mill technology consisted of surveys and comments on the performance of water mills and detailed model experiments to compare the efficiency of different arrangements. These experiments showed that, for the same fall, a wheel supplied at a high level could deliver twice the efficiency of one fed at low level. He contributed to sufficient water mill designs to ensure that millwrights took notice.

In the nineteenth century, William Fairbairn (1789-1874) made further contributions to the technology of waterwheels. These two men and others enabled water mills to remain important to the extent that, in the UK, utilised water power exceeded the available steam power until about 1860.



Matthew Boulton and James Watt discussing the condensing engine, painting on tiles by John Eyre, 1886.

West Midlands Water Mills

The West Midlands was not particularly suited to water mills, because the rivers did not have significant gradients to provide a powerful fall of water to generate energy. The side streams, however, were better. Later head races and tail races, which bypassed shallows on the rivers, fed into existing mill ponds to make use of the river water and the tail race from one mill was often followed by a head race to the next mill downstream.

By the eighteenth century there were more than fifty watermills within six miles of the centre of Birmingham, many tending to industrial rather than agricultural use. Just two of these mills remain intact, Newhall Mill in Sutton Coldfield and Sarehole Mill in Hall Green.

In the 1760s, after use by Matthew Boulton, Sarehole Mill was rebuilt. It had two waterwheels, a mill pond, two feeder reservoirs on side streams, a dam on the River Cole to the south, a mile-and-a-half of feeders and a two-hundred-yard tail race.

Water and Steam

While water mills were practically used in Roman times, the process of boiling water to produce steam was only a subject of experimentation. Around 100 AD, Heron of Alexandria described a steam-powered ball with angled jets which whirled round when steam was applied from a simple boiler. It was, in modern parlance, a reaction turbine, but a practical use had to wait for seventeen-hundred years. It was just an interesting toy at the time, and did not lead to an application to generate useful power.

In the late-sixteenth century, scientists began to study the physical world and to experiment with subjects such as how water behaved when heated and boiled. Apparatus was built to show that steam pressure would force water up a pipe, but it still seemed little more than a toy.

The following century saw the growth of the idea that steam pressure could be a source of real power but, as yet, this did not move to a practical application. Indeed, until the late-eighteenth century, boilers were not strong enough to generate significant steam pressure. At the same time, the development of vacuum pumps revealed how the power of a vacuum could be created by condensing steam in a closed vessel.

John Smeaton, by George Romney, 1779.

Thomas Savery's Steam Pump

The breakthrough in demonstrating that useful power could be obtained from boiling and condensing water came when Thomas Savery (1650-1715) invented a steam pump which worked by drawing water up into a vessel through the condensation of steam and then forced it to a height using steam pressure.

Savery proposed that it could be used to drain mines. The flooding of mines was a problem at that time, but in reality the technology of the day limited his machine to powering fountains and pumping drinking water. The difficulty was that Savery's pump only applied the vacuum and limited steam pressure directly to the water. What was needed was a means of multiplying the force which this could produce – a development which rested with Thomas Newcomen.

Thomas Newcomen's Engine

Thomas Newcomen (1663-1729), was a businessman who supplied metal goods to the local industries around Dartmouth in Devon, including tin mines which had problems with flooding. Importantly, he was also a nonconformist lay preacher with contacts throughout England.

Shortly after 1700 he began developing an engine to drain mines and possibly around 1705 he built his first working engine. No significant records exist for his early attempts to harness the condensation of steam in order to produce the vacuum needed to create power, along with the cylinders, pistons and pivoting beam to put his ideas into practice. The only use of steam pressure in his engines was to force the steam into the cylinder where it was condensed by a spray of cold water.

Among his Baptist contacts was a group near Dudley who brought him north to erect his first recorded engine, completed in 1712, to drain coal mine workings for Lord Dudley. A local industrialist produced and sold engravings of the engine with enough detail to show it was a fully-developed substantial construction in a large engine house, some forty-feet high.

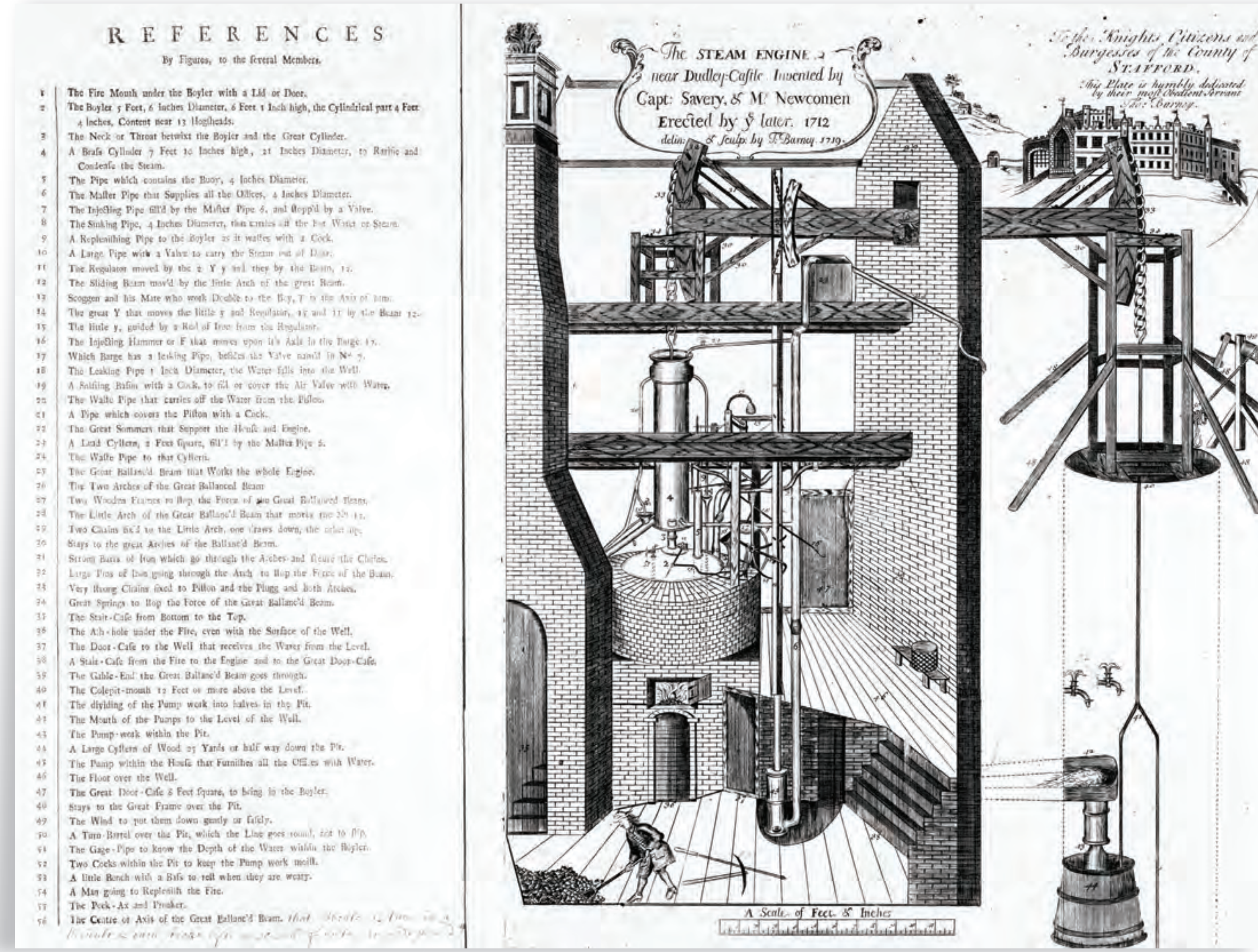
Patents were expensive in those days, but Thomas Savery's somewhat discredited design had a sweeping patent coverage for the use of steam. Thus it made sense for Newcomen, who probably already knew Savery, to let his engine operate under that existing patent, which had been extended by Act of Parliament to 1733.

Initially the adoption of the engines was slow, but it seems likely that over a hundred had been built by the time the patent protecting the design expired in 1733. The design was limited to single-acting pumping beam engines with their irregular motion. This meant that, until the 1780s, the only way to power factory machinery was to use the engine to lift water which could then pass over a water wheel, a dependable way of producing smooth rotating power.

Over thirty Newcomen engines were erected in the Midlands by the 1730s and most drained mines. None of these early engines survive, but a full-size replica of the 1712 engine at the Black Country Living Museum provides an excellent demonstration of how these engines operated. Newcomen's design was very inefficient but it was all that was available as an alternative to water power.

John Smeaton and Engine Design

Many engineers tried to improve the efficiency of the engine but all retained the condensation of steam in the cylinder with little use of steam pressure. One of the most successful of these engineers was John Smeaton who, as with water mills, surveyed



Newcomen's Steam Engine at Dudley Castle, engraving by Thomas Barney, 1719

the existing engines and carried out extensive trials on an experimental engine at his home near Leeds.

Smeaton optimised the engine design and doubled the efficiency, but the engine had to be maintained to his exacting standards - something that few owners were able to manage.

James Watt and Newcomen's Engine

Born near Glasgow just eight years after John Smeaton and similarly trained as an instrument maker, James Watt (1736–1819) was appointed instrument maker at Glasgow University. He had no contact with steam engines until the 1760s, when he was asked to repair the university's small-scale demonstration model of a Newcomen engine. Earlier repairs had been attempted but without success. Watt made it work, but it only just managed to overcome its own internal friction. Newcomen's design was badly affected by a 'scale effect' with the losses growing disproportionately as its size was reduced. If Watt had been working on a much larger model he might never have made the important breakthrough to significantly improve scientific understanding of steam power.

The Separate Condenser

One Sunday morning after church, walking on Glasgow Green, Watt suddenly realised that the Newcomen engine's problem was in trying to contain a cylinder which was hot enough to hold steam but also cold enough to condense the steam when a vacuum was needed. Why not have two separate vessels, one kept hot and the other cold, connected by a valve which opened when necessary? This was to become the 'separate condenser' which not only solved the immediate Newcomen engine's problem but facilitated the development to much greater power.

Watt made a model of his condenser and cylinder which showed that the idea worked, but it was necessary to keep the cylinder hot throughout its length, while in the Newcomen engine there was cold air above the piston as it moved up and down. Watt introduced a cover to the top of the cylinder and steam from the boiler passed first into the space above the piston and then moved to the space under the piston for the power stroke. Thus the force across the piston was boiler pressure above and the vacuum from the condenser below. Hence the design could accommodate increases in pressure and power as boiler technology improved.

James Watt studies the model of Newcomen's engine, given to him to repair, by V Parent, in Figuier, *Merveilles de la Science*, 1764.

This layout was technically much better, but it introduced a new problem. The piston could not be sealed as in a Newcomen engine but needed more accurate machining than the earlier design in fact, to an accuracy unheard of at that date. It took Watt some ten years to solve this and other problems.

From Theory to Practice; Making an Efficient Steam Engine

John Roebuck (1718-1794), a Midland industrialist who had settled in Scotland, experienced difficulties draining his mines. He put money into developing Watt's engine, yet progress remained slow. While patenting the separate condenser in 1769, Watt visited Birmingham and met Matthew Boulton (1728-1809) who needed power for his factory, the Soho Manufactory. As Roebuck's financial position deteriorated, Boulton was able to exchange all rights to the engine design for some of Roebuck's debts.

In 1774, Watt left Glasgow to settle in Birmingham and work on the engine but, as five years of the patent's life had passed, he and Boulton used the Savery patent's precedent to extend the patent to 1800. Boulton's Midland contacts, particularly Shropshire ironmaster John Wilkinson (1728-1808), finally produced accurately engineered pistons, cylinders and other components.

An experimental engine built at Boulton's Soho Manufactory showed that Watt's design gave three times the power of a Newcomen engine using the same quantity of coal, while it could also deliver twice the power for the same size cylinder. Newcomen engines could only produce useful power if the steam was condensed down to 80°C, otherwise they ran too slowly, while the Watt engine could condense the steam down to 40°C. It was this increase in temperature range within which gave both increased efficiency and increased power.

The first commercial Watt engines appeared in 1776, fully justifying the claims made for them, yet these engines were still only suitable for mine drainage and water supply.

The oldest complete working example of a Watt pumping engine is the Smethwick Engine of 1779, preserved in Thinktank, the Birmingham Science Museum. It worked for 112 years raising canal water and during that time it was rebuilt twice, but the basic design remained unaltered and some original components survived. The engine was the first to use a controlled steam valve to provide expansive working, matching the power needed without reducing engine efficiency – a basic design of Watt's single-acting engine which was built for many years.

The next stage in engine development was the need for power for machinery in factories. Boulton, Watt's partner, was the driving force. He wanted to provide direct power for rotating machinery in his works and for installation wherever he and Watt could find customers. ●

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Further Reading

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