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Introduction: a manufacturing people

'It will be seen that a manufacturing people is not so happy as a rural population, and this is the foretaste of becoming the "Workshop of the World".'

Sir James Graham to Edward Herbert, 2nd Earl of Powis, 31 August 1842

'From this foul drain the greatest stream of human industry flows out to fertilise the whole world. From this filthy sewer pure gold flows. Here humanity attains its most complete development and its most brutish; here civilisation works its miracles, and civilised man is turned back almost into a savage.'

Alexis de Tocqueville on Manchester, 1835

Britain's national census of 1851 reveals that just over one half of the economically active population were employed in manufacturing (including mining and construction), while fewer than a quarter now worked the land. The making of textiles alone employed well over a million men and women. The number of factories, mines, metal-working complexes, mills and workshops had all multiplied, while technological innovations had vastly increased the number of, and improved the capabilities of, the various machines that were housed in them. Production and exports were growing, and the economic and social consequences of industrial development could be felt throughout the British Isles. The British had become 'a manufacturing people'. These developments had not happened overnight, although many of the most momentous had taken place within living memory.

By the 1850s commentators were already describing this momentous shift as an 'industrial revolution'. The phrase obviously struck a chord, and is now deeply ingrained. Yet the term is, in fact, somewhat perplexing. It has no precise or universally accepted meaning, and can only ever be used in the loosest sense. Under 'revolution' in the *Shorter Oxford English Dictionary*, indeed, there is no definition whatever relating to this type of phenomenon. Is it, therefore, really a help or a hindrance to rely on it to describe the many new developments in manufacturing that occurred in Britain during the late eighteenth and nineteenth centuries? The idea of a 'revolution' conveys the impression that economic, social and industrial change was everywhere profound and sudden – apocalyptic even – and that old or traditional methods of production were discarded overnight, rendered obsolete by a host of new inventions or the sudden arrival of huge new mills and innovations in factory working. Rarely was this actually what happened. The 'industrial revolution' never was a deterministic force, like a volcanic eruption. Nor was it some plot, whether well intentioned or malevolent, hatched by a coterie of eighteenth-century inventors and entrepreneurs. Industrialisation might have appeared inexorable, but it was hardly planned in any sense. It did not follow a single, linear path and was often patchy or chaotic in its stuttering progress. It was neither sudden nor total.

In this book, therefore, the phrase 'industrial revolution' is used sparingly, sometimes as a convenient way of distinguishing the period under review from the twentieth century or the Middle Ages, sometimes deliberately to emphasise that while many developments took place gradually, at some times and in some places changes *were* revolutionary, such as when water-powered cotton-spinning mills transformed the Derwent Valley in the 1770s and 1780s, or when the building of blast furnaces created dramatic new landscapes around Coatbridge in the 1830s.

The term 'industrial revolution' was popularised by Arnold Toynbee who, in lectures published the year after his early death in 1881, saw the causes of change as developments in economic thought. 'The essence of industrial revolution,' he wrote, 'is the substitution of competition for the medieval regulations which had previously controlled the production and distribution of wealth.' But the phrase has a more venerable lineage than this. One of the earliest published uses – albeit in German rather than English – appeared in the mid-1840s in the first edition of Friedrich Engels' *Condition*

'Richard Arkwright's Cotton Mill' at Cromford, by William Day, *c.*1789. Arkwright's legacy was, perhaps, summarised best by the engineer James Watt: 'He is, to say no worse, one of the most self-sufficient, ignorant men I have ever met with, yet, by all I can learn, he is certainly a man of merit in his way … for whoever invented the spinning machine, Arkwright certainly had the merit of performing the most difficult part, which was the making it useful.'

PHOTOGRAPH BY CARNEGIE, WITH PERMISSION OF DERBY MUSEUMS AND ART GALLERY

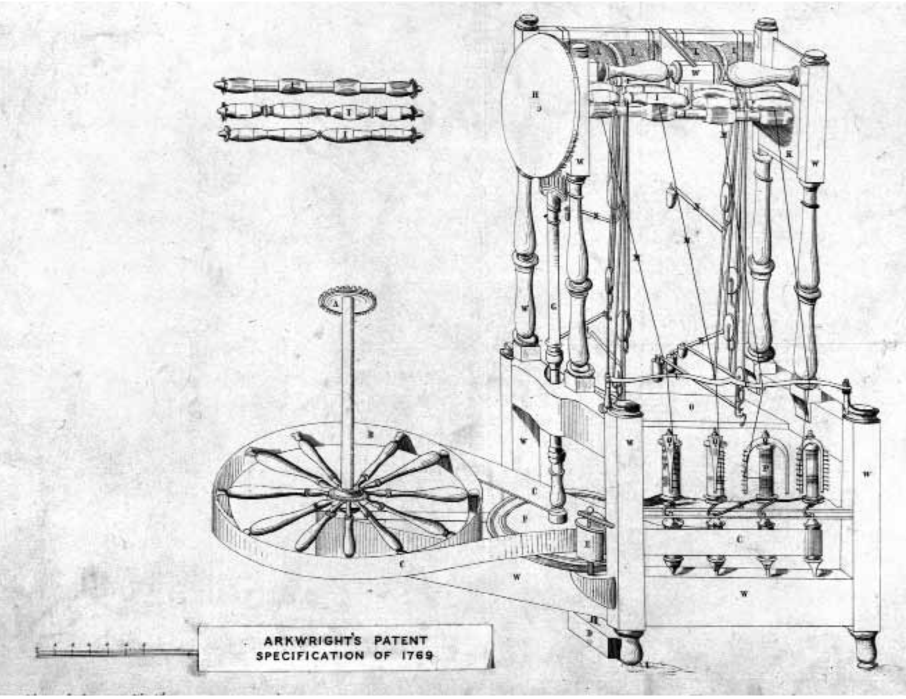
Pontcysyllte Aqueduct is one of the enduring symbols of the early industrial age. Contemporaries were quick to recognise its importance in terms of innovative design, its use of new materials and techniques, and the very boldness of its conception: Sir Walter Scott spoke of it as 'the most impressive work of art he had ever seen'. Industrialisation comprised a broad range of complementary developments in areas as diverse as engineering, materials science, machine making, design, and finance, and a few large civil engineering structures such as Pontcysyllte captured the essence of the process and the spirit of the age. The aqueduct is now the centrepiece of a World Heritage Site.
PHOTOGRAPH BY COURTESY OF ADRIAN PINGSTONE, 2008

of the Working Class in England (a work that was not published in English until the 1890s). European radicals of this era were well versed in the terminology of political 'revolution', and the use of the word to describe the economic and social changes that Engels had observed at first hand while in Manchester must have come naturally:

> The history of the proletariat in England begins with the second half of the last [i.e. eighteenth] century, with the invention of the steam-engine and of machinery for working cotton. These inventions gave rise to an industrial revolution ['*zu einer industriellen Revolution*'], a revolution which altered the whole civil society …

Sixty years later, in 1909, another continental commentator, Paul Mantoux, introduced his survey of *The Industrial Revolution in the Eighteenth Century* with a similarly straight-forward explanation:

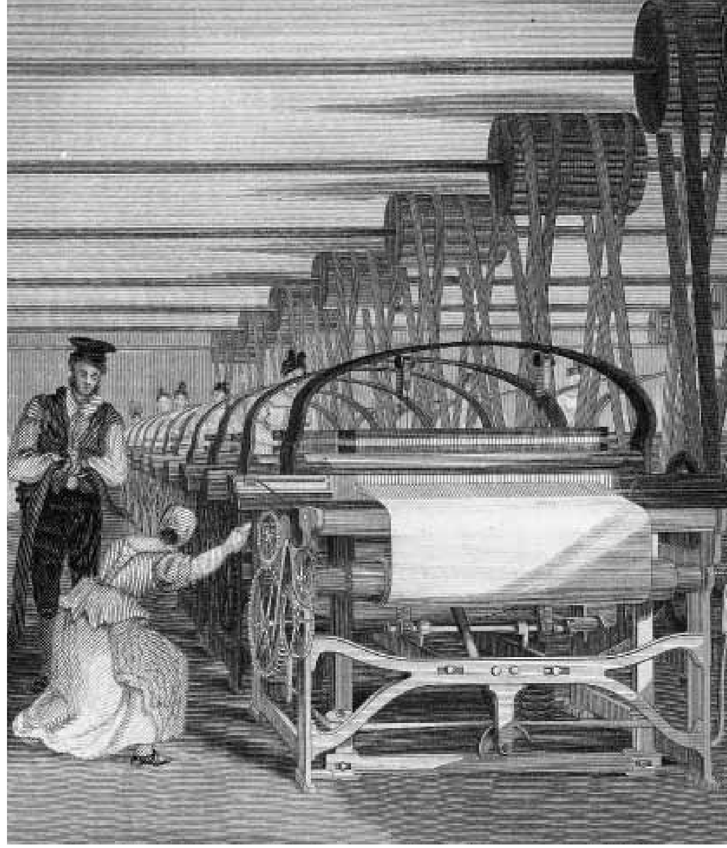
> The modern factory system originated in England in the last third of the eighteenth century. From the beginning its effects were



The patent drawing from 1769 of Richard's Arkwright's water-frame, the first successful powered cotton-spinning machine. The crucial innovation here was in using rollers that operated at successively faster rates in order to stretch or 'draw' the yarn while simultaneously imparting the necessary amount of twist. Arkwright exploited the invention vigorously both at his own mills at Cromford and elsewhere and by protecting his patent rights. There had been earlier inventions, including Lewis Paul's powered spinning machine that also used rollers and James Hargreaves' spinning 'jenny', a more rudimentary design that simply mechanised the traditional spinning wheel, and whose main drawback was that it could not operate continuously. It was Arkwright's machine that ticked all the boxes, and it was Arkwright who went on to demonstrate its true commercial possibilities and importance.

> so quickly felt and gave rise to such important results that it has been aptly compared to a revolution, though it may be confidently asserted that few political revolutions have ever had such far-reaching consequences.

Until relatively recently this kind of narrative was widely accepted. In broad terms it ran thus. In the late eighteenth century British industry, particularly the manufacturing of cotton textiles, grew at a prodigious rate, largely as the result of technological innovations in the spinning of yarn, the harnessing of water and subsequently of steam power to drive machinery, and the adoption of new systems of management in which workers' time and effort were closely directed, measured and valued. In textiles and beyond, manufacturing production came to be accommodated in ever larger workplaces, in factories or mills of a whole new type. Receptive domestic and overseas markets enthusiastically welcomed the products of these new enterprises, which were often less expensive and of higher quality than what had been available before. Strong demand and improving supply spurred on higher rates of economic growth. Part of the improvement involved new systems of production, in which various processes were mechanised and powered by a single power source – epitomised by the Arkwright-style cotton-spinning mill. Such buildings involved the gathering together of much larger workforces. Spinning mills were built in many parts of Britain, and elements of the factory system they embodied came to be adopted in other sectors of industry. Alongside this industrialisation came urbanisation, as a fair proportion of manufacturing came to be concentrated in towns and cities, to which migrants were attracted by the apparent prospects of high wages, regular employment and the availability of housing; and some were driven away from rural society because of poverty, insecurity of tenure, uncertain and inadequate remuneration or, in some cases, obligatory deference towards social superiors. Some forms of domestic manufacturing were threatened as production was mechanised, but others continued to prosper for considerable periods because their raw materials, whether textile yarns or wrought-iron rods, became more abundant or less expensive as a result of new technology.



A handloom weaver is depicted (*left*) in the *Book of English Trades* (1804–05), while (*right*) we see a depiction of powerloom weaving in 1835, one of the plates used to illustrate Baines' *History of the Cotton Manufacture*. The transition from hand to power weaving came later than the mechanisation of spinning, and it look longer to accomplish, but the contrast between these images is striking. Ranks of powerlooms, seen here attended by young women operatives, were able to weave much more quickly and cost-effectively. Progressive mechanisation such as this was one of the principal features and drivers of industrial development.
BOTH IMAGES CARNEGIE COLLECTION

The broad thrust of change which so excited the attention of contemporaries was that increasing numbers of workers had come to be tied to factory machines and to their employers' systems of time-keeping. Discipline and long hours of unremitting toil were the prices to be paid for regularity of work and high wages. There had been a remarkable, if not quite thorough, transition from domestic to factory production, and the change could be startling. Polite visitors from afar flocked to marvel at and write about 'palaces of industry'. Many came from overseas, from Sweden, Germany, France and America, from countries with their own entrenched or emergent industrial sectors. They recorded their observations because many were in Britain, formally or informally, to spy on new technologies and systems of production with a view to replicating them at home. Their detailed reports are also a reminder that throughout the period we call the industrial revolution British manufacturers faced potential competition from abroad. Such visitors naturally concentrated on the novel and the remarkable, and to many the cotton mills of Lancashire epitomised the whole phenomenon. According to Léon Faucher, a French Liberal politician, amateur historian and free-trade economist who spent time in Manchester in 1844, 'The birth of the manufacturing system, like that of Minerva, was sudden and complete; and in less than a century, its colossal, if not harmonious, proportions were fully developed. … Lancashire was its cradle.'

A manufacturing society had been born, and to many the change had taken place so quickly, and its nature was so novel, that it constituted much more than a simple increase in the rate of production. Alongside the statistics of growth, the industrial

Detail of 'East View of Derby', 1728, showing the silk mill on the river Derwent near the centre of the town. Lombe's mill possessed many of the characteristics of later textile mills: it was multi-storey; machinery was powered by a single power source; several different processes took place under one roof; and a large number of employees was gathered together in one workplace. Yet the Derby silk mill opened half a century before Arkwright's cotton-spinning mill at Cromford, demonstrating that industrialisation was not a straightforward, linear process.
BY COURTESY OF DERBY MUSEUMS AND ART GALLERY

revolution was a qualitative shift, affecting the whole of society and stimulating other developments within the British Isles and beyond, many of which increased the demand for manufactured goods. Technological developments, such as the steam engine, which at first were concerned with mining or manufacturing, were applied to the improvement of transport facilities, allowing the development of more distant markets. Similarly, cast iron, first used for constructional purposes in bridges, was employed in the frames of fireproof textile factories, which increased the output of fabrics and thread and the demands placed upon iron foundries. And industrial change was helped everywhere by a surprisingly broad range of enabling factors, such as improvements in machine making, better transport infrastructure, and from new forms of credit and financial transactions.

Recent generations have refined and re-evaluated the traditional narrative. The emphasis on inventions and revolutionary change had perhaps been excessive. The industrial history of Britain was not all about big new factories and machinery. For instance, we now know that handloom weaving continued on a significant scale for more than half a century after the powerloom had been invented, and that a fair proportion of weaving still took place in domestic settings far into the middle of the nineteenth century: a salutary reminder that the date of invention was never the same as the date of widespread adoption or displacement of older practices. Similarly, although steam power did eventually become hugely influential, water power was still of greater significance and ubiquity in manufacturing until well into the nineteenth century.

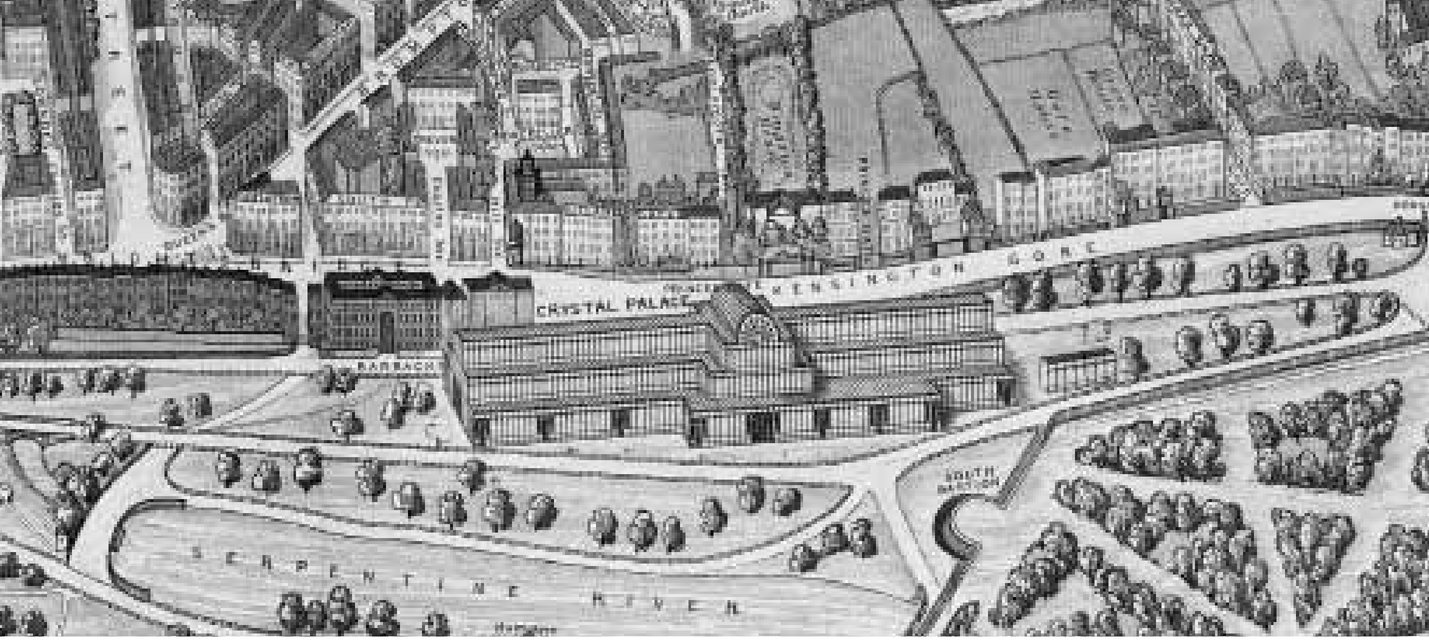
Further, an objective analysis of most industrial sectors shows that large factories were not always the norm, and that the average size of firms and factories remained surprisingly small, especially in places such as Birmingham or Sheffield and in the trades producing consumer goods. Even in the 1870s, there were armies of domestic craft workers, some of them in large towns, who never saw the inside of a 'factory'. The typical production facility, right to the end of the nineteenth century, was more likely to be a small or medium-sized workshop rather than one of the mighty mills or factories whose novelty and size drew such attention at the time.

Further, we should remind ourselves that in one or two celebrated instances large-scale manufacturing facilities had existed *before* the classic period of industrial 'revolution': as early as the 1720s in Derby, for example, there was a large, water-powered textile mill that was in many crucial aspects a direct precursor of Arkwright's mills half a century later. And this Derby silk mill continued to operate profitably throughout our period. We should always be mindful of strands of continuity from earlier periods.

Coincident with this period of historical re-evaluation, Britain has continued to see its manufacturing sector decline as a proportion of the national economy. From the viewpoint of the early twenty-first century British industrialisation no longer appears, as it did to many of our forefathers, as a continual and inexorable process of expansion and growth that could be projected into the distant future. Rather, it now looks more like one fleeting phase of the country's long and complex history, rather like the protectorate of Oliver Cromwell or the rather longer period of the Roman occupation.

This may provide a good perspective from which to evaluate British industrialisation in a balanced manner. The aim of this book is to analyse the profound changes that certainly occurred as well as the strands of continuity that ran alongside them. Where, when and how industry came to be organised, located and managed are the principal concerns of this work. As we shall see, the rise of industry could provoke almost unbounded optimism, reflecting a characteristically Victorian sense of history as the march of progress. Industrialisation could also result in what Karl Marx called the 'immiseration' of the workers. It could bring dislocation and hardship, particularly during recessions in trade. Alongside the growth of manufacturing

For centuries the Greenfield Valley, near Holywell, where water gushed from a spring for about a mile down into the Dee Channel, was one of the most abundant sources of water power in the British Isles: in the 1720s the stream powered three corn mills, two snuff mills, a fulling mill and perhaps also an iron forge. The first cotton factory in the valley, known as the Yellow Mill, was constructed by John Smalley in 1777 from stones from the ruins of the medieval Basingwerk Abbey. Other cotton mills followed. From 1740 Thomas Patten, and from 1780 Thomas Williams and others built mills in the valley to fabricate copper into sheets and bars. This view of 1792 shows, in the centre, the six-storey Lower Cotton Mill of 1785, and to the left the buildings of a works where brass and copper wire were drawn for nail and pin making.
DRAWING BY I. INGLEBY ENGRAVED BY W. WATTS. AUTHOR COLLECTION



The Crystal Palace housing the Great Exhibition was opened on 1 May 1851, an occasion celebrated by the publication by Banks & Co. of an engraved 'Balloon View of London', of which this is one small detail. Joseph Paxton's design demonstrated that new materials – cast iron and glass – could be used to create a structure ideal for its function, with a subtlety and novelty of style that gave an identity to the whole exhibition project. The Exhibition was also an international event, and some exhibits from overseas, particularly from the United States, were a foretaste of the time when Great Britain would cease to be the only 'workshop of the world'.

BY COURTESY OF IRONBRIDGE GORGE MUSEUM TRUST

came urbanisation, and in the worst parts of industrial towns the dearth, poverty and pain suffered by the poorest classes were unspeakable. Revolution or not, the period from 1700 to 1870 is perhaps the most remarkable and interesting in the history of the British Isles, and always merits re-examination.

There are many ways to approach this broad sweep of history. Economic historians can provide the perspective of numbers: increases in gross national product, fluctuations in interest rates, and, at least from the 1850s, tolerably accurate statistics of the amount of coal mined, the quantity of cotton imported, or the output of the nation's blast furnaces. Financial historians can explain the sources of the capital used to develop mines, factories and railways. Demographers point to sometimes radical movements in population, from countryside to town, or within coalfields, as well as to rapid increases, particularly in towns and cities, caused in part by the lowering of the age of marriage. Similarly, labour historians can compare wage rates in manufacturing cities with those in the rural counties, and historians of technology can explain the intricate details of the development of machinery, how the Watt pumping engine or the Stephensons' *Rocket* were constructed, for example. Archaeologists and landscape historians in recent decades have located many previously unrecognised sites of industrial activity, including textile mills in remote Pennine dales, cottages in suburban Coventry with high-ceilinged lofts built to accommodate ribbon weavers' Jacquard looms, or the routes of eighteenth-century wooden railways in the coal districts of County Durham. This study acknowledges its debts to all such approaches and attempts to draw them together, examining industrialisation by identifying those areas where developments in mining and manufacturing took place, analysing some of them in detail, and identifying individuals and groups who were responsible for and were affected by such changes.

This book focuses on the ways in which the economy and society of the British Isles were transformed between 1700 and 1870. The subject is so large and the historical themes so numerous that it has not been possible to cover every aspect of industrialisation, about the building and construction trades, for example, or the activities of 'improving' agriculturalists.

It seems appropriate to begin with looking at some of the enabling technologies and innovations, those things that were possible by the 1860s that had been impossible in 1700: thus, Chapter 2 looks at the importance of energy and the harnessing of power to machinery; Chapter 3 looks at machine making, machine tools and what was sometimes referred to as 'mechanicking'; Chapters 4 and 5 deal with the crucial areas of civil engineering and transport, both of which were vital components of industrial development.

Part II of the book then moves on with a group of chapters dealing with the 'core sectors' of industrialisation: thus, Chapter 6 looks at coal mining and the range of industries that grew up on coalfields; Chapter 7 describes a broad range of iron-making communities and their associated industries, while Chapter 8 does a similar job in dealing with the important non-ferrous metals sector, including tin, brass, copper and lead; then, at the heart of the book, Chapter 9 details the various branches of the textile industries, from cotton to wool, linen and silk; and Chapter 10 discusses the often neglected industry of paper making.

Part III is a broad survey of towns, cities and industrial communities. First, Chapter 11 examines the particular features of the manufacturing and economic lives of some of the great industrial towns and cities. The unique characteristics of London, where there was a surprising amount of industry, are described in Chapter 12. The subsequent chapter is devoted to the emergence of the 'industry' that provided recreational facilities, not just for the wealthy but by the 1860s for increasing numbers of working people. Finally, Chapter 14 discusses community, and the understanding that can come from comparison between industrial and rural settlements, and from an analysis of utopian and marginal communities.

Throughout the book there is, very deliberately, a strong sense of place. In each chapter regional variations are discussed at some length, for the experiences of no two places were ever the same, and no understanding of industrialisation can be gained without acknowledging local circumstances and changes over time. This book is not aimed at economists, and so does not include the kind of theoretical analysis that may be found in such books as Robert C. Allen's recent *The British Industrial Revolution in Global Perspective*. Allen explicitly seeks to explain *why* the industrial revolution happened in this country, contending that high wage levels and inexpensive energy produced an inevitable economic imperative towards power-driven, labour-saving innovations, and therefore industrialisation. The present book looks more at the what, the where, the how and the when rather than the why, and hopefully presents a nuanced and convincing description of what really happened on the ground. A by-product of this approach is the authenticity that comes from discussing actual people and real places.

Sir James Graham's letter, quoted at the head of this chapter, laments somewhat sadly that industrialisation had made Britain the 'Workshop of the World'. Graham was old-school: a landowner, educated at Westminster and Christ Church. He did recognise the importance of industry, but some of his social class were indignant that they were no longer accorded the respect that was their due, and yearned for an imagined medieval past. It was symbolic that the Eglinton Tournament in Ayrshire, a revival in 1839 of medieval jousting patronised by Tory aristocrats including the 13th Earl of Eglinton, was ruined by rain and traffic congestion, and that six years later, the brothers Baird, sons of a small farmer from Monkland, should have built blast furnaces within sight of Eglinton Castle. Signs of the times. Graham's remarks do not prove the Marxist concept of the immiseration of the proletariat. They do indicate an informed awareness of the scale of recent social and economic change whose significance was realised in the debate on the 'condition of England'. These changes, in communities across the British Isles, are the subject of this study.

Nine years after Graham wrote to Powis recent economic changes could appear in an optimistic light. Thomas Babington Macaulay, historian, MP for Leeds from 1832, and author of the criminal code for India, entered the Crystal Palace on Thursday 1 May 1851, the opening day of the Great Exhibition:

> there must have been near three hundred
> thousand people in Hyde Park at once. The
> sight among the green boughs was delightful.
> The boats and little frigates darting across

> the lake; the flags; the music; the guns; – everything was exhilarating, and the temper of the multitude the best possible. … I made my way into the building; a most gorgeous sight; vast; graceful; beyond the dream of the Arabian romances; I cannot think that the Caesars ever exhibited a more splendid spectacle. I was quite dazzled, and I felt as I did on entering St Peter's.

The Great Exhibition, held in the Crystal Palace in Hyde Park between May and October 1851, attracted up to 6 million visitors. This great event seemed to be a high-water mark for those who were optimistic about the forces of economic 'progress' that had in many respects transformed the British economy and society. Significantly, many thousands gained their first experience of railway travel on the excursion trains that took them to London for the Exhibition. The creation of what was fast becoming a national rail network was itself one of the wonders of the age. 'Lord' George Sanger, the circus proprietor, thought that the Exhibition symbolised the improvement that had taken place in the condition of the English (although obviously not the Irish) nation in the fourteen years since the accession of Queen Victoria, and that it demonstrated to people 'that they were living in times infinitely better than they could have imagined possible but a few short years before'. The construction of the Britannia Bridge over the Menai Straits, opened on 5 March 1850, attracted thousands of celebrating spectators, as did the opening in 1853 of Sir Titus Salt's Saltaire Mill near Bradford, which was built to incorporate 'every improvement that modern art and science have brought to light'. Even Sir James Graham recognised the impact of manufacturing industry, which, he told Parliament, 'is the tree to which our little isle owes its prosperity, which has diffused so much happiness over this great empire, and which has rendered this nation the most wealthy and the most civilised'.

In the vanguard of industrialisation were the textile industries described in Chapter 9. Famously, Richard Arkwright developed a 'water-frame' that could spin cotton yarn and which was powered by a waterwheel. More than this, he devised a whole new system of production which he went on to exploit commercially with spinning mills, at first in the Derwent Valley in Derbyshire, and subsequently in Manchester and elsewhere. He and his descendents became immensely rich. While they had a precursor in the Derby silk

Robert Stephenson's final design for the bridge opened in 1850 by which the Chester & Holyhead Railway was carried over the Menai Straits was groundbreaking: trains ran through gigantic wrought-iron tubes carried on three stone towers (the provision of anchorages in the towers for suspension chains that were never installed shows just how much this form of construction was a venture into the unknown). Great crowds gathered to see the tubes being lifted into place by a hydraulic press that was subsequently displayed in the Great Exhibition (see page 76). Queen Victoria travelled to North Wales especially to view the bridge in 1852, and thousands of her subjects were taken to see it by excursion trains. Like Saltaire Mill, it symbolised the optimism of the early 1850s.

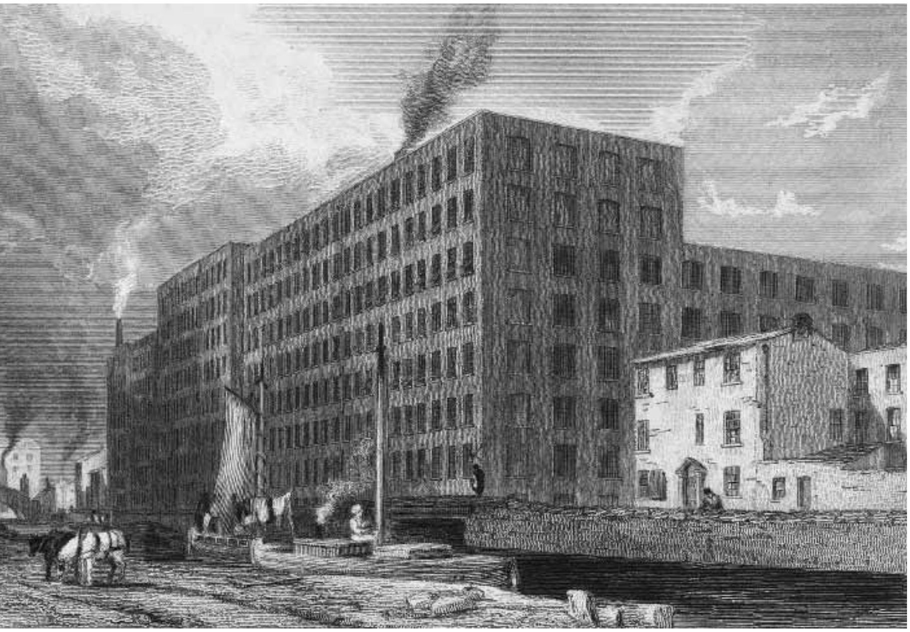
Joseph Wright of Derby is often regarded as the artist who best portrayed the industrial revolution through individual and group portraits and landscapes. His acquaintances included Richard Arkwright, Erasmus Darwin, Jedediah Strutt, Josiah Wedgwood and John Whitehurst. In this view of Arkwright's mill at Cromford he expresses amazement that such a large building remained working and illuminated throughout the night (one of the very first uses of gas lighting was in textile mills such as this). Other visitors to Derbyshire including Lord Torrington were similarly impressed. Wright's portrayal of light seems to reflect the lasting impression made upon him by an eruption of Vesuvius that he had witnessed.
DERBY MUSEUMS & ART GALLERY/BRIDGEMAN ART LIBRARY

mill of the 1720s, Arkwright's mills dramatically demonstrated the potential of the new manufacturing systems, and they were widely imitated. They were imposing buildings with single power sources in which large numbers of closely managed operatives worked for fixed hours; the various phases of production took place in different parts of the building, and materials flowed efficiently and logically from one stage of manufacture to the next. In *The Wealth of Nation*, published in 1776, Adam Smith had theorised about the division of skills and labour and dissected the art of making pins into around eighteen distinct processes. At Cromford Arkwright had already put these theories into practice for the spinning of cotton yarn. As well as developing the machines themselves, Arkwright had brought into being a new, highly profitable 'factory system'.

One evening in 1790 John Byng recorded his impressions of Arkwright's mill at Cromford:

> I saw the workers issue forth at 7'oClock … a new set then goes in for the night, for the mills never leave off working. … These cotton mills … fill'd with inhabitants, remind me of a first rate man of war; and when they are lighted up, on a dark night, look most luminously beautiful.

This exact scene – an illuminated cotton mill in a pastoral landscape – was depicted by the artist Joseph Wright of Derby. But attractive, stone-built cotton mills nestling in a picturesque Derbyshire valley were one thing. Huge steam-powered mills in Manchester a few decades later were something else. There the mills were on constricted sites next to the canal and hard by some of the least salubrious housing in the country. Manchester, the cotton capital, was the 'shock city' of the industrial age. As Douglas Farnie noted, no objective or comprehensive history of the cotton



Manchester's first large cotton-spinning mill was probably Shudehill Mill, built in the north of the town around 1782 by partners of Richard Arkwright. That mill used a steam engine to raise water for the waterwheel. Ironically, however, the relatively high cost of Arkwright's water-frames meant that most late eighteenth-century Manchester mills were designed instead to accommodate spinning mules. This engraving of 1835 shows the impressive range of cotton mills on the banks of the Rochdale Canal in Ancoats. In 1814 these factories alone housed over 160,000 spindles. A gazetteer of cotton mills still standing in Greater Manchester in the mid-1980s numbered 1,112 in all. Lancashire and north-east Cheshire had become the heartlands of cotton. (See also page 415.)

CARNEGIE COLLECTION

industry in Manchester has yet been written, but there is no denying the strength of its impact, or the strong divisions of opinion that this industrial city provoked. Manchester's great spinning mills were untypically large (Murrays' Sedgwick Mill, for example, was eight storeys high) and, congregated together, they made a profound impression. Indeed, of urban–industrial sites Manchester was the archetype. There the ambition and optimism of the manufacturer could be found in abundance. Léon Faucher wrote in 1844:

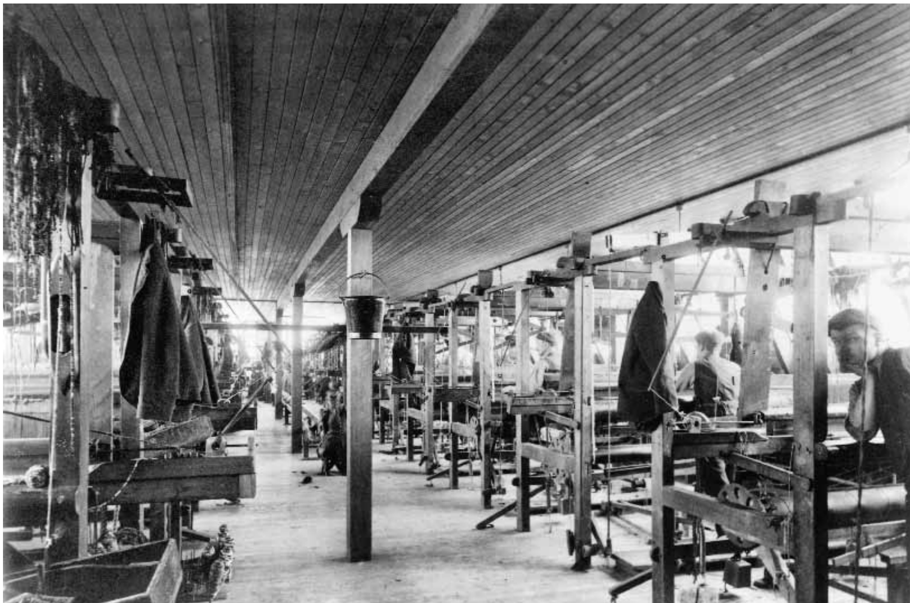
> The men of Manchester conduct operations upon the most gigantic scale, such as the imagination can scarcely embrace. I know of a spinning-mill in Manchester, which employs 1500 hands. … And a Lancashire manufacturer has exclaimed, inspired by the contemplation of this industrial omnipotence, 'Let us have access to another planet, and we will undertake to clothe its inhabitants.'

'At the present day [1844], Lancashire possesses three-fifths of the establishments devoted to the spinning and weaving of cotton; and there are more than a hundred factories in the town of Manchester alone,' wrote Faucher. 'Nothing is more curious than the industrial topography of Lancashire. Manchester, like a diligent spider, is placed at the centre of the web …'

For those who prospered during these years they could be heady times. But such optimism was not universal, and it was not sustained. At precisely the time of Faucher's visit the German radical Engels was being guided around the slums and factories of Manchester by his young companion, the Irish millgirl Mary Burns. Engels was systematic in cataloguing the horrific living conditions he had encountered in cellars, courts and houses. In particular he condemned dwellings that had been thrown up by developers on land they held only on short leases: having to return the land (and everything they had constructed upon it) to the freeholder removed all incentive to build anything permanent or in any way decent. 'I shall present the English,' he wrote to Karl Marx in November 1844, 'with a fine bill of indictment. At the bar of world opinion I charge the English middle classes with mass murder, wholesale robbery, and all the other crimes in the calendar.' Visiting Manchester in the summer of 1835 Alexis de Tocqueville made some of the same points, albeit without the political venom: the seeming pursuit of money at all costs; the lack of regulation; the primacy of individualism and the concomitant weakness of society and social institutions in the face of mercantile or manufacturing interests; and, above all, the enormous contrast between rich and poor, between the great cotton factories – 'palaces of industry' as he describes them – and the 'hovels' of the workers near the mills and down by the river. It was the haphazard, dirty, half-built and half-decayed physical character of this new industrial town that impressed him so vividly: 'The fetid, muddy waters, stained with a thousand colours by the factories they pass … wander slowly round this refuge of poverty [Little Ireland]. They are nowhere kept in place by quays; houses are built haphazard on their banks … [the river] here is the Styx of this new Hades.'

Most of these early industrial towns lacked public authorities that could impose logical planning of developments or insist upon adequate sanitation, acceptable building standards, or even supplies of clean water. Cholera outbreaks in the 1830s and 1840s created alarm among all social classes. Subsequent agitation by the Health of Towns Association led to the Public Health Act of 1848 enabling the establishment of local boards of health which began the process, described in Chapters 4 and 11, of making towns healthy places in which to live, part of which involved the application of technologies developed in manufacturing and the construction of canals and railways. Nevertheless, it was many years before there were substantial improvements in the living conditions of many of the urban working class, whose ways of life in 1870 still remained a mystery to most educated people. The Manchester journalist Robert Blatchford, writing in the 1880s, railed against the merchant princes of the city which was, in their words, 'the modern Athens', pointing out how they closed the curtains of their carriages as they passed through the teeming, squalid inner city, opening them again only when they had made good the leafy suburbs. He asked, rhetorically, 'How shall I attempt to paint the shame of modern Athens – the dwellings of her people … where a devilish ingenuity seems to have striven with triumphant success to shut out light and air.' Despite this, some Mancunians thought their town had had an unduly harsh press. In his *Manchester Handbook* of 1857, Joseph Perrin felt that, 'To the stranger Manchester is an enigma: it has been little understood and much misrepresented. Authors like Mrs [Frances] Trollope have maligned it; and even Charles Dickens, has … shown us but scant justice.' Somewhat plaintively, he announced that the town 'is not as bad as it is painted. … Even as regards the material picturesque, Manchester can boast of it. It needs artistic training, perhaps, to discern it, but it is, nevertheless, there.' In the eye of the beholder.

Poverty was not, of course, simply the consequence of industrialisation. In many parts of rural Britain in the early nineteenth century most of the population endured squalid living conditions and received meagre remuneration for their labours. The poor had suffered from over-crowding and economic insecurity



➢ Apparently archaic modes of production for specialist fabrics persisted in the textile industry long after the advent of steam-powered factories and iron machines. This view of about 1920 of a factory in Darvel, East Ayrshire, portrays effectively the atmosphere of a weaving workshop where wooden-framed looms were operated by hand. The product in this instance was chenille (the French word for caterpillar), a fairly complex fabric characterised by a protruding pile, which could be made from silk, cotton or synthetic fibres.

The Madeley Wood (or Bedlam) Ironworks was built in the late 1750s on the north bank of the river Severn a short distance from where the Iron Bridge was constructed some 20 years later. It was one of five groups of coke-fired blast furnaces built in the Shropshire Coalfield within less than five years, which marked a real revolution in the pattern of iron making in England. This view depicts the furnaces from downstream and shows in the foreground a sled, apparently being used to transport coal. Probate inventories confirm that the use of sleds was not uncommon in this part of Shropshire in the early eighteenth century.
IRONWORKS, COALBROOKDALE, 1805. AQUATINT, WILLIAM PICKETT AFTER P.J. DE LOUTHERBOURG. © SCIENCE MUSEUM/SCIENCE & SOCIETY PICTURE LIBRARY

in every great city from the times of classical antiquity. Indeed, some of the worst urban living conditions in the period under review were experienced in Dublin, the least industrialised of Britain's great cities. Nevertheless, the particular features of the great manufacturing towns, the imposing size of factories and of such structures as the railway viaduct that crosses Stockport, the flames that illuminated up every place where there were furnaces, the pervasive palls of smoke that respected no barriers of social class, caused many to react with horror as they reflected upon the lives of those who lived among such spectacles. As late as 1881 Henry George considered that the life of primitive peoples was preferable to that of the English poor, while in the decade that followed Andrew Mearns in *The Bitter Cry of Outcast London*, William Booth in *In Darkest England and the Way Out* and Charles Booth in *The Life and Labour of the People in London*, revealed the 'darkness' in which the 'submerged tenth' in London were condemned to live. As early as 1808 the poet William Blake coined the phrase '… among these dark Satanic mills' as a counterpoint to the 'Jerusalem' that he predicted might be built in England. This memorable phrase has come to be interpreted as a condemnation of factory work in general, but it was probably written with regard to the Albion Flour Mill on London's south bank rather than the textile mills of the industrial North. In *News from Nowhere* (1890) William Morris concluded that from an idyllic medieval past England had become 'a country of huge and foul workshops and fouler gambling dens, surrounded by an ill-kept, poverty-stricken farm, pillaged by the masters of the workshops'. The economic changes of the industrial revolution could be interpreted between poles of optimism and pessimism. To understand the period it is necessary to acknowledge the intensity and validity of both kinds of judgement.

Over the last forty years or so it has become fashionable to look closely at the eighteenth-century economy in search of precursors of factory-based manufacturing. Ugly new words – 'protoindustry', 'protoindustrialisation' – are deployed, with mixed success, to describe the supposed progression from a system of domestic production to one based on mills and factories. In the eighteenth century, it is suggested, merchants developed and honed the practice of 'putting out' tasks to home-based workers – usually small-holders and yeomen families with small farms – and that this provided a springboard for later industrial developments. Rightly the role of merchants is given prominence, for they were indeed pivotal in facilitating or stimulating economic activity throughout the period. Quite rightly, too, historians have drawn attention to the importance of home-based work in the eighteenth century. In many sectors and regions, such as lace making in the East Midlands, boot-and-shoe making in Northamptonshire, hardware production in the Black Country, or, classically, handloom weaving in Lancashire and the West Riding, domestically organised production formed a significant part of the economy, allowing families to supplement agricultural incomes that were meagre or seasonal. Yet in most such places these practices had long histories, and in some areas domestic production continued – albeit often in straitened circumstances – into the late nineteenth century or even beyond. The problem with the theory of proto-industrialisation is that it is difficult to demonstrate any neat progression from one older, domestic system to a novel one based on new-style factories. Rather, it appears that mechanisation and the concentration of labour and capital in larger units developed alongside rather than in substitution for more venerable types of small-scale domestic manufacturing. Some forms of domestic work – for example the spinning of textile yarns – did virtually disappear, but domestic hand-loom weaving, although much diminished, continued on a significant scale in some places, as did the manufacture of hardware. Cottages at Dudley Wood in the Black Country, designed specifically for domestic chain making, were still being built between 1884 and 1906. Professor Carl Chinn has shown that many tasks in Edwardian Birmingham, including the pasting of matchbox labels and the stitching of sacks, were undertaken by poor women and their families on 'putting-out systems', and the same was true in other great cities. In the manufacture of many lowly consumer goods the classic 'industrial revolution' had little obvious effect.

The start of the eighteenth century is a logical point at which to begin a study of British industrialisation. By that date England's economy was already well developed. There were established patterns of trading in coal, from Northumberland and County Durham to London and along the east and south coasts, as well as down the Severn from Coalbrookdale, on the Aire & Calder Navigation and, within a few years, also on the Mersey and Weaver. Commercial links from London spread across the known globe, and ships from quite small ports were trading in distant waters. Overseas produce – tea, tobacco, spices and sugar – was sold at mercers' shops in every town. England was not self-sufficient in iron, but had a long-standing import trade with Sweden.

Even earlier, the potential of the British economy had been recognised by Andrew Yarranton, an officer in the parliamentarian army during the civil wars of the mid-seventeenth century, an ironmaster, and an improver of river navigations. He proposed the extension of inland navigation by the construction of canals, particularly a link from the Warwickshire Avon near Stratford to the Cherwell between Banbury and Oxford, and the creation of manufacturing settlements at waterway junctions and other locations, including Christchurch in Hampshire, Lechlade at the head of the Thames Navigation, Wellingborough on the river Nene, Slane on the river Boyne, and the Isle of Dogs. Yarranton also urged the encouragement of ship-building, fishing, linen manufacture and iron making, particularly tinplate manufacture. He commended methods of thread making at Dordrecht, bleaching technology at Haarlem, and schools in Saxony where girls were taught to spin. He asserted that England was well endowed with wool, tin, leather, iron, lead, flesh, corn and fish, with safe harbours and timber to build ships. His considered that England, 'should be the Empory and Store House of the World but it is not so'. His proposed 'improvements by sea and land' were intended 'to set at work all the poor of England' and 'to outdo the Dutch without fighting'. Yarranton died in 1684, but many of his visions were realised in the century and a half after his death. Clearly and not unreasonably he envisaged a planned and ordered economy, logically arranged with a tidy

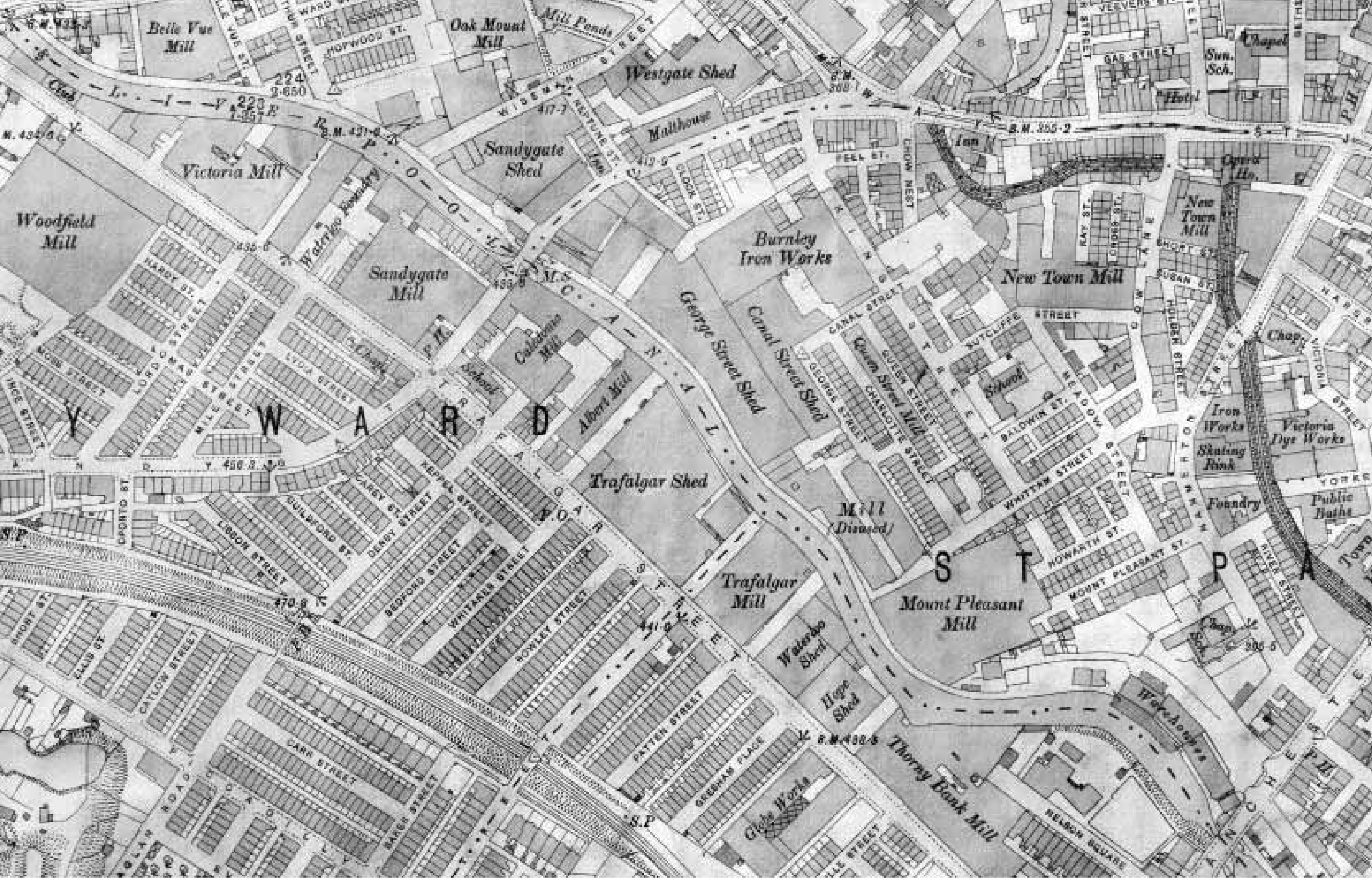
There were malthouses in every significant town in the eighteenth century, where local barley was used to produce malt for brewing. This example stands in Oundle, Northamptonshire. Ceiling heights on malting floors tended to be low, since the only activity that took place there was the spreading, turning and collecting of grain, while fenestration tended to be sparse, as in this building. The lucam to the right housed a hoist used to raise sacks of barley to the storage area, probably on the attic storey.

geography and rational social principles. The reality of what did emerge was very different. In contrast to other industrialising nations, Britain's burgeoning economy was subject to scarcely any central regulation. Nothing was planned, nothing was co-ordinated, nothing was rational except in the theoretical sense of the supposedly rational behaviour of the free market. The legacies of this almost anarchic freedom remain to this day, including in the incoherent settlement patterns of the former coalfields in the Black Country, Co. Durham or the central valley of Scotland, or in the relics of competing railway lines, the ruins of viaducts along the Derbyshire/Nottinghamshire border, of Duddeston viaduct that has never led anywhere (see page 187), or Manchester's Central Station being adapted as a conference centre.

The vitality of the eighteenth-century economy is illustrated by the characteristic 'manufactures' of many towns. The term was applied to goods which were made in particular places but traded nationally or exported. It is used by Daniel Defoe and other writers, including Stephen Whatley, who described as 'manufactures' the hats made in Dunstable, the locks produced at Wolverhampton, and the shoes sent beyond the seas from Northampton. The meaning he attached to the term is revealed when he placed malt among the 'manufactures' of Reading and Devizes. Malt was made in every town, but only in certain places in grain-growing areas was it made, for use by brewers elsewhere, on a sufficient scale for it to be described as a 'manufacture'.

This study ends around 1870, the beginning of a time of change during which the staples of the industrial revolution continued. Coal output, the production of iron (but increasingly of steel), cotton, woollen cloth and iron steamships increased, and nearly 7,000 route miles of new railway were laid in Great Britain between 1871 and 1914. Nevertheless, industrial output in Germany and the United States was increasing faster, while capacity in Belgium, France, the Austrian empire and Italy, though not matching Britain's, was developing significantly. In the years around 1870 pig iron output in Shropshire, South Wales and the Black Country peaked, and the final decline of metalliferous mining in upland regions began. During the 1870s the Solvay process for making alkali was introduced into Britain, and chemical manufacturing began to evolve into a science-based activity. The same period saw the beginnings of factory-based production of consumer goods, footwear, clothing, furniture and food, employing many women and using American technology. Many of the patterns set between 1700 and 1870 – the use of coal, its movement by canals and railways, the use of steam engines, the generation of coal gas, shift working, mule spinning and the puddling of iron, among others – continued into the twentieth century. Since 1950 all have effectively disappeared. In these respects the 'industrial revolution' might not be said to have ended until the 1980s. There are nevertheless good reasons for bringing this study to a close about 1870, summarised by the observation that, by then, Britain was no longer the world's only workshop.

During this period of industrialisation, between the 1700s and 1870, the British Isles experienced many changes other than those related directly to the economy and industry. One particular feature of



This section of the large-scale Ordnance Survey map published in 1893 shows one of the astonishing concentrations of industrial buildings and living quarters that could be found in northern industrial towns, in this case in Burnley, Lancashire. Many of the factories cluster along the Leeds & Liverpool Canal which reached the town from Yorkshire in 1796 and was extended westwards in 1801, although it was not until 1816 that through navigation to Liverpool became possible. To the east of this section the canal crosses the valley on the Burnley Embankment, 1,256 yards long and 60 feet high, an outstanding feat of civil engineering. The 'sheds' seen here are single-storey weaving factories, most of which had characteristic 'north-lit' or 'saw-tooth' roofs, which admitted the maximum amount of light without creating glare from direct sunlight. Some back-to-back houses are shown north of the canal, but the majority of terraced dwellings south of the canal follow the simple rectangular plan characteristic of many towns in the second quarter of the nineteenth century. Burnley's principal occupation was cotton weaving and by the early twentieth century it was boasted that there were nearly 100,000 looms in the town. South of the map where Manchester Road crosses the canal is the celebrated Weavers' Triangle, where there is now a visitor centre.

PHOTOGRAPH BY CARNEGIE, REPRODUCED BY COURTESY OF THE COUNTY ARCHIVIST, LANCASHIRE ARCHIVES

Britain was that the proportion of the people of the British Isles engaged in agriculture, already low by European standards, continued to diminish, and the proportion making things increased substantially, as did the percentage living in towns and cities. It was perceived that manufacturing moved from people's homes to factories; this was generally true, although substantial numbers continued to ply their skills in domestic workshops into the third quarter of the nineteenth century. Their numbers also grew. The understanding of geology and chemistry, and of civil and mechanical engineering, increased substantially, although industrial growth before 1870 owed less to pure science – except, perhaps, to geology – than to pragmatic technical advances. In manufacturing and in people's homes energy was consumed on an increasing scale, and much of it was derived from coal. Consequently, most towns were dirtier, sootier and more polluted than in the past. In Elizabeth Gaskell's novel *North and South*, published in 1854, Manchester is thinly disguised as 'Milton-Northern in Darkshire', and its pollution is powerfully conveyed: 'For several miles before they reached Milton, they saw a deep lead-coloured cloud hanging over the horizon in the direction in which it lay. … Nearer to the town, the air had a faint taste and smell of smoke.' And an anonymous visitor noted: 'The town of Sheffield is very large and populous, but exceedingly dirty and ill paved. What makes it more disagreeable is the excessive smoke from the great multitude of forges which this town is crowded with.'

The proliferation of machines – railway trains, hammers and rolling mills in forges, seemingly endless ranks of chattering powerlooms – made cities excessively noisy. De Tocqueville wrote that, 'a sort of black smoke covers [Manchester]. The sun seen through it is a disc without rays. Under this half daylight 300,000 human beings are ceaselessly at work. A thousand noises disturb this damp, dark labyrinth … the footsteps of a *busy* crowd, the crunching wheels of machinery, the shriek of steam from boilers, the regular beat of the looms, the heavy rumble of carts. … Never the gay shouts of people amusing themselves, or music heralding a holiday.' It was said that

This watercolour by Sean Bolan depicts the station at Chippenham about 1850 with *Iron Duke*, one of the celebrated 'Gooch Singles', the 4-2-2 locomotives designed by Sir Daniel Gooch that powered the express trains of the Great Western Railway from the time of their introduction in 1847 until the end of Brunel's broad gauge in 1892. Other locomotives in the class included *Lord of the Isles*, displayed in the Great Exhibition, and *Alma*, driven by Peter Mottershead (see page 198). Brunel introduced a broader gauge in order to increase stability and speed, but the inconvenience of having to transfer passengers and freight where the gauges met, as at Gloucester, Wolverhampton and Basingstoke, was too great, and from the 1860s the GWR was gradually converted to standard gauge.

Roofing materials changed dramatically as Lord Penrhyn and others began to exploit the slate resources of Gwynedd. This picture shows platforms suspended from the top of the quarry face from which workers could drill holes for gunpowder which, when fired, caused blocks of slate to fall to the quarry floor. These were worked by other quarrymen, and taken away by rail. The artist also depicts a group of spectators, and Lord Penrhyn's quarries certainly attracted a great deal of attention from travellers in North Wales. A watercolour by John Nixon, 1807.

➢ Gayle Mill, on the southern outskirts of Hawes, was built in 1784–85 as a cotton-spinning mill, powered by a 24-foot waterwheel. It was just the sort of intrusion into the peace of the countryside that so offended the sensibilities of men such as Lord Torrington.

when approaching Manchester one could hear the town before one could see it.

Britain's population increased substantially, although growth in the eighteenth century was not uniform, and the Great Irish Famine was a demographic catastrophe, in which a million people are thought to have perished and another million emigrated. By the time of the 1851 census, 109,000 people of Irish birth were living in London, with another 84,000 in Liverpool, 53,000 in Manchester and at least 100,000 in the Scottish cities of Glasgow, Edinburgh and Dundee (in Dundee the extraordinary scale of displacement is highlighted by the fact that the Irish made up 19 per cent of the population).

It was a common perception that social relationships changed in the decades before 1840, that a perceived model of a deferential society was disintegrating, and that there was a growing awareness of differences of social class. Yet some of those communities where manufacturing and mining flourished had never conformed to this kind of deferential model, while some manufacturing settlements accepted paternalistic principles as much as any village nestling in the shade of its parish church and manor house. Many commentators pointed to the emergence of – or perhaps sometimes just the increased visibility of – a new factory working class, a proletariat of wage-earners newly migrated from the countryside or elsewhere in Britain or Ireland.

The wider contexts in which mining and manufacturing developed must also be borne in mind. The economic, technological and social changes discussed below were contemporary with the governments of the Duke of Newcastle, Pitt the younger, Lord Liverpool and Sir Robert Peel; with the preaching of John Wesley, Howell Harris, George Whitefield and John Henry Newman, with visits of Wolfgang Amadeus Mozart and Franz Joseph Haydn to London; with the writings of Samuel Johnson, George Eliot and Charles Dickens; and with the architecture of Nicholas Hawksmoor, Robert Adam and George Gilbert Scott. Industry is but one thread in this broad pattern.

Several salient features of industrialisation are worthy of general comment. One is that manufacturing people were found not only in the great northern cities. Industrial change is often perceived as, or even confused with, urbanisation, although they are, of course, quite different phenomena. In some urban centres industry was pervasive, characterised by Pyne's engraving of the cotton factories alongside the Rochdale Canal at Ancoats, or the descriptions of nearby Little Ireland, a small concentration of poorly built back-to-back terraces in a loop of the Medlock. Manufacturing did help to create great cities, but in the eighteenth and early nineteenth centuries it also impacted on the geographical margins, transforming and bringing into the economic mainstream the slate quarries of Gwynedd and the copper mines of Cornwall, Anglesey and West Cork. And it was not just the extractive industries that affected rural areas. Lord Torrington, observing Askrigg in Wensleydale

Textile manufacturing developed during the industrial revolution through the contemporaneous establishment of large, steam-powered factories, and of workshops, some quite extensive in size, where machines were worked by hand or by animal power. The last decades of the eighteenth century were characterised in most textile regions by the proliferation of 'jenny shops', workshops accommodating small numbers of spinning jennies. Some continued in use, usually producing specialised yarns, into the twentieth century, such as this example at the works of Palmer Mackay at Trowbridge, Wiltshire, photographed about 1930.

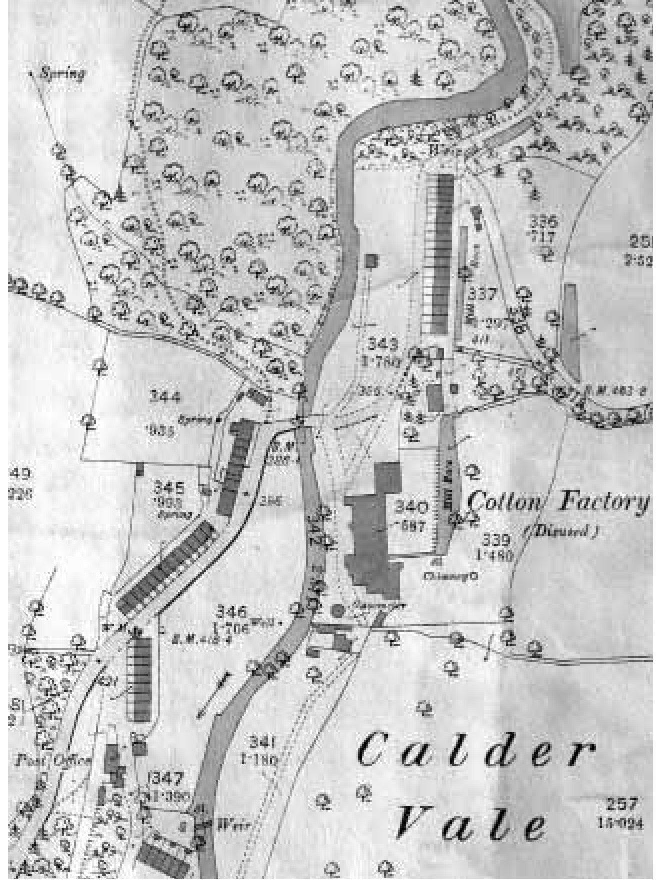
in 1792, was aware that remote communities could be transformed by water-powered cotton mills:

> Sir Richard Arkwright may have introduced much wealth into his family and into the country; but, as a Tourist, I execrate his schemes, which, having crept in every pastoral vale, have destroy'd the course and beauty of Nature. Why, here now is a great flaring mill, whose back stream has drawn off half the water of the falls above the bridge. With the bell-ringing and the clamour of the mill all the vale is disturb'd; treason and levelling systems are the discourse, and rebellion may be near at hand.

Manufacturing also transformed less isolated areas which had also been marginal to the mainstream of the economy in 1700 – for example, the valleys around Manchester and the heathlands of the Black Country. Wetlands, the Fens of East Anglia and Lincolnshire and the Bog of Allen, were also affected by new technology, and found a new economic role as sources of food or fuel for cities.

Another feature that strikes the modern eye is the wide dispersal of industrial enterprises. Workshops, small factories and mines sprang up in many places that now seem wholly unpropitious. It is unsurprising that miners followed seams of metalliferous ores to such remote places as Dufton Hush, almost 3,000 feet above sea level in the northern Pennines, but there were also dozens of little water-powered bobbin mills on the streams that thread through the hills of upland Lancashire, as well as some spinning mills high up in the fells. There were mines, most of them small ones, in many parts of Ireland, and the streams of Ulster powered numerous spade-mills. There was a certain ubiquity of 'busy-ness' in eighteenth-century Britain. In the course of time some sectors became more concentrated geographically, as the size of individual manufacturing plants increased, as transport systems developed, and as proximity to coal supplies became more crucial. But, as subsequent chapters show, there is much more to British industrialisation than the towering factories of Manchester, Leeds or Glasgow.

Importantly, too, people's horizons were becoming broader. Mining and manufacturing developed in a country that increasingly recognised a British identity, particularly after the Act of Union between England and Scotland in 1707 and the Jacobite Risings of 1715 and 1745. Ireland was also an important part of the story: the common ownership by aristocrats of land in Great Britain and Ireland, the trade across the Irish Sea, and the tide of migration from Ireland in the mid-nineteenth century make it logical to examine Ireland in this study, not least because the Act of Union



The potential of water power drew manufacturing entrepreneurs to sites in marginal locations even as late as 1835 when the Quaker brothers Richard and Jonathan Jackson established a cotton mill at Calder Vale, ten miles south of Lancaster. 'Calder' is Old English for a fast-flowing stream; this particular Calder rises on Bleasdale Moor on the western edge of the Forest of Bowland and flows into the river Wyre at St Michael's on Wyre. The map shows how weirs and leets were constructed to provide power for the mill, which, it appears, was lit by a small gasworks to the south of the complex. The Jacksons also built good-quality terraced housing for their workpeople, and in 1863 erected a church dedicated to St John, which lies south of the map. Part of the factory is shown as disused, but one of the mill buildings remains in production in 2012.

PHOTOGRAPH BY CARNEGIE, REPRODUCED BY COURTESY OF THE COUNTY ARCHIVIST, LANCASHIRE ARCHIVES

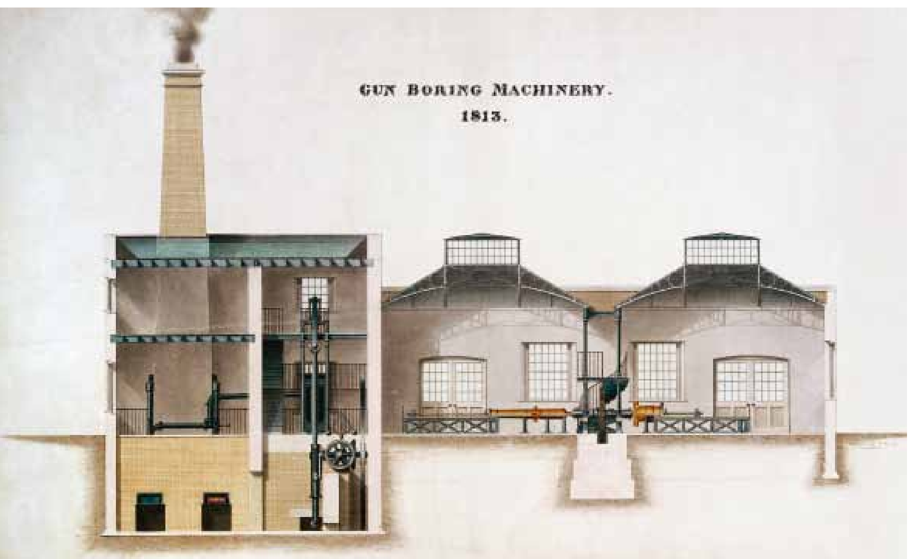
(1800) brought Ireland under the administration of the Westminster Parliament.

Looking farther afield, by 1700 British merchants had become a significant force in world markets. Throughout the period under review, Britain was at the centre of an expanding empire, focused in the eighteenth century on the Atlantic Ocean and the eastern seaboard of America, but subsequently on India and more distant colonies and possessions. Historians casually use phrases such as 'global markets', 'international trade networks' and 'overseas trade', but the profound significance of Empire to Britain's industrial revolution can easily be understated. The development of the Empire re-orientated the patterns whereby raw materials came to these islands and the markets for the goods that were manufactured here. Merchants and manufacturers were helped in some respects by the Navigation Acts – repealed as late as 1849 – which prevented foreign merchant vessels for participating fully in trade with ports in Britain or its colonies. The Empire came with high costs: it constituted an enormous financial burden to the nation, and the true balance sheet, economic, moral, social and political, is impossible to calculate. Many goods produced in Britain were traded with African rulers in return for slaves, while slaves in the Americas provided the cotton, sugar and tobacco that were processed in British towns and cities, while British merchants and manufacturers profitably sold textiles, spirits, hardware and salted cod to plantation owners. The transportation by Europeans of between 11 and 12 million Africans to work in slave conditions in the Americas must be acknowledged as part of the background against which manufacturing developed in Britain, but the bold claim that the industrial revolution was financed by the Atlantic slave trade is an exaggeration.

Beyond the colonies British merchants found ready markets for manufactured goods of all kinds. The established export trade in textiles, originally in woollens but increasingly in cotton fabrics and yarn, continued to be important in the eighteenth century as it had been since the Middle Ages. Metals and metalwares too were widely traded. In antebellum America the West was won using Bowie knives and tools from Sheffield and the Black Country. In 1848 Wostenholms', cutlery manufacturers of Sheffield, opened their Washington Works, named in recognition of the importance to the company of their American markets. British merchants also participated in many profitable re-export trades, controlling for example the distribution of goods such as sugar, tobacco and pepper to other European markets. Comparing statistics from diverse sources over long periods is problematic, but after making

This painting, in the Strangers' Hall Museum, Norwich, shows eighteenth-century merchants conducting business on a foreign beach. In 1798 William Taylor wrote of the heyday of the Norwich textile trade: 'Their travellers penetrated though Europe, and their pattern cards were exhibited in every principal town, from the frozen plains of Moscow to the milder climes of Lisbon, Seville and Naples … The introduction of their articles into Spain, Italy, Poland and Russia soon made the manufacturers amends of the capriciousness of fashion in their own country …' By this date Britain had come of age in terms of international trade and control of the seas.

BY COURTESY OF STRANGERS' HALL MUSEUM, NORWICH



This ink-and-wash drawing by W. Warcup shows gun-boring machinery in 1813 in Rio de Janeiro. It had been exported to Brazil by Henry Maudslay & Co. of London. The technology by which cannon could be bored from solid iron castings had been promoted from the 1770s by the great ironmaster John Wilkinson. Maudslay contributed much to the development of modern turning lathes, and both men belonged to networks of self-taught or mutually educated engineers whose skills, ideas and inventions drove forward the industrialisation of Britain.

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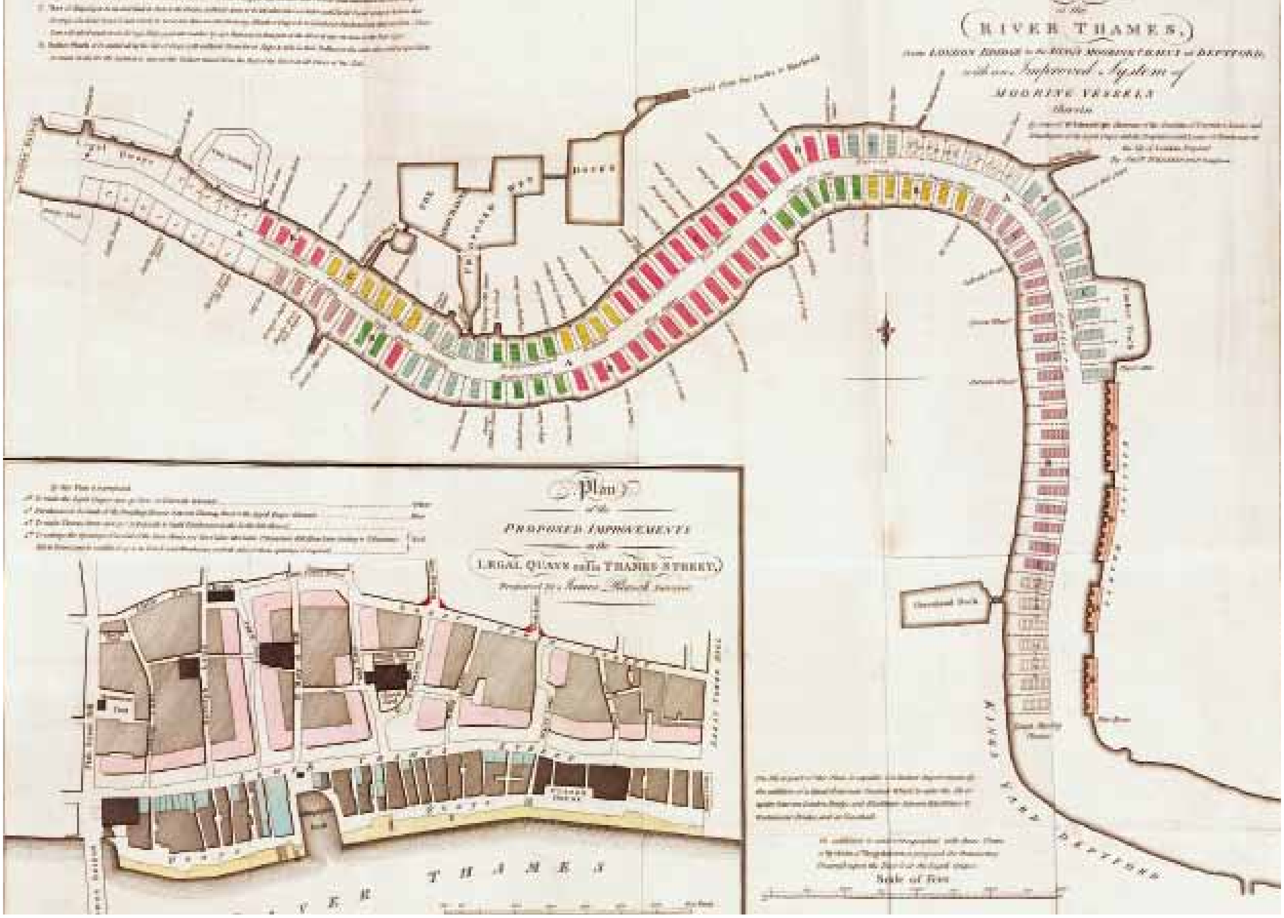
adjustments for inflation, and using official figures collected at port, one can estimate that British exports over the period 1700–1870 increased by a factor of 37.5, from £6.4 million to £240 million. British goods could be bought almost anywhere.

The crucial period of industrial development in Britain – between the beginning of the Seven Years War in 1756 and the end of the Napoleonic Wars in 1815 – was also the period of Britain's ascent to dominance as a maritime nation. The strength of the Royal Navy, which from 1805 was unchallenged by any other naval power, enabled British merchant ships to collect raw materials and deliver manufactured goods throughout the world in relative safety. Naval power was one part of a British hegemony that extended around the known world, a hegemony based on political, mercantile, military and financial muscle. Economic power grew throughout our period, helped by increasingly market-driven policies designed to promote free trade. Britain's power probably reached its zenith in the mid-nineteenth century when the nation's supremacy could be charted in several sectors. 'To Arkwright and Watt,



Throughout this period London was Britain's busiest port, handling a particularly broad range of goods. By 1796, when Edward Ogle drew this plan as part of his proposal to re-organise the handling of ships in the river, the limitations of the river wharfs and small existing docks were obvious. Ogle's management plan for the river was never implemented and instead there followed a major dock building programme by private investors and the East India Co. Despite this, most of the privately owned river wharfs remained busy and commercially viable right through to the middle of the twentieth century.

England is far more indebted for her triumphs than to Nelson and Wellington,' opined Edward Baines in 1835 as he contemplated the £570,000,000 worth of cotton goods that he calculated had been exported by British manufacturers in the previous half-century. But manufacturers and politicians were acutely aware that foreign competition was growing, and that industrial development was taking place in many other countries. Baines himself commented upon those who 'apprehend a competition [overseas] too formidable to be withstood, on the part of several foreign nations'. These included the USA, 'where the spinning machinery is equal to that of England', 'Belgium, Switzerland, and other countries of Europe, where the [cotton] manufacture exists, and is rapidly expanding', and the 'East Indies, where … the natives are supposed to have a great advantage, from their having so long been habituated to the employment, and from the excessively low rate of wages they require.' And during parliamentary debates on factory legislation MPs were quite aware that restrictive laws might erode the international competitiveness of British manufacturers. The industrial revolution was never an insular British phenomenon, for technology was transferable, and other nations were very keen to play catch-up.

Overseas trade and industrial growth were facilitated, or, indeed, made possible by the 'financial revolution' that followed the Glorious Revolution of 1688. The establishment of the Bank of England in 1694, and the founding of insurance companies, provided a measure of security for overseas traders and protection against the hazards of fire for merchants and manufacturers, as well as creating funds for investment. Recent writings by such historians as Jeremy Black have emphasised the importance of the security of financial transactions to the development of foreign trade. Also significant was the extra liquidity provided to British overseas traders by the ability of the Bank of England to construct sophisticated financial instruments that were no longer dependent upon actual bullion. British merchants could perform relatively complex transactions overseas with increasing peace of mind. Meanwhile during the eighteenth century 'country' banks were established in most market towns, continuing the practice by which local solicitors, often from the same families as the first generation of bankers, channelled their clients' money into potentially profitable investments, including manufacturing enterprises.

Indeed, no major industrial development would have been possible without money. Historians and other observers, seduced by the glamour of steam and the power of machinery, tend to overlook the fact that the less romantic conventions, practices and rules of accountancy and mechanisms for financial transfers underlay every activity described in this book. Manufactured goods had to be traded and sold for money which was the mechanism by which rents, suppliers' bills and workers' wages were settled. Historians have debated at length the processes involved in raising investment capital during the industrial revolution, but almost all are agreed that there was usually no shortage of money. Much of this capital was held in the provinces, and it is clear that many concerns were financed locally, or from contacts made within particular trades or from links established through religious bodies such as the Society of Friends or the Unitarians. Thousands of private individuals or small entrepreneurs sought to take advantage of the new investment opportunities being touted and promoted, and many did make handsome returns by way of capital growth or dividend. Many entrepreneurs spread risk by forming partnerships or by investing in several different enterprises, for limited liability for company shareholders was not introduced until the 1850s. Failure of a concern, often because of lack of cash, could be ruinous. Until 1860 only railway companies had the authority to seek funds from a large number of investors, and the consequent flow of capital into railway projects significantly aided the rapid construction of the national network. As will be revealed in several chapters below, some aristocrats also invested capital in order to develop their estates: there were fortunes to be made from the coal or ironstone that could be mined below them. Manufacturers might support canals or railways that could benefit their own enterprises as well as producing profits. Some provincial entrepreneurs found sources of finance in London, the availability of which might be determined by prevailing rates of interest. The detail of how capital was obtained is less significant than the big picture, which shows that the British Isles between 1700 and 1870 was overall a fertile nursery for enterprise, where new and varied sources of money for investment were available for those with ambitions to provide goods or services.

Change took place in a demographic as well as a financial context. In England there was a general, four-fold increase in population over the period from 1700 to 1870, from just over 5 million to rather more than 6 million in 1771, 8.6 million in 1801, 16.8 million in 1851, and 21.3 million in 1871. English demography was exhaustively analysed by Wrigley and Schofield, whose results were published in 1981. While the general upward trend is obvious, there are many refinements of detail. They showed that there were several crises in the first half of the eighteenth century, when mortality rates for particular months rose to at least 25 per cent above the trend, most notably in 1728, 1729 and 1742, and that there were lesser crises in the rest of the century, all of them impacting more severely at a national level than the much better publicised outbreaks of Asiatic cholera after 1832. There were no mortality crises in 1795 and 1800, years of agricultural shortage, which suggests that although food became expensive and even difficult to obtain, England by this date was effectively free of the threat of famine. The population of Scotland increased from 1.6 million in 1801 to 3.4 million in 1871, while that of Wales rose from 587,000 to 2.2 million in the same period. The population of Ireland rose in the eighteenth century from around 2.5 million in 1700 to about 5 million in

1801, and then increased exceptionally rapidly to 8.2 million by 1841. The Great Famine of 1845–48 caused catastrophic mortality and large-scale loss of population by emigration. By 1851 Ireland's population had fallen to 6.5 million, and it fell by another 1.1 million over the next two decades.

It is clear from the research of many scholars that population in England rose fastest where mining and manufacturing flourished and less rapidly in areas not directly influenced by industry. The availability of housing, whether by extension or multiplication of cottages in areas of open settlement or though provision by employers, appears to have been an incentive to early marriage. Wrigley and Schofield showed that the 'national average' female age at marriage fell from 26.2 to 23.4 between 1700 and 1820, which meant effectively one or two more children per marriage. Infant mortality diminished overall, although it remained high, and was part of most people's experience, even in the wealthiest classes.

The statistics of urban population growth in the early nineteenth century can be obtained from census returns and are frequently quoted, but overall figures do not convey the true level of over-crowding in some areas. In the early 1840s, for instance, Manchester and Liverpool had population densities, respectively, of 100,000 and 138,000 per square mile. Since antiquity the poorest quarters of every large city have been unhealthily over-crowded, but rarely in human history have so many people been crowded together more tightly or in worse sanitary conditions than in the poor areas of the booming cities that were created during Britain's industrial revolution.

Nevertheless, images of squalor in Glasgow or the east end of Leeds give only a partial impression of industrial communities. Many who migrated to industrial cities were drawn by the hope of better housing, increased income or greater regularity of employment. And there were keenly perceived gradations – even in Manchester – between neighbouring working-class residential areas, while more isolated industrial settlements built by entrepreneurs, such as Arkwright's Cromford, the Strutt family's Belper, Owen's New Lanark and Sir Titus Salt's Saltaire, were also significant components of the British experience.

What becomes clear throughout this book is that industrialisation was not a single phenomenon: and it certainly did not occur in the same form everywhere or at the same time. There were profound variations between different localities, even within individual sectors and trades, but some general points can safely be made. One is that the majority of those employed in new systems of manufacturing were young people. Obviously scandalous was the practice of employing very young children in mines or textile factories, before the Factory Acts sought to impose minimum age limits and maximum hours of work. Richard Oastler, the campaigner against child labour, referred in 1830 to 'those magazines of British infantile slavery – the worsted mills of the town and neighbourhood of Bradford'. Such children received a measure of attention and sympathy because early textile factories were the focus of such public interest, when they were a novelty in the 1770s and 1780s, or when some regarded them as a source of shame in the 1830s and 1840s. But children as young as eight could be found working in almost every sector of industry, loading brick kilns, breaking copper ore, hauling baskets of coal underground and assisting in the hand forging of nails or chains. In 1838 a summer thunderstorm flooded the Huskar Pit on Silkstone Common near Barnsley, sweeping 26 underground workers to their deaths. The inscription on the monument to the victims blames 'an awful Visitation of the Almighty'. It was truly awful, for the youngest victim was seven years of age, the oldest seventeen.

Some owners of textile factories, as detailed in Chapter 9, recruited 'factory apprentices', orphans, chiefly from city workhouses, who were housed in institution-like accommodation within mill boundaries. A British Parliament Report of 1819 revealed that 54.5 per cent of workers in cotton factories were aged 19 or less. In mining, similarly, around a third of underground workers in 1842 were found to be children or youths under the age of 20. The corollary or this was that in many occupations – not only the physically hardest of jobs such as mining – workers aged over 40 were considered old. Quite remarkable was Thomas Batty of Willington Colliery, who gave evidence in April 1841 to the Commission on Mines:

> Aged 93 according to his own account and that of the agents. Went down a pit when he was about 6 or 7 years of age and was employed in and about pits up to about his 85th year and has always had good health and good fortune. About 40 years ago he was made an overman and has never worked himself since.

More typical of the commission's interviewees were children such as Janet Snedden, aged 9: 'Is a trapper in the Gartsherrie Pit [in Scotland], No. 1; comes down with Janet Ritchie, a single woman who hooks on and off the corves on the chain for drawing coal up the pit. Comes down a quarter before 6 and goes up again about 4 p.m.' Or Sally Fletcher, aged 8, who worked at Mr Stock's Windy Bank Pit: 'I have worked here short of three years. I cannot read or write. I never went to any school day or Sunday. I go to work between six and seven o'clock in the morning. I thrust corves with Josh Atkinson who is 10 years of age. I sometimes go home at three o'clock. Sometimes six. I don't go home to dinner. I get it at the pit mouth. I always have trousers and jacket on and also my clogs. I am not very tired when I go home at night. We sometimes hurry 20 corves and have 400 yards to hurry them.'

According to one source Engels talked to in the 1840s, 'of 22,094 operatives in diverse factories in Stockport and Manchester, but 143 were over 45 years old'. 'Mr Ashworth, a large manufacturer,' he goes on, 'admits in a letter to Lord Ashley, that, towards the fortieth year, the spinners can no longer prepare the required quantity of yarn, and are therefore "sometimes" discharged …' In many industries it was the nature of the job, the working environment or the long hours that produced ill-health, physical deformity or premature ageing. In a marginal note of 2 July 1835 de Tocqueville wrote that Manchester's working population were 'absorbed in material pleasures and brutalised'.

Titus Rowbotham, a mechanic who had first come to work in Manchester in 1801, would have agreed:

> I have seen three generations of operatives. I know men who are of my age … who have passed their lives in tenting the *mule jenny*. Their intellect is enfeebled and withered like a tree. They are more like grown up children than the race of men I knew formerly. … The long hours of labour, and the high temperature of the factories, produce lassitude and excessive exhaustion. The operatives cannot eat, and seek to sustain life by the excitement of drink.

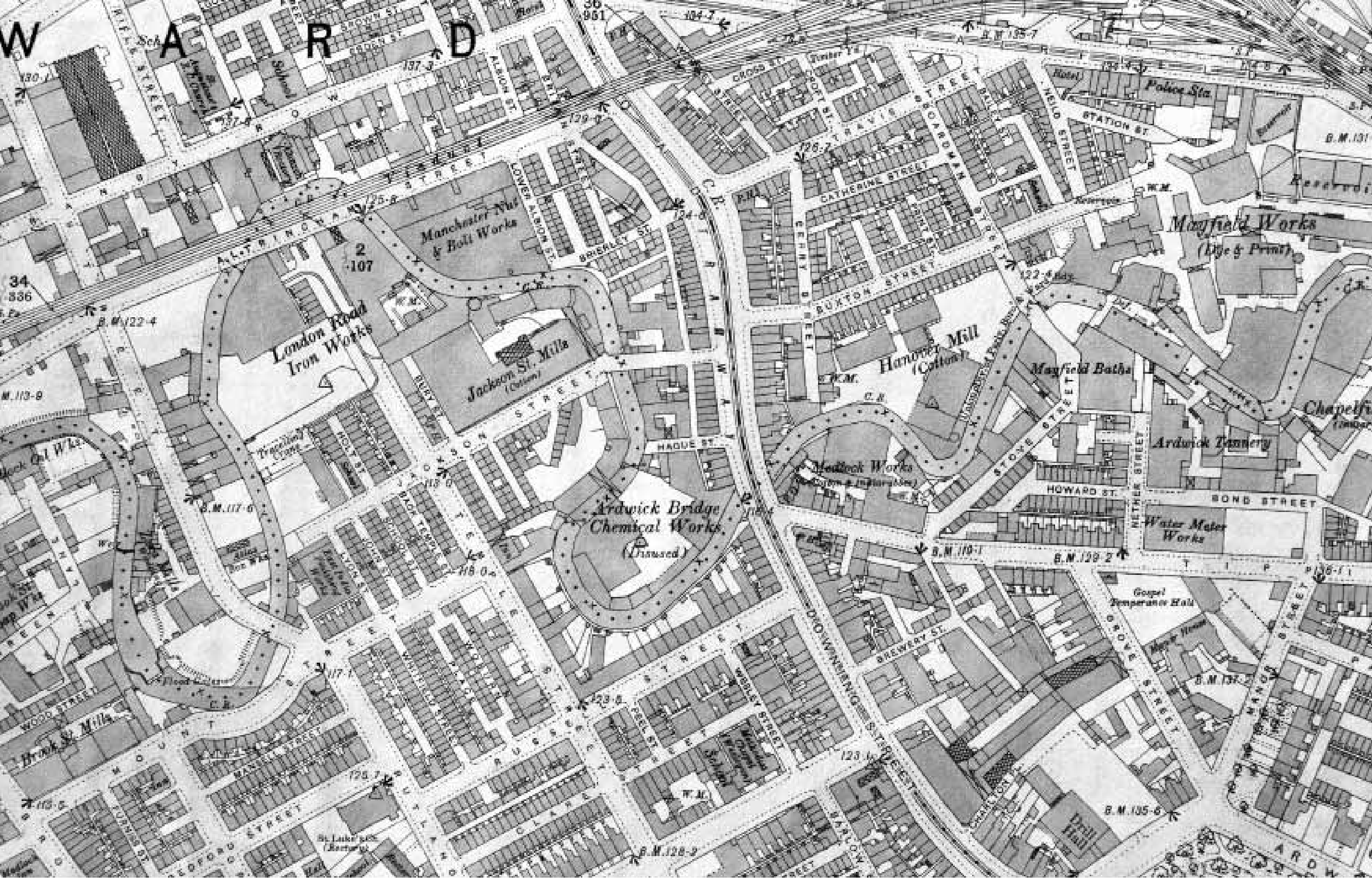
Official government documents rarely have such capacity to shock as the lengthy pages of the Children's Employment Commission (Mines) of 1842. This illustration was reproduced in the Leeds and Bradford report: 'The sketch given is intended to represent Ann Ambler and William Dyson, witnesses No. 7, hurriers at Messrs Ditchforth and Clay's Colliery at Elland in the act of being drawn up crosslapped upon the clatch iron by a woman … The turn wheel, as represented … is the least expensive, and certainly the most dangerous, as you are, upon all occasions, dependent on the man or it may be a woman, who works it … you are at the mercy of the winder.' At the time of the report William Dyson was 14 years of age, and had been working underground for eight years. Of his fellow-worker Ann, whose exact age is not given, Dyson testified: 'I have seen her thrashed many times when she does not please the [men]. They rap her in the face and knock her down. I repeat I have seen this many times. She does not like her work, she does not like that, I have seen her cry many times. The men swear at her often and she says she will be killed before she leaves the pit.'

Large numbers of women worked in factories and workshops across Britain, but some also worked in more manual occupations such as sorting coal at the pithead. In the South Lancashire coalfield in particular, the 'pit brow lasses' of Wigan and elsewhere were frequently photographed in the later nineteenth century. This photograph was taken in 1865.

BY COURTESY OF THE MASTER AND FELLOWS OF TRINITY COLLEGE, CAMBRIDGE

Like most migrant workers, Rowbotham had travelled to the town as a young man. As in all periods and places, those who chose to up-sticks and migrate in search of a better life were the youthful and the more dynamic of their communities. In sectors such as textiles, where production had formerly taken place in the family home, villages could be left with an ageing population of handloom weavers whose incomes were under threat from mechanisation but who would not have been able to make the change to factory work even had they been willing.

Factories did provide many opportunities for young women, although in mining and metal working the majority of workers were men. Collecting information for a parliamentary report in 1833 from 82 cotton factories, 65 wool factories, 73 flax factories, 29 silk factories, 7 potteries, 11 lace factories, 1 dyehouse, 1 glass works, and 2 paper mills throughout Great Britain, Dr James Mitchell calculated that, overall, considerably more than half of the workers (57 per cent) were female. More than half of the female workforce in these factories were less than 20 years old, and



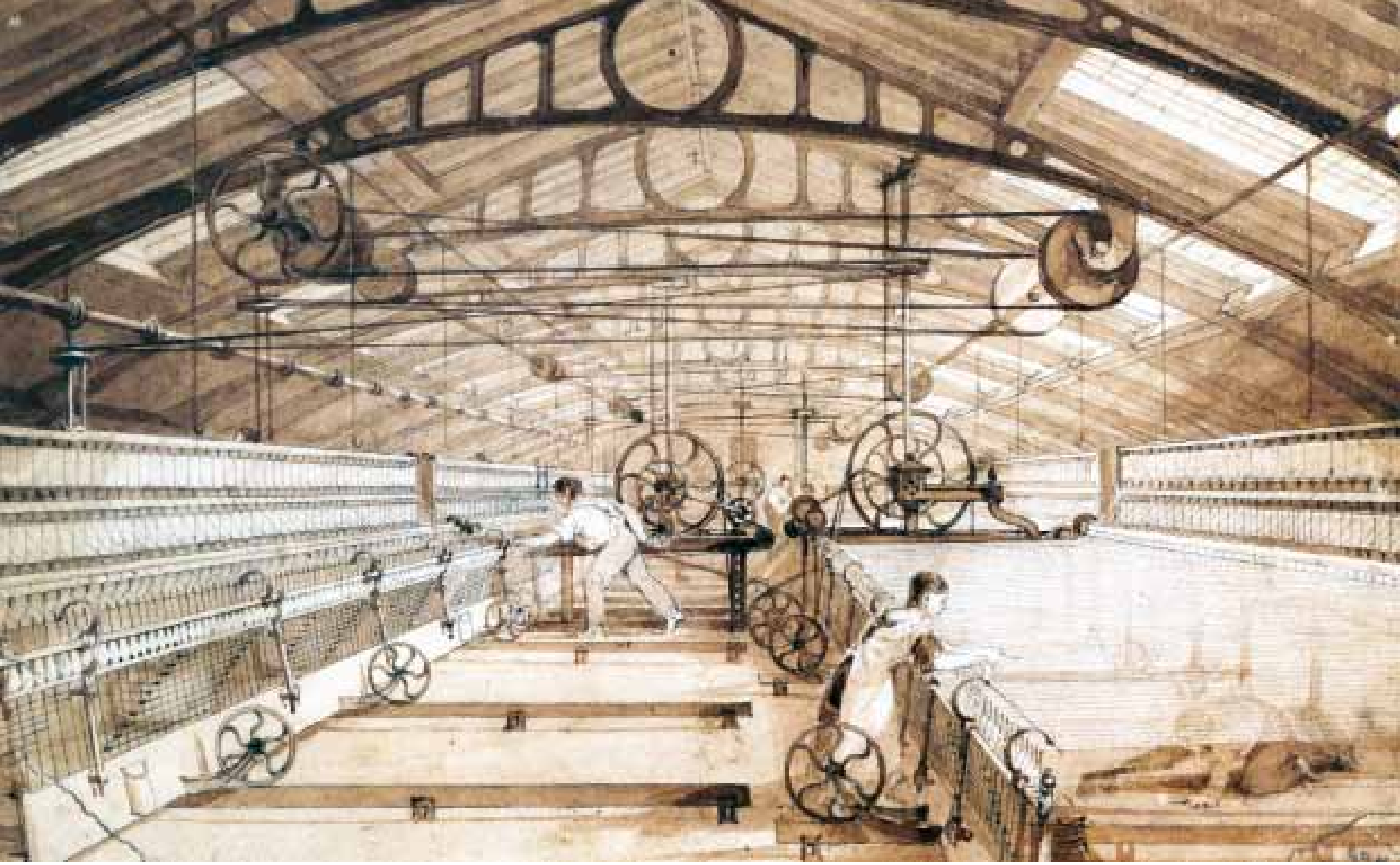
This map of 1893 of part of the centre of Manchester portrays vividly some of the characteristic features of a large nineteenth-century city. Many textile works had been built along the meandering banks of the river Medlock, but they tended to be those involved in finishing fabrics, particularly in dyeing, and used the river for process water, although there were some spinning factories which probably originally operated their machines by water power. There were also establishments linked with engineering, such as the London Road Iron Works and a manufacturer of nuts and bolts, as well as a tannery, the (by then disused) Ardwick Bridge Chemical Works, and a soap factory. There is some back-to-back housing in the north of the area, but to the south are many houses of simple rectangular plan, characteristic of the second quarter of the nineteenth century, as well as some tunnel-back houses of the kind built in large numbers in many towns after 1850.
PHOTOGRAPH BY CARNEGIE, REPRODUCED BY COURTESY OF THE COUNTY ARCHIVIST, LANCASHIRE ARCHIVES

of the teenagers he found working in the silk factories, he found that more than 84 per cent were women. In the parliamentary debate on hours of factory work on 22 March 1844, Sir James Graham suggested that women were keen to work hard: 'female adults, as well as male adults, tempted by a love of high wages, and honest gain, were disposed to flock to factories where labour might be obtained for a longer period than twelve hours.' The 1851 census shows 650,000 female workers in Britain's textile industries, compared to 661,000 men. Some women could also be entrepreneurs: an analysis of trade directories from several industrial towns found that the proportion of business owners who were female rose from around 9 per cent in the 1780s to around 12 per cent in the 1850s. Of the 'drapers, mercers and dealers of cloth' listed in a Manchester trade directory of 1788, no fewer than 15 (or 24 per cent), were women, as were 9 per cent of publicans and 13 per cent of shopkeepers. Some enterprising women even built and operated textile mills. Michael Baumber, the historian of Keighley and Haworth, cites the examples of Ann Illingworth, Rachel Leach and Betty Hudson, who did so in that part of the West Riding, while parliamentary papers in 1833 name a Mrs Doig who owned a powerloom factory in Yorkshire that employed 60 people.

Throughout the period of industrialisation neither national nor local government imposed any effective controls upon the development of manufacturing premises or of housing. Regulations did not exist about where industry could be sited, or how close to industry houses could be built; town planning, building regulations and development control were all much later innovations. Having said that, the nature of particular areas could be determined by landownership. It was possible for landowners such as the Russell family, dukes of Bedford, in the Bloomsbury area of London, or the owners of the Colmore and Calthorpe estates in Birmingham, to control development by releasing land gradually to house builders or industrial entrepreneurs or by the strict enforcement of the terms of leases. Nevertheless many well-intentioned plans for select middle-class terraces and villas, as in the west end of Leeds, were frustrated by the pressures of a land market in which there was an almost insatiable demand to build premises for manufacturing and for the accommodation of the families employed therein. There was no formal zoning, and in many parts of Manchester, Birmingham, Leeds and even London, industrial buildings stood cheek-by-jowl with workers' housing. The early Ordnance Survey maps of most towns show bewildering muddles of workshops, cottages, factories, canals, pigsties and slaughter-houses. There were elements of planning in a few areas, such as the grid of streets alongside the Rochdale Canal in Ancoats in Manchester where some of the city's largest spinning mills were built, but these were exceptional. The requirements of specific processes did lead to clusters of activity, for example along waterways: streams were used for water power, and activities that needed process water – such as dyeing, bleaching or tanning – congregated near to natural or man-made watercourses, while ease of access to transport led to other mills and factories also being built along the banks of canals or river navigations. But even here, where industrial premises were mostly highly concentrated, there were still plenty of workers' houses to be found, right next to the noxious waters of river, canal or drainage systems.

In the absence of any health and safety legislation until the mid-nineteenth century (and its minimal effectiveness for decades thereafter), industries of all sorts were potentially dangerous, and for many workers life was 'nasty, brutish and short'. We are familiar, and rightly so, with images of mining disasters and of industrial injury in mills and factories. An 1889 description of Wigan casually enumerated 11 local pit disasters in fifteen years, in which 525 men and boys had died. Such catastrophes were commonplace, and little regarded by the outside world except when something really spectacular happened – such as the 204 miners who suffocated in the Hartley pit disaster in Northumberland in 1862, or the 366 killed when the Oaks Pit near Barnsley exploded in December 1866. But early death through disease was insidious and ubiquitous. Among the lead-miners of Swaledale in the 1860s the average age at death was 42 years: for non-miners in the same communities it was 63. Lung diseases, from breathing the fine lead-laden dust, were largely responsible: at Allendale in Northumberland in 1862, 80 per cent of lead miners had chronic asthma or respiratory conditions. Some traditional industries were notoriously dangerous. In tanneries there were deep pits of noxious, slimy waters in which to drown. Foundry-workers were burned and scarred with splashes of white-hot metal, or had their lungs scorched by inhaling hot gases. Railwaymen were crushed between shunted waggons and lost limbs as they fell beneath locomotives. In mills the plethora of fast-moving unprotected machinery could be lethal to sleepy children and careless adults: in 1826 a Lancashire millworker, remembering the 1790s, wrote how, 'My Brother Joseph got his hand Catched in the factory, lost one finger & was much Cut & mangled – after that he sickend & died aged 11 years.' Such accidents were numerous beyond counting, and counted little except to the victims and their families … anyway, in most places there were plenty more where they came from.

Industrialisation was, in the main, the consequence of private enterprise. The role of the State in mining and manufacturing in Britain was modest in comparison to that of some governments in continental Europe. There was no British equivalent of Dijonval, the monumental state-sponsored broadcloth factory at Sedan, nor of the Fonderie Royale and the Cristallerie de la Reine, laid out as if components



This engraving which appeared in the *History of the Cotton Manufacture*, by Edward Baines, Jnr, published in 1835, is one of the best-known images of the industrial revolution. It shows the operation of spinning mules in the Fishwick mill of Swainson Birley, near Preston, Lancashire. The spinning mule had been invented by Samuel Crompton in 1779, combining the moving carriage of the spinning jenny with the rollers of Arkwright's water-frame; it was the most successful and widely used of the powered spinning machines and was developed into a fully mechanised, self-acting standardised machine by Richard Roberts between 1825 and 1830. The engraving shows that even the most up-to-date machinery posed dangers to the children who worked it, in this case being employed to crawl beneath the extended yarn to sweep up the cotton waste; children were also used to piece together broken ends of yarn.

of an ornamental park at Le Creusot in the 1780s. Some specific infrastructure projects were funded by town corporations, the most notable example probably being all of the enclosed docks at Liverpool (those at London, by contrast, were built with private capital, and no overall public body for the Thames existed until the Port of London Authority was created in 1908). Nonetheless, government was directly involved in the production of armaments. In 1700 there were naval dockyards at Deptford, Woolwich, Chatham and Portsmouth, and a recently founded establishment at Devonport which stimulated the growth of Plymouth. These were significant employers. In 1711 the dockyards together employed some 6,500 people. The yards grew and multiplied during the eighteenth century, and their scale can be appreciated at Chatham, in covered building slips, a mould loft completed in 1755 which measures 119 feet × 55 feet (36.6 × 17 m) with mast and spar shops below, and a three-storey rope works of 1786–91 which is 1,140 feet long (351 m), and which could produce 24-inch (0.62 m) cables. An American Quaker in 1776 remarked at Portsmouth, 'The King's Dock is sufficient to strike terror in the enemies of England. Nothing can give one a higher idea of its strength and power. Rope makers, smiths, shipwrights, mast makers, all seem to move by clockwork.' Nevertheless, most of Britain's wooden merchant ships were built in small establishments along the coast and on river banks in many parts of the country, while significant numbers were actually constructed in North America and India. By 1814 the dockyards employed 17,500 people, including about 2,000 who worked in India, the Mediterranean and the Caribbean. The separately constituted Victualling Board supplied food and drink to the Royal Navy, and in the early nineteenth century built monumental depots – the Royal Victoria Yard at Deptford, the Royal Clarence at Gosport and the Royal William at Plymouth.

The army's principal manufacturing and logistics base was the arsenal at Woolwich, which originated with a military storage depot established in 1671 on a 31-acre site. This had grown to 104 acres by the late 1770s, when construction began of a 2½-mile boundary wall, originally 8 feet (2.5 m) high. Sir John Vanbrugh and Nicholas Hawksmoor designed buildings within the complex, and a gun foundry was established there in 1717. Close to the Arsenal were the Royal Military Academy and the headquarters of the Royal Artillery. Government was also involved in the manufacture of gunpowder, at mills at Faversham (sold in 1825) and a late eighteenth-century works at Ballincollig, Co. Cork. This was sold in 1833, after which the manufacture of explosives was concentrated at Waltham Abbey, purchased by the Crown in 1787 at the prompting of Lt General Sir William Congreve. The manufactory of small arms at Enfield Lock, opened in 1816, employed about a thousand people by 1860.

Military demands influenced the production of cannon, and consequently of other iron castings, the fabrication of copper, and the introduction of steam-propelled iron ships. Indeed, the order placed with Henry Maudslay for block-making machines designed by Sir Marc Brunel for Portsmouth Dockyard was a key event in the development of mechanical engineering. Brunel and Maudslay had both worked at the Royal Arsenal. By the 1820s, in another example of innovation in the military, the mass-production of ships' biscuits at the Royal Victoria Yard at Deptford

The Royal Dockyards were among the most imposing industrial establishments in the British Isles. The yard at Deptford on the south bank of the river Thames downstream from London was founded in 1513 by Henry VIII, and Peter the Great of Russia studied there in 1698. The yard reached its zenith in the eighteenth century, and by the 1790s there were five slipways for warships in the yard. After the Napoleonic Wars the Deptford yard went into decline, since it was situated too far upstream to cope with the largest ships of the time; new ships were no longer built there from the 1830s, and it was closed in 1869. This painting of about 1750 is one of several of that period showing ships of the line being launched at Deptford. Such launchings were relatively rare events, and, as the picture shows, they attracted many spectators. The substantial brick building to the right of the ship being launched was the Grand Storehouse, and the dwelling house on the left, which still stands, was the home of the Master Shipwright. The ship was launched without its mast and rigging which might have been added at Deptford or at the nearby Royal Dockyard at Woolwich.

The British government played a relatively small role in manufacturing in the eighteenth and nineteenth centuries, but some installations that supplied the army or the Royal Navy had a grandeur that was rarely seen in private industry. Under the direction of Sir John Rennie the Royal William Victualling Yard at Plymouth was built between 1827 and 1835 to supply the Royal Navy.

The war in which Britain, France and Prussia confronted Russia and the Ottoman Empire broke out in October 1853, and on 15 March 1854 the Royal Navy despatched from Portsmouth a substantial fleet under the command of Sir Charles Napier which was to join a French squadron in attacking Russian installations in the Baltic. The campaign proved inconclusive since the commanders were apprehensive about attacking strong fortifications and the Russian use of mines had a considerable deterrent effect. At the centre of the picture is a wooden-walled ship of the line, possibly *Nepture*, flagship of the second-in-command, but Napier's flagship was the screw-propelled steamer *Duke of Wellington* which had a crew of more than 1,000 men. By this date the Royal Navy was turning more and more towards using steam-powered vessels. An oil painting by Wilhelm Melbye.

was establishing a technology that was later used by civilian manufacturers.

While the arsenal and the dockyards were evidence of military power, that power was for the most part exercised overseas, and for much of our period the military presence in much of Britain was scarcely noticeable, although not in the Scottish Highlands after Culloden in 1745, nor in Ireland in 1798. Nevertheless, press gangs influenced coastal and estuarial shipping, while the passage of columns of troops could momentarily disrupt towns of thoroughfare. To overseas visitors the lack of military visibility was as surprising as the absence of internal customs. The German Pastor Moritz observed in 1782 that, 'Passing through an English town is very strange to a foreigner. … There are no fortifications – town walls, gate or the like; no exciseman on the lookout, no menacing sentry to beware of; you pass through town and village as freely and unhindered as through wide-open nature.' The contrast with his homeland, where the gradual dismantling of inter-state customs under the *Zollverein* began only in 1818, was particularly marked.

Britain's industrial development was shaped in part by successive wars: that against Louis XIV which concluded with the Treaty of Utrecht in 1713; the War of the Austrian Succession between 1740 and 1748; the

Seven Years War of 1756–63; the War of American Independence; the wars against Revolutionary and Napoleonic France; and the Crimean War (1853–56). Manufacturing was affected by blockades that shut off supplies of raw materials or closed export markets, but modest commitments to land warfare meant that the drain on manpower was less than in Prussia or France, although the threat of militia service could shape the lives of individuals, as it did that of the engineer Richard Roberts, who about 1813 walked from London to Manchester to avoid conscription into the militia. The rapidity with which educated Englishmen flocked abroad after the signing of the short-lived Treaty of Amiens in 1802 indicates the extent to which they saw themselves as Europeans.

The war with France between 1793 and 1815, and its immediate aftermath, form a distinct phase in British history, a time of democratic aspiration and of repression by government, and in Ireland a period of awakened nationalism, repressed with less measured severity. Evangelical religion gained many adherents. Industrial labour was, relatively speaking, lavishly rewarded, but according to middle-class critics those rewards were squandered, rather than being saved for adverse circumstances. Child labour was callously exploited. The practices revealed in parliamentary enquiries of the 1830s and 1840s are disturbing, but textual analysis of evidence presented to those enquiries suggests that conditions had been worse between 1790 and 1815. London magistrates believed that there was less juvenile delinquency in the capital during the wars with France because with so many men serving as sailors more employment was available for children. Colquhoun in 1815 marvelled at the progress of manufactures after 1793, brought about by the improvement of steam engines and the deployment of ingenious machinery in the textile trades.

Some important technological developments were imported from the continent. In the early eighteenth century managers of copper plants at Bristol, Redbrook (on the river Wye near Monmouth), and Cheadle drew on the expertise of continental workers. Tinplate manufacture drew upon the research of the Frenchman René Réaumur, while the production of 'corrugated iron' in the Black Country from the 1830s followed the galvanising process patented in France in 1829 by Stanislas Sorel. The boring machines that shaped the cylinders of late eighteenth-century steam engines were derived from one built at Woolwich by the Dutchman Jan Verbruggen. The casting of plate glass was introduced from France to Ravenhead (St Helens) in 1773, and Robert Lucas Chance brought the hand cylinder method of making sheet glass from Lorraine to Smethwick. The Leblanc and Solvay processes for making alkali, the Jacquard loom and the Guibal ventilation fan were other technologies brought from the continent. Famously, the closely guarded secret of mechanised silk throwing was stolen from Italy by John Lombe, who cheekily went on to secure a British patent for his ill-gotten gain and established a large new mill in Derby to exploit it. On the other hand, British technology was itself of interest to foreign governments. John Harris has shown how spies recorded processes used in Britain and tempted skilled workers overseas. Several leading innovators and entrepreneurs were natives of continental Europe, or were descended from immigrants, including Sir Mark Brunel from Normandy, Andrew Kurtz from Würtemburg, Sir William Siemens from Hanover, Henry Bolckow from Mecklenburg, Sir Bernhard Samuelson from Hamburg, Sir John Brunner (son of a Swiss Unitarian), Ludwig Mond from Kassel, and Karl Friedrich Beyer from Saxony. A succession of British engineers founded concerns in Belgium, Russia, France and Austria. It was a two-way exchange. Furthermore the nineteenth century was a time of great migrations from Europe to the New World, and with those human tides went manufacturing knowledge and skills. Most notable of those who took their know-how abroad were the Cornish miners, who could be found throughout the Empire and in every continent, wherever there were metalliferous ores that merited extraction.

After 1789 the British were aware of continental Europe, not only because of war but also through the presence of French prisoners-of-war and royalist exiles, commemorated by memorials in Dorchester Abbey (Oxfordshire) and the parish church at New Alresford (Hants). Dartmoor Prison was built in 1809 to house Napoleonic prisoners, and a governor's house, a monument and earthworks provide evidence of the prisoner-of-war camp at Norman Cross near Peterborough. Cultural influences from the continent gradually extended throughout society. In cities, small towns and even in the remote countryside during the nineteenth century German and Italian musicians were familiar. There were 880 German musicians in England and Wales in 1881, mostly in bands of six to eight players. Many came from the barren lands of the western Palatinate around Kusel, but some from Hanover, Berlin and Frankfurt-am-Main. In 1861 they were recorded as staying at Bourne, Cambridge, Horncastle and Ironbridge among other places. Jewish sellers of 'Mizpah brooches', mostly born in present-day Poland, could be encountered throughout Britain. A group in the poorest part of Oxford in 1851 included a Hebrew writer, as well as jewellers from Nordhausen and Poznań (Posen), and in 1851 a Prussian-born jeweller was staying in a remote hamlet near Coalbrookdale. Some British forgemen and glassworkers found employment abroad, including residents in the Combe des Anglais at Le Creusot. Navvies building the Severn Valley Railway in 1861 had worked in Normandy and the Rhone Valley. International exhibitions attracted self-educated working men. A group in Banbury organised language classes to enable them to converse with their French *confrères* at the International Exhibition of 1862, while Joseph Gutteridge, a Coventry loom mechanic, visited the Paris exhibition of 1867 and studied textile manufactures in St Etienne, Lyons, Basle and Rouen.

The universities of Glasgow and Edinburgh are regularly mentioned in this study, but Oxford and Cambridge hardly at all. The latter, the only universities in England until the 1830s, excluded Dissenters, which may have driven some to Scotland or continental Europe. Dr Joseph Black, Professor of Medicine at Glasgow in 1756–66 and of Medicine and Chemistry at Edinburgh from 1766, was the academic who most influenced industrial development. His best-known research concerned latent heat. He encouraged the young James Watt, and William Reynolds attended his classes in Edinburgh. Some entrepreneurs and innovators gained experience abroad. Sir Isaac Lothian Bell studied at Edinburgh and the Sorbonne. William Losh received part of his education in Hamburg; A. G. Kurtz and John Hutchinson were fellow students in Paris; and Angus Smith attended classes given by Justus von Liebig at Giessen. In fact few elements of economic development and even fewer technological innovations were products of the education system or of theoretical science. As Peter Mathias pointed out: 'Great determination, intense curiosity, quick wits, clever fingers, luck, capital, or employment and a backer to survive the period of experimenting, testing, improving were more important in almost all fields than a scientific training.' And Edward Baines lists many textile innovations that were made by practical men of modest formal training, including 'Mr Robert' (i.e. Richard Roberts, see Chapter 3, pages 77, 81–2), the 'extremely ingenious machine-maker of Manchester' who devised a successful form of self-acting mule; 'a person named Green, a tinsmith, of Mansfield, who was the first who conceived of the idea of attaching the movements of the spindle and bobbin together' in roving frames; and 'the patent [for the dressing-machine was taken out] … in the name of Thomas Johnson, of Bredbury, a weaver in [the company's] employment, to whose inventive talent the machine was chiefly owing.'

More influential in facilitating industrial growth than most academic institutions were the literary and philosophical societies of the industrial cities, the informal associations such as the Lunar Society, and industrial concerns that served as nurseries of talent, such as Henry Maudslay's workshop. James Keir, the chemist, was for a time an employee at the Soho Manufactory and a member of the Lunar Society. He wrote in 1789 that 'the diffusion of a general knowledge of, and of a taste for science over all classes of men in every nation of Europe or of European origin seems to be the characteristic feature of the present age'.

The unseen presence of America underlay developments throughout the period. Imports from America became increasingly significant – tobacco, sugar, timber, and above all cotton, until the mid-1860s slave-grown – while iron tools, hardware, textiles and printed books crossed the Atlantic in the other direction. Elihu Burritt, who grew up in Bristol, Connecticut, wrote in 1864:

> All Americans who were boys forty years ago will remember three English centres of particular interest to them. These were Sheffield, Colebrook Dale and Paternoster Row. There was hardly a house or log cabin between the Penobscot and the Mississippi which could not show the imprint of these three places, on the iron tea-kettle, the youngest boy's Barlow knife and his younger sister's picture-book. To the juvenile imagination of these times, Sheffield was a huge jack-knife, Colebrook Dale a porridge pot, and Paternoster Row a psalm book.

From the time of the Pilgrim Fathers America was a refuge for the discontented and oppressed. After the War of Independence it was also a source of hope for those who had lost their means of livelihood, or whose political or religious views did not fit comfortably into British society. Some fled across the Atlantic because they had broken the law, others in groups organised by landowners anxious to reduce rural pauperism. People learned about America through literature and popular lectures. Frances Trollope (mother of Anthony) and Charles Dickens published best-selling books about their travels, while with the aid of lantern slides entertainers such as Henry Russell and Washington Friend provided audiences with impressions of 'the wondrous scenes of the distant west … the crowded city and the solitary forest … represented with a truthfulness which carried the imaginations of the lookers on to the shores of the Mississippi or the mighty plunge of Niagara.'

American evangelists such as Lorenzo Dow, Alexander Campbell (founder of the Disciples of Christ), Phoebe Palmer, Ira D. Sankey and Dwight L. Moody attracted crowds in Britain. Images of the United States were purveyed by nigger minstrels and by the circuses of Seth B. Howes & Joseph Cushing and Phineas T. Barnum. The significance of America emerges, for example, from the reminiscences of Adam Rushton, who learned to read at the Sunday school in Macclesfield and, on discovering the Pilgrim Fathers, 'fell into a sort of enchanted dream of a freer life in the American backwoods'.

The tomb of 'Poor Samboo, a faithfull Negro', a black cabin boy who served the captain of a ship which arrived at the tiny harbour at Sunderland Point, then an outport of Lancaster, in 1736. Sambo died shortly after the ship docked, and, since it was believed he had never been baptised, was buried in unconsecrated ground. This plaque and poem were added in 1796.

Another aspect of the imperial dimension was the presence in Britain of men and women who had grown up or worked in India, North America or the Mediterranean. Some, including many born in Spain and Portugal between 1808 and 1814, were the offspring of soldiers. Others were black people, of whom there were about 15,000 in Britain in 1800. Lord Torrington observed at Stockport in 1790 that, 'This inn is striped and barr'd with as much black timber as would build a man of war. The waiter likewise is black, a very Othello, a quick intelligent fellow who comes to swarth our breed.' In 1842 J. G. Kohl noted 'Hindoo' beggars on the streets of Manchester, while in the graveyard of the parish church of Bishop's Castle in remotest Shropshire is a stone inscribed, 'Here lieth the body of

I.D., a native of Africa, who died in this town on Sept 9th 1801. "God hath created of one blood all nations of men," Acts Ch. 17 verse 26.'

Many developments between 1700 and 1870 were dependent on technological innovation. It is not the intention of this study to break new boundaries in the history of technology, but rather to place technological developments in their appropriate contexts. Relationships with distant countries also involved technology. While cotton manufacturers in the eighteenth century learned much from India, and the Royal Navy built ships there, the capabilities of craftsmen in countries regarded as inferior were rarely recognised. Few heeded Samuel's Johnson's sage observation to Warren Hastings in 1774 that 'There are arts of manufacture practised in the countries in which you preside which are yet very imperfectly known here, either to artificers or philosophers'.

Early commentators were often quick to emphasise new technologies, techniques and mechanical devices. Some of these, such as the water-frame, the flying shuttle or Watt's separate condenser for the steam engine, were of momentous importance, but the speed of adoption of innovations could be variable, and it could take many years for new methods to displace the old. Inventions, not infrequently protected by patent, could take a long time to spread. For this reason among many, one needs to take a surprisingly long view of some of the processes involved, reinforcing the scepticism noted above of the usefulness of the term 'industrial revolution'.

Over the long term, however, the changes described did propel the national economy into an acknowledged position of international competitive superiority in the 1850s and 1860s. This is more a cause for reflection than an excuse for chauvinistic rejoicing, and in this book the use of such terms as 'world first', 'world centre of' and 'cradle of' will mostly be avoided. This study attempts to show awareness of the topography and past histories of communities within the British Isles. It does not focus unduly on celebrated places, and it attempts to heed William Cobbett's observation in 1825 that, 'Those that travel on turnpike roads know nothing of England – From Hascomb to Thursley almost the whole way is across fields, or commons, or along narrow lands. Here we see the people without any disguise or affectation. Against a great road things are made for show. Here we see them without any show.'

Despite half a century and more of retreat from manufacturing, Britain's industrial legacy is still with us. Some former mining and manufacturing sites have left little trace. Their buildings have been demolished and the 'brownfield' land re-used for housing or service industries. Other buildings have been adapted for new uses, for business or housing, or as museums. Indeed, places linked to the industrial revolution comprise about a third of Britain's UNESCO World Heritage Sites: the mining and iron-working landscape of Blaenavon; the tin and copper mines of Cornwall and west Devon; Derbyshire's Derwent Valley mills; the complex landscape of the Ironbridge Gorge; Robert Owen's New Lanark; Sir Titus Salt's mill and model village at Saltaire; and, inscribed as recently as 2009, the Pontcysyllte Aqueduct and the adjoining sections of the canal that passes over it. Yet the legacy goes deeper. Many towns that were once busily pre-occupied with mining or manufacturing have struggled to come to terms with the loss of industry: typical of such places are the iron-mining village of Cleator Moor in west Cumberland, Merthyr Tydfil in South Wales, some of the pit villages in Derbyshire, Nottinghamshire and south Yorkshire, and the cotton towns of east Lancashire. These and many other communities flourished because of the developments described in this book, and now have been left stranded, economically and socially, by the decline of mining and manufacturing in the twentieth century.

In some places, the legacy is also one of despoiled landscape or lingering pollution. Among the most ravaged was the lower Swansea Valley: its hillsides were stripped naked of vegetation by decades of toxic fumes that had poured from the copper works, smelters and tinplate works which had developed from the end of the eighteenth century; all around man-made mountains of slag and industrial waste hid the valley floor. The slopes of beautiful Swaledale were scarred by the deep ravines created by 'hushing', as torrents of water were released to flood down the hillsides to scour away the overburden and reveal – all being well – the lead-veins beneath. In the central valley of Scotland bright-pink conical 'bings', immense hills of burnt shale that was the waste product of the oil-shale industry, towered above coal-mining villages such as Addiewell and Tarbrax. Some of the lovely estuaries of Cornwall were choked with silts washed down from tin-streaming works upstream. At Widnes in the 1870s hydrochloric acid gas poured from alkali plants into the lungs of all who lived there, and when it rained corrosive acid dropped on to both people and buildings. In the towns and villages of mid-Cheshire houses and public buildings sank slowly and crazily into subsidence pits that had been created by underground salt workings. Ironically, we often now treasure the remaining evidence of such processes – hushes, pit heaps and lakes created by subsidence – and not simply for archaeological reasons. The oil-shale bings at Addiewell are now a National Nature Reserve. The 170-acre lake of Pennington Flash near Leigh, formed barely a century ago as the result of mining at Birkenshaw Colliery, now attracts more than 230 species of birds; the lake and surrounding country park are regarded as one of the premier bird-watching reserves in the North. In the Ironbridge Gorge, meanwhile, the regeneration of woodlands and the return of wildlife after several centuries of despoliation by smoke and the dumping of waste are now appreciated as one of the most significant features of the landscape.

In 1791 Arthur Young, an informed witness who is often quoted below, took an optimistic view of changes in his lifetime, exhorting his readers to

> get rid of that dronish, sleepy and stupid indifference, that lazy negligence, which enchains men in the exact paths of their forefathers, without enquiry, without thought and without ambition, and you are sure of doing good. What trains of thought, what a spirit of exertion, what a mass and power of effort have sprung in every path of life from the works of such men as Brindley, Watt, Priestley, Harrison, Arkwright, and let me add my fellow-traveller Bakewell! Who will tell me that the buttons at Birmingham are not better made because the tups around are better bred – because locks and sluices are better constructed, and that woollen cloth will not be better woven because cotton is spun in the beautiful invention of the mills? In what path of life can a man be found that will not animate his pursuit from seeing the steam engine of Watt?

He concluded, as he watched the Oxford Canal Company's engineer trying to remedy a shortage of water caused by increasing traffic, that: 'Undoubtedly the spirit of enterprise, the ardent, energetic and daring attempts that are every day made in this kingdom, are glorious exertions and do infinite honour to it.'

In the 1840s one member of the Manchester Athenaeum accepted the task of translating Léon Faucher's book about contemporary Manchester. In a short Preface, the translator, writing from the perspective of the free-trade capital of the world, gave us this:

> There is something mysterious in the rise and progress of the manufacturing system. A few mechanical discoveries, apparently insignificant in themselves, and almost unnoticed at the time of their appearance, form the nucleus of a system which grows steadily, and marches on silently, and yet, with such irresistible influence as to absorb in a few years, the olden features of society, developing new features, requiring new institutions in accordance with its new developments, and pointing to some new Destiny, ill-understood, yet instinctively believed in by all.

Marvellous and mysterious, this new 'manufacturing system' had changed the world.

Industrial change and expansion affected the British Isles profoundly between 1700 and 1870. In its wake it brought massive urbanisation, fundamental demographic and social change, the transformation of landscapes and the reshaping of the economy. It was

Few scenes in industrial Britain in the nineteenth century were as awe-inspiring as a distant prospect of the blast furnaces at Merthyr Tydfil. The spectacle impressed the King of Saxony and his entourage in 1844 (see pages 311–12). This painting shows the Cyfarthfa Ironworks, constructed under the direction of Charles Wood in the late 1760s, and the property of the Crawshay family from the 1790s. In 1806 it was the most productive ironworks in Britain, and Richard Crawshay, 'Moloch, the Iron King', was conscious in 1790 that he belonged to a generation who had transformed the iron industry. The flame-topped blast furnaces, which still stand, are evident in the centre of the picture, and the numerous chimneys carried flues from the boilers of steam engines which powered blowing machines and rolling mills. Similar scenes could be observed in the mid-nineteenth century in the vicinity of Coalbrookdale, in the Black Country, in parts of Yorkshire and around Coatbridge.

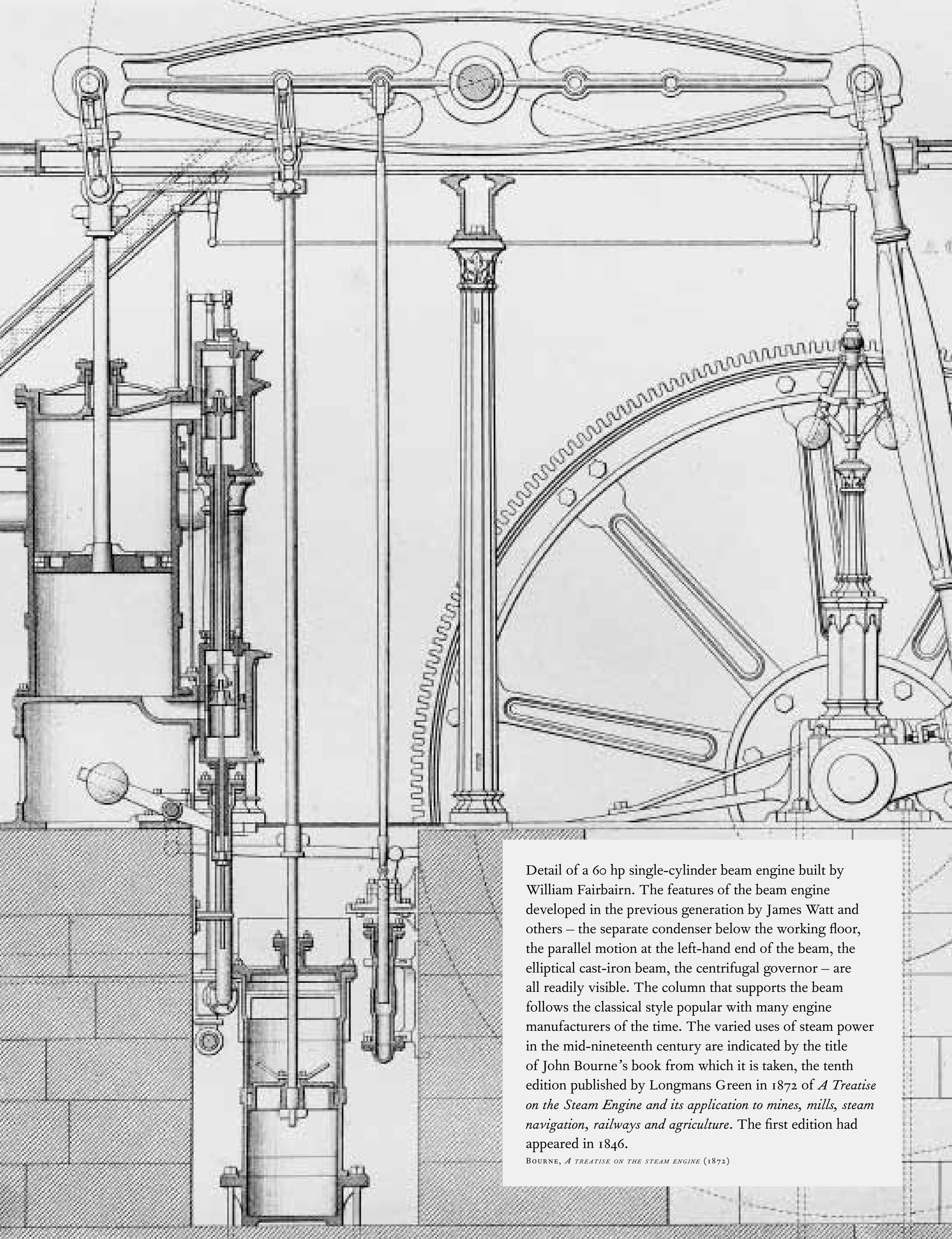
'CYFARTHFA STEELWORKS AT NIGHT' BY THOMAS PRYTHERCH, BY COURTESY OF MERTHYR TYDFIL COUNCIL

one of the most important processes in world history, a period and a phenomenon of global significance. No part of the world has been unaffected by what happened in these islands a quarter of a millennium ago, and we live every day with the consequences. The object of this study is to survey as broadly as possible the experiences of those who witnessed and lived through these changes.

Industrial history is not primarily about machines, raw materials, processes and products. It is about the people who created, innovated, laboured, suffered, acquired, bought and enjoyed, became rich or died young, lived comfortably on the profits or were crushed by the harshness of it all. None of this would have happened without people, and that is why, throughout this book, they take centre stage.

PART I

‘Illustrious followers of science’



Detail of a 60 hp single-cylinder beam engine built by William Fairbairn. The features of the beam engine developed in the previous generation by James Watt and others – the separate condenser below the working floor, the parallel motion at the left-hand end of the beam, the elliptical cast-iron beam, the centrifugal governor – are all readily visible. The column that supports the beam follows the classical style popular with many engine manufacturers of the time. The varied uses of steam power in the mid-nineteenth century are indicated by the title of John Bourne's book from which it is taken, the tenth edition published by Longmans Green in 1872 of *A Treatise on the Steam Engine and its application to mines, mills, steam navigation, railways and agriculture*. The first edition had appeared in 1846.

Bourne, *A treatise on the steam engine* (1872)

2

Fuelling growth: energy and power for industry

'He enlarged the resources of his country, increased the power of man and rose to an eminent place among the most illustrious followers of science and the real benefactors of the world.'

Memorial to James Watt, Westminster Abbey

The availability of energy determines the prosperity of economies and the comfort of societies, as anyone who queued for coal at a snow-encrusted railway yard in January 1947, or saw lights go out during the three-day week of 1974, or observed the bitterness of the miners' strike of 1984–85, will be well aware. Affordable fuel contributes to domestic well-being and stimulates enterprise, while expensive fuel raises living expenses. In 1700 many urban activities depended on the availability of fuel, to provide heat for blacksmiths' hearths, maltsters' kilns, brewers' coppers, tallow chandlers' vats and brickmakers' clamps. There were profound changes between 1700 and 1870 in the sources of energy and the ways in which it was applied, which shaped the broader social and economic changes of the period.

Wood, peat and coal before the industrial revolution

In 1700 and to a lesser extent in 1870 woodlands and forests were sources of energy and raw materials. From them came naval timbers, beechwood for chairs, twigs for baskets and besoms, coopers' staves, hop poles, pit props and split wood for crates, as well as faggots for bakers, billets for fuel in distant places, and underwood for local fires. Forests were sources of charcoal, essential in smelting and forging iron until the mid-eighteenth century and still used in iron working in the 1860s. Lime kilns on the Sussex Downs were still fired with wood in the 1780s. Firewood cut in the Chiltern Hills was taken to wharfs on the river Thames, and carried downstream to London. As early as 1689 Sir John Borlase had billets to the value of £350 stacked on one wharf at Medmenham, and wood worth £975 at Little Marlow. In 1690 William Willmott of Fingest had beech billets worth more than £230 stacked in his woods and on a Thamesside wharf. These are very large sums of money indeed. The woodlands of Buckinghamshire met much of the county's need for fuel, yet even Sir John Borlase had some coal.

Heathlands were also a source of energy. William Cobbett, visiting Thanet in September 1823, observed the paradox between the plentiful crops being gathered in and the poverty of the harvesters. He argued that

A peat cart in Langstrothdale, source of the uppermost reaches of the river Wharfe. The thin wheels enabled the cart to pass easily through turf. The author of *The Costume of Yorkshire* observed that in 1814 peat was the general fuel used in the mountainous and moorland districts of northern England, and that it was customarily dug or cut into pieces about the size of a common brick, before being dried by the sun and stacked before use. Hand-coloured aquatint by Robert Havell after George Walker.

'the more purely a corn country, the more miserable the labourers' and thought that labouring men fared better in 'the rabbit countries' where there were woods and heaths. Probate inventories reveal that before the 1750s faggots and logs were the usual fuels in central Essex. Pehr Kalm in 1748 watched furze being cut and bundled on Ivinghoe Common (Buckinghamshire), and beech twigs and bracken being collected as fuel for brick kilns on the Ashridge estate of the 3rd Duke of Bridgewater. A generation later, in the 1770s, Thomas Pennant observed that in the Severn Valley in Wales the rich burned wood while the poor used a wretched turf. The poor of Wigginton in Oxfordshire were supplied with fuel which, before enclosure in 1795, was usually bundles of furze from the parish heath, but thereafter coal. Many heathlands were enclosed during the eighteenth century, and the process continued in wetlands and uplands until the 1860s. The brothers la Rochfoucauld were surprised in 1774 to observe near London stretches of common overgrown with bracken where 'improvements', which they considered desirable, were delayed because the poor had immemorial rights to cut bracken and brushwood for firewood.

Some energy came from wetlands. Peat was the principal domestic fuel in parts of the Scottish Highlands, around the mosses of Cheshire and Lancashire, and in the Fens and the Isle of Axholme. It was being cut in marshes near Uxbridge in 1798. It was even tried as a fuel for blast furnaces in the eighteenth century, and used experimentally in finery forges in the 1820s. It was used to smelt lead ore in the Pennines, where the ruined peat store at Old Gang in Swaledale is monumental. By the mid-nineteenth century peat was supplanted by coal in the Lincolnshire Fens, but not in Cambridgeshire where 36 men were digging and carting peat at Burwell in 1861 and 50 at Isleham. Turf was particularly significant in Ireland where more than three million acres, or 16 per cent, of the land surface consisted of peat bog. Before 1946 almost all peat was cut with a spade called a slane or *sleaghan*.

Along with the properties they owned or occupied many Irishmen had rights to cut turf in particular places for their own use. Commercial exploitation grew from the late eighteenth century as the Grand Canal enabled peat to be carried from the Bog of Allen to Dublin. In Germany, Russia and Denmark peat was more than a marginal source of energy, and in the Netherlands the museum at Barger-Compascuum provides evidence of its significance.

At the start of the eighteenth century large areas of the country that were remote from coalfields or navigable water lacked energy to a significant extent. In 1698, for instance, Celia Fiennes travelled from Peterborough to Wansford and saw cakes of cow dung hung up to dry on cottage walls and observed 'it is a very offensive fewell but the country people use little else in these parts'. In his gazetteer, published in 1750–51, Stephen Whatley was impressed by the dearness of fuel around Northampton, where there was scarcely any woodland, and coals could not be supplied before the river Nene was made navigable, a process that was completed in 1761. Probate inventories illuminate the shortage of fuel around Banbury which lies 22 miles south of the Warwickshire coalfield and about the same distance north of Oxford, where Thames barges were able to deliver coal that had been imported via London from north-east England. Banbury's hinterland comprised rich arable and pasture land, but not much woodland, no peat-yielding wetlands and only small areas of open common. More than a hundred probate inventories survive for citizens who died between 1690 and 1724, of which 39 (36 per cent) record fuel, a higher proportion than in most towns. Twenty-seven refer unambiguously to 'coals', two of which value it at a shilling per hundredweight, or £1 per ton. Twenty-four inventories record firewood; seven refer to furze, five to faggots, one to broom and one to turfs, a hundredweight and a half of which were valued at 2*s.* 6*d.* In fact, coal was reaching the Banbury area, and its use was not confined to the wealthy. But it was expensive, and people also burned fuels from local woodlands and commons. The Shropshire market town of Bishop's Castle was situated a dozen miles from the nearest coal mines, but beyond hills that could be crossed only with difficulty

Locally dug peat was commonly used as fuel in the lead smelters of the Pennines. For example, there were four ore furnaces at the Old Gang complex in Swaledale, for which peat was kept in a storehouse 390 feet long and 21 feet wide (119 × 6.5 m), which could hold sufficient fuel to fire the smelter for three years. Just the pillars, foundations and end walls remain of this extraordinary building, set in a landscape where there are now few traces of any other human activity. (See also page 375.)

Charcoal was produced in large quantities in 1700 in woodlands throughout the British Isles. It was used in smelting iron ore in blast furnaces and in refining iron in forges, and also in working other metals, as well as in processes such as malting that required a smokeless fuel. For many purposes charcoal was superseded by coke or anthracite during the eighteenth century. In 1870 it was still used to refine wrought iron with particular qualities, to line moulds in foundries, and as a filter and a source of carbon in the chemical industry. The traditional way of making charcoal, by heating 'cords' of wood about 4 feet long under a blanket of earth or turf that excluded air, is demonstrated here at the Weald & Downland Museum in Sussex. Cords were trimmed before they were used. The resultant twigs were usually bundled into faggots for use in bakers' ovens, or used by local people as domestic fuel.

'Irish Peasantry: the Turf Footers'. Many Irishmen had, and many still have, rights to extract turf or peat from bogs in the parishes where they live. Cutting peat was a family activity, as indicated in this engraving of 1790.

by wheeled vehicles. Of 100 inventories taken between 1690 and 1754, 27 refer to fuel, suggesting that means of heating were highly valued. Coal is listed on seven inventories, but wood for burning is mentioned on nine, while there are eight references to broom, gorse or faggots.

Coal was naturally plentiful in those areas where it was mined, but received wisdom in the mid-eighteenth century held that it could not profitably be carried more than about 15 miles from its source or from navigable water. The Portuguese traveller Don Manuel Gonzales remarked in 1730 that in Monmouth there were fires 'in the meanest cottage' because coal was so cheap. In the Shropshire coalfield it was so slightly valued that it was rarely recorded in probate inventories. The most significant effect of coal mining in 1700 was that it enabled London to enjoy cheap energy. Most overseas visitors the capital were unaccustomed to coal and smoke, and left London with vivid impressions of their effects. Gonzalez listed characteristic English smells: tar at Wapping, herring curing at Yarmouth, and smoke in London. Pehr Kalm found that smoke-induced London fog made him ill. The fashionable physician and philanthropist Dr John Radcliffe lived in Bloomsbury Square, and spent £88 8*s*. 4*d*. on coal out of household expenses of £1,503 in the year ending Lady Day 1710.

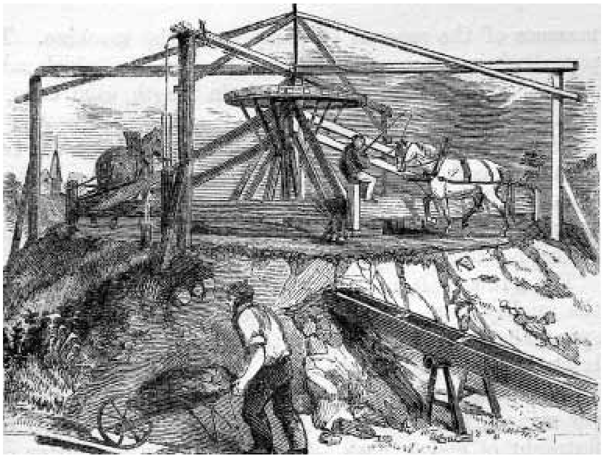
There are statistical records of the import of coal to London from 1700 onwards. The total received in that year was almost 430,000 tons, which increased threefold to almost 1,290,000 tons in 1800, and to more than 3,550,000 tons in the next fifty years. Almost all of London's coal came by sea from the North East, a trade which had began, on a large scale, in the sixteenth century. By contrast, the quantities carried to London by canal were never large – the peak was 72,000 tons in 1844 – but from 1845 deliveries by rail were recorded, which exceeded a million tons in 1855, two million tons in 1864 and three million tons in 1867, the first year in which carriage by rail exceeded that by sea, and totalled almost 4,450,000 tons in 1871. Coal from the North East was also carried to ports on the east coast and along the south coast as far west as Devon, as well as to the limits of navigation on rivers.

Diminishing supplies from heathlands and woodlands, and the incremental improvement of transport systems, led people to believe that by the 1790s coal had become the principal fuel in most parts of the country. That decade saw a substantial increase in coal output, made possible by the installation of steam winding engines at collieries and the opening of canals. Arthur Young observed that in the 1770s Essex farmers burned little else but wood, but that by 1813 coal was 'everywhere gaining ground upon wood'. French industrial spies in 1785 concluded that the combination of coal and the growing canal network, together with the absence of internal customs, gave Britain great commercial advantages, while William Blakey in 1791 thought that Birmingham had become 'the greatest magazine of hardware on earth', because fuel had 'given life to numbers of Manufactories, while many die upon the continent for want of firing'. In 1793 Lord Torrington, travelling towards Coalbrookdale, fantasised about what a man of the seventeenth century would make of contemporary England, and concluded that he would regret the disappearance of tapestry hangings and woodlands, that he would admire canals and new roads, and that coals would offend both his smell and his sight.

Between the mid-seventeenth century and 1800 the production of coal in Britain – still mainly in the north-east of England – had risen sixty-fold. Whereas the real cost of other fuels such as firewood had increased substantially over this period, the price of coal in London was more or less static, and fell in the coalfields. As we shall see in Chapter 6, by the end of the eighteenth century Britain was producing more coal than anywhere else in the world, and its low price – particularly in the coalfields and along the new transport arteries – became an increasingly important factor in stimulating the development of industry. Coal was set to become the principal fuel of industrialisation.

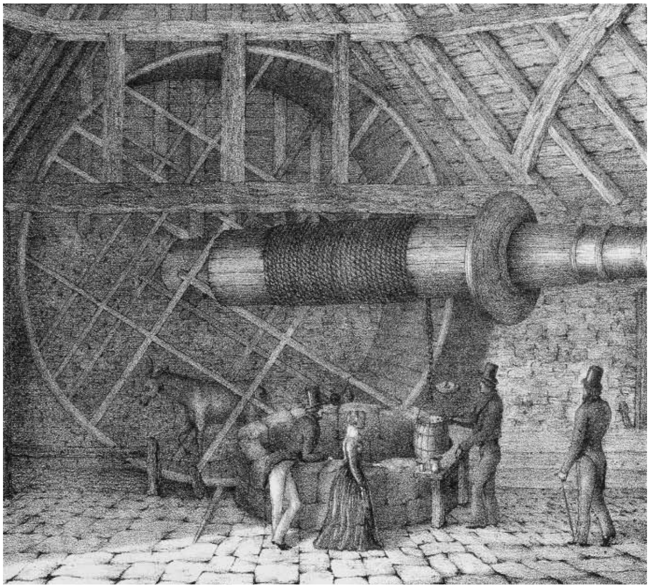
The enduring importance of muscle power, water and wind

A fundamental innovation of the industrial revolution was to be the use of heat energy to create mechanical power that could be applied to do useful work. In 1700 this had been impossible. Instead, it was human energy that wound minerals from many pits, and raised heavy loads at ports. The treadwheel crane preserved at Harwich was constructed in the naval dockyard in 1667, and the 'great crane' erected in 1735 in the Mud



Horses working machinery associated with the extraction and processing of clay for brick making could be observed on the edges of most English towns in the mid-nineteenth century. This 'wash-mill' is a large installation, operated by two horses turning a 'gin'. The man with the barrow appears to be taking prepared clay to brickmakers.

A much smaller and more common machine used in brick making was the portable clay mill, produced by many market-town foundries, that could be operated by a single horse. This view dates from 1888.



'Interior of the Well House, Carisbrooke Castle, Isle of Wight', 1850s. This working donkey wheel, whose operations are watched by thousands of visitors every year, is a well-known example of animal power. It was installed in the late sixteenth century above a well 161 feet (49 m) deep. The wooden wheel has a diameter of 15 ft 6 ins (4.7 m) with the four main spokes of each set arranged tangentially about the shaft, with subsidiary framing at right angles to these main spokes.

The tower mill at Kempsey, three miles south of Worcester was recorded in the early 1850s by the pioneer photographer Benjamin Brecknell Turner. It had a masonry tower, rebuilt after a fire in 1802 caused when a high wind caused the sails to rotate so rapidly that they generated too much friction and heat. The wooden cap could be turned by the wheel above the door and the pulley rope that dangles from it. The canvas sails were set for use. The mill was demolished in the 1870s, but the brick cottages to the right still stand.

Wilton Mill, near Marlborough in Wiltshire, dates from 1821, and is one of the best examples of the tower mills that were built during the Napoleonic Wars and the years that followed. The top and the shuttered sails are turned into the wind by a fan-tail, the invention of Edmund Lee in 1745. The mill has been restored and retains much of its original machinery.

The differences between tower mills (such as at Wilton) and post mills can be seen in this post mill built at Danzey Green, Warwickshire, about 1820, and rebuilt in 1969 at the Avoncroft Museum of Historic Buildings. The whole of this mill is rotated into the wind (or 'luffed') by the luffing pole, just visible to the rear. Flour is regularly ground on the single set of stones.

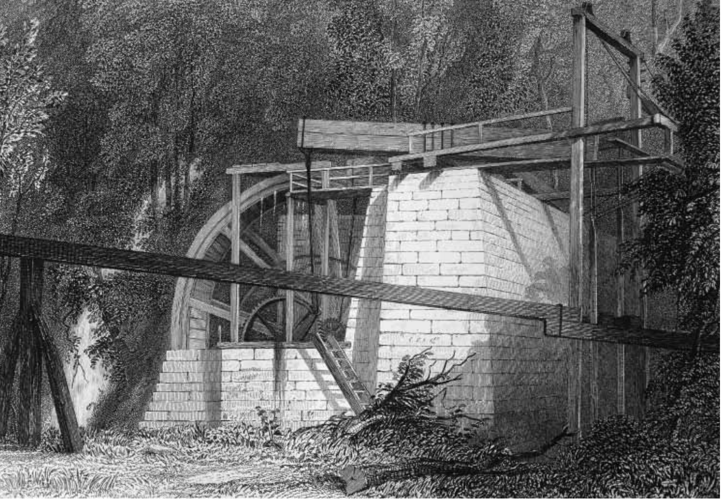
Dock by John Padmore, builder of the railway from Combe Down to Bath, was one of the sights of Bristol. The prison treadmill, invented by Sir William Cubitt, was first used at Bury St Edmunds in 1819. By 1850 such mills were installed in about 30 gaols, including Beaumaris in North Wales, where a wheel of 1829 is preserved. Treadwheels were also used to raise water from deep wells in the chalk country, as at Carisbrooke Castle, and Catherington, original site of the wheel now in the Weald & Downland Museum.

Throughout the period covered here animal power was used for a wide range of manufacturing purposes. Edge-runners, large wheels shaped from stone, running in circular tracks and powered by horses or donkeys, crushed cider apples and metallic ores and broke flax, and in Ireland pounded coal into dust to be formed into balls for domestic heating. Gins raised coal and ores from mines. Some were large: the apparatus installed at Walker Colliery on Tyneside in 1763 to raise coal from a 600-foot shaft was powered by eight horses. Horse-powered winding installations were still being constructed in the 1840s, such as that built for Langton Colliery, Nottinghamshire, now at Wollaton Hall. Horse mills were cheap to build and were widely used in the Scottish Highlands. Indeed, animal power made possible the initial development of mechanised textile-manufacturing processes. In the late eighteenth century a horse could work carding machinery supplying four spinners, while many workshops filled with spinning jennies were horse-powered. Horses also powered clay preparation machinery in suburban brickfields and threshing machinery on farms. Most market-town foundries made horse gins, and there were probably more in use in the 1860s than at any time previously.

Windmills of many shapes and sizes worked all over the British Isles in 1700 and in 1870. They were employed principally to grind grain, but they also drained wetlands and were used in smaller numbers for other purposes. In 1796, for instance, Charles Hatchet watched windmills pumping brine into evaporating pans at Northwich. Unsurprisingly, windmills were most numerous where winds were persistent and where fertile land yielded abundant crops, such as in the Fylde of Lancashire, Lincolnshire, and the coastal areas of Kent. County maps of the early nineteenth century mark 212 windmills in Essex, 79 in Kent and 66 in Sussex, while 250 have been counted on the first edition Ordnance Survey maps for Ireland, which were completed in the 1840s. Tower mills were fixed and are readily identified, but post mills could easily be moved, as evidenced by the two at Greasley in the Erewash Valley in the 1850s, one transported from Hucknall in the 1830s and the other from Nottingham in 1843.

The most eminent engineers of the late eighteenth century were involved in improving the efficiency of windmills. John Smeaton built a five-sail smock mill at Newcastle-upon-Tyne and received the Royal Society's Copley Medal in 1759 for research that included 'curious experiments concerning … windmill sails'; his treatise on milling was published posthumously and ran to several editions. Andrew Meikle, a Scottish engineer who was 'descended from a line of ingenious mechanics', invented the shuttered sail in 1772, while Sir William Cubitt in 1807 replaced canvas sails with self-regulating sails with lever-operated shutters.

The most significant application of wind power was the construction during the Napoleonic Wars and the years that followed of tower mills, which increased capacity for grinding grain during a period of rapid population growth. Of 28 dated tower mills identified by Falconer in 1980, 19 were constructed between 1780 and 1830, including those at Fulwell, Co. Durham; Lytham, Lancashire; Polegate, Sussex; and Wilton near Marlborough. Tower mills powering up to four sets of stones were built in considerable numbers in Ireland between 1770 and 1815. The best-known surviving example, 118 feet 6 inches (24.29 m) high and built between 1790 and 1810, is at the Guinness Brewery in Dublin. Some mighty tower mills were destroyed by the winds they were intended to harness. Others were commercial failures, including the 55-foot (17.76 m) tower built in 1796 by the millwright Joseph Jackson at Newport, Shropshire, which was sold in 1802 for less than half the cost of erection and soon demolished. By contrast there is the Union Mill at Cranbrook, Kent, a four-storey smock mill 72 feet (21.95 m) high on a three-storey octagonal brick base. Constructed by the



⮝ A waterwheel that appears to be driving by means of a crank a series of rods that probably powered pumps at a mine at some distance.
BY COURTESY OF IRONBRIDGE GORGE MUSEUM

⮟ This waterwheel powered the bellows of three chafery hearths in one of the forges worked by the Hanbury family at Pontypool. In 1754 the Swedish industrial spy R. R. Angerstein, whose drawing this is, was impressed by the water supply system, remarking that 'the water driving the wheels flows out of the bottom of the pond through a pipe which then bends upwards by the wheel and takes the water to the same level as that in the mill pond. The water then flows out on to the undershot wheel paddles.' By this arrangement the wheels could be kept going as long as there was water in the pond.
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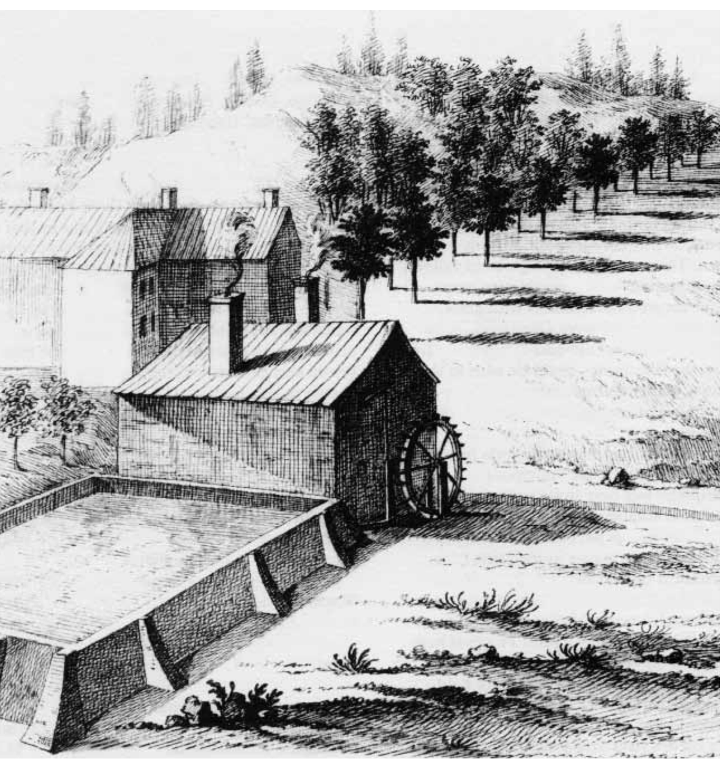
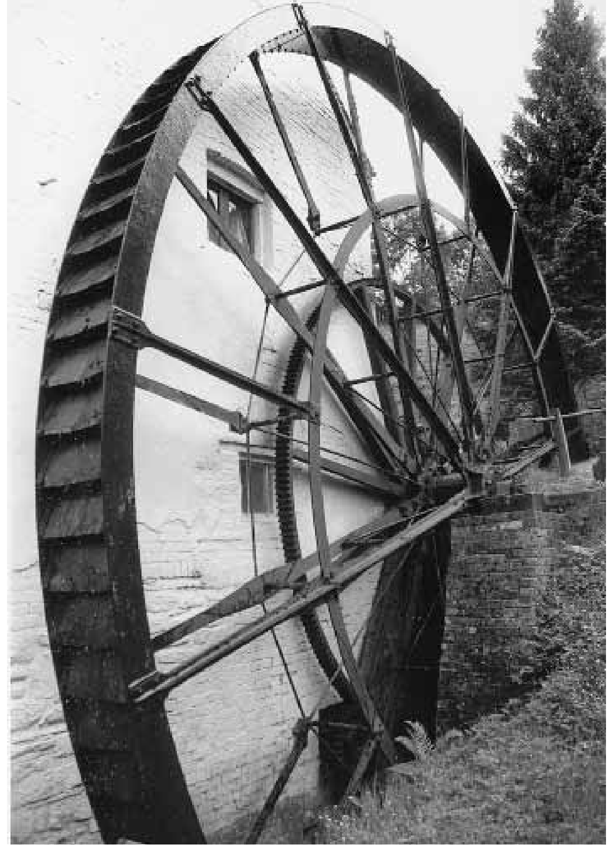




⮝ The unconventional wheel that provides power for milling grain at Daniels Mill, Eardington, near Bridgnorth. There was a mill on this site from the fifteenth century, powered by a short stream that flows into the Severn. This wheel, 38 ft in diameter with a cast-iron hub and wrought-iron buckets probably dates from a rebuilding of the mill in 1854–55. Between the wheel and the mill wall is the wallower which transmits power to a horizontal shaft that drives three sets of stones.

⮟ The waterwheel at Midleton, Co. Cork, where the multi-storey building in the background was constructed as a woollen mill in 1796. It was never used for that purpose but was adapted as a distillery from 1825. The wheel is 16 ft wide and 19 ft in diameter.

millwright James Humphrey in 1814 at a cost of more than £3,500, and equipped with Cubitt's patent sails, it was reputedly the most powerful windmill in England and still works.

The power that could be gained from water was, ultimately, of much greater significance than wind. Water power had been in use for centuries throughout the British Isles, and in many areas a map of mills working in 1870 might not be very different from one of 1700 or even 1450. Water power made possible the take-off of coke-fired iron smelting in the 1750s, of silk throwing from 1721, of cotton spinning from 1771. It remained the principal source of power for manufacturing in 1800. That was no longer so by 1870, but many significant factories utilised water power systems inherited from previous generations.

The ways in which water power was generated varied between regions. Horizontal or 'Norse' wheels were commonly used in the West Highlands, Shetland, the Isle of Man and parts of Ireland. On the slow-moving rivers of lowland England, on the other hand, most mills used broad undershot waterwheels, while in the upland zone millwrights exploited the power of small, fast-flowing streams by erecting overshot wheels, some of substantial diameter. The amount of power that a mill could generate over time could be increased by the construction of additional dams, pools and leats in order to supply either a greater or a more consistent supply of water. Richard Arkwright used soughs that drained mines and pools created by damming the Bonsall Brook to provide water to power his cotton mills at Cromford, and the completion of the woollen mill at King's Stanley, Gloucestershire, in 1812–14, for example, was preceded by the excavation of a five-acre mill pool, the diversion of the river Frome, and the rationalisation of the ownership of adjacent plots. Similar investment went into other sites used for textile manufacturing or iron working. As well as streams and rivers, there were mills on most estuaries, powered by the tide. One of the most notable of these was Three Mills at Bromley-by-Bow, where there were four 20-foot (6.16 m) undershot wheels at the House Mill, rebuilt after a fire in 1802, and three at the Clock Mill of 1817, while the site of the third was adapted for distilling gin from 1872.

Steam power was successfully applied to grinding grain from the 1780s, but in the late eighteenth and early nineteenth centuries there is plenty of evidence of investment throughout the British Isles in water corn mills, including new buildings, new pools and leats, iron wheels and gearing. In 1780 Arthur Young was impressed by the corn mill at Slane on the river Boyne in Co. Meath, which had been constructed in 1763–66: 'a very large and handsome edifice such as no mill I have seen in England can be compared with'. The five-storey stone building survives today, 138 feet long and 54 feet wide (41.3 × 16.6 m), fed with water by a stone-lined leat. The mill drew in grain from a radius of ten miles, and produced up to 17,000 barrels *per annum* of flour, which was despatched by barge and by cart to Dublin and Newry. Slane Mill was eclipsed in size by Lee Mill in Cork, where six- and seven-storey buildings were constructed in 1825–31, with waterwheels made by the local Vulcan Ironworks and mill work by Peele, Williams & Peele of Manchester. Some 50 miles south of Dublin, the mill at Milford near Carlow, built in 1790, was much admired in 1860, after the installation of new machinery by William Fairbairn.

In regions where there was potential for manufacturing most of the sites suitable for generating power had been occupied by mills for many centuries, so eighteenth-century entrepreneurs seeking to use water power could only use those sites which happened to be on the market. At some places water power was abundant. At Ludlow, for example, a mill on the river Corve and six on the river Teme were used for grinding grain, dressing leather, making paper, blowing the cupola of a foundry, fulling woollen cloth, and throwing silk. The water that cascaded through the Greenfield Valley near Holywell in North Wales was employed by cotton-spinning mills, copper works, fulling mills and snuff mills. When Arthur Young visited Blarney, Co. Cork, in 1780 he found a textile printing works, a woollen manufactory, a leather-dressing works and a paper mill, as well as associated activities, such as handloom weaving, that did not require power. More than five miles of leats were dug between 1794 and 1809 at Ballincollig on the river Lee near Cork, providing power for twelve

< The Upper Mill in the Cromford Mill complex built by Richard Arkwright from 1771 was originally a five-storey structure of local gritstone, extending over 11 bays, and was extended by four bays in the late 1780s. The two top storeys were removed after a fire in 1929. This view shows the tail race, from which water, having entered the mill across an aqueduct, originally of wood but from 1821 of cast iron, and passed over the mill's wheels, flows into the mill yard. (See also the site plan on page 395.)

PHOTOGRAPH: CARNEGIE

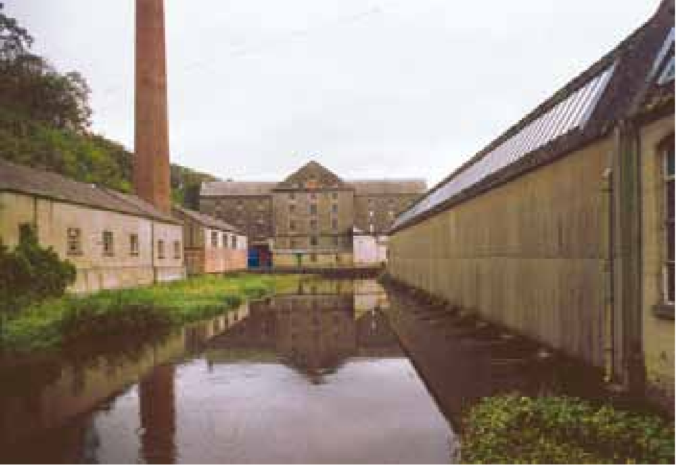
<< Once the water had passed out of the Upper Mill into the mill yard it was directed towards the Lower Mill, a 16-bay, six-storey building constructed from 1776, most of which was destroyed by fire. From about 1820 part of the flow was diverted by this weir into a channel that fed the nearby Cromford Canal.

< The so-called 'Bear Pit' in Cromford village was part of the system by which Richard Arkwright controlled the flow of water to his mills. From this stone-lined pit some water flowed to power Cromford Mills, but some was diverted to Greyhound Pool, a reservoir in the centre of Cromford village. Water was diverted there at weekends so that there was a sufficient supply for the mills on Monday mornings.

PHOTOGRAPHS: CARNEGIE

< New Lanark was notable not only as the scene of the social experiments of Robert Owen, but also as one of the most abundant sources of water power in the British Isles. The mills stood just downstream from the Falls of Clyde (the subject of one of the most memorable paintings of J. M. W. Turner), and water was fed to the waterwheels by a complex system of lades. This view shows the main lade; mill numbers 1–3 are on the left. (See also the map and photographs on pages 598–9.)

PHOTOGRAPH: CARNEGIE



The large corn mills built in Ireland in the late eighteenth century were regarded as examples for the rest of the world. The most celebrated was Slane Mill, built between 1763 and 1766 under the direction of David Jebb, who had supervised construction work on the River Boyne Navigation. It was a five-storey stone structure, reputedly the largest corn mill in Ireland, that could grind 15 tons of grain per day. It operated until the 1870s but could not withstand competition from roller mills. About 1918 it was adapted to scutch flax, and from 1935 it was used for weaving cloth for flour bags. In recent years it has been adapted as an hotel.

The *Lady Isabella* at Laxey on the Isle of Man is perhaps the most celebrated waterwheel in the British Isles and was always intended to be so. The 72 ft 6 in. (22 m) diameter pitchback wheel was installed in 1854 and operated pump rods that were carried over a viaduct of 34 stone arches to nearby lead mines. The wheel was designed as an eye-catching feature of the landscape that would attract visitors, who, many decades after the lead mines have ceased to work, still flock to see it and make use of the surrounding tea shops.

Part of the Three Mills complex on the river Lea at Bromley-by-Bow in east London. There were indeed three mills on the site in the Middle Ages, but only two by 1600. The ten-bay House Mill in its present form dates from 1776, and is a tide mill where sea and river water was trapped at high tide, and then used to turn the mill's four wheels, which operated 12 sets of mill stones. It ceased working in 1941. The adjacent Clock Mill, shown in this picture, dates from 1817, although the oast houses are probably earlier. It was associated with the trade in gin from the seventeenth century. Distilling ceased after bomb damage during the Second World War, but the buildings were used for bottling and storage until the 1980s. The Clock Mill has been adapted as film and television studios, while the House Mill is being restored by the River Lea Tidal Mill Trust.

The Melincourt Brook, a tributary of the river Neath, cascades down a fall of some 80 ft (24 m) near Resolven, and was recorded by many artists, including J. M. W. Turner. Below the falls are some buildings of one of the pre-industrial revolution ironworks in South Wales, a blast furnace that operated for about 100 years from 1708, and was out of use by 1819 when Thomas Hornor visited the site. Its bellows were powered by the overshot waterwheel shown in the picture, of unknown but considerable diameter. It was fed with water taken from a point higher up the stream by an aqueduct supported on high stone piers.

THOMAS HORNOR, 'TOUR THROUGH THE VALES OF GLAMORGAN', 1819

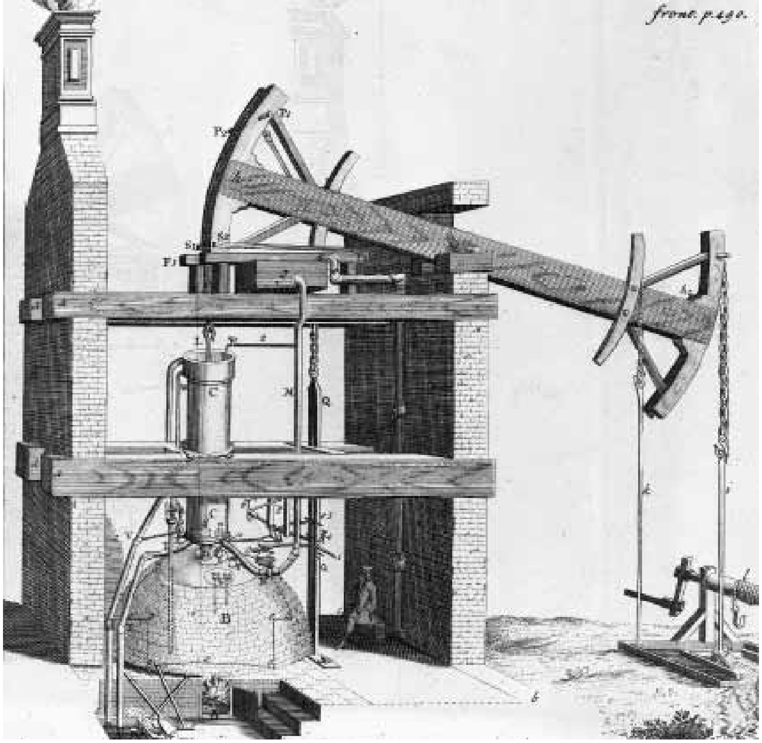
pairs of gunpowder mills. There were similar concentrations of water-powered manufacturing along the river Derwent in Derby, along the river Don and its tributaries which powered numerous grinding shops in the Sheffield area, in Carlisle and Galway, and around Edinburgh where the Water of Leith in the 1790s powered 71 mills.

Leading engineers concerned themselves with water power and its improvement. John Smeaton designed millwork for a fulling mill at Colchester in 1761, the blast furnaces at Carron near Falkirk from 1764, a forge and slitting mill at Kilnhurst in 1765, powder mills at Waltham Abbey, a paper mill at Thornton (Fife), and machinery at the Wanlockhead lead mine. He used wrought-iron waterwheel buckets and cast-iron gearing from the 1770s, and his posthumous treatise on millwork covered water as well as wind power. Thomas Telford wrote a paper on mills and collaborated with the ironfounder William Hazledine, who sprang from a mill-wrighting family and provided machinery for many watermills. William Fairbairn, an engineer of the following generation, introduced ventilated waterwheel buckets in 1828–29 and demonstrated the efficiency of the breastshot wheel. His treatise on mills ran to four editions between 1861 and 1878. Benôit Fourneyron from Le Creusot demonstrated an effective water turbine in 1827, and turbines were subsequently manufactured by British engineering companies. Williamson Bros (later Gilbert Gilkes & Gordon) of Canal Head, Kendal, established in 1853, made their first turbine in 1856 and employed 80 people by 1861. Turbines had replaced waterwheels at many mills by 1870.

Some celebrated wheels are evidence of the significance of water power in the early and mid-nineteenth century. One of the sights of South Wales was *Aeolus*, the 50-foot (15.4 m) waterwheel, designed by Watkin George, which powered the blowing cylinders of the blast furnaces at Cyfarthfa. In 1827 William Fairbairn designed two wheels 50 feet in diameter and 10 feet (3.1 m) wide, for the Catrine textile mills in Ayrshire which were equally famous and worked until the 1940s. The cotton mill at Egerton near Bolton, taken over in 1829 by the brothers Ashworth, was well known for its 62-foot (19 m) waterwheel, whose admiring spectators were invited to sign a visitors' book. The basement in which five waterwheels provided power for the machines at Stanley Mill, Gloucestershire, was intended, like the forehearth areas of some eighteenth-century French blast furnaces, to provide a sublime vision for spectators. The most spectacular British waterwheel was the 72 foot 6 inch (27.5 m) diameter *Lady Isabella*, built in 1854 to drain the metalliferous mines at Laxey in the Isle of Man. It was designed as an eye-catching monument, and attracted tearooms and guesthouses.

A revolution in power: the development of steam

In 1712 a steam engine was erected by Thomas Newcomen to pump water from coal mines at Coneygre near Dudley, the first economically significant application of steam power. Although Newcomen is one of the most famous of engineers, many aspects of his career are obscure. It is known that he was an ironmonger working in Dartmouth, and understood the need to drain mines in the west of England. He regularly purchased iron from forges in the Stour Valley, and had other links with the West Midlands through his Baptist faith. The 'atmospheric' engine that was to bear the name of Newcomen had a beam with a brass cylinder at one end and chains attaching it to a pump at the other. Steam at atmospheric pressure was admitted to the cylinder and then condensed by a water jet, allowing the piston in the cylinder to be forced down by atmospheric pressure, before being raised again by the force of the pump rod. The engine was the first self-acting machine apart from the clock, and employed no parts that were not comfortably within the manufacturing capacity of contemporary craftsmen. Little is known of the engine's evolution before 1712, but it is likely that experimental engines were constructed. *The Compleat Collier*, written in the North East and published four years before the Coneygre engine was built, makes the tantalising comment that 'there is one invention of drawing water by fire which we hear of'. The Newcomen engine was deemed to be covered



This engraving of 'The engine to raise water by Fire' was published in the *Universal Magazine* in September 1747, more than three decades after a Newcomen engine successfully began to pump water from a mine near Dudley in 1712. The Newcomen engine was thermally inefficient, but its impact can easily be underestimated. About 100 were working in England by 1733, and doubtless many more by 1747, and this was only one of several images that celebrated one of the most influential inventions of the early eighteenth century. In this example the cylinder is mounted above the boiler, from which a flue extends through the wall of the engine house. The beam is balanced on the opposite wall, and attached to it, outside the engine house, are rods operating pumps in a mine.

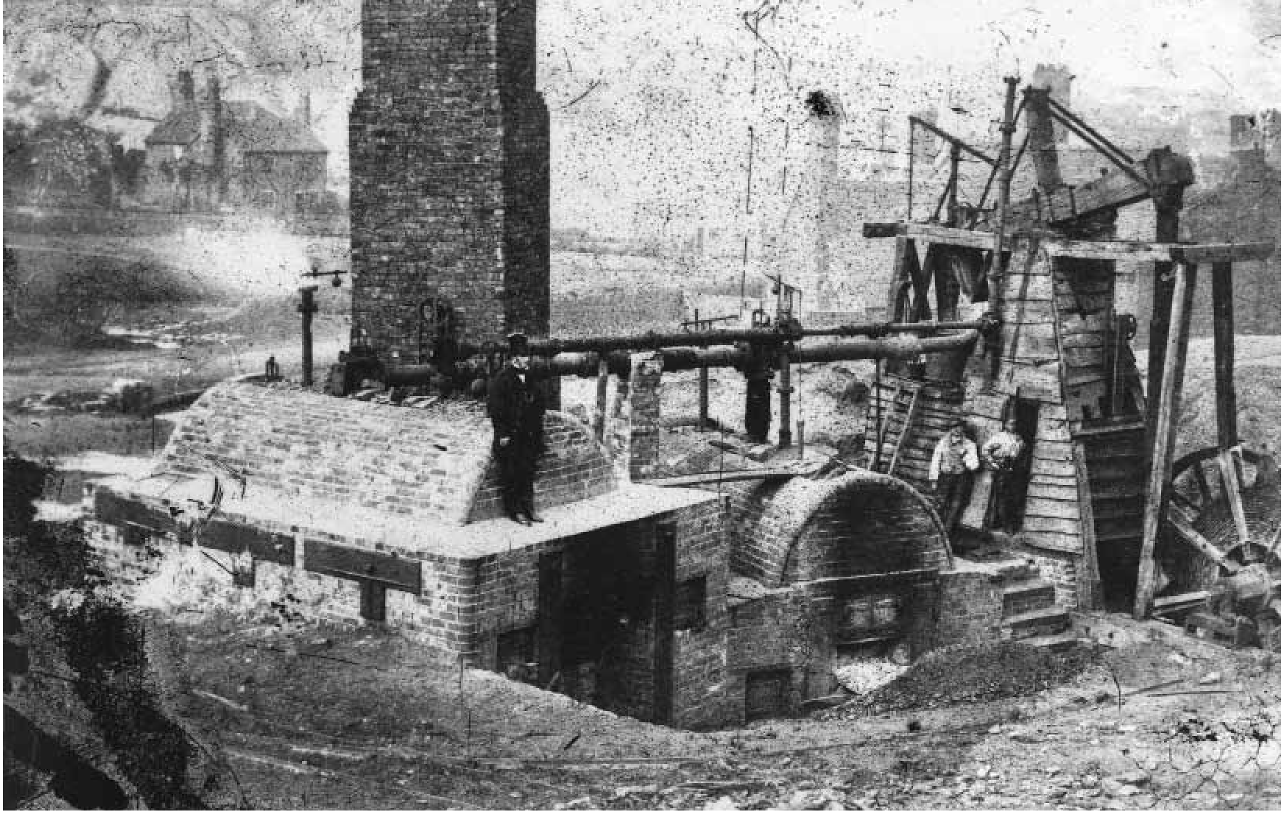
The replica Newcomen engine house at the Black Country Museum, showing the beam, balanced on a bob wall and attached to pump rods extending into the shafts of a mine.

by the patent granted in 1698 to Thomas Savery and controlled after his death until its expiration in 1733 by a consortium called 'the Proprietors of the Invention for Raising Water by Fire'.

The Newcomen engine was adopted quickly. There were more than a hundred in Britain by 1733, with examples in every major coalfield and the principal ore-mining regions. The first in Ireland was installed in the Kilkenny coalfield in 1740. Its inefficiency was of little consequence at collieries, where the engine's boilers could be fired with coal that was otherwise unsaleable, although there was more incentive to reduce its fuel consumption at ore mines, to which coal might well have to be transported over long distances. Nevertheless a Cornish miner reflected that 'Mr Newcomen's invention of the fire engine enabled us to sink our mines to twice the depth we could formerly do by any other machinery', and as many as 70 engines might have been working in Cornwall by the 1770s. Some incremental improvements were doubtless made to the engine in the mid-eighteenth century, such as those carried out by John Smeaton at Chacewater in 1775, but it is difficult to assess either changes in technology or the number of engines built between 1733 and 1776. Their significance was recognised in 1747 by a Frenchman who wrote,

> England has more than any other country of those machines so useful to the state which readily multiply men by lessening their work; and by means of which one man can execute what would take up to thirty without such assistance.

Newcomen engines were used for pumping water rather than powering machinery. Thus, from

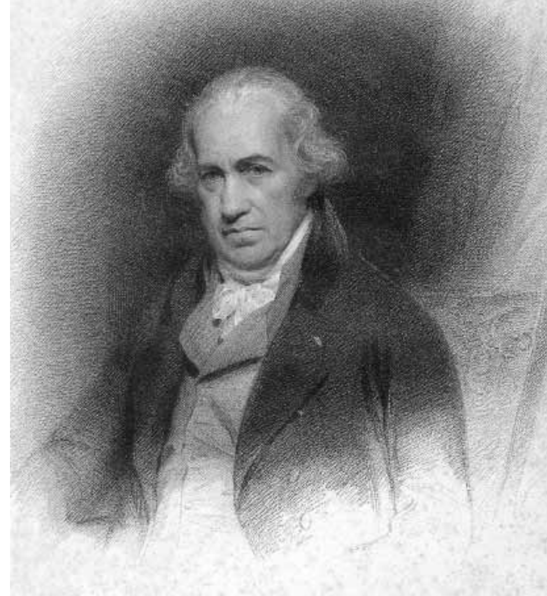


The construction of Newcomen engines continued after the introduction of the much more efficient Watt engines in the 1770s and well into the nineteenth century. With the use of cranks Newcomen engines could be adapted to provide rotative motion, and many of the hundreds of engines built in the 1790s to wind coal from pits were of the Newcomen type. They included this example built by the Coalbrookdale Company. On the right and in the centre are boilers supplying steam to a small engine whose workings are protected from the elements by a wooden shed rather than an engine house. The beam operates a drum which wound coal and probably men from the pit in buckets attached to a three-link wrought-iron chain. Ancient steam engines of several types were still working in the Coalbrookdale area in the late nineteenth century and attracted considerable interest from visiting engineers, and, in this instance, from a pioneer photographer.

September 1743 a Newcomen engine was employed at Coalbrookdale to pump water that had passed over the waterwheels of the ironworks in which Abraham Darby II was the principal partner, back up to the topmost pool in the system, an innovation which for forty years enhanced the effectiveness of water-power installations and enabled the builders of blast furnaces, forges and textile mills to use steam indirectly to produce mechanical power. Applying steam power directly to machinery was to come considerably later.

The history of steam power in the last quarter of the eighteenth century is necessarily dominated by the enigmatic figure of James Watt, not simply because he was an engineer of remarkable talents, but because the archive of the Boulton & Watt partnership is voluminous and, in the absence of other documentation, is the principal source of evidence concerning their competitors. Understanding of developments is made difficult by the heroic status conferred on Watt by Victorian writers, and by the apparent impertinence of questioning aspects of the career of one who is commemorated by statues in Edinburgh, Glasgow and Birmingham and a colossal memorial in Westminster Abbey.

While working in Scotland in 1763–66 Watt developed a separate condenser for the steam engine, and secured a patent for it in 1769. In 1774, when Matthew Boulton accepted John Roebuck's share in the patent in settlement of a debt, he persuaded Watt to move to Birmingham. The following year their steam engine partnership was formalised, and Boulton used parliamentary contacts to obtain 'James Watt's Fire



➢ The enigmatic figure of James Watt, a polymath and certainly a genius, but one whose concern to defend his patents and the interests of his partners may have inhibited the development of the steam engine in the 1790s. His historical reputation has been shaped in part by the survival of his company's copious archives. Engraving by C. Picart after a drawing by W. Evans. from the painting by Sir William Peechey.
BY COURTESY OF IRONBRIDGE GORGE MUSEUM TRUST

➢ 'Mr Watt's Patent Rotative Steam Engine, as constructed by Messrs Boulton & Watt, Soho from 1787 to 1800, 10 Horse Power'. This drawing shows the essential features of the Watt rotative engine: the separate condenser, the parallel motion, the centrifugal governor and the sun-and-planet drive. This engine had the wooden beam that was usual until the development of the elliptical cast-iron beam by the Yorkshire engineer John Banks. The concept of horsepower as a means of expressing the power output of an engine was developed by James Watt.
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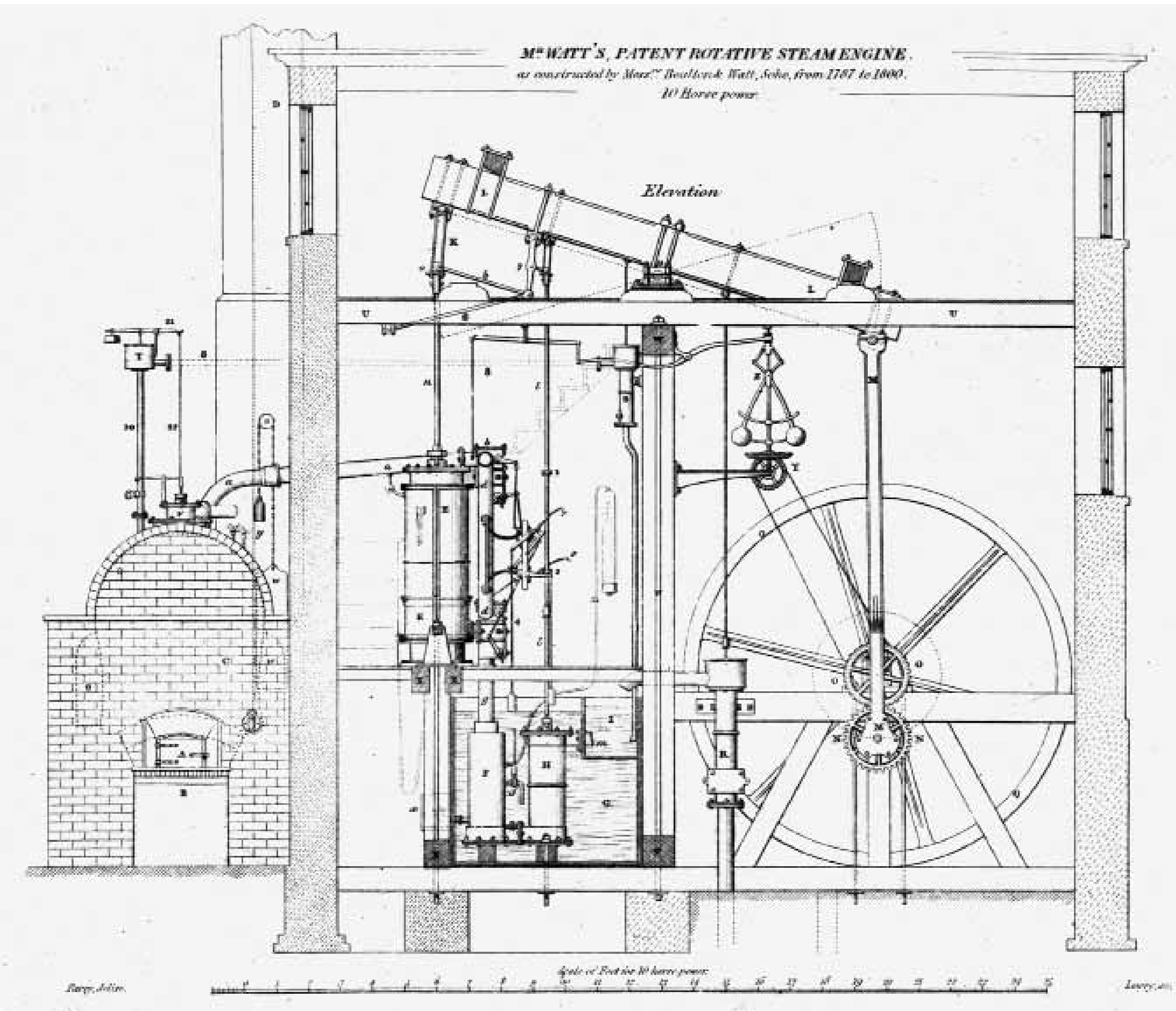
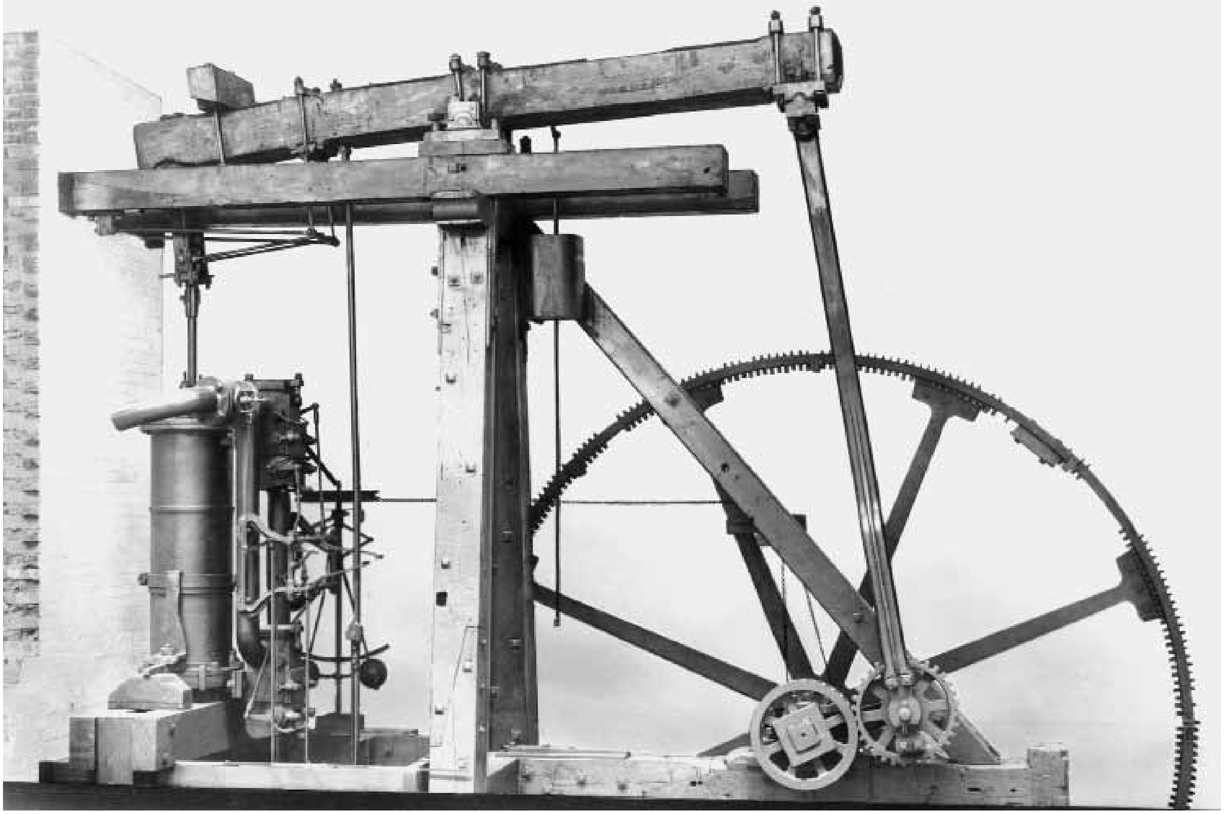




The first Boulton & Watt engines, like contemporary Newcomen engines, provided only reciprocating motion, which could be used to operate pumps but not to drive machinery. In the early 1780s Watt used the 'sun-and-planet' motion to create a rotative engine which did not infringe the crank that had been patented by James Pickard. Watt also developed in this period the double-acting engine in which steam enters the cylinder at each end, forcing the piston up or down before it was exhausted out to the condenser, and he also began to utilise the centrifugal governor which ensured that an engine operated at a constant speed. This engine, which incorporates all these features, was used from 1788 to power metal-polishing machinery at Boulton & Watt's Soho Manufactory. It survives complete and essentially unaltered and is now displayed in the Energy Hall of the Science Museum, London.

Engines Patent Act' which extended the patent for the separate condenser until 1800. The first working engines were built in 1776, draining a colliery at Tipton and operating the bellows of John Wilkinson's blast furnace at Willey. In 1778 the first of many canal pumping engines was constructed at Spon Lane on the Birmingham Canal. Interestingly, the principal payments made by most customers for Boulton & Watt engines were annual premiums, calculated on the estimated saving over the use of a Newcomen engine. A strong demand for engines with greater efficiency came from mine owners in Cornwall – where the high price of coal was a major cost factor – and much of the partners' energy was expended there.

In the early 1780s Watt developed the double-acting engine, in which steam was applied on both sides of the piston stroke, and in 1784 patented parallel motion, his means of ensuring that the piston rod of a double-acting engine remained vertical. He wrote in 1808 that, 'I am more proud of the parallel motion than of any other mechanical invention I have ever made'. Parallel motion is a mechanism of remarkable mathematical beauty, and it made possible the elliptical cast-iron beam for steam engines which was developed by the Yorkshire engineer and scientific lecturer John Banks.

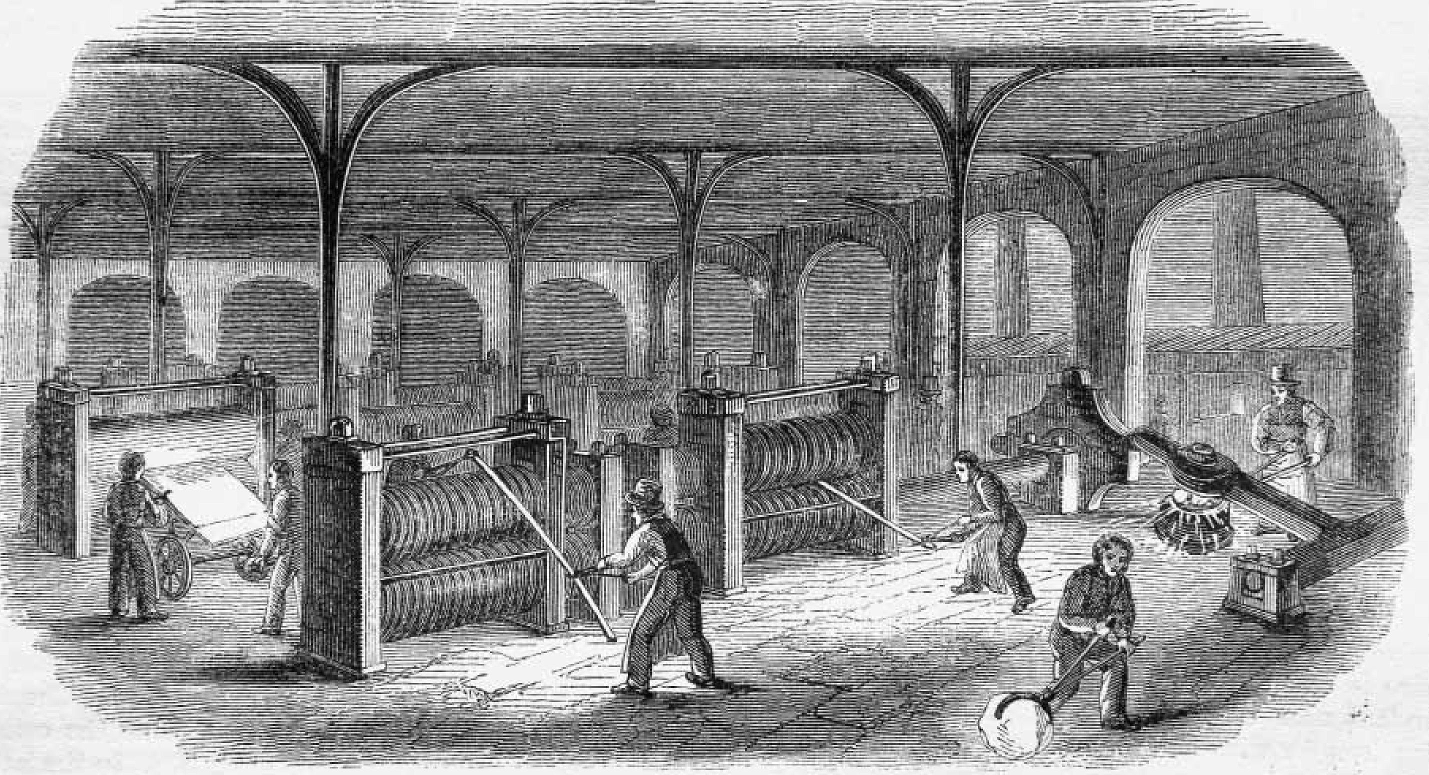
There was growing demand from entrepreneurs for a rotative engine that could wind coal up shafts, work hammers or drive rolling mills and textile machinery. The crank, the obvious means of creating rotative motion from a beam engine, had been patented in 1780 by a Birmingham engineer, James Pickard of Snow Hill, who built an engine driving a mill for grinding metals. It worked until 1879. In 1781 Watt

➢ A monument that provides evidence for the continued construction of 'atmospheric' engines after James Watt took out his patent. This Newcomen engine was installed at the colliery at Elsecar in the West Riding of Yorkshire, probably in 1787, the date on the engine house. Its original wooden beam was replaced by a cast-iron beam in 1795. It worked regularly until 1923 and could still be steamed in the early 1950s.

devised the 'sun and planet' motion which achieved the same effect without infringing Pickard's rights. The partners produced some 'sun and planet' engines until 1802, although Pickard's patent expired in 1794, after which most engines were built with cranks.

The first Watt rotative engine operated a hammer at John Wilkinson's Bradley Ironworks near Wolverhampton, where it was working by May 1783. Others had contemplated applying cranks to Newcomen engines, and many did so in the 1790s. William Reynolds wrote in 1782 that he and his father considered using a 'common fire engine' (i.e. a Newcomen engine) to work a corn mill. Richard Arkwright was the first cotton spinner to employ steam power, installing Newcomen engines which recycled the water that powered machinery at Haarlem Mill, Wirksworth, in 1780 and Shudehill Mill, Manchester, in 1783, but the first rotative Boulton & Watt engine to work a cotton mill was completed at Papplewick, Nottinghamshire, in 1785. Matthew Boulton argued in 1790 that the Watt engine was 'the most powerful machine in the world'. It was, he claimed, the most tractable and the most regular, more uniform in its action than a waterwheel, that its power could be scientifically measured, that it could be applied 'to every purpose that requires either Rotative or Reciprocating motion', citing its use in weaving ladies' garters and fine muslins, spinning silk and cotton, drawing coals, copper, salt and men from deep mines, pressing oil and sugar, grinding corn, mustard, drugs and dyewoods, making paper, draining land and pumping water to make canals navigable.

In the British Isles between 1776 and 1800 the Boulton & Watt partnership was responsible for the erection of 183 reciprocating and 268 rotative engines, a total of 451, in addition to 24 built overseas. By 1825 the company had made 1,095 engines. It was once believed that the introduction of the Boulton & Watt engine halted the construction of Newcomen engines, and that Boulton & Watt's output represented the total number of steam engines working in 1800. But in 1967 John Harris showed that this assumption was untenable, and in 1980 Robey and Kanefsky, using cautious and conservative methodology, positively identified 2,191 engines constructed within that period, the majority of which were of the Newcomen type. Contemporary estimates of the numbers of engines in particular regions – about 200 in the Shropshire coalfield alone, for example – suggest that the total should be somewhat larger, perhaps about 3,500. Only 10 of the 43 English counties lacked at least one steam engine in 1800, and in Wales and Scotland there were significant concentrations on the coalfields. There were about a dozen in Ireland, and some Irish ironfounders circumvented patent restrictions by constructing 'pirate' engines before 1800. Many engines built in the

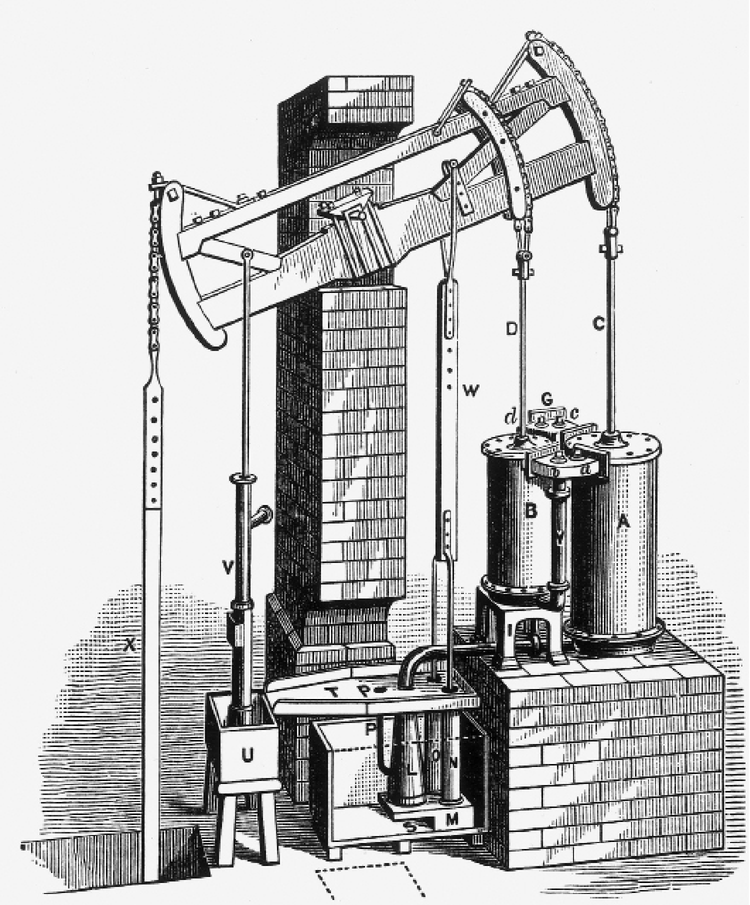


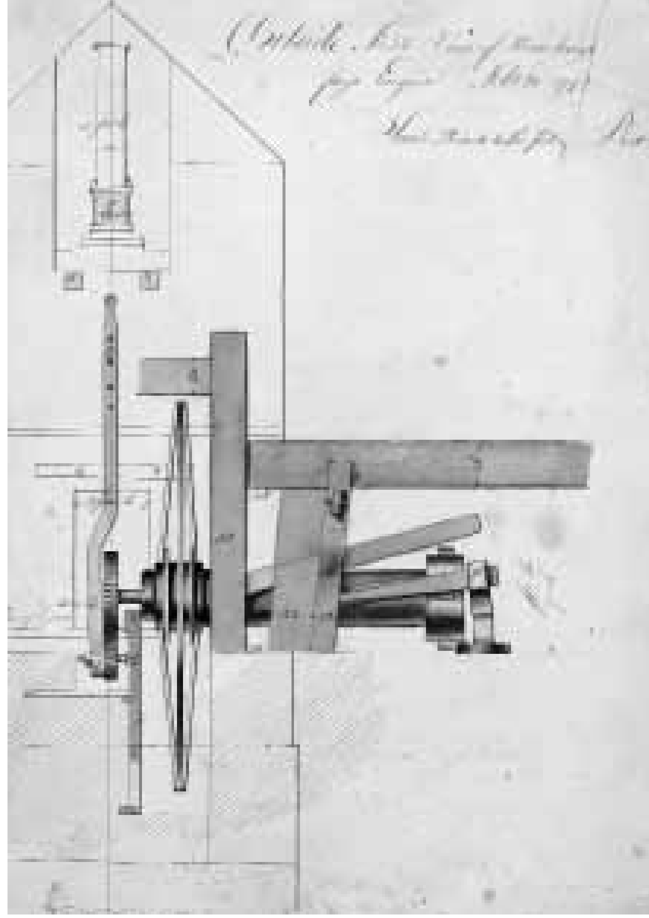
The Coalbrookdale Company's forge at Horsehay was one of the first such ironworks where the machinery was operated by steam power. Some of the first Boulton & Watt rotative engines were installed to work hammers in the forge in 1784–85, while the rolling mill was powered by an atmospheric engine adapted for rotative motion, which was replaced in 1809. This view of the forge dates from about 1840. It does not include the engine house, but steam power operated the hammer on the right, to which a worker appears to be taking a ball of iron from a puddling furnace, as well as the rolling mills, which are producing both round iron, in the centre, and iron plates to the left.
BY COURTESY OF IRONBRIDGE GORGE MUSEUM TRUST

1790s were 'common' engines, erected at coal mines where fuel was available at minimal cost. One such was that constructed in 1795 at Elsecar, now the only Newcomen engine remaining on its original site.

In the 1790s James Watt and his partners were concerned about the way their patents were being infringed by the construction of 'pirate' engines with separate condensers, for which they were paid no royalties. Neo-conservative historians have suggested that the Boulton & Watt patent retarded the high-pressure steam engine – and hence economic development – for about sixteen years, but it may be doubted whether the patent inhibited either the technological development or the proliferation of engines. Innovations were stimulated as the capacity to build machines expanded in London, Manchester, Leeds, Cornwall and elsewhere. The sketchbook of the ironmaster William Reynolds, for instance, shows that engineers in the 1790s were experimenting with configurations other than the traditional beam engine. Nevertheless Boulton & Watt did significantly obstruct the activities of some of their competitors. Informers alerted them to infringements of their patents and provided details of the activities of other companies. Boulton & Watt purchased land next to Matthew Murray's Round Foundry in Leeds in the hope of constraining its extension, made threats to his craftsmen, and contested his patents. Edward Bull devised an inverted vertical engine in which the steam cylinder was placed directly above the pump. Boulton & Watt brought legal proceedings against this in 1793, and these continued until they obtained a favourable verdict in 1799, but only after Bull had died a broken man. Nevertheless, Bull engines worked successfully at waterworks and were still being installed in the 1850s – there were at least twelve in the London area, one of which is preserved at Kew Bridge.

Jonathan Hornblower also began experiments with steam power in 1776, and in 1781 was awarded a patent





In the early 1780s Jonathan Hornblower developed a compound engine, in which steam having been used at high pressure in one cylinder was exhausted to be used at a lower pressure in another, before passing to the condenser. Hornblower was one of the engineers accused by Boulton & Watt of infringing Watt's patent for the separate condenser, which did not expire until 1800. The rightness of Hornblower's cause was affirmed by the ironmaster William Reynolds, but litigation impeded the adoption of his engines.

One of the engines that provided power for the machinery at the Horsehay forge; a drawing which shows the engine house in outline, the connecting rod linking the piston to the flywheel, and the shaft that conveyed power to the machinery. This sketch, dated 21 February 1793, appears in the Sketch Book collected by the ironmaster William Reynolds which records many of the outstanding innovations of the time.
SCIENCE MUSEUM. WILLIAM REYNOLDS SKETCH BOOK

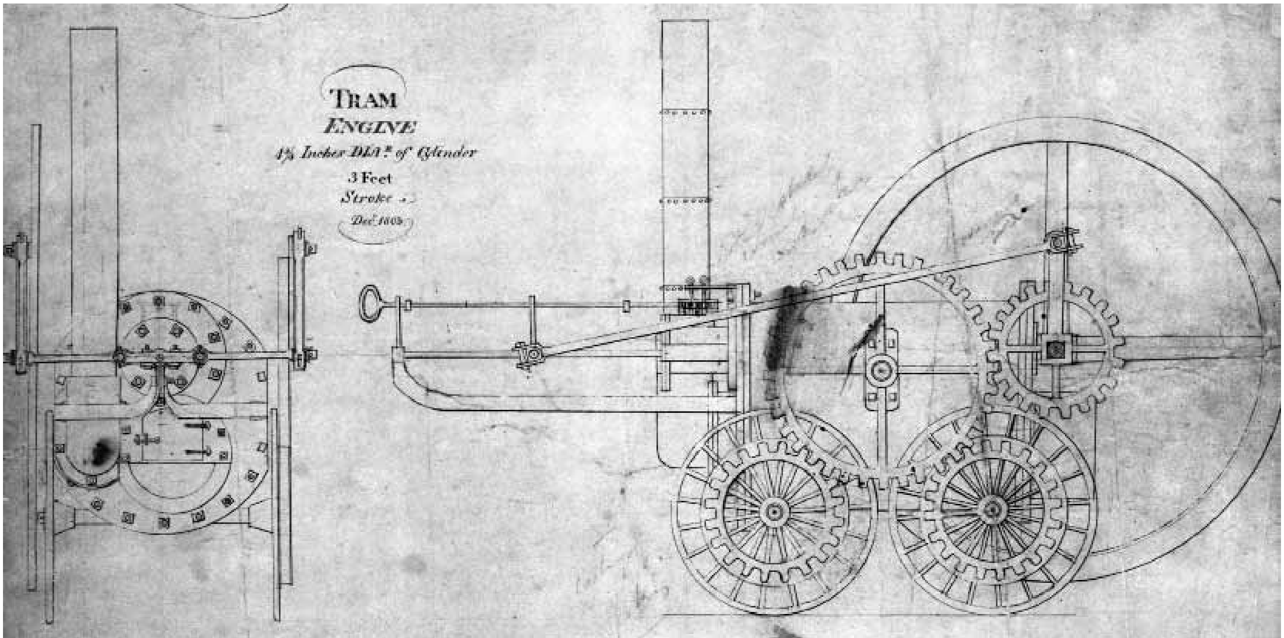
for a form of compound engine of which about a dozen were built. Hornblower, with John Winwood, a Shropshire-born Bristol ironmaster who purchased a share in his patent, argued in a memorial in 1788 that the compound principle was not an infringement of the patent protecting the separate condenser. Threats of litigation from Boulton & Watt inhibited the building of further Hornblower engines in Cornwall. A decision by the Court of the King's Bench in January 1799 found that an engine built by Jonathan Hornblower's brother, Jabez Carter Hornblower, did indeed infringe the patent, and Boulton & Watt used the ruling to enforce premium payments from users of Jonathan Hornblower's engines, although he was not concerned personally in this case. William Reynolds, who as a precocious 19-year-old in 1777 considered Watt 'one of the greatest philosophers in Europe', supported Hornblower, telling him in 1792 that his engine was much superior to that of Boulton and Watt. James Watt did not favour the use of high-pressure steam, and even after the expiry of the separate condenser patent his company, in which he was no longer an active partner, sought a bill in Parliament to deter Richard Trevithick from his experiments in this area.

The rate of engine building increased rapidly in the 1790s, and experimentation continued. In 1780 Watt wrote that 'every man who is obliged to live by his profession ought to keep the secrets of it to himself so far as is consistent with the use of them, it is only people of independent means who have a right to give away their inventions without attempting to turn them to their own advantage'. Concerned that posterity should give him his due, he asserted in a memorial in 1786 that, 'the General theory & Principles on which the perfection of Steam Engines depends, were first discovered by J. Watt at Glasgow in Scotland in the year 1763 & were the consequence of a laborious course of experiments that he made for that purpose'. He displayed elements of paranoia, but was clearly concerned that he would not spend his old age in penury, as many did including Andrew Meikle, Richard Trevithick and the brothers Fourdrinier.

James Watt senior retired in 1800 to Handsworth, where his fertile mind and dexterous hands were occupied in devising a means of replicating sculptures, but his company continued under the direction of the sons of the founders, M. R. Boulton, James Watt junior and Gregory Watt, who entered the partnership in 1794. After James Watt junior died in 1848 the firm was known as James Watt & Co.

The expiry of the separate condenser patent in 1800 stimulated innovation. The significance of the event was widely recognised. The Coalbrookdale partners promptly stopped their blast furnaces at Horsehay, between 21 September and 6 October 1800, 'to alter the engine to Watts'. The same year the Newcastle engineer Phineas Crowther patented a vertical winding engine that was used at many collieries in the North East. The grasshopper beam engine was patented by William Freemantle in 1803; then, in 1805, Matthew Murray introduced a side-lever engine that was developed to power ships; and two years later Henry

A drawing, believed to have been made by John Llewellyn of Pen-y-darren, showing Trevithick's tram engine, December 1803. Richard Trevithick was responsible for many innovations in steam technology, particularly for showing that steam could power locomotives to run on roads or railways. In 1802 he built a locomotive at Coalbrookdale designed for use on a plateway, but there is no evidence that it was used, perhaps because of the death of William Reynolds, the ironmaster, in 1803. He subsequently built a locomotive for another plateway, the 9½-mile Merthyr Tramway which served the Dowlais, Pen-y-darren and Plymouth ironworks. It had a single horizontal cylinder and an 8 ft flywheel, and displayed two innovations characteristic of subsequent steam railway locomotives: coupled wheels, and the exhausting of steam with smoke from the boiler up the chimney. The locomotive was demonstrated successfully in February 1804, but it broke the cast-iron plate rails upon which it ran. Merthyr's ironmasters continued to operate their tramways with horses, but in other parts of Britain engineers followed Trevithick's example in building locomotives, which, on stronger wrought-iron rails, achieved greater success. A model of the Pen-y-darren locomotive, built for the Welsh Industrial & Maritime Museum, is displayed at Cyfarthfa Castle.



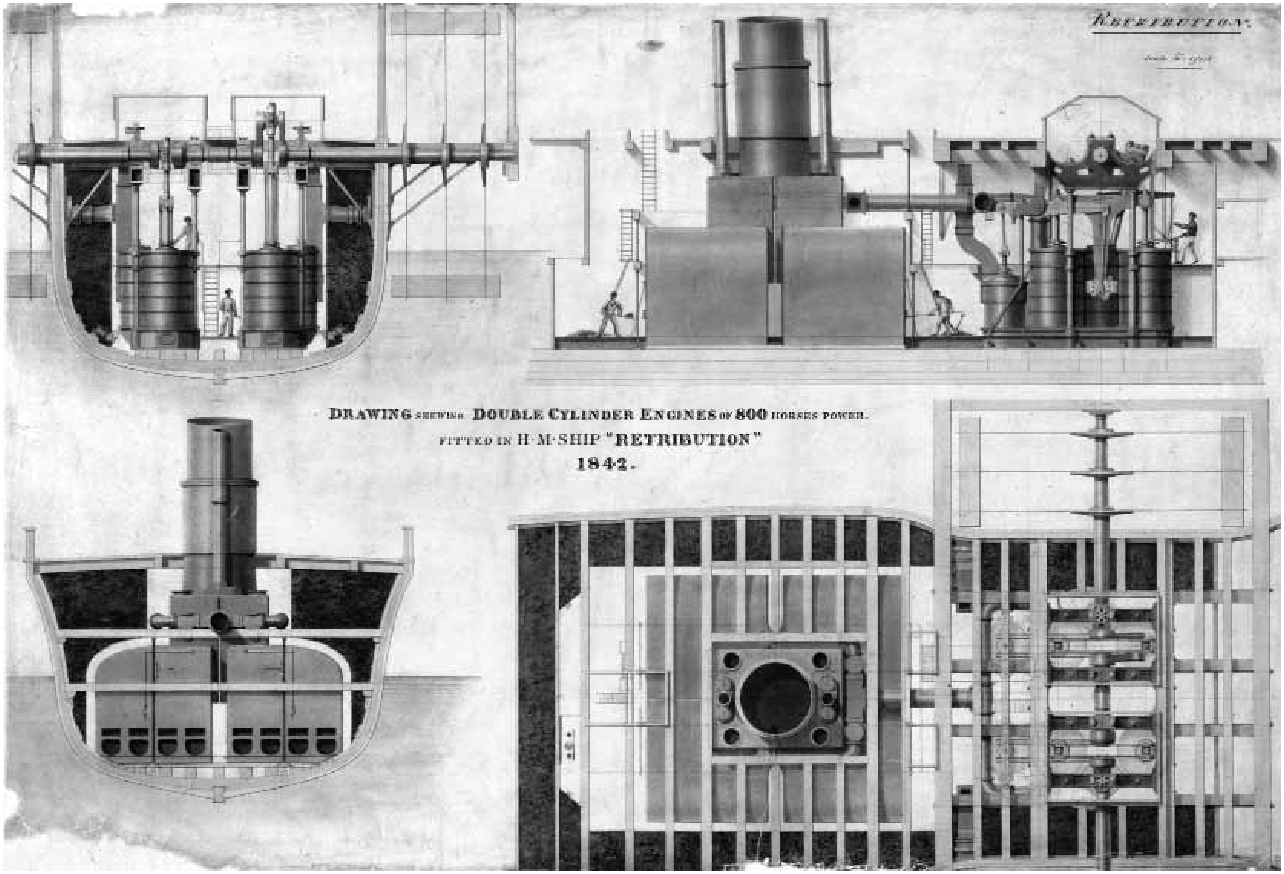
This locomotive *Puffing Billy* and its sister *Wylam Dilly* were built by William Hedley and Timothy Hackworth in 1813–14 for use on a 5 ft gauge railway at Wylam Colliery near Newcastle (see map on page 346), and provided the first practical demonstration that steam locomotives could effectively move substantial loads on rails. Investigations in 2008 by forensic mechanical engineers showed that *Puffing Billy* was the older of the two. The locomotive originally had eight wheels, but still tended to cause cast-iron rails to break. It was rebuilt with four wheels when wrought-iron rails were laid on the Wylam Railway about 1830. The two locomotives worked until 1862 when the railway was converted to standard gauge. They were photographed in that year, and *Puffing Billy* was first demonstrated at, and then sold for £200 to, the forerunner of the Science Museum, London, while *Wylam Dilly* went to Edinburgh and is now displayed in the Royal Museum. A working replica of *Puffing Billy* dating from 2006 is demonstrated at Beamish.

Maudslay patented the table engine, a configuration in which the cylinder was mounted upon a base of that shape. Arthur Woolf patented a boiler for producing high-pressure steam in 1803, and a compound engine in 1805.

Richard Trevithick was already developing a high-pressure engine by 1796 and used versions of it to power a steam carriage in 1801 and locomotives from 1802. He also designed the Cornish Engine, the first of which began work at Wheal Prosper in 1812. It proved to be an economical means of draining mines or pumping water or sewage. Many engineers made incremental improvements to it after Trevithick went to Peru in 1816 (to help introduce steam power to drain silver mines), and examples were still being built into the twentieth century.

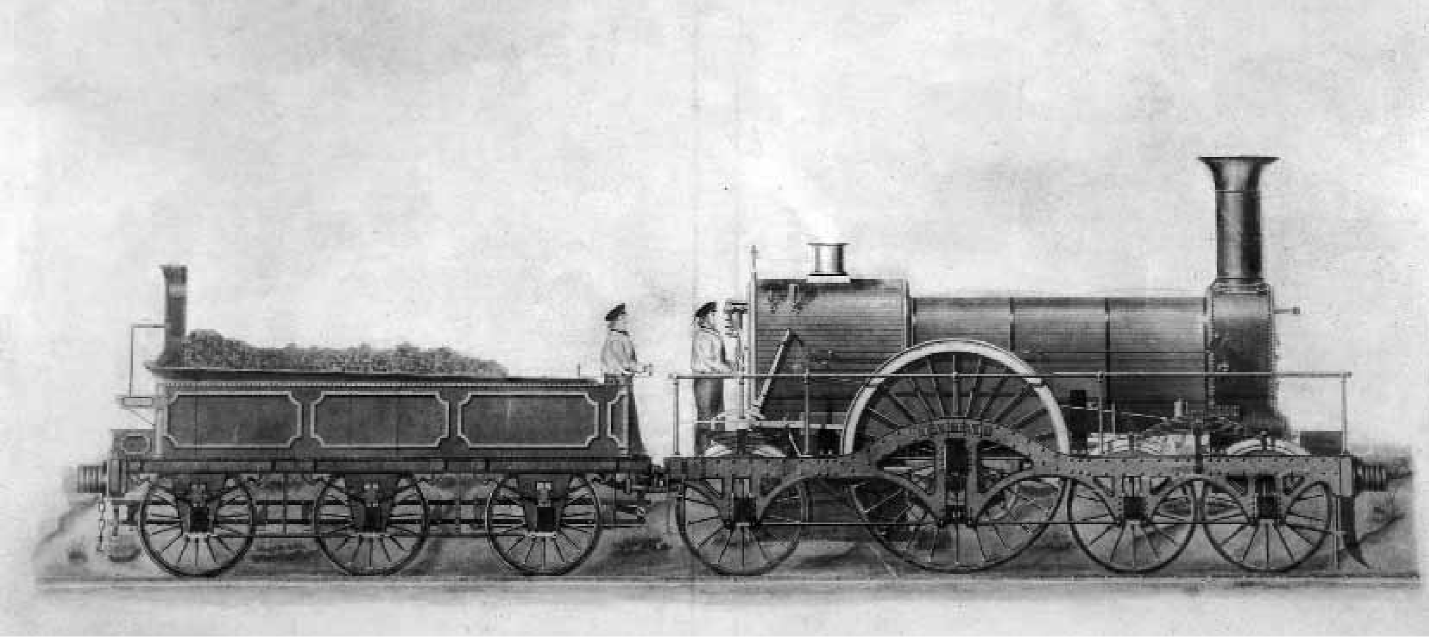
Similarly, the steam locomotive underwent many changes between 1802 and 1829–30, at which point it became the motive power of the main-line railways. Trevithick experimented with a horizontal engine in 1802. Fears of uneven cylinder wear constrained development, but by the 1860s horizontal engines were being produced in large numbers. The basic form of the portable engine, a locomotive-style boiler mounted on wheels with an engine on top, was standardised by Ransomes of Ipswich from the 1840s, and thousands were built by engineers in towns all over Britain. Self-propelled versions, or traction engines, appeared in the 1850s and were developed in the 1860s by Fowlers of Leeds and Aveling & Porter of Rochester.

By 1840 it was easy to assume that steam engines supplied most of Britain's energy. Several



This engine, designed by Joseph Maudslay and supplied by Henry Maudslay & Co. to the Royal Navy to power the 1,641-ton wooden paddle frigate HMS *Retribution*, is of the twin-cylinder or 'Siamese' type, in which two vertical cylinders are arranged side by side, with their piston rods attached to a common T-shaped crosshead. The Siamese engine was intended to replace earlier side-lever engines, but proved only marginally smaller and lighter. Siamese engines were installed in several warships, but they were never built in large numbers. As ships became larger from the mid-nineteenth century some of the constraints on engine size were removed, and the vertical inverted direct-action engine in many forms, compound, triple- or quadruple expansion, came to be used in most steamships, and such engines continued to be installed until after the Second World War. *Retribution* was laid down as the *James Watt*, but was re-named on launching on 4 July 1844. She was deployed in the Black Sea and the Baltic during the Crimean War, and in the Far East during the Second Opium War in 1858–59. She was sold for scrap in 1864.

estimates were made of numbers in use. One source in 1825 counted 290 in London, 90 in Glasgow, 212 in Manchester, 83 in Bolton, 67 in Stockport, and 130 in Leeds. In 1838 there were 29 in Dublin, 50 in Belfast and 240 in Birmingham. Steam power after 1800 made possible the growth of mining and manufacturing, for in well-populated England most potential sites for water-powered mills were already occupied. Yet water power remained significant. It was calculated in 1838 that the textile industry drew its power from 3,053 steam engines and 2,230 waterwheels. Water power appeared to be eclipsed because on a national scale it could not fulfil the growing demand for energy of nineteenth-century manufacturers. William Fairbairn declared in 1864 that 'the time has not yet arrived when it can be dispensed with … in our own country'. In Scotland and Ireland, less densely populated than England, the use of water power went on increasing



The Great Western Railway's 4-2-2 locomotive *Tartar*, built at Swindon in 1848, was of the same class, designed by Sir Daniel Gooch, as *Iron Duke* (illustrated on page 18). It could haul trains of 100 tons and more at 80 mph and elegantly exemplified the progress made in locomotive design in little more than 30 years after the building of *Puffing Billy*. Watercoloured drawing by E. Rees.

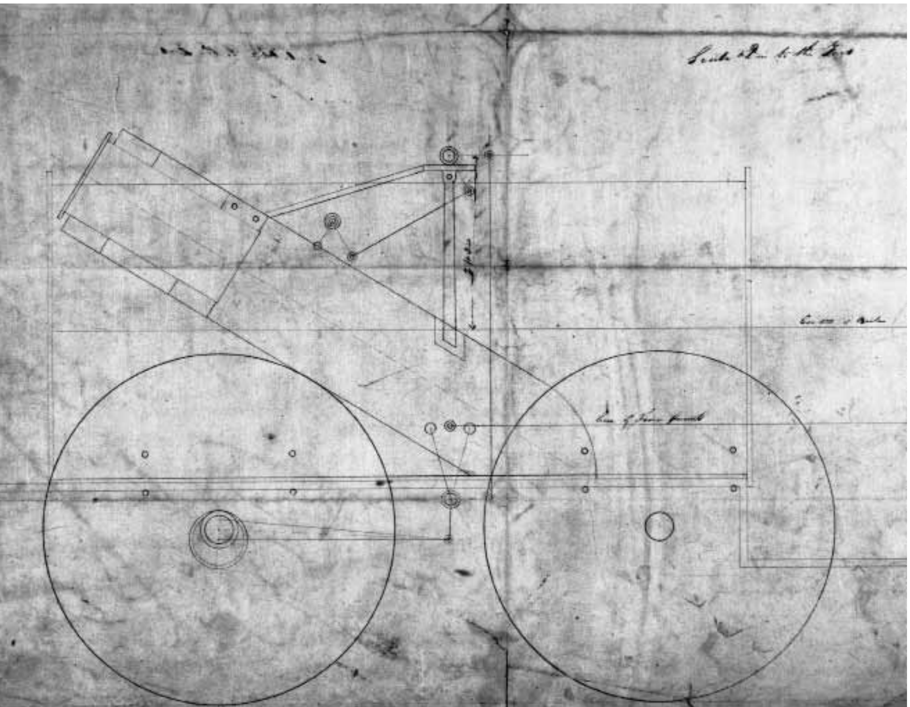
Undated photograph of Springwell Colliery Engine No. 2, County Durham, a locomotive that was built by Robert Stephenson in 1826. Steam locomotives proliferated in the North East Coalfield in the decade after the construction of *Puffing Billy*, and in 1823 George Stephenson began to build a works specifically for the construction of locomotives in Forth Street (now South Street), Newcastle-upon-Tyne, which was managed by his son, Robert Stephenson, from whom it took its name. Some of the first locomotives constructed there, in 1826, were for the Springwell Colliery, about three miles south of Gateshead. They had long lives, and No. 2 survived to be photographed here, probably in the 1850s or 1860s. The metal leaf springs which are visible were probably not original features.

until the 1860s. The abandonment of many sources of water power after 1870 was in fact a consequence of increasing imports of grain. Flour production was concentrated in mills using roller-milling technology, most of them on the coast. At this time many ancient watermills ceased to grind flour, but manufacturers using water power employed it as long as their businesses flourished, replacing waterwheels with turbines, and from the 1880s using turbines to generate electric power. Amid mounting concern regarding climate change and energy production, the period between 1870 and, say, 2020 might come to be seen as a curious interval in the history of the British Isles, a time when the country's abundant water power was not utilised.

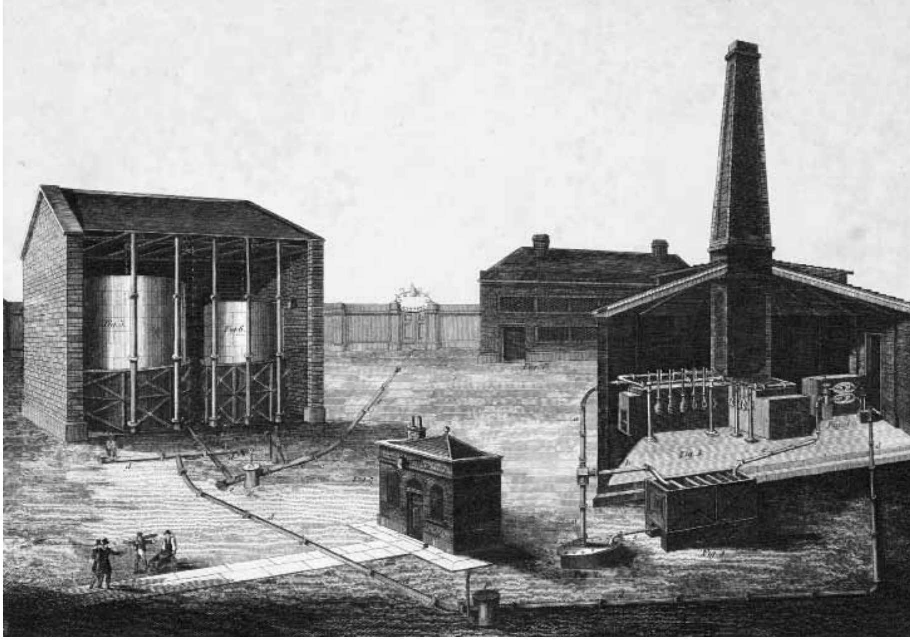
The choice of power sources available to factory masters in the early decades of the industrial revolution can be illustrated by the case of the cotton-spinning mill at Sutton-in-Ashfield, which was worked by the hosier Samuel Unwin. In the 1750s Unwin built a water-powered mill that was used for silk throwing, fulling woollen cloth, and twisting yarn for framework knitters. Then, in the 1770s he replaced it with what came to be known as 'the old Mill', a cotton-spinning factory where by 1784 120 people were employed. This mill's machinery was first operated by a horse capstan or possibly by oxen; subsequently it was worked by a 24 foot (7.4 m) diameter waterwheel fed from an enormous 8½-acre pond. A windmill on top of the mill worked pumps which returned water to the pool after it had passed over the wheel, and before 1790 this windmill was supplemented by a Newcomen pumping engine, probably by Ebenezer Smith & Co. of Chesterfield. Unwin explained in 1791 that its fuel costs were lower than those of a rotative engine since it was worked only when water supplies were low. Nevertheless shortly before he died in 1799 Unwin installed a rotative steam engine.

As well as providing heat and power for homes and industry, coal could produce flammable gas. The properties of coal gas were demonstrated in the closing years of the eighteenth century by William Murdock and others, and from the first decade of the nineteenth century gas lighting companies proliferated in British towns. The first commercially successful engines which used 'town gas' to produce mechanical power were built from 1860 by the Frenchman Etienne Lenoir. Gas engines were subsequently built by numerous British engineering companies and were economical sources of power for urban workshops and small factories which produced, for example, footwear and clothing.

With the proliferation of steam engines and manufacturing processes that required heat, the demand for coal increased hugely between the 1770s and the



Drawing showing the wheels of a steam locomotive designed by Robert Stephenson, possibly for the Canterbury and Whitstable Railway. The Canterbury and Whitstable Railway opened on 4 May 1830. Most of its 6-mile route consisted of inclined planes worked by stationary engines, but there was a 1¼ mile stretch of level track at Whitstable on which Stephenson's locomotive *Invicta* operated passenger trains. *Invicta* is now preserved in the Canterbury Heritage Museum.



The year 1810 saw the first recorded use of coal gas in Belfast. Work on this building on the Ormeau Road began in 1822. It was privately owned until 1874 when it was bought by the City Corporation. The gas undertaking prospered under municipal ownership and produced profits which subsidised the rates, other Corporation activities, electricity generation, parks, libraries and public baths, and they contributed substantially to the cost of building the City Hall. Several municipal gas concerns had prestigious office blocks like this one, and the gas payments office in central Birmingham is now part of the city's art gallery.
PHOTOGRAPH: CARNEGIE

From the first decade of the nineteenth century gasworks, initially intended primarily for providing gas for street or factory lighting, were established in most substantial towns and cities in the British Isles, and by 1870 there were gas suppliers in almost every community that had claims to urban status. By this time gas engines, more compact and more efficient than steam engines, were beginning to power the increasing numbers of factories of modest size that were manufacturing consumer goods. This illustration is a diagrammatic representation, published in 1819, of one of London's many gasworks. The retort house is on the right. This is one of the many images of gas production and distribution that form part of the extensive collection of industrial art, now held at Ironbridge, that was built up by Sir Arthur Elton.
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1860s, and the domestic needs of a growing population. The canal system transformed the pattern of distribution: by the 1840s there were few significant towns in England that were not within easy reach of navigable waterways, and in the 1860s almost every town in the British Isles could receive coal by rail. The demand generated by steam engines prompted a steady increase in coal production. The best estimates suggest that national output by 1871 had reached 115 million tons, by which date energy was available on a scale many times greater than it had been in 1700.

Such an increase in coal consumption inevitably brought significant problems. From a modern perspective the long-term implications for global warming are immediately obvious. Contemporaries, too, were well aware of the ill-health and misery that could be caused by the blankets of smoke around mines and factories and which hung in palls over towns and cities. Yet many regarded the steam engine as a source of prosperity and comfort. Sir John Sinclair wrote in 1825 that the steam engine

> has increased indefinitely the mass of human comforts and enjoyments: and rendered the material of wealth and prosperity everywhere cheap and accessible. It has armed the feeble hand of man with a power to which no limits can be assigned; completed the dominion of mind over the most refractory qualities of matter; and laid a sure foundation for all those future miracles of mechanical power which are to aid and reward the labours of after generations.