3 Making Iron: the technology

Before issues in relation to the economic history of the iron trade can be addressed, the technology of ironmaking must be discussed, because this profoundly influenced the way in which production was organised. Production must also be set in the wider context of the iron trade as a whole. As already mentioned, the trade was divided into two sections. Firstly, the production of iron required special works, built for the purpose, but only a small (but highly skilled) workforce. Secondly, its manufacture into useful artefacts was labour intensive and commonly required only relatively simple equipment. The entrepreneurs in production were called ironmasters, while the manufacture and distribution of finished goods was the field of ironmongers. This chapter will mainly focus on the production of iron. Its first section will examine the pre-Industrial Revolution technology of iron production. The second will then describe the new processes introduced in the 18th century using coke. The third part will consider other kinds of mill involved both in the preparation of iron for manufacture and in finishing manufactured goods, with a final glance at manufacture itself.

The traditional charcoal-based ironmaking processes

A new method of making iron was introduced into England at the very end of the 15th century, replacing an even older one, the bloomery process. That process, not finally displaced until the 18th century, involved the reduction of the ore direct to metallic iron in the solid state. Production was of a single bloom at a time. Unlike later ones, this was not a continuous process. The resultant bloom was then forged into a bar. Anciently the power both for blowing the bellows and wielding the hammer was purely manual, and the forges were not necessarily fixed in one place, but were thus sometimes described as itinerant (*forgiae errantes*).[1] The process seems to have been quite widespread, including some areas that had no iron production in the early modern period, such as Northamptonshire and the Blackdown Hills in Somerset.[2] Production per forge may have been as little as three tons per year.[3] In the fourteenth century however, water-power was applied to

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1. Tylecote 1992, 75-6; Schubert 1957, ch. viii; Mott 1961; Morton & Wingrove 1970; Hart 1971, 1-8.

2. Sanders 1994; Griffith & Weddell 1996. The reasons for the disappearance of the industry in these areas is not clear. Northamptonshire ironstone is not a rich ore. It is possible that the bloomery industry relied on richer deposits, where the ore had been weathered at the outcrop of the seams and that all useable ore was worked out in the medieval period: conclusions from discussions at conference of Historical Metallurgy Society at Northampton in September 2001.

3. Hodgkinson & Whittick 1998.

the process, probably first to the bellows and only later to the hammer.[4] The date of this innovation is not wholly clear, as contemporary references to ironworks are often vague and could apply either to manual or powered bloomeries. The earliest clear documentary evidence comes from 1408, from accounts for Kyrkeknott at Bedburn in County Durham. However, this was certainly not the first, as the men who built it went from Bedburn to Wakefield and Rotherham to see a similar forge.[5] Such a water mill at Chingley in Kent apparently dating from the early 14th century has been excavated, and if the date is right this must be among the earliest in Britain.[6] This use of water power meant that the forges were now fixed, but their output was still only 25-30 tons per year per bloomery.[7] Nevertheless the powered bloomery forge does not seem to have replaced manual bloomeries everywhere, as the latter seem to have been the basis of the Forest of Dean iron industry until the arrival of the blast furnace.[8]

At about the period when the powered bloomery was spreading in England, a new process was developed in Europe. In this, the iron was melted in a furnace and cast into pigs. Such a furnace has been excavated at Lapphyttan in Sweden, which probably operated in the 13th century, and other examples have been found in Mark in Westphalia, Germany, some also dating from the 13th century.[9] Such furnaces were probably essentially simple versions of the blast furnaces of the early modern period, which will be described below. Pig iron, the product of such furnaces, is a brittle material, which cannot be wrought. Accordingly a second process was undertaken. The pig iron was remelted in a hearth before a blast of air from bellows. As it melted, the drops of iron were collected on a staff, which was spun in front of the blast, so as to spread the drops out. This also decarburised the iron and resulted in the formation of a ball of iron, known as an osmond.[10] So far as is known this process was not used in Britain in the medieval period,[11] although osmonds were being imported from northern Europe by 1325.[12] It was however introduced in the Elizabethan period to provide the raw material for the production of wire at Tintern.[13]

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4. As note 1; excavations: Crossley & Ashurst 1968; Tylecote & Cherry 1969; 1970; Gould 1969; documented bloomeries: Crumpe 1950; Awty 1960; 1977; Louis 1930; and next note.

5. Tylecote 1992, 76; 1960; Lapsley 1899; Mott 1961, 157; Mott & Wilkinson.

6. Crossley 1975c, 2 6-17. The existence of an iron mill at Bescot in Walsall in 1306 has been claimed. The presence of a bloomsmithy there is certainly indicated by field names and remains of an ironworks were found there in the 19th century, but the references of 1306 and 1318 are merely to a mill, probably meaning a corn mill: Dilworth 1976, 85-6; *cf.* Willmore 1882, 242; B.L., MSS. Nero c.xii, f.133-133b (old foliation), translated and printed in *Walsall Records*, nos. 22 36. In 1617 John Wollaston rented certain water mills and also a meadow formerly the pools of New Mill and of 'a building called an iron mill or smithy'. Whether this refers to the same place is not clear, and this evidence only points to there having been a bloomsmithy, which had ceased operating by that date: Willmore 1887, 242; Walsall Archives, 277/233, 6-7 (a transcript of a survey of Walsall dated 1617, now in Staffs. R.O., Weston Park documents).

7. The output at Kyrkeknott was 195*lb.* per day, which is 26 tons per year, if it was used 300 days: Mott 1961, 149; Lapsley 1899. As to output see Schubert 1957, 346-7; see also chapter 6.

8. Hart 1971, 5-8; Cohen 1953; *V.C.H. Glos.* v, 265 339 and *passim*.

9. Björkenstam 1995, 149-52; Kempa & Yalçin 1995; Knau 1995; Rehren & Ganzelewski 1995.

10. Schubert 1957, 299-302.

11. Craddock (1997) has suggested that the 'King's great forge' in the Forest of Dean may have used this process, because the feedstock included old bloomery cinders. However it may merely have been a powered bloomery of the kind mentioned in the preceding paragraph. On this ironworks see also Hart 1971, 3-6; *V.C.H. Glos.* v, 265.

12. Gras 1918, 379 ('Ferro de osmond'); Schubert 1957, 111.

13. Schubert 1957, 299-302. The wireworks were at various times supplied from forges at Machen (Glam.), Monkswood and Pontmoel (Mons.), Lydbrook (Glos.), Shelsley (Worcs.), and Hubbals Mill (Salop.): Foley a/c; Donald 1961, *passim*.

An improvement in the process was probably invented in what is now the Walloon speaking part of Belgium (then belonging to Burgundy).[14] As with the osmond process, bar iron was produced in a two-stage process. Firstly pig iron, a brittle material containing 4-5% carbon, was made in a blast furnace; then this was fined in a forge to make (malleable) bar iron, which is commercially pure iron, though in practice never wholly free of slag. This finery process is sometimes referred to in modern books as the Walloon process, but this derives from Swedish terminology. The process was introduced to Sweden in the early 17th century by Walloons, and bore their name to distinguish it from the German process, which was more widely used there.[15] From the County of Namur in Belgium, this process spread to the *pays de Bray* on the eastern boundary of Normandy, and reached the Weald from there in the 1490s.[16] However it does not seem to have become widespread even there until the 1540s, and only spread to other parts of England and Wales from the 1550s. It was not adopted in north Lancashire until about the beginning of the 18th century.[17]

The main raw materials for making iron were iron ore (known as 'mine') and charcoal (often simply called 'coal'). For some ores limestone or some other material was needed as a flux. Charcoal was a renewable resource, being made from wood from coppices, which were cut on a regular cycle of 14 or so years. The rules for this were contained in a series of Tudor statutes. The first timber statute was however somewhat earlier and merely permissive. It was dated 1482 and permitted owners of woods in forests and chases to inclose them after felling, so that grazing animals did not prevent regrowth.[18] This was followed by an Act dated 1544, which obliged owners to inclose woods and required them to leave twelve standels per acre to grow into timber.[19] This temporary act was renewed periodically and made permanent in 1572.[20] To this had been added a further restrictive measure in 1559, prohibiting the use as fuel of timber growing within 14 miles of the coast or a navigable river for making iron. This act is often misunderstood,[21] for the timber whose use was forbidden was trees that would square to one foot. This left a great deal of smaller wood that was available for making charcoal in such areas. Initially, the Act did not apply in the Weald,[22] but that area was subjected to a similar regime by acts of 1581 and 1585, following complaints of a fuel shortage in London.[23] These timber laws, which provided the basis for woodland management in Britain for the next couple of centuries, probably did not restrict the iron industry significantly, since sound timber (that is the trunks of large trees) were generally too valuable for other purposes for it to be burnt. Furthermore the

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[14]. Tylecote 1992, 95-8; Awty 1981; 1987.

[15]. Nisser 1987, 15-37 46. The blast furnace seems to have been improved in the same region, by building it of stone. This is termed in Sweden the 'French Furnace', distinguishing it from the *mulltimmerhytta*, built of timber and earth with a stone lining. Since the timber and earth furnace and also the German forge were not known in Britain, they have no contemporary English names: *cf.* Hildebrand 1992, 48; 1995, 30.

[16]. Den Ouden 1985; Awty 1978; 1979; 1981; 1987; Tholander & Blomgren 1986. These predate the publication of the work of Knau and others (see note 9 above), which has opened up the issue considerably. The first such ironworks in Britain was until recently thought to be Newbridge (in Hartfield, Sussex), but recent work suggests that Iron Plat (properly Queenstock) Furnace in Buxted was worked in the time of Chancellor Morton (d.1500): Cleere & Crossley 1995, 111-3; Combes & Whittick 2002.

[17]. Harris 1988, 11-18.

[18]. Statute 22 Ed. IV, c.6.

[19]. Statute 35 Hen. VIII, c.17.

[20]. Statute 13 Eliz., c.25.

[21]. Clow 1956 (refuted by Flinn 1959b). *cf.* the choice of a 15 mile distance from navigable water in maps in Willan 1936, 32 & 68.

[22]. Statute 1 Eliz., c.17.

[23]. Statute 23 Eliz., c.5; Statute 27 Eliz., c.19; *Remembrancia*, 164.

coppicing system enabled a landowner, by cutting part of his woods each year cyclically, to draw a regular income from them. A coppicing cycle of 16 years was used in several areas, but others can be found. The wood for ironmaking was usually sold by the cord, a pile of wood usually containing 128 cubic feet. Practices varied considerably, but more in terms of organisation than technology.[24] Some of these organisational differences will be examined in the next chapter.

There were two main types of mine in use in the period under consideration, argillaceous ironstone (siderite) which occurs in seams in the coal measures and was often mined in conjunction with coal, and oxide ores (haematites). Argillaceous ironstone consists of impure iron carbonate, which was converted to the oxide, often in a structure very like a limekiln, a process known as calcining. This ironstone was usually high in phosphorus, which caused the iron to be brittle when cold ('coldshort'). The oxide ores can be divided into limonite, that is brown (or hydrous) haematite, found in the Forest of Dean and just north of Cardiff, and red haematite (known as redmine) found in Furness and West Cumberland. Other sources of ore, such as the ironstone of Cleveland and Northamptonshire, though important in the 19th century, were little used (if at all) in the preceding centuries.[25] The arrangements for the supply of ore to furnaces varied considerably. In the Forest of Dean mining was undertaken by Free Miners, who enjoyed the right by custom. In the Black Country the ironmasters left mining to coalmasters and bought ore from them, but the Bringewood partnership ran their own mines on Clee Hill.[26] In Furness some of the furnace companies had their own mines, but there were also independent mines run by distinct partnerships. In Yorkshire the Spencers mined ironstone themselves for Bank and Barnby Furnaces.[27]

The first stage of smelting in the indirect process took place in blast furnaces, which were essentially smaller and less sophisticated versions of those still in use today. The furnace consisted of a vertical shaft lined with refractory stone (later firebrick) and supported by a structure built of stone (or brick), often at least 30 feet high. The top of the furnace was reached by a bridge, usually from an adjacent hillside. From there the furnace was charged with mine and charcoal usually with a small amount of limestone as a flux. Towards its base the shaft narrowed like a hopper (the 'bosh'), so that the charge descended gradually into the lowest and hottest part of the furnace (the 'hearth'). The stack was pierced at its base by arches in two of its adjacent walls, the blowing arch and the casting arch, leading to structures known as the blowing house and the casting house. From the blowing arch came a blast of air provided through a pipe called a tuyere from a pair of large bellows, which were operated by a water wheel. Bellows were often replaced in the late 18th century by blowing cylinders sometimes worked by a steam engine. Through the casting arch the slag was removed from the furnace, as periodically was the molten iron, which collected in the bottom of the furnace. The slag, a dark green

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[24]. Hammersley 1973; Flinn 1959b; Hammersley 1957; *cf.* Schubert 1957, 218-24; Jones & Harrison 1978, 800-03. Woods supplying Hales Furnace were cut every 16 years between 1659 and 1674: Herefs. R.O., E12/VI/KC/63. In the following decades those at Upper Arley (Staffs. now Worcs.) followed this cycle: *ibid.* 81-3 111. John Hanbury of Pontypool wrote of cutting at 16 or 17 years' growth: Schubert 1957, 430.

[25]. Tylecote 1991, 201-04; *cf.* the distribution of furnaces.

[26]. SW a/c; Foley a/c; Herefs. R.O., E12/VI/KBc/4; BW a/c.

[27]. Spencer l/b, *passim*, *e.g.* 25 Dec. 1742.

glassy material consisting mainly of calcium and iron silicates, was removed in barrows and usually just dumped, but was occasionally cast into blocks for use as building material or ground up as a raw material for glass. The molten iron tapped from the furnace was run into channels dug on the floor of the casting house. These channels were commonly laid out to as to resemble a sow suckling her piglets, giving rise to the terms 'sow iron' and 'pig iron.' The cast iron thus made contained a few percent of carbon and was not malleable. Alternatively the molten iron might be run into moulds set in a casting pit in the floor of the casting house for making cast iron goods such as forge hammers and cannon, or ladled into moulds to cast pots, bushes and other small cast iron goods.[28]

The next stage of the production of bar iron took place in a forge, usually a single storey building containing one to three finery hearths (but most often two), a chafery hearth, and a hammer (or two). For example Tib Green Forge (close to the boundary of Staffordshire and Cheshire) in 1735 had a coal house of two bays of timber and thatch and a forge of four bays of timber and boarded.[29] The fineries and chafery were rectangular boxes of iron plates surmounted by a chimney and provided with bellows, rather smaller than those of the furnace, but again driven by waterwheels. The finery was six and a half to seven foot long, whereas the chafery was about three foot longer. Both were two and a half to three foot wide. The object of this finery process was to remove the carbon from the iron to produce bar iron. Bar iron is often (but inaccurately) referred to as 'wrought iron'. That term ought strictly only to be applied to manufactured ironware.[30] That was certainly how the term 'wrought iron' was used by the Customs, which from 1660 had a rate of export duty for:[31]

> 'iron wrought viz. axes, adzes, hoes, armour, bites, knives, locks, fowling pieces, muskets, pistols, cissors, stirrops, and all carpenters' and gravers' tools, jackwork, clockwork and all ironmongers ware perfectly manufactured'.

A charcoal fire was made in the finery and the pig was introduced through a hole for that purpose in the exterior wall. Iron from this was allowed to melt and fall into the hearth. This descended though the coals and collected in the bottom. It was stirred with an iron bar ('ringer') and periodically lifted by the finer with an iron cross-bar ('furgon' or 'furgeon') to the top, where the blast through the tuyere from the bellows caused it to melt again, so that more of the carbon was oxidised. When, as a result of progressive decarburisation, the iron would no longer be melted with the normal blast, the blast through the tuyere (and thus the operating temperature) was temporarily increased, so as to melt it one last time. After this, the iron was gathered into a ball, called a 'bloom' or 'loop'. The finer next lifted this bloom out of the hearth and dragged to the anvil

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28. Tylecote 1992, 95-98 122-34; Tylecote 1991, 209-22; Schubert 1957, ch.14; Daff 1973; Baker 1944; Morton 1966; plate in Chaloner 1960.

29. Cheshire R.O., DEO 187/1.

30. Since bar (and rod) iron were an intermediate product, which required to be further made (that is wrought) into useful artefacts, they are better described as 'unwrought iron', but that term is rarely found.

31. Book of Rates appended to Statute 12 Car. II, c.4.

where it was given a few strokes of the hammer to consolidate it ('shingling'). The bloom was returned then to the finery to await the attentions of the hammerman.[32]

The hammer had a head usually weighing five hundredweight mounted on a wooden shaft ('helve'), which passed through a pivot consisting of a cast iron ring ('hurst'). The hammer was operated by a waterwheel turning another wheel on which there were cams. The cams struck the helve between the head and the hurst, thus lifting it and the head. The head then dropped on to an anvil, made (like the head) of cast iron, and of similar size. This arrangement is known as a belly helve, in contrast to a nose helve where the lift was provided beyond the head and a tail helve (or tilt hammer), which was pushed down beyond the pivot. The nose helve seems to have been little used in finery forges probably because the lifting mechanism would have obstructed the working space. Tilt hammers seem to have been reserved for working on smaller pieces of iron and steel using a lighter hammer, probably because of the strain that would be imposed on the helve by a heavier hammer.[33]

The hammerman took a bloom from the finery and, working outwards from the centre, drew it out into a bar, reheating it as necessary in the chafery. The initial session under the hammer produced a dumbbell shaped 'ancony', comprising a bar of about the final dimensions with two unworked knobs of unequal size at each end, one needing a single reheating before it was fully drawn out and the other two. Since the iron was now in the solid state, it would hardly be affected by impurities in mineral coal, which (probably in the form of coke) was often used in chaferies if it was available, except in making the best quality of iron.[34]

The quality of the iron depended to a considerable extent on the purity of the ore. English bar iron was in the 18th century classified into best (or tough), ordinary, blended and coldshort. Pig iron made from haematite ores was similarly called 'tough' and that from argillaceous ironstone 'coldshort', though strictly the terms were applicable to bar iron made from them, rather than to the pig iron itself. Iron was coldshort (that is brittle when cold) if phosphorus was present as an impurity. However if sulphur was present, the iron was redshort, that is liable to break when hot, making it impossible to forge. The term 'blended' or 'blend' seems to refer to the use of two types of pig iron, but a similar result could be obtained by smelting a mixture of ironstone from a coalfield and haematite, though this might still be called 'tough' rather than 'mixed' pig unless the poorer ore was the main one used. For example, Robert Morgan of Carmarthen used a mixture of ores, as he exchanged redmine from Furness for locally mined ironstone, which was then shipped on to Sowley in Hampshire.[35]

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[32]. Tylecote 1992, 101-03; Tylecote 1991, 233-34; Schubert 1957, ch.16 app.17; den Ouden 1981; 1982. The terminology is of French origin as a result of this 'Walloon process' coming ultimately from a French-speaking part of what is now Belgium: Schubert 1957, 240; Awty 1981; 1987.

[33]. Examples of nose helves (with a cast iron helve) and of tilt hammers are preserved at Abbeydale Industrial Museum in Sheffield. Wortley Forge has a belly helve (but again of cast iron). The use of cast iron for the helve is a nineteenth century innovation. Earlier the helve was always of timber.

[34]. Tylecote 1992, 103-05; Tylecote 1991, 246-48; Schubert 1957, ch.16 and app.17.

[35]. Johnson 1952, 333-4; Schubert 1957, 233-4 306 310-11; Ince 1991b, 56; Johnson 1954, 36-42; Morgan l/b, 12 Jan., 29 Mar., and 7 June 1760.

Tough iron was needed for purposes where it was subject to stresses and strains, for example for the body of edged tools and horseshoe nails. Due to its brittleness, coldshort iron was less useful, but did very well for ordinary nails, and was indeed preferred for that because it was easy to work and 'point[ed] more minutely than other iron without cleaving'. Ordinary Stockholm iron was considered as good as English tough iron and some American. Gothenburg iron (made in central Sweden) and some Russian iron such as 'Sable' (made in the Urals) seems to have been somewhat less good, but was probably widely used by village blacksmiths in the 18th century. Russian iron was also slit to make hoops. However other kinds of Russian iron such as Mullers and Tula seem to have been even cheaper than English coldshort and probably used for the same purposes.[36]

The new coke-based ironmaking technologies of the 18th century

Pig iron

A major limitation on the ability of the iron industry to expand was its reliance on charcoal, for if charcoal was used faster than the wood from which it was made grew, there would inevitably be a crisis after a few years when the fuel supply was, at least temporarily, exhausted. Accordingly, the smelting of iron with coal (or coke) was long sought after. The first known attempt was as far back as the 1590s, when Thomas Proctor built a furnace to use a mixed fuel at Shipley Hurst near Bradford in Yorkshire. This was an ordinary blast furnace, save that it was ill-built, the walls being too thin. He sold this works to Edward Cage, who found that the metal produced was so bad that the forgeman at Somerbridge (near Dacre in Nidderdale), who tried it in a forge there, would not have taken Shipley pig iron as a gift.[37] Much less is known of several subsequent patents, such as that obtained by John Robenson (or Rovenzon) in 1612, but they were evidently not successful.[38]

The most famous early proponent of pitcoal smelting was Dud Dudley, but only because he wrote about it.[39] His father Lord Dudley was exploiting the resources of his estates in what became the Black Country and coal (probably in the form of coke) was probably first tried at the end of the annual blast. Lord Dudley obtained

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36. *J.H.C.* xxii, 851-2 (20 Apr. 1737); Britannicus 1752. For clench nails the Navy Board specified 'Swedish iron or best English rod iron called horsenail rod iron or best tough rod iron' N.M.M., POR/A/1, 22 Oct. 1696; note also *Angerstein's diary*, 201-3 and *passim*; Floren & Ryden 1996, 265-301; Prankard a/c, *passim*.

37. Collinson 1996.

38. A patent was granted in 1607 to Robert Chauntrell and John Astell, following experiments by the former. Chauntrell was connected with Monmouth Forge, which he had built in 1603 in partnership with Thomas Matthew of Radyr in Glamorgan. He had also been one of the tenants of Matthew's furnace at Pentyrch from about 1600 to 1603 and pig iron for Monmouth Forge presumably came from there. However Chauntrell had sold his share at Monmouth in April 1605, almost two years before the patent was granted, yet it is possible that the experiments took place at Pentyrch: patent: P.R.O., C 66/1699; *cf.* Collinson 1996, 207; Monmouth: P.R.O., C 33/110/286 & 391; P.R.O., STAC 8/218/16; P.R.O., C 2/Jas. I/C22/69; Pentyrch: Riden 1992b, 74-78. Simon Sturtevant obtained a patent in 1611, but this was void because he was outlawed at the time, enabling John Robenson to obtain a similar one: Daff 1972, 11; treatises by Sturtevant and Rovenzon bound with 1854 edition of Dudley 1665. The name of the latter patentee was probably Robenson, but has been misread.

39. Dudley 1665.

a licence in 1619 to exploit Robenson's patent, and he then renewed the patent in his own name, but Dud's attempts during the 1620s to exploit the process ultimately failed (partly for non-metallurgical reasons), first at Cradley where a dam probably burst, then at Himley where his father displaced him by letting the furnace to Richard Foley, and finally at Hasco Furnace.[40] One party to the subsequent litigation denied that he had made iron, though Dud Dudley claimed in his *Metallum Martis* to have done so, but that the 'charcoal ironmasters' (probably meaning Foley) were not prepared to pay for what they evidently regarded as poor quality pig iron. This subject has been much discussed, and is therefore only mentioned briefly here. The best view is probably that Dud Dudley made pig iron, but not of a quality acceptable to charcoal ironmasters for conversion to bar iron, perhaps on account of the impurities in it.[41] In the late 1660s, after publishing his book, Dud Dudley built a further furnace at Dudley,[42]

> for making iron or melting down ironstone with charcoal made of wood and pitcoal together to be blown and set on work by the strength of men and horses'.

By 1674 Sir Clement Clerke was a partner in this, but the business of which it had become part was sold, following litigation that resulted from Clerke having mortgaged his share. The association of several forges with this business suggests that Dudley Furnace was supplying pig iron to them, but it is not clear how long this fuel (made of a mixture of wood and pitcoal) remained in use. There is certainly no reason to believe the furnace operated after 1681.[43] That the use of mineral fuel remained a possibility is suggested by the reference to 'pig iron made with charcoal or partly so at Dudley Furnace' in a 1673 agreement.[44]

The enterprises described above were unsuccessful. Commercial success in coke-smelting was initially linked exclusively with the production of cast iron goods, an area which Dud Dudley evidently investigated, as he claimed to have various cast iron vessels made of pitcoal iron (presumably cast in the 1620s) in his house at Worcester.[45] This development was in turn related to that of foundries for remelting iron, as distinct from blast furnaces where ore was smelted to make iron.[46] These foundries

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[40]. At Hasco the ultimate problem was that Dud chose to pursue a claim the manor of Himley and other property, which was inconsistent with his title to the furnace. In order to keep Himley from his creditors Lord Dudley had put the manor briefly in Dud's name and Dud then delivered it to others. Dud asserted this to be a genuine gift (though none was intended), but he could not at the same time claim to be a lessee of part of it. The claim ultimately failed, because Humble Ward (whose son married Lord Dudley's one legitimate granddaughter) had bought up a prior mortgage. This enjoyed priority over both the grant and the lease. After Dud had spent time in prison for contempt of court, he eventually was confirmed in what he had truly been given and disclaimed all other title: King 1996a; 2002b.

[41]. Dudley 1665; Smiles 1863, 43-59, reprinted with uncritical comment *Ind. Arch.* 12(3) (1977), 253-64; Rollinson 1921; Mott 1934; Schubert 1950; Bedford-Smith 1949?; Morton & Wanklyn 1967; King 1996a; Evans (D.E.A.) 1996; King 1999a, 61-2; King 2002b (where I have discussed this at length). Dud Dudley's complaint was that they 'not only detained his stock, but disparaged his iron' (Dudley 1665 (1854 edn), 12). 'Charcoal ironmasters' is probably an oblique reference to Richard Foley who owned virtually all the ironworks in the vicinity, but was (though by then deceased) probably too respected a person for Dudley to be able to criticise directly. Possibly Dud may have intended also to include Thomas Nye and Thomas Chetwynd: *cf.* King 1999a.

[42]. P.R.O., E 112/538/94; *cf.* E 112/502/70; King 2002a; 2002b.

[43]. *Ibid.*; King 2002a; 2002b; Schafer 1971, 29-31.

[44]. Herefs. R.O., E12/VI/KE/50. This agreement between John Finch and two of Philip Foley's managers will be discussed further in the next chapter.

[45]. Dudley 1665 (1854 edn), 11.

[46]. References to founding can be occur from medieval times, but on examination all turn out to relate to brass or lead or to be references to blast furnaces. Thus the gunfoundries of the Weald were all blast furnaces, and the Earl of Worcester's Vauxhall Foundry seems to have cast brass ordnance. However this was also equipped to make small arms and the leather guns that were used in Gustavus Adolphus' campaigns in Germany: Ffoulkes 1937; Thorpe 1932; Jenkins 1936, 28-33; for the use of leather guns during the Thirty Years War see Wedgwood 1938 (1999 edn), 236.

arose out of the development of reverberatory furnaces (or cupolas or cupiloes) for smelting copper and lead. Such 'air furnaces' had been used since medieval times, but only for bell-founding. Dudley had used 'an old belhouse for a bloomery' at Okham Slade in Clifton (near Bristol) in 1651, and he was followed by Sir Clement Clerke also near Bristol from 1678, and then by his son Talbot Clerke. This resulted in the successful smelting of lead near Bristol and of copper at Putney in the 1680s, and in the floatation of two chartered joint stock companies in the early 1690s to exploit these successes. In both cases, Talbot was a promoter of the company, but not a charter member of it.[47] In the early 1690s the reverberatory furnace (in this case known as an air furnace) was successfully applied to ironfounding. There was a foundry for remelting iron at 'Fox Hall' (*i.e.* Vauxhall), and the air furnace there was described as 'the first of these and built by direction of Sir Clement Clerke'.[48] He was no doubt building on his success with reverberatory furnaces for copper and lead. This foundry probably belonged to the 'Company for Melting Iron with Pitcoal', a third chartered company of which Talbot Clerke was an Assistant (*i.e.* director), and one whose close association with the lead company is shown by the extreme similarity of their charters.[49] This company, as the 'Company for Melting Iron with Pitcoal at Lambeth', supplied shot, bombs, and grenado shells to the Board of Ordnance in 1693 and 1694, Thomas Fox being the founder. However some of this shot was probably made by Thomas' brother Shadrach Fox at Coalbrookdale, which as 'Corborow Dale in Shropshire' was the site of another early remelting furnace. Before 1696 Shadrach had been 'employed casting bombs and other things for the government', while undertenant of Coalbrookdale Furnace, and obtained his own lease of the Coalbrookdale Works in 1696.[50] However, with few orders from the Board of Ordnance, he was less successful subsequently. Neither the foundry at Coalbrookdale nor that at Lambeth seem initially to have operated for more than a few years, but another contemporary one at Southwark, the Falcon Foundry, remained in use into the 19th century.[51] This development of air furnaces for remelting pig iron was a major achievement of Sir Clement Clerke and of the Company for Melting Iron with Pitcoal, and for the first time permitted iron foundries to exist as something distinct from blast furnaces.

Thomas Addison of Whitehaven, the Company's Deputy Governor, obtained a patent for 'running iron with pitcoal' in 1692, and presumably assigned this to the Company on its formation the following year. This led Addison, probably on behalf of the Company to build a blast furnace at Cleator in Cumberland in 1694.[52]

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47. I have dealt with all this much more fully in King 2002a.

48. J. Woodward, 'Observations', f.99; King 2002a. Ruth Brown has kindly confirmed that Fox Hall was indeed at Lambeth from P.R.O., WO 51/49, 96 99.

49. Carr 1913, 228-30.

50. P.R.O., WO 51/48, f.3; WO 51/49, ff.56 71; WO 47/18, p.23 35 75 77; C 11/1379/19; E 112/829/34; E 112/833/957; E 134/4&5 Anne/Hil./19.

51. King 2002a. The Falcon Foundry may have possibly belonged to a rival 'Company for Making Iron Ordnance,' probably the 'Company for Making Iron Ordnance in Moulds of Metal', who supplied carcasses and grenado shells (but not ordnance) to the Board of Ordnance in 1693. An advertisement of 1723 relating to this Falcon Foundry indicates that it had previously belonged to Richard Jones. This Richard Jones had begun supplying the Board of Ordnance with roundshot made by remelting old guns in summer 1706, before being permitted in November the same year to set up a foundry in the saltpetre house at Woolwich Arsenal: Scott 1913 iii, 109; P.R.O., WO 51/48, 24v; P.R.O., WO 47/23, pp.320 and 403; WO 47/24, pp.97, 101 and 151; Flinn 1961, 56. As Richard Jones also supplied cannon, it is likely that he had a blast furnace in the Weald, but it is inherently improbable that old guns should be taken to the Weald for remelting. By 1759 (or perhaps a few years later) it belonged to Joseph Wright & Co. (or Wright & Prickett), who became Prickett & Handasyde in the late 1780s: P.R.O., WO 47/53-120 *passim s.v.* 'gunfounder'; Hodgkinson thesis, 111.

52. Beckett 1981, 28-9; Tyson 1999, 3-10; Woodcroft 1854, no.291

However it is possible that coke-smelting was first tried out at Coalbrookdale, as Shadrach Fox was asked by the Board of Ordnance to settle a dispute between him and 'the patentees for running iron with pitcoal' in 1695, shortly before the Board awarded him a contract for casting shot.[53] Shadrach Fox's career at Coalbrookdale came to an abrupt when the furnace there blew up, probably in 1701.[54] It was probably for this reason that in 1701 he and his brother Thomas, who had been the founder at Lambeth, rented Wombridge Furnace, which had probably lain idle since Philip Foley gave it up about 30 years earlier. To supply this furnace, they bought 'coales and ironstone' from the coal works of Isaac Hawkins at Malins Lee (in Dawley, Shropshire), where Shadrach had been living in 1696. Since it came from a coal works, this coal must have been pitcoal and not charcoal. The fact that coal was mentioned suggests that the quantity was significant, and that it was used in smelting, not merely for calcining ore. However coke-smelting seems to have enjoyed only limited success in this period, as Cleator Furnace went over to charcoal in 1699, and Wombridge only operated for a single blast, before Thomas Fox (who was in charge there) died owing money to Isaac Hawkins.[55] Shadrach Fox, unable to pay his debts, was later obliged to go beyond the seas, apparently to Russia.[56]

Shadrach Fox's success in smelting iron with pitcoal at Coalbrookdale was perhaps one of the things that encouraged Abraham Darby in autumn 1708 to take over the furnace, which had lain derelict since it had blown up. However his great success was undoubtedly due in large measure to his development of a new method of casting pots. He moulded these in 'green' (*i.e.* moist) sand rather than in loam. This new method not only required less labour, since it involved reusable patterns, but also enabled him to make his pots thinner than those of his rivals. Since each pot required less iron than those made by older methods, he was able to undercut other producers in price. Previously the pattern had been destroyed in removing it from the loam mould, so that a new pattern had to be made for each casting. Darby was a partner in the Bristol Brass Mills and began foundry work at his foundry in Cheese Lane, Bristol about 1705, as indicated by his purchasing pig iron from the (Foley) Forest Ironworks. There Darby seems to have required large pigs for casting, for which the founder was paid extra. A few years later Charles Axford (another Bristol ironfounder) was buying grey pigs from them, and paying a slightly higher price for these charcoal pigs than forge owners. Having thus achieved some success at Bristol, Darby moved to Coalbrookdale where he would have the benefit of a larger supply of pig iron and one under his own control, as well as the use of the air furnace (or furnaces) built there by Shadrach Fox. Nevertheless, as N. Cox has shown, it was not without some difficulty that Darby established a viable business, one whose main function was to cast pots.[57] Thus Abraham Darby's success, in

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53. P.R.O., WO 47/18, p.23 35 75 77.

54. P.R.O., C 11/1379/19. The date of the explosion is perhaps indicated by the furnace lease being sold in November 1701 to Thomas Fox for less than the mortgage previously secured on it. *Cf.* Cox 1990, 131; Trinder 1973, 20; Mott 1957b, 85.

55. E 112/829/34; E 112/833/957; E 134/4&5 Anne/Hil./19; Beckett 1981, 28-9; Tyson 1999, 3-10. Wombridge Furnace is omitted from its owner's rental for 1672, presumably because it was unlet, and there is no reason to believe that it was used in the following decades, though the landowner's records are relatively sparse: Shrops. R.O., 625/15.

56. P.R.O., C 11/1379/19; *cf.* Cox 1990, 131; Trinder 1973, 20; Mott 1957b, 85. The date of Shadrach's departure is not quite clear, as his son stated his father had gone abroad 'about 1702', but Mott noted the birth of a child to Shadrach in 1704. That Russia should be his destination is interesting, since Peter the Great was engaged in expanding the iron industry there in this period: *cf.* Kahan 1985, 2-4.

57. Cox 1990; Mott 1957b, 83-5; Trinder 1971, 20-26; Raistrick 1953, ch. 2-3; Schubert 1957, 268-70; King 2002a; pig iron: Herefs. R.O., E12/VI/DFf/5-13, 'Blakeney', 'Redbrook' and 'Bishopswood' [Furnaces], *passim*. The transactions particularly mentioned appear at E12/VI/DFf/3, f.19 E12/VI/DFf/11, f.5 and E12/VI/DFf/13, f.4. For Axford see also note 66 below. Patterns are mentioned in the 1718 inventory for Coalbrookdale: Raistrick 1953 (1989 edn), 301-7; Downing: P.R.O., C 54/5428/9, inventory, Cradley Furnace.

producing cast iron pots with coke iron at Coalbrookdale more cheaply than his contemporaries could using charcoal iron, depended on three developments. Firstly there was the application of the air furnace to remelting pig (or other cast) iron, the invention of Sir Clement Clerke. Secondly pig iron was produced with coke rather than charcoal, patented by Addison and used by Fox; and thirdly the moulds were made by Darby's own patent method using 'green' sand. Only when these were combined by Abraham Darby at Coalbrookdale in 1708 was success achieved. This also explains why Darby only patented his potfounding methods, and not smelting iron with coke.[58] This ironfounding business provided a secure commercial basis for experience to be gained in managing coke blast furnaces, thus eventually providing the basis for the general adoption of coke smelting.

Darby's achievements in pot-founding with coke pig iron led to a divergence in the iron industry. One branch used coke to produce cast iron goods, and the other used charcoal to make forge pig iron, from which all bar iron came. The accounts of the Coalbrookdale Company in the 1720s show iron from the blast furnaces there being cast into pots. This was both at the two blast furnaces and also at nearby air furnaces, where pig iron from the blast furnaces was remelted. No pig iron was supplied to forges, except Coalbrookdale Middle Forge. This received under 40 tons between 1720 and 1722 and then no more (except one small parcel) until 1728, after which coke pigs were used on a small scale there.[59] The reasons why coke pig iron was hardly used in forges until the 1750s have been controversial, and will be considered in chapter 5. With this minor exception, all Coalbrookdale pig iron seems to have been exclusively supplied for foundries to use, something for which it was particularly suitable. According to Graffin Prankard in 1730 it was 'so much esteemed [at Bristol] that without some part of it mixt with pigs they scarce presume to make any castings. The Virginia [pig iron] will do with a small quantity of it for cart boxes, but for furnaces pots and backs they use large quantities of it'.[60] It was shipped down the river Severn mainly to Thomas Goldney, a partner who was resident in Bristol where there were independent (that is unattached) foundries.[61] Other customers included Edward Kendall, who was from 1717 a partner in a foundry in Stourbridge,[62] William Phipps of Tewksbury, Abraham Freeth, and Richard Baddiley. Freeth was the company's main customer in Birmingham and may merely have been a mere merchant and wholesaler, but Baddiley was a Birmingham ironmonger or ironmaster. He was one of the partners who built a new Rushall Furnace in 1717, which was intended to be blown with coal, if possible, otherwise with charcoal. The very irregular nature of his purchases and their small size suggests that he had a foundry, presumably in Birmingham where he lived, but that it was supplied from

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58. Patent 380; Raistrick 1953, 21-22.

59. Raistrick 1953, 56; CBD a/c. Some sculls (a steely crust from furnace ladles) were however sold to the owner of Caynton Forge in the 1720s.

60. Prankard l/b, 17 Jun. 1730.

61. Cox 1990, 133-40; CBD a/c. For the Goldney family see Stembridge 1998.

62. CBD a/c; Worcs. R.O., 898.4 BA 8441/6(iii). Edward Kendall bought out his partners in 1723 and 1724 and gave the land to trustees to build a Presbyterian Manse in 1743.

another furnace, presumably Rushall. This, in turn, explains why Rushall hardly features among the furnaces that supplied the forges of Edward Knight & Co. in the Stour valley.[63]

A small number of coke blast furnaces were built in the years following the premature death of Abraham Darby I in 1717. The Vale Royal Company, who included Darby's former partner Thomas Baylies, built Sutton Furnace (at St. Helens), probably to use coal mined nearby by another of the partners.[64] In 1723 Isaac Cookson and others built a blast furnace at Little Clifton in Cumberland, apparently to supply a foundry on Old Trunk Key (or Quay) at Gateshead.[65] A group, mainly of Bristol Quakers including William Donne, established a furnace at Bryn Coch near Neath in 1727, the lease specifically authorising them to mine enough coal for two blast furnaces and one air furnace. In 1732 they bought from the Axford family their ironfoundry in Back Street (now Jacob Street) in Bristol, where Charles Axford had apparently begun ironfounding about 1709, and this was thenceforth called 'the Welch Ironfoundry'.[66] However it is possible that Bryn Coch Furnace was initially not very successful. Richard Ford wrote in late 1733, 'I have long been fearful Donne & Co. would make another attempt at Neath for want of our pigs, but if they do I am of the opinion they will meet with their old fate.'[67] Willey Furnace was converted to coke in 1733 when it was leased to Richard Ford and Thomas Goldney, two of the Coalbrookdale partners. They hoped to benefit from orders for steam engines, following the expiry of Thomas Savary's steam engine patent, under which Newcomen engines were produced.[68] A small number of other coke furnaces followed in the 1730s and 1740s, including Whitehill (Co. Durham) and Maryport (Cumb.).[69] Bersham Furnace (Denbs.), exceptionally, alternated between fuels, having 'ceased blowing with charcoales and went on blowing with cokes for potting' on 3 Feb. 1721. This was repeated periodically in the following years.[70] The divergence between the foundry and forge branches of the industry was quite marked: in a period when there was considerable traffic in pig iron up the river Severn, the only pig iron going downstream came from Coalbrookdale and Willey Furnaces.[71] Furthermore the accounts of the Knight family's forges in the Stour valley in north Worcestershire, which in the 1730s and 1740s show pig iron being obtained from almost every furnace in western Britain do not record the receipt of any from Coalbrookdale (except once) or from Bryn Coch, and the only pig iron from Willey is likely to have been made before that furnace was converted to coke.[72]

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63. CBD a/c; Rowlands 1975, 62; Birmingham Archives, Galton 84; *cf.* SW a/c. Rushall furnace has nevertheless been classified as a charcoal furnace in chapter 6, partly because there is no other obvious source of pig iron for forges in the area, such as [West] Bromwich. Possibly like Bersham (see below), it could use either fuel.

64. King 1993, 8-13.

65. Riden 1992c, 39-41; 'Newcastle partnership deeds', 169-71.

66. Bristol R.O., 4658(6)a-b; 09458(21); P/St.J/ChW/1(c)-(d); PR/St. P. & J.; 21782/xiv/159/B; *cf.* pig iron sales in Herefs. R.O., E12/VI/DFf/5-13, 'Blakeney', 'Redbrook' and 'Bishopswood' [Furnaces], *passim*. Initially Axford's foundry like Darby's may have used brass.

67. Ford l/b, 24 Dec. 1733.

68. Raistrick 1953, 59-62; Trinder 1973, 24-5 28-9; Ford l/b, 26 Mar. 1733 and *passim*; as to steam engines see Rolt & Allen 1997, 58-107.

69. Trinder 1973, 24-5; Riden 1992c; Riden 1993, 116-7 126-8.

70. Lloyd 1973, 54-55.

71. Cox 1990, 138. For upstream traffic see chapter 4.

72. Ince 1991b; SW a/c. The Willey pig iron in question was used in years up to 1736/7, but the vendor is not named as Ford and Goldney but as Richard Knight, who had been a partner in the preceding Willey Company. The accounts probably record when pig iron was used, rather than when it was bought and a considerable stock was kept in hand. It is thus not unlikely that it was made several years earlier, before the end of the preceding lease and during Richard Knight's partnership at Willey. However the furnace had probably only been in blast once between 1729 and the grant of the lease to Ford & Goldney in 1733: Downton a/c; *cf.* Page 1979, 8. The only delivery of Coalbrookdale pig iron to the Stour Forges was in 1754, and this will be discussed in chapter 5.

There was in this period a relatively small range of commodities that were made of cast iron. Cooking pots and similar vessels were probably the most common. Cylinders for steam engines began to be made of cast iron in the early 1720s. This provided an important new outlet for the coke blast furnaces, and (as mentioned) encouraged two of the Coalbrookdale partners to lease Willey Furnace in 1733.[73] Iron cannon required by the Board of Ordnance continued mostly to be cast in the Weald at furnaces using charcoal until near the end of the Seven Years War, though some merchant guns were made at Coalbrookdale during the War of Austrian Succession.[74] However after the Seven Years War coke furnaces became increasingly important and not long after the Board of Ordnance specified that guns should be cast and bored from solid in 1775, gunfounding at Wealden furnaces ceased.[75] With a few exceptions such as Abraham Darby III's bridge at Ironbridge, cast iron did not begin to be used for structural purposes until the 1790s. However, during that decade it was found that the propensity of cotton and other textile mills to burn down could be reduced if their beams were made of cast iron rather than timber. Cast iron pillars had been used in a couple of churches in the 1780s and (with iron ties) in William Strutt's mills at Derby and Milford in the early 1790s, but the first building with a complete iron frame was a mill in Shrewsbury built in 1796-7. This was followed by others at Salford, Leeds, Belper and elsewhere, but only after 1800. Other iron bridges only began to be built in the late 1780s and 1790s. The widespread use of structural ironwork was accordingly a 19th century phenomenon.[76]

One of the difficulties in dealing with molten metal or other material at very high temperatures is that of containing it. For this purpose, some refractory material must be used. The traditional one was stone, probably mainly sandstone. However, in the late 17th and 18th century fireclay and firebrick began to be used instead. This had been used in the Stourbridge glass industry since 1610 or earlier.[77] Its first use in metallurgy seems to have been in the reverberatory furnaces developed by Sir Clement Clerke. 'Clay' (probably meaning fireclay) was mentioned in the accounts for the late 1680s of the cupola near Bristol that had belonged to his son Talbot.[78] It is probably significant that its source should be within a few miles of the unique horse-mill powered blast furnace at Dudley, in which Sir Clement was a partner in the early 1670s.[79] The use of fireclay for hearths for iron furnaces is specifically mentioned in a 1725 mining lease to Humphrey Batchelor, a Stourbridge glass-maker, but not in an earlier one of 1709.[80] Batchelor is named in the

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73. Rolt & Allen 1997, 48 67 148ff; Raistrick 1953 (1985 edn), 53 316-7

74. Hodgkinson 1996b; Trinder 2000, 27; Goldney a/c.

75. Braid 1992c; Hodgkinson 1996b, 164; Brown (R.R.) 1994; P.R.O., W0 47/83, pp.240 265 327.

76. Skempton & Johnson 1962; Fitzgerald 1988; Trinder 1979; Benson 2000.

77. As early as 1566 the manorial court of Amblecote near Stourbridge forbad the digging of clay by anyone living outside the manor: *V.C.H. Staffs.* xx, 56-7; Charleston 1984, 73-86; Guttery 1956, 7.

78. King 1999b, 48. This cupola at Stockley Slade was at this time in the possession of Gravely Claypoole, a manager appointed by Lord Grandison during litigation between Clerke and Grandison. Stourbridge clay was certainly used there in 1754: *Angerstein's dairy*, 133. This source indicates, contrary to what I said in King 1999b that this cupola remained in use into the 1750s.

79. For this furnace see above and King 2002a; 2002b.

80. Dudley Archives, DE4/3, Kingswinford leases, 8 Nov. 1709 and 27 Jul. 1725; *cf.* Guttery 1956, 32 43. Humphrey Batchelor also appears as a minor buyer of Swedish iron periodically from 1729 to 1732 from Graffin Prankard of Bristol: Prankard a/c. This was probably a mere bye-trade.

accounts of the Coalbrookdale ironworks as the vendor of 5 tons of Stourbridge clay in 1720, and 'Sturbridge brick' was also in use there by 1718.[81] Precisely how the Coalbrookdale Company used this material is not wholly clear from their accounts. It was not the main lining of the hearth and boshes as hearth stones were obtained from Highley. However, the purchases may coincide with the furnace being out of blast for relining, so that the fireclay may have been used in the relining. It is also likely that it was used for lining the air furnaces, in which pig iron was remelted for foundry use. It is not clear how rapidly stone was replaced by firebrick as the lining material for blast furnaces. When there was a sudden failure of the in-walls (above the boshes) both at Coalbrookdale New Blast Furnace and Willey, Richard Ford decided at Willey to 'make 'em up with brick as fast as possible', adding, 'I am of the opinion the present misfortune will be for our future advantage for I believe the fluxing of the inwalls was the chief reason the furnace did not carry a better burthen.'[82] Horsehay Furnaces were similarly built with a brick lining. On the other hand, hearth stones are referred to the the accounts of Snedshill Furnace in the 1780s. Certainly in the 19th century the hearth was made of firebrick, but the chronology of the transition from refractory stone to firebrick remains unclear.[83]

During the 18th century there seems to have been little change in the design of blast furnaces apart from a gradual increase in height and size generally. One area in which there was some change was in the blowing apparatus. The opinion was expressed about 1710 that haematite ores could not be used without being fluxed with cinders, as these rich ores were hard to melt. This possibly explains the long persistence of bloomeries in the Furness region.[84] This problem is likely to have been resolved by increasing the blast to the furnace, and so raising its temperature. The performance of the Coalbrookdale Furnaces certainly seems to have been improved in the early 1730s by increasing the blast.[85] The blowing apparatus was almost invariably water-powered until the introduction of James Watt's steam engine with its quicker stroke. The first application of a steam engine directly to blowing was at John Wilkinson's New Willey Furnace, where a beam engine was used to blow the furnace directly in 1776. Apart from this, steam engines only began to be used for blowing (rather than pumping water back over the dam) in the 1780s, after Watt managed to obtain rotary motion from his engines. Nevertheless it is possible that the steam engines (Newcomen engines) at Ketley and Madeley Wood pumped water almost directly on to a water wheel, rather than into a pond above the furnace. In the same period there was another development, which in the long term was probably more significant. From the 1750s, the bellows began to be replaced by blowing cylinders. Horsehay and Ketley were built with these rather than bellows. Isaac Wilkinson patented a method of blowing using blowing tubs, and this was used (or at least tried) at Dowlais Furnace in Merthyr Tydfil, built in 1757 and one of the first coke furnaces in south

[81]. Shropshire R.O., 6001/329, 4 31; 6001/330, 37; Perry 2001, 75.
[82]. Ford l/b, 10 Dec. 1734.
[83]. The surviving lining is of firebrick at Morley Park (Derbs.) and Newland (Cumbria), last used in the 1875 and 1890 respectively; for dates see Riden & Owen 1995, 118 146-7.
[84]. Woodward, 'Observations', f.99.
[85]. Mott 1958, 70. This will be discussed further in chapter 5. For a detailed discussion of the combustion of coke and how it applied to blast furnaces see Rehder 1987, 37-8.

Wales. James Knight also patented a system of blowing tubs, which was installed at Bringewood, but apparently not even at his firm's other furnaces.[86]

The early coke furnaces were not necessarily more productive than their charcoal contemporaries. The first Horsehay Furnace ran continuously for three years during its first blast, making 819 tons per year, compared to 400-500 tons from the two Coalbrookdale Furnaces together in the early 1730s, and 670 tons in 1737 after the blast was improved.[87] While this output was larger than that of some contemporary charcoal furnaces, it was no greater than was achieved when charcoal furnaces operated continuously over a long period: Redbrook Furnace produced 913 tons per year in 1703/4, during a campaign which lasted about 22 months and made over 1600 tons in all. Similarly Blakeney Furnace made 1251 tons in the year 1701/2 in the midst of a blast lasting almost 2½ years, while Aston Furnace often made over 800 tons *p.a.* in the 1750s.[88] These are nevertheless exceptional cases. As will appear in chapter 6 (see fig. 6.13), the average for charcoal furnaces hardly ever exceeded 600 tons per year, whereas coke furnaces averaged 700-800 tons between 1760 and 1790, after which their average output increased rapidly.

One factor that facilitated the increase at the end of the 18th century was having the furnace blown through two (and later three) tuyeres, thus improving the penetration of air into the charge. This enabled the furnace to operate at a higher temperature, and increased its output. The first such furnace was probably one built in 1789 at Cyfarthfa (in Merthyr Tydfil). In 1799 Horsehay Furnace was rebuilt with two tuyeres. In the early 1770s each of the two Horsehay Furnaces had made 1100-1300 tons per year, and a single furnace made 1458 tons in 1796. However each made 1917 tons in 1805.[89] The prerequisites for this innovation would be the use of blowing cylinders (rather than bellows) and particularly the ability to produce pipes with airtight joints through which to convey the blast to the furnaces. Such furnaces seem often to have been rather taller than usual. The surviving furnaces at Neath Abbey (built after 1792) have three tuyeres and stand 53½ and 63½ feet high. In 1791 Richard Crawshay described his Cyfarthfa Furnaces as 60 feet high and as each producing 1400 tons per year, both rather more than was usual in other areas.[90]

The developments, described above, come from a period when there was a great expansion in coke smelting. No doubt, this expansion provided a healthy climate for technological innovations to be adopted. Until 1755 only a handful of furnaces produced coke pig iron. In the late 1750s eight new coke furnaces were built in

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[86]. Smith 1979; 1981; Tylecote 1992, 124; Ince 1989; Ince 1991b, 25-6; Trinder 1973, 34-41; 2000, 28 47-50; Hayman *et al.* 1999, ch.4.

[87]. Mott 1958, 69 72; HH a/c; Snedshill: P.R.O., C 12/211/5, schedule.

[88]. Foley a/c; SW a/c; Ince 1991b, 89.

[89]. Mott 1958, 83; 1959a, 280; 1959b, 46-47 (citing Beck, *Geschechte des Eisen* (Brunswick 1896-7) iii, fig. 209); 1796 and 1805 lists. The 1770s and 1805 figures are the average per furnace.

[90]. Evans 1990, nos. 329 385; 1993, 28; W.K.V. Gale regarded the Corbyns Hall Furnaces in the Black Country (built as late as the 1830s) as particularly tall, but they were only 40-45 feet high: Gale 1966, 57; *cf.* 1967, 49 60. For Neath see Ince 2001, 28ff. Bersham Furnace near Wrexham built in 1796 may belong to this category. I am grateful to Peter Hutchinson and David Cranstone for help on this point and to the latter for sight of his unpublished report on Bersham. It must however be noted that an argument from surviving remains of a furnace almost inevitably refers to its final form, not its initial one.

Shropshire and two elsewhere. By 1788 there were about 50 coke furnaces, of which 21 were in Shropshire. Eight years later almost 90 of the 104 furnaces in England and Wales were coke ones. In 1810 there were 223 furnaces in use in Great Britain (of which 30 were in Scotland) and barely more than a dozen of the English ones used charcoal.[91] The output of pig iron rose from under 25000 tons in the early 1750s to 66000 tons in 1788, to 250,000 tons in 1805, and it then doubled about every 20 years until the 1880s.[92] The great growth will be examined further in chapter 6.

New fining methods for making bar iron

During most of the period under consideration in this thesis, charcoal remained the normal fuel in the finery hearth, but in the second half of the 18th century new methods of producing bar iron were devised, using coal or coke in air (or reverberatory) furnaces, and many of these processes were patented. The standard work on the subject by G.R. Morton and N. Mutton is largely a review of such patents.[93] The following account will therefore seek also to identify the places and people concerned in this advance, and so distinguish between the commercially viable and mere curiosities. The new processes ultimately proved a resounding success, and replaced the old charcoal finery process, but success was not immediate, and many of the early patents were only used by their inventor. In all of these patents, the key was to prevent sulphur in the mineral fuel from contaminating the product, by keeping the metal separate from the fuel in reverberatory furnaces. Iron with any significant sulphur content is 'redshort', that is brittle at red heat and so incapable of being forged into useful wrought iron goods.

Several of the earliest processes were of a type referred to as 'potting and stamping'. The ideas involved may go back as far as the 1720s when Thomas Tomkyns obtained a patent in the name of Roger Woodhouse. Tomkyns 'who was not being proof against the temptations of Exchange Alley, was deeply involved in the calamities of the South Sea and other bubbles', with the result that he had a deficit of over £40,000 in a public treasurership. In 1728 Tomkyns was seeking release from prison, so that he could superintend works at 'Oakamore' (near Cheadle) in Staffordshire, where the workmen were in danger of being dispersed when they had 12 months experience of the process.[94] However he was not released and nothing came of this. According to Charles Wood, writing about in 1766, the pig iron was melted in an air furnace without pots upon a sand bottom. 'Good iron was made but the small quantity ... and the great waste of metal obliged them [*i.e.* Woodhouse and his financiers] to give it up.' Charles Wood wrote that he had tried this, and had found the sand bottoms only lasted two or three days and the cinder stuck the iron to the bottom.[95] These remarks were occasioned by his hearing of a patent granted to the Cranage brothers, following experiments in Thomas

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91. Scrivenor 1841, 86 93-95; 1810 list; the number of charcoal furnaces in 1796 and 1810 results from counting known charcoal furnaces appearing in the lists.

92. Riden 1994; Riden & Owen 1995, table 1.1.

93. Morton & Mutton 1967; Tylecote 1991, 233-40; 1992, 126-8.

94. *Cal. Treas. Pap. 1720-9*, 233 274 525-8; *Cal. Treas. Bks. & Pap. 1729-30*, 103 117 218; Cambridge U.L. MS. Ch(H) 89/12/3; Treadwell 1974, 107-8; Butler thesis, ch. 1, 28-33. There had been a traditional forge at Oakamoor belonging to the (Foley) Staffordshire Partnership, which was presumably replaced by the patent process. By the 1740s there was a tinplate works: Johnson 1954, 49-52; Awty 1957, 109 115.

95. Gross 2001, 72.

Tilley's air furnace (probably at Coalbrookdale). According to Joseph Banks, the iron made there was good but the process was not as profitable as expected due to the large waste of iron. Someone else reported that the iron was not fit for nails. The Cranage process was thus no great success.[96]

A second series of attempts (again failures) concerned making 'pig or sow iron' or 'raw iron or iron metal prepared' direct from iron ore in reverberatory furnaces. This is closely associated with the Wood family, members of which later succeeded with potting and stamping. The head of the family was William Wood, a Wolverhampton ironmonger, who became a partner in certain Shropshire ironworks in 1715. His firm was subsequently interested in Tern and Sutton Forges and Bersham and Ruabon Furnaces.[97] One of the patented processes was devised by his son Francis at Bellingham in Northumberland, and another was (supposedly) used at Frizington near Whitehaven.[98] However the affair was used as a vehicle for fraud, by raising money by advance sales of product and stockjobbing, and it ended in infamy.[99] Kingsmill Eyre enrolled a patent specification in 1736 for something similar. This indicates that the ironstone was calcined. Then it and coke were pulverised, and heated with a flux. When melted, old iron, nut iron, or hammer slough was added, which improved the yield.[100] It was alleged on behalf of Woodhouse's patent (mentioned in the previous paragraph) that Francis Wood had observed and copied the methods used by Tomkyns under it.[101] If so, it may have been the existence of that patent that induced William Wood to patent a process starting with ore. Despite the failure of this, pulverisation and the use of a flux prefigure the potting and stamping process of John and Charles Wood (sons of William). Accordingly, the notorious failures of the 1720s may nevertheless have provided valuable metallurgical know-how that remained in the family.

John Cockshutt of Wortley Forge also carried out experiments on a sort of coke bloomery, apparently in the early 1750s, and to his surprise obtained good iron. He included the process in a patent dated 1771 that was otherwise concerned with certain improvements to the charcoal finery process, but he did not develop the process commercially.[102] However the first major advance was achieved by Charles and John Wood, sons of William. John acquired Little Aston Forge in 1746, and also he owned Wednesbury Bridge Forge, both in Staffordshire, while Charles was a partner in the firm that established Low Mill at Egremont in Cumberland as an ironworks in 1749.[103] Charles experimented

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96. Gross 2001, 72; Broadbridge 1980, 135-9; Mott 1959b, 48; The process was apparently used at the Coalbrookdale Company's Pendleston Mill (thus known as Bridgnorth Forge), which they had leased in 1760: Shropshire R.O., BB/E/7/2/1; BB/E/1/6/8, f.15; BB/E/1/6/8, f.12; BB/E/1/3/10; Raistrick 1953, 85-7 212 215-6 225.

97. Treadwell 1974; Flinn 1961; Butler thesis, ch.1, 31-3; P.R.O., E 112/1339/21; Morton & Mutton 1967, 722-3; patents 489 502 and 553 (with specification). There were two patents taken out by the Wood family, each used for dubious financial dealings. On the first occasion, money was raised from the (united) Society of Mines Royal and Company of Mineral and Battery Works. These companies had once had interests in metal mining and wiredrawing. However, they had long since ceased to have any business of that kind, but had recently been used for other purposes. On the second, the victim was Daniel Ivie, but it also involved an attempt to procure the incorporation of 'The Company of Ironmasters of Great Britain'. Wood then tried to compensate Ivie by selling him an ironworks in Denbighshire, for which he had not paid.

98. Treadwell 1974; Riden 1993, 112 125-6; Butler thesis ch.1, 32.

99. As note 97.

100. Patent 553 and specification.

101. Cambridge U.L., MS. Ch(H) 89/12/3.

102. Morton & Mutton 1967, 725; Gross 2001, 206; Lewis c.1775, 90-90a; patent 988 (and specification).

103. Little Aston: Gould & Morton 1967 (1982 repr.), 25-6; however the correct date for his acquisition is 1746, when the forge was sold by John Mander & Co. to Edward Knight & Co., who resold it to Wood: Knight 142, 1746/7, p.6; Wednesbury Bridge: Dilworth 1976, 108-9; Low Mill:

with a pitcoal bloomery in 1752 and exchanged material with Cockshutt, but evidently gave up.[104] Instead both brothers concentrated on recycling scrap iron. This, usually described in the Customs accounts as 'bushel and cast iron', was imported from Holland and other parts of northern Europe.[105] Bushel iron was 'a sort of refuse iron that smiths cannot use'.[106] In 1753 Charles Wood described experiments with making pots with local and other clay, and he then built a furnace for working up scrap.[107] In 1754 he visited the Midlands with Gabriel Griffiths (another Low Mill partner). Charles' observations at John's Wednesbury Bridge Forge indicate John was doing something similar, involving a 'furnace' and placing scraps 'in the pots'. Charles also displayed an interest in the production of clay (evidently fireclay) at Stourbridge, comparing their methods to the 'Lowmill method of grinding ... clay'.[108] R.R. Angerstein (also in 1754) described John's raw material as iron filings and later as bushel iron.[109] In 1775 Marchant de la Houlière also found John Wood using scrap.[110] It (and perhaps other methods of recycling scrap) were used in a small number of other forges in the late 18th century. These included Brightside Forge, built in 1763 on the river Don below Sheffield by Binks & Co. and described as 'a tosshammer work for working up Hollands scraps',[111] and also Marston Forge in Cheshire where Nicholas Ryder advertised in 1768 for a 'good baller of scrap iron [who] understands balling and heating the balls in an air furnace'.[112] By 1790 'balling furnaces' were quite widespread in England,[113] also including Wick ironworks near Bristol, which is perhaps the best documented.[114] This process remained in use until the 20th century, though no longer using fireclay pots. Since the starting material was already largely malleable iron, these works were not, strictly, making iron, but rather merely recovering it for reuse.

Charles Wood's notes suggest he also experimented with 'cold short metal' (probably pig iron). This is not surprising, since his firm were also mining iron ore and therefore probably had a blast furnace, though it is not clear where. The date of this is unclear,[115] but it was not until 1761 and 1763 that the Wood brothers obtained patents. Charles was then hindered by most of his partners becoming bankrupt in 1763, as a result of the failure of a tobacco importing business.[116] In 1766 Charles Wood moved to Merthyr Tydfil, and built a forge at Cyfarthfa for Anthony Bacon (a London merchant) and William Brownrigg, both with Cumberland origins.[117] This forge was a potting and stamping work. It had six races branching from the grand race

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Carlisle R.O., D/Lec/60/26. The same firm also built Dalston Forge: Carlisle R.O., D/Hud/8/27; DRC/2/43-44.

104. Gross 2001, 202-9.

105. P.R.O., CUST 5/*passim*. It is listed (misleadingly) in the tables in Schumpeter 1960 as 'cast iron'.

106. Evans 1992, 189.

107. Gross 2001, 210-6.

108. Hyde 1973, 39; patents: Morton and Mutton 1967, 723; Daff 1972, 12.

109. Angerstein also found scrap being reworked at Cradley: *Angerstein's diary*, 47 179-80 348.

110. Morton & Mutton 1967, 723-4.

111. Sheffield Archives, ACM/S378, 306; King, *North*.

112. *Aris B'ham Gaz.* 26 Dec. 1768. However Marston was an ordinary single finery forge according to the 1790 list.

113. 1790 list.

114. Ellacombe 1881, 231; Bristol R.O., 14851/HA/B/10-12.

115. Gross 2001, 215-6 218-9. No date is associated with the latter text, but it follows an entry dated 17 Nov. 1761, though a letter from Isaac Wilkinson dated 1751 is interposed between the two passages. Mining: Carlisle R.O., D/Lec/60/26.

116. P.R.O., C 54/6160 nos. 3-6.

117. Gross 2001, *passim*; Namier 1930, 24 44-5.

bringing water from the river, powering a clay mill, a chafery, two sets of stampers and two hammers.[118] The process involved three successive fining processes: first the iron was granulated or cast into thin plates or 'flourished' in an ordinary refinery using a pitcoal fire (which had the effect of removing silicon from it) and was then stamped and washed to remove cinder; secondly it was heated in fireclay pots with a flux, thereby removing sulphur; and finally it was heated in a pot (without any flux) to decarburise it, after which the resultant 'loop' was forged with a hammer in the usual way.[119] A somewhat similar process was patented by John Roebuck of the Carron Company in Scotland.[120]

John Wright and Richard Jesson of [West] Bromwich Forge simplified Wood's process in 1773 by replacing coal with coke, thus eliminating the stage of the Woods' process where a flux was needed. Their process, using pots, seems to have been adopted at a number of ironworks in the Midlands during the late 1780s, shortly before the patent expired. The air furnaces in which it was conducted were known as melting fineries. Until 1785, the patent was probably only used at the patentees' works at [West] Bromwich Forge and Wrens Nest at Linley, north of Bridgnorth.[121] From about 1785 melting fineries were built at various ironworks mostly in the west Midlands. The numbers of them appear in the 1790 ironworks list, and this information will be used as the basis for an estimate of output in chapter 6. Pots (for this process) were being used at Horsehay and Coalbrookdale until 1798 and to a modest extent thereafter.[122] The production of 'stamp iron' began at Upper Mitton Forge in 1795, and increased output there from 450 tons per year in 1795 (made in traditional fineries) to almost 1300 tons per year in 1799, apparently without significant expenditure on new plant.[123] Jesson simplified the process further in 1783 by abandoning the use of pots in favour of piling his refined iron. The use of 'piles' (fireclay tiles) began at Horsehay in February 1798, just after Jesson's patent expired, but this seems to be related to the adoption of puddling rather than Jesson's improvement to the stamping process. Nevertheless the use of piles was a temporary phase at Horsehay, the numbers of them used being much lower from 1800. The conversion to puddling increased output from six to eight tons per furnace per week. 'Stamped iron' production under the name of 'buzzing' probably remained in use at Coalbrookdale and Eardington in Shropshire until at least 1812.[124]

The puddling process, which eventually replaced all its predecessors was developed by Henry Cort of Fontley, near Fareham (Hants.), but a somewhat similar process was patented by Peter Onions, also in 1783. The latter is said to have worked for William Reynolds (of the Coalbrookdale Company) at Ketley in 1784, but his address in his 1783 patent specification was 'Myrther'. He was probably connected with the Dowlais ironworks at Merthyr Tydfil, though he was at the associated Pentyrch Forge in 1788. Accordingly his improvement to the process was probably a further development of the processes of the Cranages and of Wright and Jesson.

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118. Gross 2001, xx-xxi
119. Morton & Mutton 1967, 723-4; Gross 2001, 70.
120. Morton & Mutton 1967, 724.
121. Morton & Mutton 1967, 725-6; Bromwich: Dilworth 1976, 47-9; Wrens Nest: *V.C.H. Shrops.* x, 352.
122. Mott 1959b, 48-50; Morton & Mutton 1967, 725-6; 1790 list.
123. SW a/c.
124. Mott 1959b, 49-53.

Table 3.1 Yields from pig iron for Cort's and other new processes

Cort trials/table

Both Cort and Onions eliminated the granulation and washing stage of the previous processes, removing the slag (which was lighter) instead by stirring the molten iron in the furnace with an iron rod, a process known as puddling. Onions' method differed from Cort's in that Onions used a forced blast.[125] Henry Cort's other great achievement was the introduction of rolling into the production of iron (as opposed to cutting or reshaping otherwise finished bar iron), something that will be considered further later in this chapter. After the initial shingling under a hammer to consolidate the bloom, it was passed through grooved rolls, which on successive passes through different grooves gradually reduced the cross-section of the bar. Cort's second patent (of 1784) combined puddling and rolling. This became the most important process for making malleable iron during the Industrial Revolution.[126] Rolling will be discussed in a later section.

Cort demonstrated his process in a number of places, but ironmasters were evidently not generally willing to take out licences for it,[127] probably because the new process was not then achieving better yields than by stamping (see Table 3.1). In 1787 Cort tried again, asking a royalty of 15 shillings per ton for iron made by his methods. In May 1787 he agreed a rate of 10 shillings with Richard Crawshay, who erected six 'Corts fur.' and a rolling mill at his works at Cyfarthfa in Merthyr Tydfil and was making 15 tons per week in June 1787, 20 tons per week a year later and perhaps 80 tons per week in the early 1790s.[128] In 1788, Crawshay proposed that the royalty should be reduced to five shillings. John Cooke of Kilnhurst Forge near Doncaster expressed an interest in the process around this time, as did Mr Gibbons, who had recently taken over Cradley Forge near Stourbridge.[129] However, the process was apparently only in use at Fontley and Cyfarthfa when the 1790 list was prepared. Some of the blooms made at Cyfarthfa were rolled by Folliot, Scott & Co. at Rotherhithe, but they ran into difficulties, partly at least due to the poor quality of the blooms supplied.[130] Other evidence suggests the process may have been used at Penydarren (also at Merthyr Tydfil) from 1788, at Wilsonstown in Scotland from 1789, and possibly also at Wortley by 1790.[131] At this point Cort ran into severe difficulties as a result of the death of Adam Jellicoe, a relative of his partner Samuel Jellicoe. Unknown to Cort, money that Adam had lent to Cort consisted of funds in his hands as a naval paymaster.

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125. Patent 1370 (specification); Morton & Mutton 1967, 726-7; Mott 1985, 13-15; Evans 1990, xiv nos. 71 95; Trinder 2000, 46. Onions was a brother-in-law of John Guest, the Dowlais manager, and his original patent is among their archives: Elsas 1959, 186-7 245. Guest seems to have recruited others of his Shropshire relatives for Dowlais, including one of my Firmstone ancestors: King *c.*1953, probably based on parish registers.

126. Morton & Mutton 1967, 724-6; Mott 1959b, 47-54 *passim*; Mott 1985, 27-46.

127. Places where it was demonstrated included Pitchford on 10-11 Nov. 1784, Wednesbury Field Forge on 24-26 November 1784, and Ketley on 15 Dec. 1784: Staffs. R.O., D 694/1/12/36. It was also demonstrated in 1784 near Newcastle, where Landell & Chambers (of Derwentcote Forge) and Hawkes & Co. apparently took out licences for it: Robinson & McKie 1970, 140-3 151. Hawkes & Co. seem to have built Lumley Forge on the strength of this, and also to have leased land for a rolling mill, but it appears that no rolling mill was erected: Sandbeck estate office (Maltby), MTB/A27/2-3 MBT/A50/1 & 15 EMS/16/10 EMS/40, 36-7. However the 1790 list only mentions balling furnaces at these places, and they may therefore only have been recycling scrap, perhaps under Cort's first patent. Exchanges of views (prior to the appearance of Alexander 2002) between Eric Alexander and myself on the subject matter of this paragraph have been mutually profitable.

128. Science Museum Library, Weale mss., 371/3, 187-96; 1790 list.

129. Science Museum Library, Weale mss., 371/3, 194-5 202.

130. Evans 1990, 6-31 *passim*.

131. Hyde 1977, 91. The sources for the first two are the Weale mss. The evidence in the case of Wortley is less clear. It may be based on a reference to 'a rolling mill heretofore used as a tin mill' in a lease of 1793. The 1790 list mentions four fineries, a tinmill and various other plant. This may suggest that the process was transferred to Wortley after Crawshay's partnership with James Cockshutt was dissolved in September 1791, upon which the latter presumably returned to the family forge at Wortley: Sheffield Archives Wh.M. 590; 1790 list; *cf.* Evans 1990, 118 181 and *passim*.

Samuel paid the firm's debt and thus obtained the firm's assets, but the Navy Board, on which the patent rights had devolved, did not seek to enforce them, so that the patent in effect lapsed.[132] The process was by 1797 evidently in use at Ketley, one of the places where it had been demonstrated in the late 1780s,[133] but to what extent it was used elsewhere during the 1790s remains unknown.

Cort's process was in fact only suitable for fining white cast iron, which is low in carbon and silicon. This may have been the problem that Folliot, Scott & Co. experienced. In order that ordinary grey pig iron from the blast furnace could be used, preliminary refining was needed. The refinery (or running out furnace) was a coke-fired hearth in which the pig iron was laid. Air was blown down into the charge for about two hours, melting it in an hour and a half and then oxidising the silicon, which entered the cinder formed in the process. The iron was then run out into an iron trough, from which the cinder (which floated on the iron) was removed by lowering a dam at the end. The white iron thus produced, now known as refined iron or finer's metal, was hard and brittle, but the ideal charge for the puddling furnace.[134] This process was not dissimilar to the first stage of many of the earlier processes, but was evidently not identical, as its nature had to be demonstrated to the workmen at Horsehay in 1797.[135] This process may have been devised by Peter Onions, as Richard Crawshay expressed the view that 'patent blooms' should be made white, as Onions was doing at Pentyrch. Finer's metal was certainly made at Pentyrch by 1791.[136] The combination of this with Cort's development of puddling and rolling provided an effective means of producing bar iron from any kind of pig iron, and was a great success. Nevertheless to produce the best iron (as opposed to common iron), at least in some places, a further stage was included. Instead of puddled balls being shingled under a hammer into halfblooms, the iron was stamped into a plate which was then broken into pieces by a machine. The pieces were then examined and sorted according to their quality, piled on 'slate stones', and heated in a balling furnace to welding heat, at which they readily united. Only then was the iron shingled into a halfbloom and rolled. Finally iron might be finished under a light planishing hammer.[137] Puddling was widely adopted during the 1790s and 1800s. Events at Horsehay have already been mentioned. John Knight & Co. in the Stour valley replaced stamping at their Mitton Forges with puddling in 1799. Their Wolverley Old Forge began puddling shortly after, but within a few years it was being used exclusively for heating and rolling blooms made elsewhere. The date 1799 is significant because Cort's second patent expired in June 1798.

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[132]. 1790 list; Mott 1985, 57-64. Cort's Fontley Works do not appear in the 1790 list, perhaps because they were temporarily out of use due to Cort's bankruptcy. However they came back into use subsequently in the hands of his partner, Samuel Jellicoe: Hants. R.O., Land tax, Titchfield (Sarisbury).

[133]. Mott 1959b, 50; 1985, 48-9.

[134]. Gale 1966, 30-40.

[135]. Mott 1959b, 50.

[136]. Evans 1990, xiv nos. 71 95; the process must have been an improvement to Onions' patent, as it does not seem to be mentioned in his specification: Patent specification, no. 1370.

[137]. This description (in the Weale manuscripts) seems to be based on one by Joseph Dawson of Royds Hall in Yorkshire, a partner in the Low Moor Ironworks at Bradford: Science Museum Library, Weale mss., 371/2, 421-4. It is part of a description of iron production (*ibid.*, 408-27), other versions of which appear at *ibid.*, 428-35 and 504-11. A covering letter from Dawson is at *ibid.*, 480ff and a draft of James Weale's reply at *ibid.*, 512ff. Cort's specification made the additional balling stage optional: Mott 1985, 37-8 (quoting patent specification).

The advantage of the new processes was that they did not require any charcoal. However the disadvantage of the early ones was that a lot of pig iron was needed. A figure of 32 *cwt.* pig per ton of bar iron is frequently quoted for potting and stamping. This figure comes from an estimate dated 1787, which formed the basis of the discussions between Henry Cort and Richard Crawshay in May 1787. That yield was presumably one provided by Crawshay. Cort claimed that his process would produce a saving in cost by a better yield, producing nearly 23¾ *cwt.* rather than a ton of iron from the same materials, and that the iron would be equivalent to Swedish, selling at £22. 10*s.* 6*d.* short weight rather than £16 per ton long weight for mill bar. Cort was accordingly claiming his process required 27 *cwt.* of pig per ton bar.[138] However, the yield at Horsehay, when it was using the potting and stamping process in 1796 and 1797 was 29.6 *cwt.* per ton,[139] which suggests that Cyfarthfa was still using the process Charles Wood had brought there in the 1760s, rather than the improved processes of Wright and Jesson. After Horsehay went over to puddling in 1798, the yield was consistently below 27 *cwt.* per ton, as in Cort's calculation ten years earlier. That is about equal to the best yield achieved using charcoal fineries.[140] Further developments took place subsequently, including the so-called 'wet puddling' process where iron oxide was added to the puddling furnace charge,[141] and Bessemer's process for producing mild steel from pig iron, which has ultimately led to mild steel replacing wrought iron for most purposes.[142] However, these belong to a period beyond that of this study.

A testimony to the quality of puddled iron may be found in the attitude of the Navy Board to it. They had bought bar iron for use by their smiths since the 1720s, but this had almost all been Swedish, of which a considerable proportion was the best Swedish iron, known in England as oregrounds iron, and much of it the best marks (*i.e.* brands) of that.[143] Cort's iron was bought by the Navy during the 1780s,[144] but it is not clear if this continued beyond Cort's bankruptcy. In 1804 William Taitt (of Dowlais at Merthyr Tydfil) and John Knight each had a naval contract for 190 tons of British iron, which was possibly not quite the first as the accounts of John Knight & Co. indicate their sales to the Navy began in 1799/1800 with one of 12 tons, probably as a trial, followed by almost 200 tons the next year.[145] In 1807 there were complaints as to the quality of certain second oregrounds iron (from Sweden), and when the importers were unable to fulfil the Board's demand that all its Swedish iron should be first oregrounds, the Board apparently decided that the whole 1362 tons wanted for 1809 should be British. This is likely to be a reflection of the improved mechanical properties of the iron, as a result of its having been rolled rather than forged into bars.

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[138]. Science Museum Library, Weale mss., 371/3, 181-2; cited Mott 1959b, 50; Hyde 1977, 87-8. An even worse yield (35.2 *cwt.* pig per ton bar) is also quoted by Hyde (*Ibid.*) for Cyfarthfa, probably from Scottish R.O., Melville Castle Muniments, GD 51/10/17.

[139]. Mott 1959b, 50-3.

[140]. Mott 1959b, 50-3; Hammersley 1973, 604.

[141]. Gale 1966, 66-8; 1967, 62-5; 1969, 46-9; Birch 1967, 191-2.

[142]. Barraclough 1990b; Gale 1966, 100-1; 1967, ch.6; 1969, ch.6; Birch 1967, ch.14; Smith & Gale 1987. The 'Real Wrought Iron Company' in America is said to produce iron in small quantities. The preserved open hearth furnace at Ironbridge Gorge Museum is understood not to have operated recently. Wrought iron is today only used where an authentic material is specified for the repair of an iron artefact in a heritage context.

[143]. King 2003. The Board also bought ready-made ironware and nails from ironmongers. Of this the nails and some of the ironware were certainly made partly of English iron.

[144]. Mott 1983, 42-46; Evans 1990, no.115.

[145]. King 2003 from P.R.O., ADM 106/3621, 5 61-2; ADM 106/2668, 26 Nov. 1804.

Nevertheless, oregrounds iron continued to be imported for conversion to steel, because good steel could not be made unless the iron had a very low level of impurities.[146]

Steam Power in the forge process

For most of the period covered by this thesis the only source of artificial power had been from the water-wheel. This changed during the 18th century with the invention of the steam engine, but it was only in the 1780s that this began to make a significant difference in the iron industry. The older Newcomen (or common) engine was too slow for most purposes other than pumping water. However John Wilkinson, who supplied the cylinders for many of James Watt's early steam engines (with their separate condensers), was keen to have a steam hammer. An attempt to build one (probably driving the hammer direct from the engine) failed in 1777, as it knocked itself to pieces. Rotary motion from a steam engine by means of a crank was devised in 1779 by Pickard. Partly to avoid infringing Pickard's patent and partly for the benefit of its flywheel effect, James Watt produced a 'sun and planet' motion, with the drive from the engine being applied near the rim of a flywheel. This provided rotary motion, which could be used to drive a wide range of machinery, including turning a rolling mill or a wheel with cams for lifting a forge hammer. John Wilkinson had such an engine in the forge at his Bradley works (at Bilston) in 1783, and another was set up at Horsehay in Shropshire the following year. They were rapidly followed by others, including the Union ironworks and the King and Queen ironworks, both at Rotherhithe. The latter, belonging to Gardner, Manser & Co., experienced considerable difficulties with their mill and with the Boulton and Watt steam engine that drove it.[147]

The steam engine was the main source of power for making iron during the Industrial Revolution, including around Birmingham. However it was not a lack of power that had prevented the iron industry from expanding, but the need to rely on charcoal. Though the convenience of being able to set up a steam engine almost anywhere, rather than only where there was an unused fall of water, no doubt assisted industrial development, it was probably not the key factor. Nevertheless it is clear that steam engines did play a significant role in that expansion. It has been argued that there was a power crisis in certain industrialising areas during the Industrial Revolution.[148] However recent work has suggested that this was probably only a fairly local one, since there was ample unused water-power available in the wider region.[149] Nevertheless, much of the potential power supply lay outside the coalfields that provided the raw materials for ironmaking. Accordingly, without

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[146]. King 2003 from *inter alia* N.M.M., CHA/N/1, 119ff.; SW a/c; P.R.O., ADM 106/1655, John Wilson & sons; ADM 106/2672-4, *passim*. Note also trials carried out by the Navy of the strength of three kinds of British iron in 1807: P.R.O., ADM 106/1655, John Wilson & Son to Board 27 Jul. 1807.

[147]. Dickinson & Jenkins 1927, 145-64; 247-9; Tann 1970; 1981; von Tunzelmann 1978; Rolt & Allen 1997. Note also the plan of the King and Queen Ironworks printed by Tann (1970, 82); *cf.* Birmingham Archives, B & W box 36/13.

[148]. Pelham 1963; Chapman 1971. The latter was concerned mainly with textile manufacture.

[149]. Gordon 1983. R. Gordon estimated the power available over a large area of Central England, and suggested that there was substantial unutilised power. The case made by Pelham and Chapman (see previous note) nevertheless remains correct, but only in respect of certain small heavily industrialised regions, such as parts of Lancashire, Yorkshire and around Birmingham. However Gordon has substantially underestimated the amount of water power in use, as he has failed to take into account certain significant users of it, including the iron industry and corn milling. Nevertheless it is apparent that mills in purely rural areas, remote from the main manufacturing areas were mostly corn mills: see histories of mills in *V.C.H.*, *passim* and the surveys by Gordon Tucker, D.T.M. Booth and others in *Wind and Water Mills*; Booth 1978; Coates & Tucker 1978; 1983.

the steam engine the expansion of the iron industry might still have happened, but the need to carry raw materials and semi-finished products to places where there was power to drive forges and rolling mills would significantly have increased the costs of the industry.[150]

Water-power in manufacturing processes

What has been said above is almost entirely concerned with the production of bar iron, but a bar of iron was not a consumer good. Bar iron was instead the raw material for the manufacturers, who produced consumer goods. A great deal of manufacture involved purely manual processes, but artificial power was nevertheless used in some cases, principally in the preparation of their immediate raw materials from bars of iron. These processes mostly fall into two groups, forging and rolling. However the earliest, the sharpening of edged tools, is something of an exception, as it is neither of these, and follows manual processes, rather than preceding them. In these, the water-power was used to turn a grindstone. One of the earliest such mills so far identified was near Witton (now in north Birmingham). The mill was occupied by 1510 by a man who was described in 1518 as a bladesmith, though this was not called a blade mill until 1582.[151] Over the following centuries, such mills were built in large numbers particularly around Birmingham and the Black Country, and also near Sheffield where they are known as cutlers wheels, scythesmiths wheels, and so on.[152] There were sword mills at Shotley Bridge in County Durham and scythe mills in south Derbyshire as well as a few elsewhere,[153] but the Crowleys' works at Swalwell and Winlaton near Newcastle had 'blade mills'.[154] Nevertheless, blade mills (by whatever name) were quite scarce, except around Sheffield, Birmingham, and the Black Country.

Forges and Tilts

As explained above, finery forges usually had belly helve hammers, which were lifted between the pivot and the head. However for later stages in the processing of iron, tilt hammers were often preferred. These were lifted by striking the tail of the hammer downwards, in some cases with a strike rate of 240 per minute.[155] This rapid strike rate was particularly suitable where the work-piece was relatively thin and would thus cool

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150. This is similar to the case made by R. Szostak (1991, ch.3), who argued that transport improvements in Britain were crucial to the expansion of the iron industry, but that argument fails (as mentioned in chapter 1), because it was generally not necessary to transport raw materials over significant distances in order to produce iron. However without the development of the steam engine, his case might have had some merit.

151. *V.C.H. Warws.* vii, 257. The existence of a scythemill at Chaddesley Corbett (Worcs.) in 1481 is reported: Simmonds 1980, 41. I have not verified the source for this.

152. *V.C.H. Warws.* vii, 253-69 *passim*; *V.C.H. Staffs.* xx, *passim*; Dilworth 1976, *passim*; Frost thesis, 576-8; Crossley 1989, *passim*.

153. Sword mills: King, *North*, from Jenkins 193; Richardson 1973; Atkinson 1987; Hughes 1952, 59-62; *Northumberland County History* vi, 302-3; and Durham U.L., HC I and HC II, *passim*. There were in fact two mills at Shotley Bridge, the other two suggested by Richardson (1973, 60) were the same ones at other dates. Scythe mills in S. Derbs.: Hey 1990, 359, citing I.S.W. Blanchard, 'Economic Change in Derbs. ...' (Ph.D. thesis, London, 1967), 356-7.

154. Flinn 1955, 258.

155. The Finch Foundry at Sticklepath near Okehampton has two hammers, a steeling hammer depressed by 16 cams on each revolution of the water-wheel and a plating hammer with 12 cams: this gives a striking rates of 240 and 180 per minute when the water-wheel was running at 15 r.p.m.: Barron 1983?, 15-16.

rapidly. The earliest application of the tilt hammer in Britain seems to have been in wiremills. Wiremills were relatively scarce, the earliest in Britain being that built at Tintern in 1566 by the Company of Mineral and Battery Works. The iron used for this process was made by the osmond process, mentioned earlier. This produced an osmond, a ball of iron, which was then drawn out into a small bar using a tilt hammer.[156] The bars were reduced to rods using straining hammers, rods that 'drew hollow' being sold to nailmakers. The good rods were then made into wire by drawing them through holes of successively decreasing size in a drawplate. The power for drawing the wire was provided by a water-wheel, the wiredrawer gripping the end of the wire with tongs attached to the wheel. Tintern was for many years the only wiremill in Britain, but it was joined in 1607 by one at Whitebrook, also in the Wye valley and belonging to the same company.[157] This was followed by one at Thurgoland near Barnsley, sometimes known as Wortley old wiremill, probably in the mid 17th century,[158] and in the early 18th century by several in the West Midlands belonging to Turton and Webster. Steel wire may also have made by the 1750s, as Joseph Webster the wire-maker was having steel slit at (Nechells) Park Mill near Birmingham, and John Kettle the Birmingham steelmaker partnered John Ryland in Prestwood (or Halfcot) wire mill in Kinver from 1759. Joseph Webster was apparently making wire from crucible steel in 1807, but his large scale production of steel music wire only began in the mid 1820s.[159] Ryland and his successor J.W. Phipson were probably members of the family who made pins in Birmingham.[160] The uses of the resultant wire included making woolcards, pins,[161] and needles. By 1730 the needle industry of Redditch and Studley was using 'needle mills' for pointing and scouring the needles. Though research has been carried out on this industry,[162] neither the distribution and dates of use of the mills nor the sources of the needle wire they consumed seem to have been adequately determined.

Water-powered hammers were also used to produce iron plates. There was an armoury mill at Lewisham (Surrey), described in 1646 as 'formerly used for grinding armour and other implements', but little is known of it.[163] An iron battery for the manufacture of armour plate was set up at Dartford

[156]. Schubert 1957, 300-2; Donald 1961, ch. 7-8.

[157]. Donald 1961, 86ff.; Tucker 1973; 1978; Paar & Tucker 1975.

[158]. Elliott 1988, 137; Crossland 1994, 218; Sheffield archives, SpSt.64713/6, will of William Wood (d. 1689). The date of this wiremill is uncertain: '1624' has been claimed, on the basis of a date plaque reported to be on the building, but this is probably too early for it to have become a wiremill, as the Company of Mineral and Battery Works monopoly was then still being enforced.

[159]. Horsfall 1971, *passim* esp. 28-36 65-6 70-2; Webster 1880, *passim*; SW a/c (Park Mill); they also had a mill at Halfcot in Kinver: *V.C.H. Staffs.* xx, 147. Horsfall (1971, 35-6) claimed Joseph Webster made steel wire by 1766. This is due to a misreading of Webster (1880, 75), who says pianos were first made in London in that year using German wire. His father had begun making steel music wire in about 1827, and captured the market for it within a few years.

[160]. *V.C.H. Staffs.* xx, 147; Phipson also succeeded Ryland at Weybridge Forge in Belbroughton: Worcs. Land tax, Belbroughton (Belbroughton yield). This must be the family who made pins in New Street, Birmingham, where Thomas Phipson succeeded his father-in-law Samuel Ryland in 1785: Gill 1952, 96; *V.C.H. Warws.* vii, 102-3; Allen 1929, 19n; Hopkins 1998, 9 50. The standard accounts of these works describe the process as a purely manual one, but the association with mills producing wire suggests that this is misleading. No doubt those observing it only reported the final stages, carried out in Birmingham.

[161]. Donald 1961, 103; Unwin 1904, 164-71; *Remembrancia*, 519-26.

[162]. Morrall 1854; Rollins 1966; 1984, 48-9; Jones 1978; 1984. Needles were also made in Alcester: Lane 1977, 231-7. For the mills: Booth 1978, 29-33; Rollins 1966; 1984, 48-9; Tucker 1982, 8-9. There have been a total of almost 20 mills (though not all at the same time) in a region on the border of Worcestershire and Warwickshire including several in Stoke Prior and Feckenham. Space is not available to list them all.

[163]. P.R.O., E 317, Kent 30; Hogg 1963, 88-91 93. The description might suggest this was a blade mill.

in Kent in 1595.[164] There was in 1597 a forge making frying pans at Crayford (Kent), associated with an early slitting mill.[165] Frying pans were also produced by members of the Hallen family at Keele (Staffs.), Coalbrookdale, and elsewhere in the Midlands from the late 17th century.[166] Around the same time John Podmore used Broadwaters Forge near Kidderminster to make saws and probably also Wannerton Forge (nearby) and Holdbury Forge.[167] Street Furnace in Cheshire was converted to a forge in 1701 to produce saltpan plates for the Cheshire salt industry.[168] Another use for iron plates was the production of spades and shovels. It is not always easy to distinguish forges producing these from other plating forges or from blade mills. Indeed many may have been used for more than one process, for example by plating iron for scythes, as well as grinding them. There was a group of these in and around the Black Country. Gig Mill Forge in Stourbridge was probably a plating forge by 1721, but is first referred to as a spade forge in 1764.[169] However, particularly in the late 18th century, there were others scattered across the countryside (see appendix 17), which is hardly surprising since agriculture was a major market.[170] Nevertheless, plating forges were not plentiful.

At Sheffield there was a variety of forge known as a tilt, used 'for forging out small bars of iron and steel'.[171] These were perhaps introduced from Germany in about 1730. Among the earliest at Sheffield were Pond, Brightside, Parker, and Wicker Tilts, all of which were built in the 1730s, but certain others cannot be precisely dated.[172] Clatterbatch Forge in Stourbridge was described in 1767 as having a Yorkshire tilt for drawing steel, but it had probably been a plating forge since the 1670s.[173] Kings Meadow Forge (later Royal Forge), also in Stourbridge was built in the 1660s and was shortly after used in the course of the tinplate experiments of Andrew Yarranton and Ambrose Crowley (of which more below), but was later used successively by Sir Ambrose Crowley, Benjamin Harvey, and

164. Donald 1961, 129 from *A.P.C.* xxv, 116.

165. P.R.O., REQ 2/254/53.

166. Keele & Knutton: Plot 1686, 335; MacInnes 1986, 55; Harley (Salop.); *V.C.H. Shrops.* viii, 89; Coalbrookdale: Wanklyn 1982, 5; Mott 1957b, 85-6; CBD a/c; Hyde 1973, 54; Drews Forge in Halesowen (by 1682): Worcs. R.O., Consistory wills etc., Cornelius Hallen 1682; P.R.O., PROB 11/686, q.250; Hallen 1885, 31 46; Worcs. R.O., 705:260 BA 231 & 233; 705:382 BA 4600/2 3 & 14 etc. Swindon (from 1704): Herefs. R.O., E12/II/4/2, schedule of leases; Clatterbatch Forge at Stourbridge (by 1728): Hallen 1885, 46-7; *Aris B'ham Gaz.* 14-28 May 1764. At Harley (1658-64) the occupant, Cornelius Hallen, was a 'batterer', an occupation usually associated with brass battery works, but perhaps here refers to plating iron. For the Hallen family generally see Hallen 1885.

167. Johnson 1950, 44; 1954, 42; Worcs. R.O., Consistory wills, Edward Podmore 1708 and John Podmore 1720. I have failed to identify Holdbury Forge, but it might be Oldbury.

168. Johnson 1954, 41 48-9; Cheshire a/c; Awty 1957, 108.

169. 'The Gig Mill lease' appears in the inventory of Ambrose Crowley of Stourbridge ironmonger, suggesting that it was then a forge: P.R.O., PROB 3/20/150; *Aris B'ham Gaz.* 16 Apr. 1764. A gig mill was concerned with the cloth trade, but was prohibited in the mid 16th century. Nevertheless a few remained in use as indicated by prosecutions in the Exchequer recorded in Elizabethan and Jacobean memorandum rolls (P.R.O., E 159). Others include Churchill and Stakenbridge Forges: Pagett 1993, 30; Crompton 1991, 50; Withymoor: Crompton 1991, 14; Chandler & Hannah 1949, 100; Hinksford: Foley E12/S [box 660]; E12/S/4/2, no. 5; E12/S/113 [Forges].

170. Cleator: Carlisle R.O., D/Lec.240/misc./service agreements (1756); Whitehaven R.O., D/Lin/2/7/1-2; Whitenell (in Ulverston) (1756) and Bottlingwood (in Wigan): Lancs. R.O., DDx 379/2; Sticklepath (1807?): Barron 1983?; deed of 1807 exhibited there. I have heard that this was the latter use of Dalston Forge (Cumb.).

171. W. Fairbank, *A correct plan of the town of Sheffield* ... (1771)

172. Hey 1991, 181-2; Crossley 1989, *passim*; King. *North* from Sheffield Archives, ACM/S.377-378; ACM/S.158, *passim*

173. *Aris' B'ham Gaz.*, 14 May 1764 *cf.* 26 Dec. 1769; Schafer 1971, 30; Flinn 1962, 11 & 185; Worcs. R.O., 899:31 BA 3762/5.

then the Homfrays, probably in conjunction with their adjacent steel furnaces.[174] Unfortunately it is not possible to say much more than that these forges existed, for little is known in detail of the technology that they employed.

Another kind of plating forge was used in the production of the barrels of muskets and pistols. First the bar iron was made into long plates, known as skelps, using a forge hammer. Next the barrel was formed either by joining the two outer edges of the skelp around a rod or, for better guns, by winding it spirally round the rod. This was a manual process carried out by a gunbarrel forger. After this a mill was again employed for boring the barrel and grinding it off on the outside to remove imperfections along the seams. The mills used for this purpose were all near Birmingham, which became the centre of the gunmaking industry in the 18th century. These mills are sometimes referred to as forges but also as boring mills or just as mills. When called forges or mills, they can only be distinguished from other kinds of these by their owners being identified as gunmakers. None of these boring mills is known to have been used as such before the 18th century, and it is not known how London gunmakers bored barrels before that, when gunmaking was centred almost exclusively on London.[175] However water-powered boring mills were also used in finishing the barrels of cannon and presumably must have been used almost as far back as cast iron cannon were made. Steam engine cylinders were also bored in much the same way, after iron cylinders came into use in the 1720s, and a boring mill was set up at Coalbrookdale for this purpose in 1734.[176] There were various designs of boring mill, but that producing the best results turned the cannon against a fixed tool that was advanced on a ratchet as boring proceeded. This sort of boring mill, together with casting cannon solid (rather than with a core), was patented by John Wilkinson in 1774. However, his boring mill was not in fact original, as there was a similar one at the Royal Brass Foundry at Woolwich. As a result, his patent was revoked in 1779.[177]

Rolled iron

Tin had long been used to provide a protective coating for iron to prevent it rusting, and its application to otherwise finished iron goods had in England long been the business of the whitesmith. The application of tin to unfinished plates of iron was begun in the Upper Palatinate in medieval times and spread to Saxony in the 16th century. Tinplate was imported mainly from Hamburg to London in considerable quantities in the early 17th century.[178] An attempt was made to introduce its manufacture at Wickham in Hampshire about 1623. While the plate mill there probably remained in use for about a century, it is not clear how successful it was in making tinplate.[179] After the Restoration Andrew

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174. *V.C.H. Staffs.* xx, 60; Worcs. R.O., 899:31 BA 3762/5, copy deed of 1706 & undertaking of 1722; Dudley archives D/Pit/7/4; Perry 2001, 129.

175. There is no adequate account of the boring mills of the Birmingham area. Some are mentioned as mills (rather than as boring mills) in *V.C.H. Warws.* vii, 253-69, but in many cases (as Harborne and Hazelwell Mills) the evidence that they were boring mills depends solely on the occupiers being known makers of gun barrels: *cf.* Bailey & Nie 1978. For particular mills: Wednesbury: Dilworth 1976, 114; Maney: Birmingham Archives, j437-8; MS/13/2/12 & 23 (wills); *Aris B'ham Gaz.* 19 Jan. 1767 7 Aug. 1769 26 Sep. 1769; Land tax, Sutton Coldfield; Minworth: *Aris B'ham Gaz.*, 28 Sep. 1767; N.L.W., Picton Castle 221; *cf.* N.L.W., Tredegar 87/977; Troyal Forge or Lodge Forge, Cradley: *Aris B'ham Gaz.*, 9 Nov.1767 8 Oct. 1781; Land tax, Cradley; Hemlingford or Kingsbury Mills (in Kingsbury): *Aris B'ham Gaz.* 21 May 1781; Coleshill: Birmingham Archives, Norton 1823-9.

176. Rolt & Allen 1997, 56; Raistrick 1951, 66 132; Trinder 2000, 27.

177. Braid 1991c; Trinder 2000, 48-9.

178. Minchinton 1957, 1-3; Gibbs 1950, 399.

179. The mill was established under the patronage of the Earl of Southampton and was let in 1628 to two men including a London girdler, the guild to which tinplate workers then belonged. It is referred to as a plate mill in 1648 and as an iron mill in 1720: Hants. R.O., 5M53/511-2; Hants. R.O., wills, 1720/A96; Bartlet 1974, 4; Minchinton 1957, 4 8 249 (printing Knight 6443); Gibbs 1951a, 33-4.

Yarranton and Ambrose Crowley traced the import trade back to Saxony. When they reached there, they were able to observe the production process. On their return they carried out experiments at Kings Meadow Forge in Stourbridge and at Wilden near Kidderminster, where they experimented with rolling the plates rather than forging them (as in Germany), though a forge hammer was probably still used for part of the plating process. This led to the erection in 1670 of Wolverley Lower Mill as a forge and rolling mill. However the development of this mill as a tinplate works was inhibited by the renewal by William Chamberlaine of a patent granted to him and Dud Dudley a decade earlier.[180] The mill at Wolverley contained an ordinary forge hammer, used for drawing out blooms of iron into bars and a chafery (though no finery), a plating hammer (subsequently used to make frying pans), and a rolling mill (used to slit iron). This suggests that the intended process involved both forging and rolling, in contrast to the later process where iron was rolled hot into plates, which were then finished by cold-rolling the plates.[181] Knowledge of the process used at Wolverley was probably taken to Pontypool when the son of the slitter at Wolverley moved there. Certainly by 1697, John Hanbury had a mill rolling 'Pontypool plates' there, but this was almost certainly (untinned) blackplate, rather than tinplate.[182] Indeed the initial development (in the 1700s) of Pontypool japanned ware (consisting of lacquered iron plates) may have resulted from the a need to find a way of preventing goods made of blackplate from going rusty.[183] It is possible the second rolling stage (cold-rolling) was introduced at this time.

The other major difficulty in producing tinplate concerned pickling the plates in an acidic liquor to remove every trace of surface oxidation. Credit for improvements in pickling is generally attributed to the French chemist Réaumur in work that was published in French in 1725 and in English in 1728. However, the date when large scale tinplate production began has been a matter of controversy, some writers pointing to 1697 and others to about 1728. This can be resolved with data from the Gloucester port books, which show 'iron plates' as a regular (but minor) commodity passing upriver from 1704, but do not mention tinplate until 1725.[184] As with the introduction of coke pig iron for making cast iron goods (mentioned above) three separate technological advances were needed to produce an effective industry, hot-rolling developed in the Midlands in the 1670s, then cold-rolling probably at Pontypool, and finally improved pickling in the 1720s. This led to an expansion in the production of tinplate in the succeeding decades. Some of the earliest mills in England were quite scattered, at Woollard (Somerset), Oakamoor (Staffs.), Bringewood (Herefs.), and Wortley (Yorks.). However most of the new mills of the 1740s and 1750s were in south Wales, at Kidwelly, Carmarthen, Ynyspenllwch (Swansea valley), Ponthir (near Caerleon), Melin Griffith (near Cardiff), and Ynysygerwyn

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180. Minchinton 1957, 6-7; Brown 1988; King 1988. Yarranton's colleague was almost certainly the father of Sir Ambrose Crowley, the great ironmonger in London and near Newcastle. John Chamberlain (various spellings) had been an agent for the Earl of Southampton in managing and then lessee of the Earl's ironworks at Titchfield and Sowley from 1601 until 1635. It is therefore possible that William Chamberlaine was connected with the mill at Wickham, but there is no evidence of this: Bartlet 1974, 1-2; King 2002b, 48-9. I am grateful to Jeremy Greenwood for further details on Sowley.

181. For the later process see Minchinton 1957, 250-3; Jenkins 1995, 63-142; for Wolverley Lower Mill see King 1988.

182. Minchinton 1957, 10. This has been claimed as a beginning of tinplate manufacture in Britain, but the evidence points to the product being not being tinned. Certainly tin is not mentioned among the costs of production about 1704: Schubert 1957, 429. The confusion may have arisen from Edward Lhwyd's description of the plates made being 'as thin as tin': *Phil. Trans.* 27, 468 quoted Jenkins 1936, 220 and Gibbs 1951, 49-51.

183. For this industry see John 1953, esp. 28-35. The suggestion as to the reason for its development is mine. At a later period japanning was primarily decorative and often applied to tinplate.

184. *Gloucester Portbooks database.*

(Neath valley). Subsequently, south Wales was the main focus of the industry, and remained so until recent times.[185]

Yarranton and Crowley probably first thought of introducing rolling into the tinplate production process because they were familiar with the slitting of bar iron into rods for nail making. Slitting was a two stage process, first a piece of iron cut off a bar (using water-powered shears) was passed between flat rolls to form it into a plate. Then it was passed between grooved rolls (cutters or slitters), which cut it into rods. Contemporary illustrations indicate that a mill normally had two sets of rolls and two waterwheels (usually one each side of the building). In one arrangement one wheel turned the lower roll of each set directly and was connected through a cog mechanism to drive the upper roll of the other set. In others both rolls were driven by cogs.[186] At a mill at Halesowen in 1786 the slitters were '10 inches in diameter of iron plates with steel edges; 6 plates in the upper slitter and five in the under with two thick side pieces for slitting ¼ inch iron; half that number for ½ inch iron, that is ¼ inch slit 13 pieces at once time, ½ inch 7 at once, ¾ inch 5 at once, inch 3 at once'.[187]

This process was introduced by Sir Bevis Bulmer in 1590 when he brought Godfrey Box of Liège over to build and run a mill at Dartford.[188] A second slitting mill (which was also used to make plates for frying pans and dripping pans) was established at Crayford in about 1597.[189] The first slitting mill in the Midlands was built by Walter Colman and Thomas Chetwynd at Rugeley in about 1610 and was copied from the one at Dartford, which they had visited several times.[190] The next was Hyde Mill in Kinver, built by Richard Foley in 1627. There is an oft-repeated folktale about how 'Fiddler' (or Flautist) Foley travelled into Germany (or Sweden or Russia) to discover how iron could be slit. If this had any basis in fact, it is probable the musician was actually Richard Foley's brother-in-law, George Brynley, particularly as the earliest version of the legend refers to his family, not the Foleys. That family managed Hyde Mill for over a century after it was built, and owned its freehold from 1648. Indeed the person responsible for the discovery of new technology (albeit by industrial espionage) is far more likely to have exploited it by physically building a mill and running it himself as its slitter, rather than by paying some one else to do it. Furthermore, Richard Foley was already an important ironmaster by 1625, and would not have the time to spend that the tale implies in wandering around Germany (or Sweden or Russia) to discover how to slit iron, but might well have financed it. Indeed, espionage in Germany seems relatively improbable when the process was already known in England, including somewhere as close as Rugeley.[191]

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185. Brooke 1944-8; BW a/c.

186. Birmingham archives, B & W box 30/13; Jenkins 1936, 9-23 [=Jenkins 1918]; Schubert 1957, 304-11; Tann 1970, 74; Tylecote 1992, 105 143-4. The illustration, reproduced by Schubert (1957, 309) and Jenkins (1936, 20) from Emerson (*The Principles of Mechanicks*, 1758), cannot be quite correct, as it would require streams to be running in opposite direction on the two sides of the mill, which would be difficult in practice. No doubt there were variations in precisely how the mechanism was set up.

187. Birmingham archives, B & W box 30/13.

188. Jenkins 1936, 13-14.

189. P.R.O., REQ 2/254/53.

190. King 1999a, 71-2.

191. King 1999a, 62-3 and *passim*. The earliest written version of the legend comes from the manuscript history of Dr. Richard Wilkes of Willenhall, probably written in the 1750s. For Hyde Mill generally see Cooksley 1981.

Hyde Mill was followed by Bustleholme Mill (between Wednesbury and West Bromwich), Wilden Mill, and Cookley Mill (on the river Stour respectively below and above Kidderminster), all built before 1650.[192] The greatest concentration of such mills was in and around the Black Country. The Stour valley was particularly advantageous geographically for such mills, as it lies between the river port of Bewdley and the manufacturing Black Country. In the late 18th century there were no less than five slitting mills in the parish of Kinver, most of them of the largest size.[193] Mills in that area often operated under a sort of putting out system, by which an ironmaster or ironmonger sent bar iron to the mill for slitting, receiving back the same iron in rods on payment of an appropriate fee.[194] This applied to Hyde Mill from 1647, to Wilden and Bustleholme Mills in their early years, to Stourton and Wolverley Lower Mills from 1703, and to Bustleholme again from 1709.[195] Apart from the cost of the mill itself, which might well be rented from a landlord, a mill owner operating under this system required little capital, and little management time was needed organising supplies and sales. Accordingly it was entirely feasible for the slitter to manage the mill, as was done by Richard Fisher at Cookley in 1653.[196] He could even own the business, as John Cooke did at Stourton from 1703 when, following Richard Wheeler's bankruptcy, Philip Foley found he could not persuade anyone else to lease the mill.[197]

Though the greatest concentration of slitting mills was around the Black Country (see appendix 16), there were a number further afield, scattered mainly across the northern Midlands. These were usually owned by an ironmaster who almost certainly used them mainly (or exclusively) to slit the iron made in his own forges. This applies to Tibberton, Tern, and Ryton Mills in Shropshire, though not to Tern in its earliest years.[198] It also applies to Consall, Oakamoor and Rugeley in Staffordshire between 1688 and 1710,[199] and to Colnbridge, Kirkstall and Renishaw in Yorkshire and Derbyshire, to Pontymoel Mill at Pontypool and to New Weir and Lydney Mills in Gloucestershire. Kilnhurst and Rotherham Mills in Yorkshire fit the pattern too, but also cut some imported iron for third parties.[200]

A similar pattern was sometimes found in the West Midlands. Bustleholme and Wilden Mills while owned by Philip Foley in the 1670s were mostly slitting iron for him, though there were also a few outside customers.[201]

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192. King 1999a, 72-3; Bustleholme (1628): Dilworth 1976, 59-60; P.R.O., C 2/Chas.I/F15/12; Wilden (*c.*1633): P.R.O., E 112/258/144; Cookley (*c.*1639): P.R.O., C 8/192/54.

193. *V.C.H. Staffs.* xx, 145-8.

194. I have explored these arrangements in detail in King 1999b, 72-4.

195. Hyde: Cooksley 1981; Wilden: P.R.O., E 112/258/144; Bustleholme: Dilworth 1976, 58-64; Stourton: *V.C.H. Staffs.* xx, 145 from Herefs. R.O., E12/VI/KL/22 *cf. ibid.*/16; Wolverley Lower Mill: SW a/c; King 1988, 109. That they were operating under a putting out system is in most cases a deduction, on the basis that their owner was not a producer of iron, but there is direct evidence for Bustleholme about 1634 and from accounts in the case of Hyde Mill in the 1670s and 1690s and for Stourton, Hyde and Wolverley Lower Mills after 1725: P.R.O., C 2/Chas.I/F15/12; Foley a/c; SW a/c.

196. P.R.O., C 8/192/54.

197. Herefs. R.O., E12/VI/KL/16 22.

198. Trinder 2000, 24-6; 1996, 15-17; 1973, 17 29.

199. Staffs. a/c.

200. King, *North*; King 1999b, 73-4; Hart 1971, 44-5; Coates & Tucker 1983, 54-7.

201. Schafer 1978, 66 89-90; Foley a/c.

A few decades later the relatively short-lived mill at Lower Mitton was probably also slitting its owners' iron.[202] The close association of more than half of the mills mentioned with forges is hardly surprising since they were located within or adjacent to forges. A stage in the transition, towards the system of slitting for others, can be identified in the organisation of the Foley Staffordshire Works, for the slitting mill at Oakamoor Forge was not used after 1694, and that at Consall Forge only slit 10 tons per year (probably for local sale) after 1708. Both forges had previously slit the most of the iron they made, but subsequently sent most of it to Rugeley for slitting.[203]

There is a further group of slitting mills, mainly located in the Trent valley and built from the 1730s onwards during the time when Russian iron was being imported in large quantities. These included mills at Derby, Wychnor, and Borrowash, which lay between Hull, the port of import, and the Black Country where the iron was made into nails.[204] However certain of these also made hoops for barrels (see below). Though not in the Trent valley, Sampson Lloyd's Birmingham Mill and Francis Homfray's Gothersley Mill (in Kinver) seem to belong to this class, although Francis Homfray also made iron himself nearby at Swindon.[205] The connection of certain mills with Russian iron is demonstrated by Graffin Prankard's accounts for his import trade in iron through Bristol, for almost all the major buyers of Russian bar iron other than his fellow Bristol iron merchants were the owners of slitting mills. These buyers were John Brindley of Hyde Mill, John Machin who had Stanton's Mill near Birmingham, and Edward Kendall of Stourbridge who had Cradley Mill, as well as Sampson Lloyd and Francis Homfray (already mentioned).[206] This slitting of Russian iron was clearly not a putting out business requiring little capital, but those just named (except perhaps Brindley) were either ironmasters or ironmongers rather than independent mill-owners. In the same way, Middlewood, Owlerton and Pondmill slitting mills at Sheffield were not associated with any other forge and must be presumed to have processed imported iron.[207] Similarly, though there were forges at the Crowleys' Winlaton, Swalwell, and Teams Mills near Newcastle, the choice of Newcastle was almost certainly dictated by the availability of coal near a port to which Swedish iron could readily be brought. However, the Crowleys later developed the practice of sending iron from London rather than importing it direct from Gothenburg and Stockholm.[208] It was advantageous to import bar iron and have it slit in England, rather than to import rod iron, because iron drawn or hammered into bars less than ¾ inch square was considered to be manufactured iron, and so bore a higher rate of import duty than bar iron.[209] There was also a group of mills in the Mersey valley in the mid 18th century,[210] which were probably also largely processing imported iron.

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202. For this forge and slitting mill see Worcs. R.O., Hartlebury manor rolls, BA2636/21 (book for 1670 on) f.3; BA2636/21 (book 1690-1701), f.29 & 34; BA2636/22, 43775, p.27; BA2636/23, 43777, f.226; BA2636/23, 43779, f.168; BA2636/53, 44035, f.113.

203. Staffs. a/c.

204. Riden 1990; Gould 1981; King, *North*.

205. Lloyd 1972, 101-6 114-5; *V.C.H. Staffs.* xx, 146 213.

206. Prankard a/c; Hyde: Cooksley 1981; Stanton's Mill: *V.C.H. Warws.* vii, 256; Pelham 1963, 71-2; Cradley: Dudley Archives DE4/3, leases Rowley.

207. Crossley 1989, 2-3 9-10 113-4; King *North*. Some of these works had forges, but they do not seem to have been making iron.

208. For these works generally see Flinn 1962. For discussion of their trade see next chapter and King, *North*.

209. Crouch 1725, 176-7. The duty was the same on 'rod iron', 'iron drawn or hammered less than ¾ inch square', and 'all other manufactured iron'. Port books frequently described bar iron as being not less than ¾ inch square.

210. Awty 1957, 105-108.

By the 18th century there was a group of slitting mills grouped around London. These included the earliest two in Britain, at Dartford and Crayford in northwest Kent. However, the main business of such mills in the 18th century seems not to have been making nail rods but hoops for barrels. This trade probably derives from patents granted in 1678 to Thomas Harvey for making round iron for bolts and in 1683 to William Loggins for 'making several things of iron by millwork only instead of hand and hammer as sheaths, tire [tyre] for wheels, plates for fenders, half-rounds of iron for kettles and other things of constant use'.[211] A description of making hoops (dated 1785) indicates that the first stages were identical with those of other slitting mills, but the resultant rods were reheated and passed through the rolls again to flatten them into hoops.[212] The patentees were successive owners of Crayford Mill,[213] but Dartford Mill, Ember Mill (in Thames Ditton), Ham Haw Mill at Weybridge, and several other mills in Surrey and Buckinghamshire (all listed as hoop mills in appendix 17) subsequently participated.[214] Among the largest buyers of such hoops was the Victualling Board, which was responsible for victualling the Navy. The earliest traceable purchase of such hoops for naval victualling dates from 1684, shortly after the second patent. The earliest suppliers were William Pawlin (Loggins' partner at Crayford) and Anthony Tournay (a London ironmonger who imported Swedish iron).[215] Other customers for hoops no doubt included vintners and brewers. Ember Mill was in 1693 converted to make iron and brass wire by John Stapleton. This business was evidently not successful and John Hitchcock and Thomas Wethered joined him and probably altered the mill so as to be able also to roll hoops, though various brass products continued to be made for some decades.[216] In 1706 a group of London ironmongers including Anthony Tournay and James Berdoe made an agreement with Hitchcock to make 300 tons of hoops for them and 50 tons for Wethered and Walter Kent (another partner in Ember Mills). Ambrose (later Sir Ambrose) Crowley joined in it, agreeing not to sell iron hoops, probably in consideration of the other mills not making rods for nailmaking. The ironmongers and Crowley entered into a similar agreement with Charles Manning of Dartford Mill, and another with 'one Coggins' [?Loggins] for 'Crawford Mill'. These apparently contained provisos that they should be void if rival mills were set up. Manning used this clause as excuse for breaking the agreement, asserting that 'about a year after the articles [of agreement] Sir Ambrose Crowley bought a mill near Newcastle where he cut and slit iron into hoops'. This presumably refers to his purchase in 1708 of Swalwell Mill near Newcastle. Manning's action led to litigation over the agreement.[217]

From about 1705 the vendors of iron hoops to the Victualling Board were almost invariably the owners of one or more of the slitting mills around London. The main exceptions to this are sales by John and then Theodosia

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211. Patents nos 207 and 229.

212. Science Museum Library, Weale Mss. 371/4, 298. This is described as 'Raby's evidence H. Lords p.142'. Raby is probably Alexander Raby, a London ironmonger, who owned Downside Mill at Cobham and Coxes Lock Mill at Addlestone (both in Surrey): Buttriss 1985; Humphries 1954; various papers in Crocker 2000.

213. P.R.O., C 78/923/3; C 105/33/10.

214. The history of the Surrey mills is given by Potter 1982 and Stidder 1990. However I have succeeded in adding considerable further detail using P.R.O., ADM 20/35-265 (Victualling volumes) and ADM 112/162-205 and other sources, but this work remains unpublished and is too detailed to be given in full here. For Dartford Mill see *V.C.H. Kent* iii, 388. Wraysbury Mill (Bucks.) belonged to Jukes Coulson & Co. until its conversion to a copper mill in 1772 and there was another ironworks at nearby Horton: *V.C.H. Bucks.* ii, 126.

215. P.R.O., ADM/20, 35-48 *passim*.

216. Surrey R.O., G97/13/624 654; P.R.O., E 126/20, fo.174v-176v; *cf.* P.R.O., C 8/458/26; Potter 1982, 220; Stidder 1990, 116.

217. P.R.O., C 5/355/57; C 8/458/26; Swalwell: Flinn 1962, 52-54.

Crowley in the 1720s and 1730s (evidently from their Swalwell and Winlaton Mills) and by Richard Thomlinson (probably from Teams Mill also near Newcastle).[218] In 1782 the Board faced with the Thames mill-owners acting in combination approached Henry Cort (then the Navy Board's ironmonger for Portsmouth dockyard), and he contracted to recycle old hoops sold him by the Board. This gave him experience in rolling iron, which was an important step towards his successful development of his puddling and rolling process for making iron,[219] which has been described above.

Other evidence for the production of hoops outside the Thames region during the 18th century is scarce. John Hanbury recorded the cost of making hoops in 1704, but that his mills only made ten tons per year.[220] However it is not unlikely that the slitting mills near Bristol, such as Willsbridge and Combsbury (now Congresbury), may have made hoops for the wine trade.[221] When Angerstein visited Derby Mill in 1754 he noted that it made hoops, as well as nail rods for the Belper nail industry.[222] The buyers of hoops from this and other mills in the Trent valley must have included brewers at Burton, who were exporting beer through Hull to Russia and other parts of northern Europe by the 1740s, their return cargoes including iron.[223]

Unfortunately no good contemporary description has been found of the process devised by Harvey and Loggins around 1680. Its ability to produce round iron (for bolts) and half-rounds, presumably, indicates that the rolls used had hollows of the appropriate shape. Passing bars 'between two large metal rowlers, which have proper notches or furrows in the surface' is mentioned in the specification for an otherwise improbable patent by John Payne of Bridgwater, but this does not seem to have been a primary object of his patent.[224] A subsequent patent concerned with rolling was that of John Purnell dated 1766, for 'making ships bolts, large rods of iron and steel, and iron wire of various sizes'. The diagram in the specification shows rolls with gaps of different sizes. These could have been used to reduce the cross-section of a piece of iron by successive passes through the rolls, instead of cutting it lengthways as was done in a slitting mill. However the diagram shows ridges on one roll slotting into grooves on the other, which might make it difficult to feed into the mill a piece of iron of a significantly larger cross-section. Later rolling mills dispensed with the ridge and instead had grooves in each of the rolls. Purnell had a practicable process, and it was no doubt used at his slitting mill and tinmill at Framilode, which operated with his rolling mill and wiremill at Froombridge.[225] A rolling mill for round copper bolts, where the cross-section of the bar was reduced by passing it successively through smaller holes between grooved rolls was patented by William Forbes, a London coppersmith in 1783. This refers to the

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218. Vict. a/c.
219. Mott 1983, 28-29 and *passim*
220. Schubert 1957, 429-30.
221. Ellacombe 1881, 231; William Donne told the Commons in 1737 he had two slitting mills near Bristol, of which one must have been Combsbury, to which Graffin Prankard sent iron for slitting in 1734: *J.H.C.* (1737) xxii, 854b; Prankard a/c 27 Jul. 1734; June 1736; information from Mrs G. Bedingfield, citing Weston super Mare L.S.L., notes of Preb. Alex Cran, private deeds and P.R.O., PROB 11/917, will of William Donne.
222. *Angerstein's diary*, 201-2; Robson 1964.
223. *Ibid.*, 202; Owen 1978, 32-67; various Hull port books.
224. Patent 505 (and specification); Mott 1983, 34-5. The patent and specification cover several disparate ideas, some of which appear to be impracticable.
225. *V.C.H. Glos.* x, 150 164.

initial bar being made four-sided in a 'common rolling mill'. There was certainly a rolling mill for bolts at Rogerstone (near Newport) in the early 1790s.[226]

The diagram in the 1766 Purnell patent specification also shows two other features usual in later rolling mills. Firstly it shows a metal cog-wheel for linking the two rolls and ensuring that they ran at the same speed, which would render a second waterwheel unnecessary. Secondly, though not new (since it is shown in one of Angerstein's drawings), there was a metal wobbler box with a square hole matching a square section on the end of the roll's spindle, which provided some play and enabled the mill to run smoothly even if the alignment of the rolls with their power source with not quite perfect.[227] Furthermore this may be the first application of rolling to wire production. Joseph Webster was having steel for his wire slit at Park Slitting Mill at Nechells near Birmingham a couple of decades earlier, but his firm used drawplates until rolls were set up at Plants Forge in 1815.[228]

As already mentioned, Henry Cort's first rolling mill was for recycling old iron hoops into new ones. He evidently observed the similarity between the iron produced by shingling balls of recycled scrap from a balling furnace and blooms from the finery (or his puddling furnace). After shingling under a hammer, he rolled these out into bars rather than forging them.[229] This rolled iron was no doubt more homogenous and certainly more even in section than that produced with a hammer. This, along with puddling and the development of processes using coke as fuel rather than charcoal, were the technological developments that permitted the great expansion of British iron production that took place at the end of the 18th century and during the 19th. The early stages of that expansion will be considered further in chapters 6 and 8.

Conclusion

The processes described in the preceding section were all water-powered. Though steam power was available for pumping water from the 1710s,[230] it was only around 1780 that steam engines began to be applied to powering other machinery. This had to await James Watt's invention of the separate condenser, which enabled engines to operate with a faster stroke rate, and his devising of methods to convert the linear motion of a piston into rotary motion to drive machinery. However from the 1780s steam engines began to be used in considerable numbers (as mentioned above) to drive forges, to turn rolling mills, and to blow furnaces.[231]

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[226]. Patent 1381 (specification), dated 24 Nov. 1783; 1794 list. For Forbes see Harris 1992, 182ff.

[227]. Morton & Mutton 1967, 724-5; Mott 1983, 34-5; Tylecote 1992, 128; the wobbler box is shown in *Angerstein's diary*, 202. Patent 1381 (specification) also shows cogs linking the rolls.

[228]. SW a/c; Webster 1880, 74.

[229]. Mott 1983, ch. 3-5.

[230]. Rolt & Allen 1997.

[231]. Dickinson & Jenkins 1927, 146-64 245-9; Tann 1981, 6-7; Kanefsky & Robey 1980; von Tunzelmann 1978.

The water-powered processes that have been described did not in most cases produce finished goods. In almost every case manual processes were needed to turn iron (or tinplate) from the forge or mill into consumer goods. This work was commonly carried out in workshops attached to (or even within) the workmen's homes. Many villages had a blacksmith,[232] making horseshoes and miscellaneous iron goods required by rural communities. However most manufacture took place on an industrial (or proto-industrial) basis in specialist regions, particularly Birmingham and the Black Country and around Sheffield. In such areas the manufacture was organised by entrepreneurs, such as ironmongers, who put material out to the workmen and paid them when they returned the finished goods. In both these cases this specialisation goes back at least into the 16th century.[233] Manufacture at Newcastle on a large scale only began when Ambrose (later Sir Ambrose) Crowley began establishing 'factories' near there, and this seems to have been organised on an industrial basis from the beginning, without the intervention of any proto-industrial stage with dual employment.[234] Iron manufacture was labour-intensive and required only simple tools, such as hammers and tongs with an anvil, the hammer sometimes being a treadle-driven oliver. This manufacture gave work to thousands of blacksmiths, locksmiths, scythesmiths, cutlers and nailers, not to mention allied trades such as tinplate workers, wireworkers, gunsmiths, and whitesmiths. These thousands of men (and sometimes women and children) made iron into an enormous variety of finished wrought iron goods.[235]

Nails were also made near Wigan and Belper, respectively near slitting mills at Brock Mill and New Mills at Makeney.[236] This can probably best be described in terms of colonies of workmen being collected around mills associated with their trade. However, the ready availability of coal was also an important factor, and both north of Sheffield and in the Black Country nailers were concentrated where there was coal, rather than close to the mills.[237] Nevertheless, coal cannot be the only factor at work here, since large scale manufacture did not develop in certain other areas rich in coal, such as east Shropshire and (until 1690) Newcastle. The difference between these on the one hand and Sheffield and the Black Country on the other seems to be that the former had easy access to water transport, enabling them to sell coal to distant customers, whereas the latter two were relatively distant from navigable water.[238] The high cost of road transport compared to river freight meant that the latter were only able economically to market their coal locally. This made coal for smiths comparatively cheap and encouraged the development of manufacture there. A great deal more might be said about the manufacture of iron into useful consumer goods and tools, but space is not available to discuss this in detail.

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[232]. Hoskins 1965, 167-8 193; *cf.* distribution of customers in Prankard a/c; Maister; Hodg.

[233]. Hey 1971; 1972; 1990; 1991, 93-196; Rowlands 1967; 1974; 1975; 1989.

[234]. Flinn 1962; *cf.* Levine & Wrightson 1993.

[235]. Rowlands 1973; Hey 1972.

[236]. Awty 1957, 81-2 106-7; Robson 1964; Hey 1972, 42; Janson letters, 22 Aug. 19 Nov. 1737; Riden 1990, 67-71.

[237]. Hey 1972, 31-41; Frost thesis, 452-96. My own unpublished work on occupations in Kinver confirms the dearth of metalworkers. The parish lies in the Stour valley and had several slitting mills and forges, but the tradesmen of the town of Kinver were almost all engaged in retail trades and those related to leather and cloth. The significance of nailing is perhaps overstated in *V.C.H. Staffs.* xx, 148.

[238]. Wanklyn 1982; Trinder 2000, ch.1; Levine & Wrightson 1993. The lack of much discussion of iron manufacture in these standard accounts of these industrialising areas is quite striking.