Hot blast iron smelting in the early 19th century: a re-appraisal

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ABSTRACT: The introduction of hot blast was the most important development in early 19th century iron smelting. The conventional story of James Beaumont Nielson's 1828 patent has been widely accepted since the 1840s. This paper re-appraises the development of hot blast in the light of an earlier patent of Thomas Botfield, and suggests that many elements of Botfield's development anticipated those of Nielson. The role of Gilbert Gilpin, and through him connections with John Wilkinson and the iron industry in South Wales, are also discussed. It is argued that the early development of hot blast iron smelting in fact remains poorly understood, and some suggestions are made for improving understanding.

Introduction

The development of hot blast has been described as 'the most important single innovation … in the age of iron' (Birch 1967, 181). Certainly it ranks alongside the development of the blast furnace, and the introduction of mineral fuel, in enabling a significant step-change in the production of cast iron. The invention of hot blast is conventionally associated with James Beaumont Nielson, who took out his first patent in October 1828. Nielson's story is one of an outsider to the industry developing a new technology – initially in the face of opposition from a suspicious and conservative establishment, but subsequently universally accepted. This trajectory is familiar in narratives of 18th and 19th century technological development: it is evident for example in the stories of Abraham Darby and Henry Bessemer, and, to some extent, John Wilkinson. All four entrepreneurs feature in the influential *Industrial Biography*, produced in 1863 by an author of improving self-help books – Samuel Smiles – who was an enthusiast of heroic individualism; his perceptions have coloured subsequent interpretations.

More recent studies have perhaps inevitably shown that such developments were more complex, and, critically, were often arrived at by more than one person at around the same time. This has been shown in the case of iron smelting with mineral fuel (King 2002) and iron puddling (Hayman 2004; Hayman 2008). Similarly, Nielson was unlikely to have been alone in attempting to develop hot blast. This is evident from the zealous way in which he protected his patent through extensive litigation, seeking to establish that any earlier attempt by others did not anticipate his own invention. One of these was a patent taken out in January 1828 by Thomas Botfield, a Shropshire ironmaster. Although dismissed during Nielson's legal arguments, the wording of Botfield's patent in fact suggests that several of Nielson's principles (if not his details) were indeed anticipated. Although it is not clear that Botfield's patent was ever successful, it is argued that Nielson's version of events – which has been generally uncritically accepted since the 1840s – obscures a more complex picture, and that in fact the early development of hot blast iron smelting remains poorly understood.

The invention of hot blast

James Beaumont Nielson was born at Shettlestone, near Glasgow, in 1792; his father was an enginewright at Govan colliery. James was apprenticed to his brother at Oakbank foundry, and in 1814 was employed as an enginewright at William Taylor's collieries in Irvine (Smiles 1863, 150-1). Largely self-taught, he became the foreman at Glasgow gas works in 1817, and sub-

Table 1: Use of hot blast at the Clyde Iron Works, 1829-1833 (after Percy 1864, 398).

	Tonnes of coal used to make each tonne of iron	Tonnes of pig iron produced per furnace per week
Cold blast with coke	8.2	37.5
Hot blast with coke	5.3	54.9
Hot blast with coal	3.0	62.2

Note: The figures have been converted at 50.8kg per hundredweight

sequently introduced a range of innovations including iron roofing, clay retorts, and heating the retort ovens by burning waste coal-tar in its liquid state (Thomson 1870, 215). It was probably this latter development which drew the attention in 1824 of an ironmaster, who, concerned about the difference between winter and summer output of blast furnaces, had concluded that atmospheric sulphur was responsible; he asked Nielson whether 'a method similar to that used to purify coal gas could be used to purify the blast' (Corrins 1970, 236). Nielson expanded on his ideas in a paper to the Glasgow Philosophical Society the following year.

At the time, the universal opinion of ironmasters was that 'the colder the blast the better' (Percy 1864, 397). This opinion was the result of 'long-continued observations' in which individual furnace production was greater in winter than summer; as a result 'the greatest efforts were made in summer to obtain the blast as cool as possible' (Marten 1859, 62). As Nielson's method ran counter to received wisdom he was not able to experiment on a full-scale blast furnace immediately. Instead, his first experiments took place in 1828 in a foundry cupola at Colin Dunlop's Clyde Iron Works, where the blast temperature was raised by around 10˚C. As a result of this work he took out his first patent in October of that year for the 'application of air to produce heat in fires, forges or furnaces, where bellows or other blowing apparatus are required' (Patent 5701). The following year he was able to apply the principle to the main furnace, where the blast temperature was raised to around 95˚C by using heated wrought iron chambers at each of the tuyeres; the detailed specification for this apparatus was patented in February 1829 (Birch 1967, 183). Further experiments took place in order to increase the temperature of the blast whilst at the same time attempting to overcome problems of oxidation, expansion and cracking in the heating apparatus. By 1832 Nielson had developed the 'cast iron tubular oven', to which, two years later James Condie of the Blair Ironworks added the already well-known water-cooled tuyere (Anon 1842, 20-1; Percy 1864, 400-1). This combined apparatus was capable of heating the blast to more than 315˚C (Clark 1836, 378-82).

The efficiencies made possible by this system soon became apparent. Nielson was later able to show that for every unit of fuel burned in heating the blast, three or four units were saved of the fuel used in the furnace (Richards 1884, 72). Nielson's invention also made it possible to use the local Lanarkshire 'splint' coal without coking (Mitchell 1984, 21-2). As a result, in 1831 raw coal was 'successfully substituted for coke' at the Calder Ironworks; two years later the Clyde Ironworks also switched to coal, and by 1836 the process had been adopted by all of the Scottish ironworks (Percy 1864, 395). Consequently Scotland was able to produce the cheapest iron in Britain during the 1830s (Hyde 1977, 151). Table 1 shows the fuel savings made at the Clyde Ironworks using the hot blast process, first with coke, and then with coal.

The foregoing story represents the conventional narrative of Nielson's invention. However, his status as the inventor of hot blast is due in large part to the extensive litigation which he pursued during the lifetime of his patent. He ultimately won the legal battle, and so his side of the story has dominated historical understanding of the development of hot blast. Even at the time his claim to primacy in inventing hot blast was fiercely contested, and the court records contain several interesting insights into developments by others – including Thomas Botfield. Indeed it has been suggested that the proceedings of the trial – at which 163 witnesses were called – represent a 'compendium of the principles of ironmaking' in the first few decades of the 19th century (Birch 1967, 185). Technical and historical details recorded during the various court cases are considered below; at this stage it is sufficient to make two general points which emerge from the litigation. Firstly, it is clear that that several ironmasters had previously considered heating the blast, and some claimed to have experimented with it. Secondly, Nielson's initial efforts were unsuccessful. Certainly John Percy was of the opinion that Nielson's hot blast 'was a lucky hit rather than an invention properly so called' and that Nielson 'had at first no adequate conception of the value of his invention' (Percy 1864, 395-7).

Adoption and early development of hot blast

Legal disputes notwithstanding, the ultimate success of hot blast – regardless of the technical superiority or otherwise of Nielson's patent – is evident from its rapid and widespread application. By the end of the 1830s hot blast was also being widely adopted in England for use with bituminous coal. Hot blast was first introduced to Staffordshire in 1832, ultimately resulting in a four-fold increase in production from each furnace (Marten 1859, 88-9). The expiry of Nielson's patent in 1842 ensured that hot blast gained much wider acceptance after the 1840s. Indeed the relative position of the Scottish industry appears to have declined from the mid-1840s – partly as a consequence of the take-up of hot blast elsewhere in the United Kingdom, and partly the result of increasing competition for coal and ironstone resources in Scotland (Campbell 1955, 211-5). Hot blast was also rapidly adopted on mainland Europe and in North America, both in new coal- and coke-fuelled furnaces, and in existing charcoal-fuelled furnaces. Perhaps not surprisingly, hot blast gained ground most rapidly where fuel costs were high (Fremdling 2000, 214-5).

Although hot blast was developed as a 'coal technology' it was also applied to charcoal ironmaking (Evans and Rydén 2005, 9-10). On mainland Europe, various attempts had been made to emulate the rapid growth and success of the late 18th century British ironmaking model – mineral-fuelled smelting, refining and puddling – but these had not always been successful *en masse*; instead elements of the British system were selectively adopted with greater success. Hot blast was one of these elements which appears to have worked well: it was adopted very rapidly, even in quite conservative ironmaking areas and establishments. For example the long-established French ironmaking complex at Allevard appears to have adopted hot blast for its charcoal furnaces as early as 1832 (Samson 1998, 85). Between 1837 and 1844 the total number of charcoal furnaces in blast in France declined from 433 to 369, but the number using hot blast increased from 38 to 115. By 1844, 154 of all 430 French furnaces in blast were using hot blast – around 36% (Fremdling 2000, 216).

Hot blast for charcoal ironmaking also gained acceptance in North America. In New Jersey, the Scranton brothers introduced hot blast at their Oxford furnace in 1834 (Eggert 1994). By 1836 the Snow Hill furnace in Maryland had a hot-blast stove mounted on the top of the furnace which made use of the furnace gas (Alexander 1840, 93-4). By the late 1830s hot blast was also being used in bloomery hearths at Clintonville, New Jersey (Pollard and Klaus 2004, 22-4). Some Canadian sites appear to have switched between hot and cold blast depending on the quality of the ore and the intended market (Samson 1998 84-5). By 1859, 271 of the 711 charcoal blast furnaces in the United States were using hot blast more or less permanently (Council *et al* 1992, 163). This figure – around 38% – was comparable with the situation in France fifteen years earlier. However this did not result in an increase in American efficiency; indeed the next thirty years saw relative decline. American furnaces used more or less the same amount of fuel (around 2.3 tonnes) to smelt a tonne of iron in 1860 as they had in 1840, whereas in France during the same period the amount of fuel used had declined from 2.6 tonnes to 1.6 tonnes per tonne of iron produced (Allen 1977, 608). Similarly, in Germany the introduction of hot blast enabled greater efficiency – at first in charcoal-fuelled furnaces, then in furnaces using a mixture of charcoal and coke, and finally in a fully coke-fuelled industry by the 1860s (Brose 1985, 553-6). The enthusiastic adoption of hot blast technology by charcoal ironmasters across Europe was largely a consequence of the cost savings that could be made.

Away from the charcoal-smelting industries, hot blast was also of considerable interest to American ironmasters who wanted to exploit the vast anthracite reserves of eastern Pennsylvania. Indeed the Franklin Society offered a gold medal prize in 1825 for successfully smelting not less than 20 tons of iron using anthracite (Yates 1974, 207). In May 1827 the Pennsylvanian engineer Joshua Malin had built a half-scale furnace which used anthracite: the key features were a circular hearth and a strong, but unheated blast (Malin 1827, 217-9). In the following year Benjamin Howell of New Jersey made 'successful experiments in reducing the ore … with anthracite', although he appears to only to have applied heated air to the subsequent puddling rather than to the smelting process (Howell 1838, 167). Frederick Geissenhainer built a small experimental hot blast anthracite furnace in 1831 in New York; he patented his process two years later and in 1836 established short-lived but large-scale operations (Eggert 1994).

At the same time experiments with anthracite were taking place in South Wales. Here the British Iron Company at Abercrave had attempted to use anthracite as early as 1824-6 but was unsuccessful, despite technical assistance from David Mushet (Birch 1967, 169-70). Ten years later George Crane and David Thomas – owner and manager respectively of three blast furnaces at Ynyscedwyn, near Swansea – discussed the application of the Nielson process to anthracite smelting. Thomas travelled to Glasgow to see Nielson's hot blast for himself, and returned with a licence and an engineer to help construct the ovens (Rees 2008, 96-7). On 7 February 1837 the first anthracite-smelted hot blast iron smelted was cast at Ynyscedwyn; later that year Crane declared that 'the success of the experiment … has been, in every respect, of so satisfactory a description' that he was in the process of converting his remaining furnaces at Ynyscedwyn to anthracite (Crane 1837, 117). Crane patented his development, but was contested: the case of Crane versus Price found that where one patent incorporates another (in this case Nielson's hot blast principle) it can only be used under licence from the older of the two patents (Webster 1844, 377-413). Therefore Crane did not profit as much as he would have wished from the development of anthracite hot blast. Moreover some varieties of Welsh anthracite were prone to violently breaking up during smelting, blocking the blast and 'gobbing up' the furnace (Percy 1864, 494-5). By the 1850s Welsh anthracite iron smelting was in decline (Birch 1967, 170).

In contrast, the American industry prospered, although not without Welsh help. The Welshman Benjamin Perry was contracted by William Lyman to build an anthracite furnace for Burd Patterson of Pottsville, Pennsylvania; this was in blast from October 1839 (Eggert 1994, 20-33). Perry built two more anthracite furnaces the following year. The Lehigh Coal and Navigation Company had already successfully operated a hot blast anthracite furnace for several months in 1838 before approaching David Thomas with a generous relocation offer. Thomas accepted, and the Lehigh Crane Iron Company's first anthracite furnace came into blast on 4 July 1840 at Catasauqua (Williams 1994, 30). The company rapidly expanded, with three furnaces in blast by 1842 and another three over the next few years. In 1845 the Montour rolling mills were built to produce Welsh-patented 'Evan' rails and by 1856 were producing 20,000 tonnes of rails per year (Williams 1994, 30-1).

One key aspect, as the process later developed, was the re-use of waste heat and, later, the ignition of waste gases, to heat the blast. In particular the principles of regenerative heat exchange – introduced by Stirling's 1816 invention of the 'heat economiser' – were later applied to the design of hot blast stoves, enabling operating temperatures of over 1000°C from the 1850s onwards (Cowper 1866; Anon 1873; Bone 1928, 728; Daub 1974, 260-1; Sier 1995, 103-29). In practice the capture of blast furnace gases for ignition was found to be technically difficult, and, this process was developed more quickly in mainland Europe and the United States (Blackwell 1853, 189). The European charcoal industry, probably prompted by relatively high fuel costs, was at the forefront; Württemberg, a relatively small-scale centre of charcoal-fuelled smelting, was an early pioneer in the re-use of waste gases for heating the blast (Plumpe 1982). In Britain, the Baird brothers took out a patent for using the waste heat from the blast furnace in 1849 (Birch 1967, 175). By the end of the 19th century, blast furnace waste gases had also begun to be used as a source of fuel for gas engines (Lawton 2011, 82-93).

The Botfield coal and iron business

The Botfields were the dominant English ironmasters during the first few decades of the 19th century, yet their story remains little known. The family appears to have settled in Dawley (Fig 1) in the late 17th century, possibly moving there from west Shropshire. Beriah Botfield (1702-1754) was born in Dawley, and may have been the son of Dawley-born Thomas Botfield who was associated with the Pitchford ironworks in the early 18th century (Urban 1860, 470-1; SA 1514/492). In 1753 Beriah Botfield, described as a 'collier', became one of four partners in a mining venture at Lightmoor in neighbouring Little Dawley. Within a year that business had expanded sufficiently to enable investment in a 'steam or fire engine' (SA 1681/183/7). In 1758 a new partnership was established to develop the ironmaking side of the business. Beriah's son, Thomas Botfield (1736-1801) – then an agent to the estate of Isaac Hawkins Browne – was one of the original partners of this new Lightmoor Furnace Company; by the end of 1758 work had already begun on the furnace 'together with a fire engine and other buildings necessary' (SA 1681/183/8).

Thomas was one of the younger and more dynamic partners in the Lightmoor enterprise, and his vigorous management enabled him to increase his shareholding and gain improved access to capital and support from other Shropshire businesses (Trinder 2000, 82-4). He had become the manager of Browne's Old Park estate in the 1760s and that decade also saw his marriage and the birth of his three sons Thomas (1762), William (1766) and Beriah (1768). Thomas Botfield invested heavily in the Dawley collieries during the 1770s, the returns on which enabled expansion into other industrial enterprises (Luter 2005, 4-5). He began to develop the Old Park ironworks from 1788. The proximity of the Shropshire Canal (completed in 1793, and enabling connections with Birmingham, the Trent, the Mersey and the Severn) was critical to the success of the works; indeed it became 'the life-blood of the Botfield empire' (Hadfield 1985, 155-8; Luter 2005, 10). Initial investment was made on the forge side, which had four fineries and two forge engines in 1790, a 'new puddling furnace' in 1794, and a 'new rolling mill' by the end of 1797 (JRL BOT 1/8; JRL BOT 2/24/1). By this time three blast furnaces were also in operation at Old Park; in 1796 they had produced 5,952 tonnes of pig iron (Evans 1993, 92).

Thomas Botfield, now in his sixties, needed assistance in developing the next phase of the works. For this, he turned to Gilbert Gilpin (1766-1827). Gilpin had started his career working for the Wilkinsons at Bersham ironworks, but grew 'weary of the arrogance and conceit of John Willkinson' and left in 1796 (Evans 1990, 31). After a few months with Boulton and Watt in Birmingham he left for the rapidly developing ironworking districts of south Wales where he observed and became involved with several enterprises. Gilpin returned to the Midlands in the summer of 1799 and was promptly taken on by Botfield (Clarke nd). Under Gilpin the Old Park works was completely overhauled: by 1801 a new rolling mill had been installed, powered by a 42kW Boulton and Watt engine and a Boulton and Watt blowing engine had also been purchased for the four blast furnaces (Trinder 2000, 51-3). That same year Thomas Botfield died, and the estate passed to his three sons, with William inheriting the principal responsibility for the business – although the three brothers met every quarter to plan the next three months' work and to divide the profits.

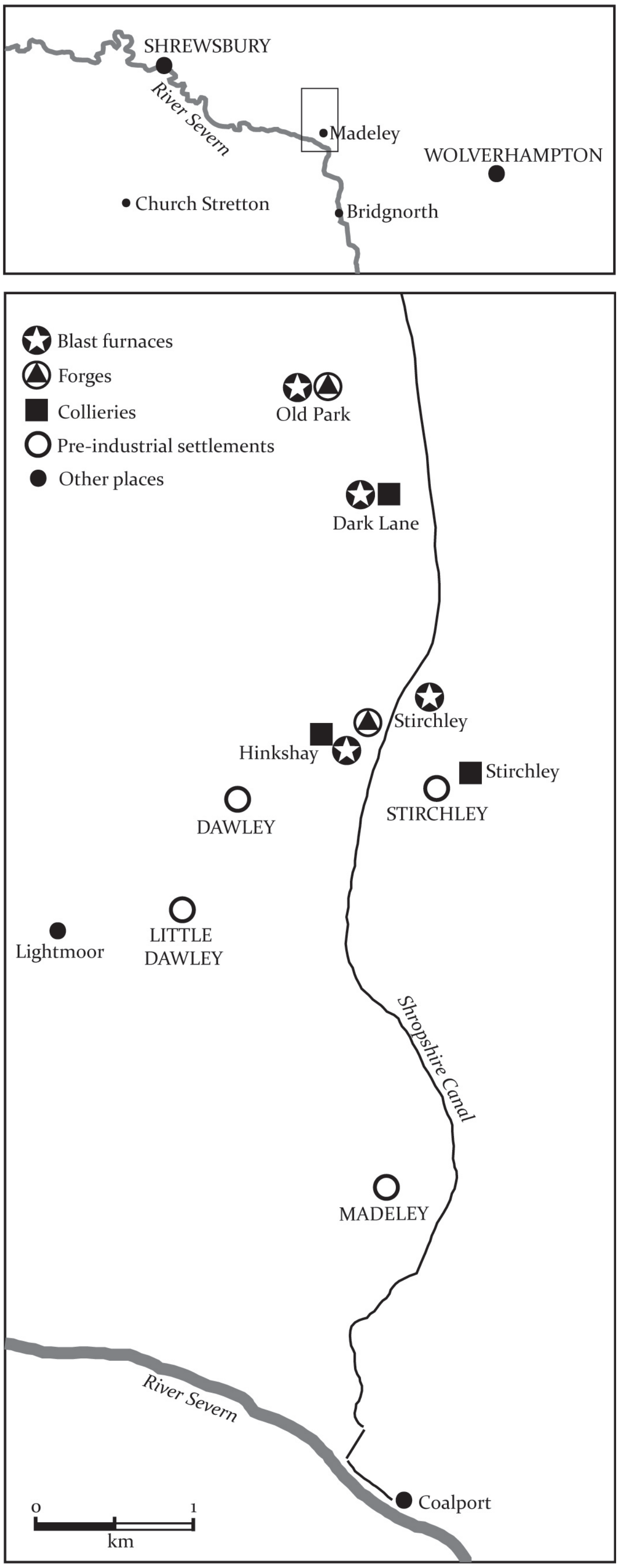

Figure 1: Map showing the locations of the principal Botfield sites mentioned in the text.

Gilpin continued to be involved, and appears to have been given a fairly free hand to manage day-to-day operations. During this period Gilpin was also responsible for a number of other innovations which were critical to the expansion of the Botfield concern. One of these was the use of small 'snapper' furnaces which remelted pig iron in batches of 10-15 tonnes, enabling greater control over the quality of iron being produced for the forges – an idea evidently derived from Wilkinson's cupola. Gilpin also invented wrought-iron chains for 'the raising of coal and ore from the mines', which probably took place in *c*1803-4; he subsequently developed an improved winding capstan which had applications at sea as well as on land (Page 1908, 479-481). Although the colliers were initially wary of Gilpin's chain, some improvements ensured its acceptance, and by 1807 some 2,000m of chain were in use in the Botfields' own pits, with another 8,000m sold to the Lilleshall Company (Luter 2005, 11). Meanwhile the works prospered: in 1806 the four Old Park furnaces had produced 8,359 tonnes of pig iron (Evans 1993, 97). The following year the output of pig iron had increased to 9,200 tonnes, half of which was converted to wrought iron in the works forges (Luter 2005, 12). The Old Park works was now the largest ironworks in Shropshire and, after Cyfarthfa, the second largest in Great Britain; that year William Wilkinson noted that the Botfields governed 'the iron trade of Shropshire ... with a lordly sway' (cited in Trinder 2000, 83). Not long after, the Royal Society of Arts awarded Gilpin a silver medal and 30 guineas for his safety chains; this may have influenced his decision to leave the Botfield concern and set up on his own as a chain maker, which he did between 1811 and 1814 (Clarke nd).

William and Thomas' brother Beriah died in 1813, and his place in the company was taken by his son (also Beriah). By 1815 the Old Park works consisted of four blast furnaces, a forge and associated collieries; customers included Boulton and Watt of Birmingham, John Bradley of Stourbridge and John Hazeldine of Bridgnorth (JRL BOT 3/1/1-2). Despite the departure of Gilpin and the loss of Beriah, Thomas and William continued to invest – both in the existing site at Old Park, in two separate furnaces at Dark Lane, and in collieries at Dark Lane, Hinkshay and Stirchley (Fig 1).

Stirchley was also on the Shropshire Canal, and it seems likely that its potential as an ironworking site had been recognised whilst the canal was being constructed. The brothers acquired property there in 1803, 1811 and 1813 (SA 513/2/9/5/4-6; SA 512/2/3/1/55) but due to the slump in the iron trade, building work at Stirchley did not start until May 1822. Three furnaces were completed by November 1823, and the first iron was cast on 9 February 1824 (JRL BOT 2/31/2). A fourth furnace was built during 1826, and by January 1827 all four furnaces were in blast. However this situation did not last and 1827-1828 saw several interruptions to furnace operation. No 1 furnace in particular saw much modification, including repairs to the casting arch, the 'air furnace', a chimney at the furnace and other work; additional improvements were made at this time to the blast system for all furnaces, including the replacement of boilers and further adjustments to the pipes (JRL BOT 2/31/2).

By 1829 furnace operations at Stirchley appear to have settled down, and that year the forge came into operation, although located approximately 800m away. At the more closely integrated Old Park site the furnace blowing engine also supplied blast to the refinery, and the same arrangement was employed at Stirchley – although here of course the refining of the pigs for puddling took place on the furnace site rather than at the forge. Abraham Ball was paid in the autumn for 'laying & fixing Blast pipes to Cupels & Finery, & Water pipes to Finery & Casting Houses' (JRL BOT 2/31/2). Initially Stirchley forge contained 12 puddling furnaces and four reheating furnaces; it produced 3,644 tonnes of hoops, sheets, bar and plate in its first full year of operation in 1830 (JRL BOT 2/25/1-3). In that year the Botfield enterprise as a whole produced 15,300 tons of pig iron, only slightly less than the Lilleshall company who were then the largest producers in Shropshire (Trinder 2000, 83-4). By 1839 the term 'boiled iron' regularly appears in the forge accounts (JRL BOT 2/25/1-3). This probably refers to the process of 'pig boiling' that was the characteristic of the so-called 'wet' puddling process which was widely adopted at this time; essentially this eliminated the need for the refinery (Gale 1971, 161). By 1853 there were 29 puddling furnaces at Stirchley, although the refinery on the furnace site remained in use, suggesting that at least some 'dry' puddling may have continued at Stirchley forge until that date (Belford 2011, 15-7).

Thomas Botfield died in 1843 and his brother William in 1850, so control of the family business passed to their nephew, the younger Beriah Botfield (1807-1863). A keen art collector, the younger Beriah was also MP for Ludlow in the 1840s and 1850s. Barrie Trinder has suggested that the gradual decline of the Botfield family's business was symptomatic of the Shropshire iron trade's failure to adapt to modern methods (Trinder 2000, 85-6). However a more pragmatic explanation is that the younger Beriah was more interested in his art collection and parliamentary career and so did not invest sufficient energies in sustaining his uncles' business. In 1856 the Botfield lease expired and Beriah Botfield either could not or would not renew it. As a result the Botfield estate was broken up. A newly-formed Old Park Iron Company took over blast furnace operations on both smelting sites whilst Stirchley forge (Botfield's own property) was sold off. The Old Park ironworks closed in 1877 and at Stirchley only two furnaces were ever in blast; by 1883 they were described as 'dismantled' (Riden and Owen 1995, 46). Stirchley forge, which by the 1870s had 40 puddling furnaces and four rolling mills, continued in operation for a further 15 years, its life probably prolonged by the construction of the Coalport branch of the London and North Western Railway along the line of the old canal between 1857 and 1861 (Belford 2011, 16-7).

Thomas Botfield's hot blast patent

Thomas Botfield's patent, dated 2 January 1828, was for 'certain improvements in making iron, or in the method or methods of smelting and making of iron' (Patent 5596).

At the heart of the broadly-worded and wide-ranging patent was the use of a chimney to increase the rate of draught, but it is clear that the process involved hot blast, and the re-use of waste gases is also implied. The patent also referred to the use of salt. After the usual preamble, the principle of the patent was clearly stated:

> 'The principle is for causing or obtaining a blast of atmospheric air sufficient to smelt, fuse, run or made pig, cast or crude iron from ironstone or ore. The blast is to be produced by means of rarified air, gas flame or heated air, and is to be applied in or to a blast furnace, cupola or air furnace.'

Central to Botfield's patent was the addition of a chimney (Fig 2). The blast was to be increased by:

> '… the draft [sic] of a powerful chimney or chimnies [sic], which may be built separate at any distance that may be most convenient, or may join to or be made part of the blast furnace or cupola, as may be found most desirable and best to answer the purpose required, and which is to be connected by a flue or flues with the cupola, blast or air furnace; but in case this draft [sic] should not prove sufficient for the purpose of smelting the ironstone or ore, I propose and intend to apply and use the common blast from machinery to assist the blast from the draft [sic] of the chimney. This is to be used at the same or any other twire [tuyere].'

This perhaps implies that Botfield had attempted to use a chimney on its own but had found it insufficient. The chimney was the main focus of the case against Botfield during the Nielson trials (see below), however Botfield clearly refers throughout his patent to 'heated air', going on from the previous paragraph:

> 'And I claim a right and mean to use the atmospheric air either separate or mixed with gas flame and heated air.'

This is perhaps the most significant statement in the patent: heated air is clearly a key part of Botfield's process. The reference to 'gas flame' implies re-use of waste gases, although there is actually nothing in the wording or illustration of the patent to suggest that this was actually a key part of the process. Nevertheless, at least in theory, Botfield appears to have anticipated most of the elements of hot blast as it ultimately developed during the 1830s and 1840s. Two principal issues now need to be considered. Firstly, could Botfield's system have actually worked, and did Botfield experiment with hot blast at Old Park or Stirchley? Secondly, where did Botfield's idea come from – was it in fact his own invention, or was the idea derived from others?

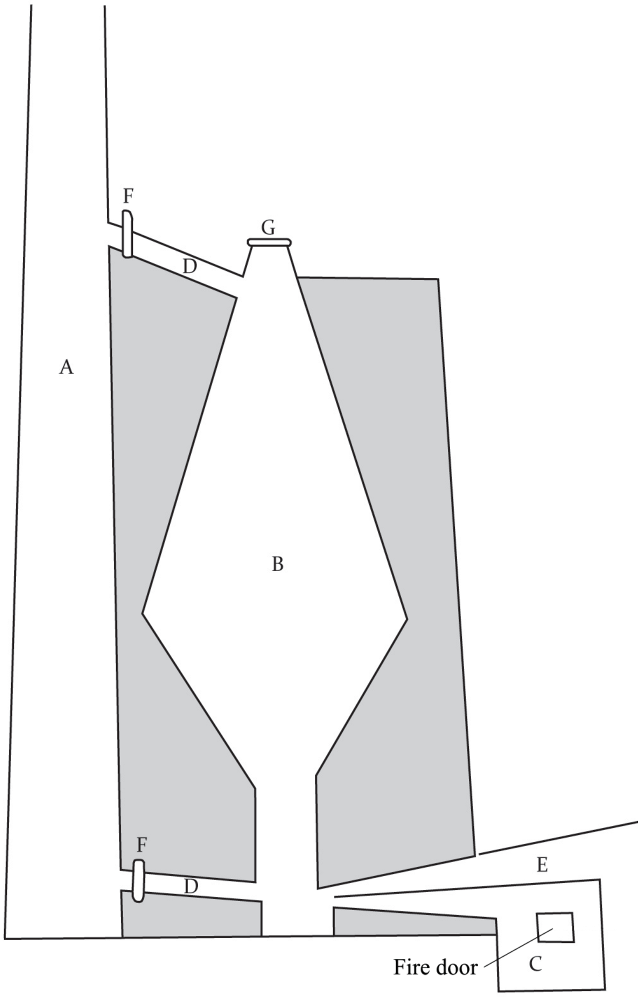

Figure 2: Botfield's hot blast system, redrawn from the original patent. Descriptions of the various components are taken from the patent text.
A: chimney,
B: blast furnace,
C: oven, air furnace or fire place,
D: flues to connect the furnace with the chimney,
E: space open to admit atmospheric air to the tuyere, which may be introduced below or on the sides as well as above the tuyere, or may be introduced at all these places, as circumstances may require,
F: dampers to stop or regulate the draft of the flues to the chimney,
G: cover for the top of the furnace, to be opened when the materials are being put in to charge the furnace.
Note the unambiguous hot air oven (C) in this drawing which predates Nielson's patent by nine months.

Botfield's hot blast system in theory and in practice

The viability of Botfield's patent was considered during the Nielson trials, however the nature of the evidence needs to be considered in the context of the legal process. The legal aspects of the 'great hot blast affair' have been described in detail by Corrins (1970) and are only summarised here. The principal action against Nielson was brought by the Baird brothers and their allies. The

Bairds were colliery owners who expanded into iron smelting; their Gartsherrie furnace was blown in during May 1830 and incorporated hot blast with Nielson's agreement (Corrins 1970, 235). However, perhaps frustrated by the 'frequent stoppages and relatively low temperatures' of the new method, the Bairds did not take out a licence and had stopped using hot blast by November (Corrins 1970, 239). At around the same time William Dixon of the Govan and Calder ironworks had also begun to use hot blast, adapting the technique to smelting with coal. Dixon agreed not to patent his improvements, in return for which Nielson permitted Dixon to use hot blast at two of his furnaces 'free of duty' (Corrins 1970, 240). This in turn encouraged the Bairds to resume the use of hot blast, and in 1832 they came to an agreement with Nielson to pay a royalty of one shilling per ton of iron produced at their Gartsherrie furnaces (Birch 1967, 184). However, after taking further legal advice, the Bairds again took Nielson to court and their 1833 action encouraged others. Yet the Bairds lacked the resources to enter into potentially expensive litigation at this stage; consequently they withdrew, entered into a new agreement with Nielson, and continued to build their business (Corrins 1970, 243-4).

These legal actions were the preamble to a more protracted dispute. In 1839 the Bairds stopped paying royalties and united with William Dixon and others into an impressive combine whose various members were strategically deployed in a series of court cases against Nielson (Corrins 1970, 246-7). These cases were brought between 1840 and 1843; other than the Bairds' own action, the most significant case was probably that of the Househill Coal and Iron Company. As one would expect, Nielson's legal team interpreted the words of his patent – and those of others – in order to further their argument. Thus the number, form, location, construction and operation of the 'heating vessels' (hot blast stoves) specified in Nielson's patent were irrelevant: the 'object of the invention is to secure the heating of the air in its transit, so … I don't care what is the form of the vessel … [and] the manner of applying the heat is immaterial'. Where the wording was more specific, his lawyers argued that it wasn't meant to be: 'the word intended there was affected not effected – it was a mere misprint'; or: 'it is quite plain that in the whole of this specification, air vessel means air vessels' (Anon 1842, 7-8). Put simply, Nielson won the legal argument (and perhaps played a more sophisticated political game than his opponents); for the rest of his life James Baird still bitterly lamented the fact that the final judgement against the Bairds was made by the same man who had encouraged them to fight Nielson's patent thirteen years earlier (McGeorge 1875, 62).

This background is important in understanding the nature of the evidence presented by both sides, and the opinions expressed as to the viability of the various antecedents to Nielson's invention. Botfield's patent was dismissed as not anticipating Nielson's patent in any way. In court Nielson's lawyers emphasised one particular aspect of Botfield's patent: the chimney, intended to increase the rate of draught. They stated that Botfield's patent was 'not for altering the character of the atmospheric air, and … not for altering the character of the blast' (Anon 1842, 14). Nielson's lawyers produced David Mushet as a witness who, appropriately prompted, dismissed Botfield's patent as the greatest 'of all the absurdities' (Anon 1842, 22). However he did acknowledge that with 'a good roaring flame, the air would have an effect'; in other words, pre-heating would occur and the broad principles of Botfield's patent were sound, even if their application was flawed (*ibid*).

Botfield's rationale for the use of preheated air, as described in his patent and understood by his contemporaries, was simply to increase the draft of air through the furnace. The inclusion of the 'space open to admit atmospheric air' at the base of the furnace ('E' in Fig 2) suggests that the gas pressure at the base of the furnace could not be significantly above atmospheric pressure; consequently the furnace described in Botfield's patent is arguably not a blast furnace but an enhanced natural-draught smelting furnace. Perhaps the important aspect of Botfield's patent, therefore, is not so much the heating of the air but the use of multiple tuyeres. Rehder (2000, 68) has observed that the use of multiple tuyeres significantly reduces the amount of power needed to maintain the same flow rate.

So, the Botfield chimney might possibly have worked as a means of increasing the air flow. Thus Nielson's legal counsel, Lord Cottenham, was probably correct to argue that although Botfield 'certainly' used hot air, it was 'for the purpose of increasing the draft [sic], not for any chemical purpose that the hot air might have', leading 'rather to the conclusion that at the time the advantage of hot air was not known, at all events not known to him, or otherwise he would have specified it' (Webster 1844, 274). Nevertheless the Botfield patent clearly specified the use of 'heated air', and in the case of Nielson and others versus Thompson and Foreman (in 1840) it was argued that Botfield's patent did indeed anticipate that of Nielson. In this sense, Botfield was just as much in the dark as Nielson had been – again, in John Percy's words, with 'no adequate conception' of the principles of using hot blast (Percy 1864, 395). This does not, however, mean that he was not heating the blast.

There remains the question of whether Botfield actually employed his patented system at his own ironworks. The Botfield accounts appear to make no specific mention of 'hot air ovens' until the 1840s. The core of the Botfield business was at Old Park, and the records show no interruption of normal blast furnace practice during the late 1820s, when one would have expected either experiments leading to the specification set out in the patent, or the application of the system after the patent was registered. Regrettably the remains of the Old Park works were destroyed during the construction of Telford New Town in the 1970s (Brown 1998, 309-10). Although some archaeological work was undertaken, this comprised a limited watching brief which only recorded a small part of the site and does not appear to have encountered any remains of hot blast apparatus (Smith 1977). The records of this fieldwork are now lost.

The Botfield ironworks at Stirchley is another possible candidate for the early use of hot blast. Certainly the four furnaces here were served by four 'hot air ovens' in 1856 (JRL BOT 4/4). This appears to have been a fairly conventional pre-Cowper arrangement, with the four ovens located between the blowing engine at the southern end of the site and the 'tuyere houses along the back of the furnaces'. A water regulator controlled the blast between the blowing engine and the 'hot air ovens'. There were two blast mains: the first supplied Nos 1, 2 and 3 furnaces, the second supplied the refinery, with a subsidiary pipe to No 4 furnace (JRL BOT 4/4). This layout probably resulted from the original construction sequence, the fourth furnace being constructed two years after the others.

The installation of these particular 'hot air ovens' appears to have taken place in the early 1840s (JRL BOT 2/31/3-4). This implies that Botfield's earlier system did not work (or was not installed), and instead he waited for the Nielson patent to expire before installing hot blast. The Stirchley accounts are not specific on the installation of a hot blast system in the late 1820s; however, as noted above, they do record a considerable amount of interruption and rebuilding on the site during the period when Botfield's system may have been installed. Thus No 1 furnace was blown out in June 1826, rebuilt, run briefly over the winter and then blown out again by May 1827. Both No 1 and No 2 furnaces did not resume production until February 1828, but were blown out again in early summer. Work during the autumn of 1826 and the latter part of 1827 included new blast pipes for all furnaces and new boilers (JRL BOT 2/31/2). The Botfield accounts also record repeated repair and replacement of blowing engines during this period. At the end of 1828 Thomas Jones was paid for extensive work at No 1 furnace which included 'taking down and rebuilding a chimney' (JRL BOT 2/31/2).

It is clear that operations at Stirchley were problematic during 1826-9, and one of the main issues appears to have been the operation of the blast system. It is tempting to suggest that this represents a period of experimentation – firstly with a prototype of the Botfield patent, then perhaps a refinement of it, and finally the abandonment of the Botfield system in favour of more conventional arrangements. The replacement of the blowing engines hints at the possibility that the original installation was intended to work with Botfield's chimney, but when this method did not work it was found that more powerful engines were required. Of course it is also possible that this troubled period of operation simply reflects a conventional process of getting any array of new blast furnaces to work smoothly and efficiently. However, unlike Old Park, the Stirchley ironworks has considerable archaeological potential. Here all four of the original 1820s blast furnaces have recently been found by the present author to survive in a good state of preservation. Preliminary investigations have determined that many original features survive – both on the furnace stacks themselves and in the surrounding ironworks complex, including the 'hot air ovens' and the refinery (Belford 2011, 42-5). Further work is continuing.

Botfield – innovator or imitator?

Several questions remain about the origins and authorship of the specification as described in Botfield's patent. Thomas Botfield appears not to have been closely involved in the day-to-day management of the ironworks, instead he preferred to develop his country estates at Hopton Wafers (Shropshire) and Brecon (Powys). He only took out two patents, of which hot blast was one; the other, dated 26 July 1809, was for an 'improved construction of iron or metal roofs for houses and other buildings' (Patent 3246). This was a method of prefabrication using cast-iron plates. A prototype of this system survives at the aptly-named 'Iron House' on Botfield's Shropshire estate at Hopton Wafers; this incorporates a cast-iron barrel vault with a variety of joints and flanges as described in the patent. The development of iron roofing appears to have taken place at the Old Park ironworks (Luter 2005, 12). This was during the period when the observant, imaginative and enterprising Gilbert Gilpin was most active in developing his various inventions and improvements. It would be surprising if Gilpin, as superintendent of the works, was not aware of Botfield's roofing experiments taking place on the site. Indeed it seems likely that, given his hand in other innovations, Gilpin was at least partly responsible for the development of the iron roof system.

Gilpin had also worked for John Wilkinson precisely when Wilkinson himself may have experimented with hot blast. Again, the evidence for this largely comes from the Nielson litigation. Former Wilkinson employees were deployed on both sides of the argument. James Russell testified how the blast passed through a cylinder with 'a grate put under it, and a flue that went twice round the cylinder to heat it' (Anon 1842, 89). Thomas Leadbetter agreed that after some experimentation this cylinder was laid horizontally ('like an engine boiler with flues'); it was placed 'between the blast and the furnace' and heated by a fire underneath (Anon 1842, 91-2). John Shaw, who with his father had built the brick flues for this apparatus, corroborated Leadbetter's testimony that Wilkinson had deployed a 'small water-twyre' after the failure of a conventional cast iron one (Anon 1842, 93). In total the Bairds called 20 witnesses in support of Wilkinson having used some sort of hot blast at Bradley at some stage for a few months in the 1790s (Corrins 1970, 253). The failure of the Bradley experiments was said to be due to the scorching of the leather 'bags' which connected the blast pipe to the tuyere – later practice used telescopic metal pipes instead, 'so that when the hot blast was again introduced the difficulty Wilkinson felt did not exist' (Randall 1879, 30).

Whilst John Wilkinson's role in the development of hot blast remains uncertain, he was certainly an ironmaster who was not afraid to experiment. His father Isaac had invented the blowing cylinder. This was first installed in the forges at Backbarrow (Cumbria) in 1737 and was later developed for blast furnace use and was first deployed in south Wales during the late 1750s (Cranstone 1991, 88; Ince 1989, 108). The 1757 Wilkinson patent had comprised an iron cylinder reciprocating in a water-sealed wooden tub; this was later adapted by John Wilkinson as the 'water regulator' which equalised the blast from steam blowing engines (Ince 1989, 108). At his Bradley works Wilkinson used blowing cylinders and 'regulating bellys' which enabled him to increase the pressure of the blast and so improve the efficacy of the limestone flux (Morton 1966, 54; Smith 1966, 57-8). The Bradley works was certainly a likely location for any hot blast experiments, with many of the other elements of the system already in place there.

So it is possible that Gilpin had witnessed some of Wilkinson's experimental work. It is also possible that his time in south Wales – where hot blast was also adopted very early – had provided further ideas about manipulating the blast of the furnace. He may therefore have come to the Botfield enterprise with some ideas of his own. Why then did he not develop them and patent them? Perhaps his experience with such matters under the Botfields was not a happy one. After all he had developed the chain from which they ultimately made a great deal of money; possibly the roofing patent was actually Gilpin's idea for which Thomas Botfield gained the credit. Either way, Gilpin left the Botfield concern to set up on his own shortly after the roofing system was patented. There is no firm evidence to suggest that he worked on hot blast whilst at the Botfield ironworks, however – apart from the suggestion of repeated experimentation at Stirchley in the late 1820s – it is not yet entirely clear that Thomas Botfield did either. On balance it seems probable that Gilpin, the self-motivated serial inventor, would have been more aware of the theoretical and practical ramifications of the process than his employer. Gilpin, latterly resident in Dawley, died in November 1827; within a month, Botfield submitted his hot blast patent.

Hot blast re-appraised

Regardless of whether Thomas Botfield actually invented his own hot blast process, or indeed whether he applied this invention to his own furnaces, two facts remain. Firstly, the Botfield patent does describe the use of 'heated air' in the blast furnace. Secondly, it pre-dates the Nielson patent. This raises the question of whether other possible antecedents to the Nielson patent were also valid, and even successful. For example, Stirling's invention of the 'heat economiser' in 1816 certainly influenced the later development of the regenerative principle; that is, re-using waste gases to heat an inflowing air draft (Daub 1974, 260-1; Sier 1995, 103-29). In 1825 Chapman developed a process for re-using the smoke of steam boilers, and in so doing found it was necessary to 'heat the air before its admission' into the firegrate (Anon 1842, 13). The hot blast system needed several elements to work effectively. It needed a powerful and regular blast – so Wilkinson's steam-powered blowing cylinders and water regulator were essential ingredients. It needed an efficient method of warming the blast – something Nielson himself struggled with. The water-cooled tuyere was needed to transmit the heated blast to the furnace. The long-term success of hot blast also involved the re-use of waste gases.

The triumph of hot blast was ultimately the result of all previous inventions and discoveries coming together, along with a large degree of geological serendipity – it worked best on the Scottish raw coal, and was only later adopted in the conventional coke-fuelled industry. This to some extent echoed Abraham Darby's experience with coke smelting: he was successful because of the combination of elements which went into his furnace – both in terms of the furnace design and the actual ingredients of the smelt. Was Percy therefore right to suggest that hot blast was Nielson's 'lucky hit'? This paper has looked at Botfield as a possible rival inventor to Nielson, but in the process it has emerged that Botfield also owed a great deal to Gilpin. Gilpin in turn would have been influenced (however reluctantly) by John Wilkinson, who himself stood on his father's shoulders. Equally, looking to later developments in the process, its true efficiency was not realised until Whitworth and Cowper had developed their hot blast stoves.

Historical approaches to this period are constrained by their reliance on accounts, litigation and patents. The patent system tends to create winners and losers in the narrative of human ingenuity, and skews our understanding of technological development. The high cost of taking out a patent in the early 19th century (aside from any research and development costs) was an important consideration. In 1828 the English patent system was essentially that of the 17th century Statute of Monopolies. An inventor would apply to the state, in the form of the Attorney General or Solicitor General, for 'letters patent' (*literae patentes*, that is, open letters). The principal object was to ensure that the interests of the state were not affected; there was no formal examination of the patent's originality, and it was only from the 1730s that a detailed specification was required (MacLeod 1988, 40-8). The applicant had to 'negotiate a bureaucratic maze' requiring several levels of official approval – this needed the inventor to spend considerable time in London and to distribute fees and favours (MacLeod and Nuvolari 2010, 8). A patent for England and Wales cost roughly £100, more than double that to extend it to Scotland and Ireland; the drafting of the specification could also cost several hundred pounds, and later, as the system became more complex, the services of a patent agent might add another 10-25% to the costs (Dutton 1984, 86-96). Although the state was responsible for registering the inventor's claim, regulation and enforcement were entirely up to the patent-holder being able to defend his claim in the civil courts (MacLeod and Nuvolari 2010, 21-2). This is why the drafting of the specification was so important; it had to be sufficiently opaque to make it difficult for rivals to copy it, but sufficiently robust to survive litigation.

The need to fund the patent – as well as potentially to defend it in open court – meant that an inventor often needed a sponsor at an early stage; consequently his bargaining position was weak and 'he ran a substantial risk of losing his unprotected secret in the course of negotiations' (MacLeod 1991, 893). The system was therefore biased in favour of relatively wealthy individuals such as Botfield and Nielson, and against those with less support, such as Gilpin. Potential patentees had to balance their desire to 'prove primacy of discovery' with the need to ensure sufficient development time so that the 'industrially useful … patent would be relevant to a wide segment of industry' (Guise-Richardson 2010, 386). Clearly Gilpin, by using his employer's facilities to develop his ideas, was in a weak position. Nielson, although initially reliant on the patronage of others, was able to manipulate the legal process to his advantage. The litigation not only validated the technicalities of the patent but also established him at the centre of the narrative of hot blast. This aspect of the Nielsen case was echoed in other prominent patent litigation struggles: the achievements of Alexander Graham Bell, for example, were recognised because of 'the additional "invention" undertaken by the lawyers', whose actions ultimately 'endorsed a unitary theory of telephone technology and its origin' (Beauchamp 2010, 877).

Arguably the complexity of the early 19th century iron industry was such that no individual could reasonably claim credit for a single invention. Indeed, as Richard Hayman has pointed out in the context of puddling, ironworking in this period was 'essentially a collaborative culture' (Hayman 2004, 120). Certainly, in the wider history of technology, social networks have been shown to be an important factor in the successful development and implementation of inventions (Swanson 2009, 520-1). Such collective invention remained outside the patent system and is thus largely unrecorded, yet for important aspects of later industrial development the role of collaboration and knowledge sharing was significant. Networks rather than patents resulted in improvements to the application of steam power in Cornish mining during the first half of the 19th century, and led to technological advances in iron making in Cleveland during the later 19th century (Nuvolari 2004; Allen 1983). Therefore a more profitable way of considering hot blast, and indeed other metallurgical innovations of this period, would be to abandon the Smilesean trope of the heroic individual altogether and focus instead on understanding incremental technological changes through rigorous archaeological methods.

Conclusion

Further work is clearly needed to more fully understand the development of hot blast. Even considering the limitations of the historical sources, it is clear that Nielson was not the first. What is more, he could not have attempted it without the application of earlier inventions by others – and hot blast would not have developed in the way it did without further invention and innovation. Botfield's patent is interesting, not so much because of its technical merits, but because it reveals a more complex picture. It is clear that the archaeology of hot blast installations has considerable potential to reveal more about the invention, adaptation and development of hot blast during the first half of the 19th century. Indeed good quality archaeology, supported by appropriate and relevant metallurgical analysis, is the only way that the truth of Nielson's claims can be tested.

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