Discovery of the Process for Making Anthracite Iron

IN THE eighteenth century charcoal was the principal fuel used for smelting iron. When in the course of time the demand for iron increased and the hardwood forests used for making charcoal became smaller, ironmasters looked for other fuels. In Britain and continental Europe they turned to soft coal, which was generally located near deposits of iron ore and from which coke could be made. Anthracite deposits were more scarce. Only a few of the many blast furnaces in Europe—those located near the veins of anthracite—would benefit if a way could be found to use this "stone coal," as anthracite was then commonly called.[1]

The situation in the United States was far different, with the development of an entire industry at stake. Deposits of bituminous coal lay for the most part beyond the mountains, far from the centers of population and the extant means of transportation. The iron-rich ridges and valleys of eastern Pennsylvania and New Jersey, however, lay near extensive fields of anthracite. The canals which penetrated into the anthracite regions in the second quarter of the nineteenth century linked cities, towns, and deposits of iron ore, limestone, and anthracite like beads on a chain.

[1] The first description of the discovery of the anthracite process appeared in 1841 in the form of a book and may have helped to advertise the process among ironmasters: Walter R. Johnson, *Notes on the Use of Anthracite in the Manufacture of Iron with Some Remarks on Its Evaporating Power* (Boston, 1841). The next published attempt at a history of the process was an article by William Firmstone, written in 1874. Firmstone was then ironmaster at the Glendon Iron Works near Easton, Pa. He wrote that he derived some of his facts from Johnson's book and others "from my own notes and observations." "Sketch of Early Anthracite Furnaces," *Transactions of the American Institute of Mining Engineers*, III (May, 1874–February, 1875), 152–156. Shortly thereafter James M. Swank described the discovery in his publications: *The American Iron Trade in 1876* (Philadelphia, 1876), 139–142; and *History of The Manufacture of Iron in All Ages* (Philadelphia, 1884), 265–276. Another nineteenth-century account of the discovery is recorded in John B. Pearse, *A Concise History of the Iron Manufacture of the American Colonies up to the Revolution and of Pennsylvania until the Present Time* (Philadelphia, 1876), 231–243, 261–263.

At this early stage in the development of American industry domestic blast furnaces supplied most of the demand for iron which, however, was small. In 1830 the furnaces of the United States produced 165,000 tons of pig iron and imported an additional 1,000 tons, mostly from England.[2] But the situation was rapidly changing. Railroads were being laid; these needed large quantities of iron. In general, the growth of American industry depended on an immense and reliable supply of pig iron of good quality at relatively low prices.

Thoughtful men recognized the need and realized that a cheap process for smelting iron with anthracite might help to supply it. In his annual message to the General Assembly of Pennsylvania in 1838 Governor Joseph Ritner declared: "The successful union of stone coal and iron ore, in the arts, is an event of decidedly greater moment to the prosperity of our state, than any that has occurred since the application of steam in aid of human labor."[3] Advertising the need for finding a way to make anthracite iron, the Franklin Institute of Philadelphia as early as 1825 had offered a gold medal to the person who would manufacture the greatest quantity of iron using no other fuel but anthracite, the quantity to be not less than twenty tons.[4] For several years in the 1830s the Lehigh Coal and Navigation Company, which had built and was operating the canal between Easton and the coal fields north of Mauch Chunk (now Jim Thorpe), promised to grant free water power and reduced prices for coal to any company that could successfully develop a process for reducing iron ore with anthracite. Toward the end of the decade Nicholas Biddle in Philadelphia and some of his associates offered a

2 Peter Temin, *Iron and Steel in Nineteenth Century America: An Economic Inquiry* (Cambridge, Mass., 1964), 264, 281. For the general economic importance of the anthracite process to the development of the American iron industry, see also Alfred D. Chandler, Jr., "Anthracite Coal and the Beginnings of the Industrial Revolution in the United States," *Business History Review*, XLVI (1972), 145–146, 159–165.

3 *Pennsylvania Archives*, Fourth Series, IV, 474.

4 Notices of these and other awards of the Institute are to be found in the various addresses of the Committee on Premiums and Exhibitions of the Franklin Institute, usually printed as appendixes to the *Journal of the Franklin Institute* (hereinafter *J.F.I.*). In 1825, 1827, 1831, and 1833 the award was to go to the person using anthracite exclusively, but in 1828 the gold medal would have been given to the person successfully smelting iron ore using not less than one-half anthracite as fuel.

prize of $5,000 to the first person who could keep an anthracite furnace in blast for three months.

In the first two decades of the nineteenth century there were widely scattered attempts at using anthracite to smelt iron. A few of these had a limited success. George Crane reported that as early as 1804 a Mr. Martin in Britain obtained a patent for an anthracite process.[5] In the United States, Jesse B. Quinby in Maryland and Peter Ritner in Pennsylvania, brother of the future governor of the state, made iron with anthracite mixed with other fuel. In 1826 the Lehigh Coal and Navigation Company built a small furnace near Mauch Chunk and, after unsuccessful experiments with the use of anthracite, abandoned the project. The 1827 volume of the *Journal of the Franklin Institute* contains a description of an anthracite blast furnace devised by Joshua Malin of Lebanon, Pennsylvania.[6] At Vizille, near the border of France and Switzerland, a company produced iron in 1826 and 1827 by mixing anthracite with coke.

The attempt at Vizille was the only one of the early experiments which received much publicity.[7] There, the company involved had spared no expense and had lost 200,000 francs. Anthracite at Vizille was mixed with coke in varying proportions, using a cold blast. As the ratio of anthracite to coke was increased, the furnace tended to clog, its heat diminished, and the quantity and quality of the iron produced declined. When at last pure anthracite was used, the results were disastrous. "The draught and flame at the mouth were almost extinct; the blast returned by the tymp, and by the tuyeres, throwing out frequently the scoria, the coal, and even the metal; this became so thick, that they were compelled to draw it out almost entire from the hearth, by blows."[8] The author of this account blamed the failure of the experiment on the density of the coal and its tendency when ignited to burn slowly and to break up into small pieces. This, he said, stopped up the furnace

5 *J.F.I.*, V (1838), 126–127.

6 *Ibid.*, IV (1827), 217–218.

7 See especially M. Robin, "On the Use of Anthracite in the Smelting Furnace of Vizille," *Annales des Mines*, 1834, translated for the *Journal of the Franklin Institute* by S. V. Merrick and serially reprinted in XIX (1835), 264–269, XX (1835), 341–347. Mr. Robin was one of the men responsible for the Vizille experiment. See also W. R. Johnson, 14–26.

8 *J.F.I.*, XX (1835), 344. *Tymp*, mouth of the hearth; *tuyeres*, nozzles through which the blast is forced into the furnace; *scoria*, slag.

and impeded the action of the blast.[9] The inference was that, at the very least, the blast would have to be applied at a high pressure in order to penetrate the burning anthracite, whose density was much greater than that of coke or charcoal.

His account made no mention of another possibility, namely that of heating the blast before applying it to the furnace. Even as the experiment at Vizille ended, attempts were being made in Scotland to find a profitable way of smelting the low-grade black-band ore of that country (which was in part bituminous coal to begin with), using raw bituminous coal and coke as fuel. The method involved a hot blast and was developed by James B. Neilson, manager of a gas works in Glasgow, in connection with "Mr. Mackintosh, long known for his inventive genius" and a Mr. Wilson, one of the proprietors of the Clyde Iron Works.[10] In 1828 Neilson patented a stove for producing a hot blast which within a few years became extensively used in the British iron industry. In a five-part serial published in the *Journal of the Franklin Institute* in 1835, Mr. Dufrenoy, Engineer of Mines in Paris, described the success of this hot blast operation in enthusiastic terms.[11] When the temperature of the blast was heated to 612° F., a temperature somewhat above that needed for melting lead, he said, the amount of fuel, flux, and air needed to smelt a given quantity of iron ore was reduced, crude coal could be substituted for coke, and the time needed for the operation was lessened. He noted that twenty-one iron works in Scotland and England, containing sixty-seven blast furnaces, were then working with hot air, and remarked: "The iron made at these furnaces is generally No. 1, proper for casting the nicest work."[12]

Nowhere in this serial did Dufernoy discuss the possibility of using the hot blast to facilitate the reduction of iron ore with anthracite—in spite of the fact that, by the time this article ap-

9 *J.F.I.*, XIX (1835), 265.

10 *Ibid.*, 122.

11 "Report to the Board of Directors of Bridges, Public Roads, and Mines, upon the Use of Heated Air in the Iron Works of Scotland and England," Paris, 1834, translated by S. V. Merrick and reprinted in *J.F.I.*, XIX (1835), 122–125, 208–220, 269–275, 348–357, 415–423. A notice of the success of Neilson's hot blast furnace first appeared in the *Journal of the Franklin Institute* in 1830. *J.F.I.*, IX (1830), 215–216.

12 *J.F.I.*, XIX (1835), 124.

peared, other people were seriously considering the possibility and at least two inventors (Benjamin B. Howell and Frederick W. Geissenhainer) had achieved some success. Dufernoy's only reference to anthracite was a remark that "The coals, very rich in coke, which are dry, and resemble anthracite, can be employed in a crude state, in furnaces working even with cold air."[13]

Howell, an ironmaster then living in Philadelphia, may not have known of Neilson's invention when, around 1828, he successfully produced malleable iron from ore, using anthracite and (as he later claimed) a stream of hot air. However, Howell circumvented the basic problem rather than solved it. Anthracite was already being used in furnaces designed for refining iron, for example, changing pig into wrought or bar iron. The problem was that of finding a method of obtaining pig iron from the ore, using anthracite in a blast furnace. Howell used an improved bloomery furnace to produce "malleable" or refined iron directly from ore.[14] Perhaps he also produced pig iron with the same type of furnace. Certainly, as John B. Pearse later declared, Howell "anticipated everyone in the use of anthracite, and even Geisenheimer's [*sic*] claims seem to relate to this method as improved by the use of hot blast."[15] But Howell's discovery was of no great commercial use, for iron in quantity cannot be produced directly from the ore in a refining furnace. When Howell later disputed the claim of George Crane to being the first to smelt iron successfully using both anthracite and a hot air process, he impressed no one greatly,[16] for Crane and his associates had solved the problem on a commercially useful scale with a blast furnace.

By contrast, Geissenhainer's successful experiments attracted considerable attention. Geissenhainer was born in Germany in 1771 and became a Lutheran clergyman. In 1793, he came to the United States and spent some years in eastern Pennsylvania, where he engaged in the smelting and refining of iron. After 1808 he was pastor of the Old Swamp Church in New York City, but he kept up his interest in the iron industry. For several years prior to 1831

13 *Ibid.*, 423.

14 *Ibid.*, VII (1829), 138–140. The specification of Howell's patent, which appears in these pages, does not mention a hot blast.

15 Pearse, 243. Howell described his experiments in *J.F.I.*, XXV (1838), 166–168.

16 For example, W. R. Johnson does not even mention Howell.

he owned and operated a small charcoal furnace in Schuylkill County, Pennsylvania. He also built a small furnace for experimental purposes in New York City, where, as he later claimed, he invented an anthracite process for smelting iron ore. In 1831 he applied for a patent, describing his process in part as using "a blast, or a column, or a stream, or current of air in or of such quantity, velocity, and density or compression as the compactness or density and the continuity of the anthracite coal requires. The blast may be of common atmospheric *or of heated air. Heated air* I should *prefer* in an economical point of view."[17]

Geissenhainer's reasoning can be summarized thus: get the blast strong to compensate for the increased density of the anthracite. The velocity should be in direct proportion to the greater density of anthracite by comparison with charcoal. Basically, if the furnace is properly constructed, a blast at a sufficiently high pressure will prevent clogging. If, in addition, the blast is hot enough, the prevention of clogging will be enhanced and the amount of fuel needed to smelt a given quantity of iron ore will be diminished.

Geissenhainer received his patent December 19, 1833. A commentator writing for the *Journal of the Franklin Institute* described his assumptions and expressed a hope that "he may find his theory, or rather his practice, correct." The same commentator thought that the instrument which Geissenhainer described was "deficient in those practical details which are requisite to enable any one to follow the process described."[18] Perhaps the commentator was right. Geissenhainer built the Valley Furnace on Silver Creek in Schuylkill County and for two months in 1836 made iron using anthracite and a hot blast. Then his machinery broke down. He worked to improve it, but died in May, 1838, before his new plans could be put into effect.

In the several years following Geissenhainer's discovery there were some other attempts at smelting iron with anthracite, variously using a hot and a cold blast. In December, 1834, Thomas S. Ridgway of Pottsville, Schuylkill County, received a patent for the design of a blast furnace to make anthracite iron. His furnace was based on an assumption that the weight of the ore, flux, and anthra-

[17] Swank, *History of the Manufacture of Iron*, 267; W. R. Johnson, 12–13. See also *The National Cyclopaedia of American Biography*, XI (1909), 175.

[18] *J.F.I.*, XVII (1834), 395.

cite in the stack was largely responsible for clogging. He used a cold blast and provided separate carbonating and fuel stacks. As a result, he said, the top of the smelting fire "will be from four to six feet high above the hearth, that being about the maximum height that a blast can be forced through anthracite coal; whereas the usual height to which it is forced in a charcoal furnace is thirty-five feet."[19] The Committee on Science and the Arts of the Franklin Institute expressed an opinion that Ridgway's chemical views were "wholly unsound" and that his furnace failed to appreciate the real reasons why previous attempts to use anthracite to smelt iron had failed.[20]

The editors of the *Journal* were much more favorably impressed with the results of an experiment with a hot blast at the Oxford charcoal furnace in Warren County, New Jersey, hailing it as "this first successful experiment of the kind in our country."[21] The owners of the furnace, Henry, Jordan & Company, had acquired it in 1832 and for several years used it in the ordinary way with a cold blast. Then, in June and July, 1835, they made their successful experiment, using charcoal derived from oak and chestnut as a fuel. "This plan of supplying the furnace with air at an elevated temperature, is upon a principle said to be in use in Germany. It consists in using the cold air from the bellows, through tubes laid adjacent to the most highly heated part of the furnace, in place of heating it by separate fuel, in an apparatus detached from the furnace."[22] That is to say, Henry, Jordan and Company did not use Neilson's oven but developed their own.

19 *Ibid.*, XX (1835), 40. *Stack*, the upper part of a blast furnace, into which layers of ore, fuel, and flux are introduced from the top.

20 *J.F.I.*, XX (1835), 78–79. A somewhat similar furnace for smelting iron with anthracite was patented by Isaac C. Bryant of Philadelphia Dec. 31, 1838. Instead of using several stacks to reduce pressure on the burning coal, however, Bryant provided for two or more boshes, "the object being to diminish the pressure of coal on the lower or customary bosh." *J.F.I.*, XXVIII (1839), 383–384. *Bosh*, widest part of a blast furnace, sloping down to the hearth in which most of the actual smelting takes place.

21 *J.F.I.*, XX (1835), 361–365. When this operation at the Oxford furnace took place, Geissenhainer had not yet put his furnace into blast.

22 *Ibid.*, 363. For fuller coverage of the role of the Oxford furnace in the development of the iron industry see W. David Lewis, "The Early History of the Lackawanna Iron and Coal Company," *The Pennsylvania Magazine of History and Biography* (PMHB), XCVI (1972), 424–468.

Why did the ironmasters take so long to accept the hot blast as the principal key to making anthracite iron? By the end of 1835 the hot blast had been used successfully to smelt iron ore with charcoal, bituminous coal, and coke. Furthermore, the peculiar properties of anthracite as a fuel were now well known in the cities of the Atlantic seaboard. Unlike soft coal, wood, or charcoal, anthracite would not respond favorably to a cold draft or an ordinary blast from a pair of bellows. Erskine Hazard, one of the founders of the Lehigh Coal and Navigation Company, had noted this in a dramatic passage in which he recorded final success in getting anthracite to burn.[23] The selling of anthracite to the public had depended on a redesign of stoves and grates, in part to prevent cold drafts.[24]

Several years later, George Crane stated the basic oddity of anthracite as a fuel: "One evening, after I had placed a piece of it upon my parlour fire (which had before been made up with bituminous coal) and had allowed it to arrive at a red heat, upon my applying as fierce a blast to this piece of coal as I could raise from a pair of bellows, I noticed the appearance of a black mark or spot upon that part of it where the air impinged upon it; on my continuing the like rapid current, in the same direction, I shortly blew the fire out of it. I at once perceived that the effect of the strength of the current of air, when cold, which we of necessity are obliged to blow into our furnaces to secure the passage of the blast through the high and dense column of materials contained in an erection like a blast furnace, instead of encouraging ignition, was actually unfavourable to it. On giving the thing but a moment's reflection,

23 In 1812, when fuel was scarce, Hazard and his associates obtained a cartload of anthracite. They wasted it in unsuccessful attempts to get it to burn. Another cartload of the stone coal was procured, "and a whole night spent in endeavoring to make a fire in the furnace, when the hands shut the furnace-door and left the mill in despair. Fortunately, one of them left his jacket in the mill, and, returning for it in about half an hour, noticed that the door was red-hot, and upon opening it was surprised to find the whole furnace of a glowing white heat. The others were summoned, and four separate parcels of iron were heated and rolled by the same fire before it required renewing. The furnace was then replenished, and, as *letting it alone* had succeeded so well, it was concluded to try it again, and the experiment was repeated with the same result." Quoted in Richard Richardson, *Memoir of Josiah White* (Philadelphia, 1873), 32.

24 Frederick M. Binder, "Anthracite Enters the American Home," *PMHB*, LXXXII (1958), 82–99.

the question promptly occurred to me, What would be the effect of turning a blast into a furnace upon this coal, which would itself burn—which would itself melt lead?"[25]

Most ironmasters did not regard the problem as simply as Crane did. With the possible exception of Geissenhainer, they were not scientists. They were practicing mechanics or (as one might say today) engineers, skilled in the art of making iron. They preferred experience over experiment, and the experience of ironmasters in attempting to make anthracite iron had produced two obvious results: (1) there had been limited success using a cold blast; and (2) anthracite, which was naturally denser than other fuels, became denser still when burning. Even Geissenhainer seems to have relied as much on increasing the pressure of the blast as he did on heating it.

In addition, the physics and chemistry of the hot blast were not yet understood. For example, Thomas Clark, a professor of chemistry at Marishal College, Aberdeen, expounded a theory to explain the increased efficiency of the hot blast operation with coke or charcoal. "In the manufacture of cast-iron . . . experience has taught us, that a certain temperature is required in order to work the furnace favourably, and all the fuel consumed so as to produce any lower degree of temperature is fuel consumed in vain." A cold blast meant that a lot of fuel was consumed at a temperature too low to reduce iron. "The expedience of previously heating the blast obviously removes this refrigeratory, leaving the air to act in promoting combustion, without robbing the combustion of a portion of the heat it produces."[26] Whatever the merits this theory might have for explaining why with a hot blast a given quantity of iron could be smelted with less fuel than it could with a cold blast, it contained nothing to explain why a hot blast might be expected to overcome the greater density of anthracite in a blast furnace. In fact, the reasons why the hot blast might make anthracite work in smelting

[25] George Crane, "On the Smelting of Iron with Anthracite Coal," reprinted from the Proceedings of the British Association for the Advancement of Science in *J.F.I.*, XXV (1838), 129.

[26] Thomas Clark, "On the Application of the Hot Blast, in the Manufacture of Cast-iron," read in 1835 and reprinted from the Transactions of the Royal Society of Edinburgh in *J.F.I.*, XXIV (1837), 50–51.

iron were not fully understood until decades after the process itself had become standard in the United States.[27]

Crane, like other owners and ironmasters, operated on the basis of experience and intuition. He was an Englishman who had come to the business of making iron after spending fifteen years in the hardware trade in Birmingham. In the 1830s he was operating three furnaces at Yniscedwin (Ynscidwin) near Swansea, South Wales. He used coke in these furnaces, which he had to transport from a distance. Since his plant rested on the only deposit of anthracite in Wales, he stood to profit if an economical way could be found to make a good quality iron from anthracite. Accordingly, he and some of his employees, especially his ironmaster, David Thomas, experimented over the years to see how this could be done.[28]

Thomas had been born on a farm in South Wales. At the age of seventeen he had gone to work for the Neath Abbey Iron Works. After five years there and a short period spent in Cornwall erecting a pumping engine, he moved to the Yniscedwin works, where at the age of twenty-three he became superintendent of the furnaces. Three years later Crane acquired the Yniscedwin works. Following years of experimenting with anthracite, Crane and Thomas finally concluded that the hot blast might be the missing link. Crane then sent Thomas to the Clyde Iron Works to see how Neilson's stove worked. "After the most careful examination, Mr. Thomas determined that the hot-blast was just what was wanted for an anthracite-furnace. He returned to Yniscedwin with a license from Mr. Neilson, and an expert mechanic who understood the construction of heating-ovens, and at once proceeded to construct hot-blast ovens, and erected them at the furnace which was known as the 'Cupola furnace,' 11 feet bosh by 45 feet high. The furnace was

27 A sense of the enormous strides made over an eighty year period in understanding the science of making anthracite iron can be gained by comparing the following accounts: M. Daubrée, "On the Application of Anthracite for Smelting Purposes," translated from *Annales des Mines*, XIV, and reprinted in *J.F.I.*, XXVII (1839), 259–263; Frederick Overman, *The Manufacture of Iron In All Its Various Branches* (Philadelphia, 1854), 434–440; J. E. Johnson, Jr., *The Principles Operation and Product of the Blast Furnace* (New York, 1819), 5–97. Sir Lothian Bell, working in the third quarter of the nineteenth century, is generally credited with the greatest developments in understanding the science of blast furnace operations.

28 Solomon W. Roberts, "Obituary of George Crane, Esq.," *J.F.I.*, XLI (1846), 214–216.

blown in, February 5, 1837; the success was complete; and anthracite-iron continued to be profitably made from said furnace without intermission."[29] The quality of the iron thus produced, according to Crane, was excellent.[30]

Others, however, doubted the quality of iron produced by the hot blast process. Mr. Wood of the Abersychan Iron Works, Pontypool, writing in the *London Mining Journal*, asserted that iron made with a hot blast was less strong than iron produced with a cold blast. "That this is a fact, is now established beyond a doubt, by numerous experiments by different parties." He reported that a bar of iron made with a cold blast broke at 2,009 pounds, whereas a similar bar made with the hot blast broke at 1,568 pounds. The reason for the relative weakness of hot blast iron, he declared, lay in the fact that it contained five per cent impurities as contrasted with three per cent impurities for cold blast iron.[31] Another correspondent to the *London Mining Journal* disagreed, at least as far as the hot blast used in connection with anthracite was concerned, saying that "pig iron obtained from the use of anthracite coal, by Crane's process, is not at all weakened by hot blast, but is better calculated for the founder's use than any he had seen, that beams cast from this iron of the same pattern with others from coke iron No. 1 had twenty per cent the advantage. The reason, he says, why pig-iron smelted with anthracite is not weakened by the hot blast is the great quantity of carbon it contains."[32]

This controversy over the merits and demerits of hot and cold blast iron, whether produced with coke or with anthracite, continued for several years.[33] But it did not stop enterprizing iron-

29 Solomon W. Roberts, quoted in Samuel Thomas, "Reminiscences of the Early Anthracite-Iron Industry," *Transactions of the American Institute of Mining Engineers*, XXIX (1900), 903–904. Crane obtained his British patent for the anthracite process on Sept. 28, 1836. *J.F.I.*, XXXIV (1842), 134.

30 *J.F.I.*, XXV (1838), 128. A description of his process, as stated in his patent, appears in *ibid.*, 405–406.

31 *J.F.I.*, XXIV (1837), 348–351.

32 *Ibid.*, 435.

33 See, for example, the report of experiments on hot and cold blast iron conducted by William Fairbairn, *ibid.*, XXVIII (1839), 334–345, 386–395; also the report of the Committee of Judges on Iron and Steel of the Franklin Institute, *ibid.*, XXX (1840), 381–382, and the report of tests made on anthracite iron by Richard Evans in *ibid.*, 405–408.

masters from going ahead with an attempt to start a commercially successful anthracite hot blast operation.

Solomon Roberts, a nephew of Josiah White, who was co-founder with Hazard of the Lehigh Coal and Navigation Company, heard of Crane's new process. Roberts was in Britain studying railroad iron.[34] He immediately informed his uncle of the successful experiment. This was several months before Crane reported on his success to the Chemical Section of the British Association for the Advancement of Science, whereby his work became more generally known. Thus White knew of Crane's process before many others could have been aware of it, and without doubt he disclosed his knowledge to the other directors of the Lehigh Coal and Navigation Company.

About this time the Company and some other coal operators with mines near Mauch Chunk were pursuing an experiment of their own with anthracite. The work was being done by Joseph Baughman, Julius Guiteau, and Henry High of Reading (Baughman, Guiteau & Company). F. C. Lowthorp of Trenton, New Jersey, was also one of the partners. At first they experimented with the small furnace abandoned by the Lehigh Coal and Navigation Company, using about eighty per cent anthracite. Their results were so encouraging that they built a new furnace near Mauch Chunk in 1838, in which they used anthracite exclusively and applied a hot blast. The furnace worked successfully for about five weeks, when the supply of ore gave out. It was replenished; some improvements were made; and operations were recommenced and lasted for about three months. In all, about 100 tons of iron were produced with anthracite. Then, the experiment of Baughman, Guiteau & Company was halted for reasons not sufficiently described. In a letter written in 1840, Lowthorp, after describing the operation as a success, observed that "The above experiments were prosecuted under the most discouraging circumstances."[35]

Possibly because of this failure White and his colleagues decided

[34] Years later Roberts wrote, "At the time of my going abroad, anthracite coal was nowhere used for smelting iron ore; but in May, 1837, I saw the problem successfully solved by means of the hot blast, by the late George Crane, of the Yniscedwin Iron Works, near Swansea, in South Wales." Solomon W. Roberts, "Reminiscences of the First Railroad Over the Allegheny Mountain," *PMHB*, II (1878), 388.

[35] The letter is printed in full in W. R. Johnson, 32–36, and in Pearse, 239–242.

against the risk of attempting to duplicate what Crane and Thomas had successfully accomplished. Instead, they sent Erskine Hazard to Wales to persuade Crane to come to Pennsylvania. While Hazard was abroad some of the directors of the Lehigh Coal and Navigation Company formed an iron company, to which the name Lehigh Crane Iron Company was given.[36] Despite the inducement of the name, Crane could not, or would not, come to Pennsylvania. In attempting to get his process patented in the United States, he had run into the barrier of Geissenhainer's prior claim and was involved in litigation, which eventuated in his purchase of Geissenhainer's patent. Crane, however, did agree that Thomas should come, and Thomas was willing, though it was "his ambitious and energetic wife" who made up his mind for him on this point, according to Thomas' son Samuel. So David Thomas contracted to serve as superintendent at a handsome salary, which was conditioned on the venture's commercial success.[37]

Then came the business of getting the proper machinery. This was a major problem, not only for the Lehigh Crane Iron Company, but for American industry in general. White and Hazard, being expert mechanics, were able to appreciate the nation's shortage of mechanical skills and equipment for making machinery. Without much doubt, in turning from Baughman, Guiteau & Company to Crane and Thomas, they were bargaining for the mechanical skill to make the process work as well as for the process itself.[38] Samuel Thomas later emphasized that nowhere in the United States was the expertise and machinery needed for all the parts to be found. Later attempts to procure cylinders at Boston and New York failed: "At this time there was not a boring-mill in the United States large enough to bore a cylinder of 60 inches diameter." In building the first furnace of the Lehigh Crane Iron Works, "The

36 The name "Lehigh Crane Iron Company" appears on the articles of agreement between Hazard and Thomas, dated Dec. 31, 1838. As so often happened with manufacturing com panies in that period, formal incorporation did not occur until sometime after the company had been created. In this instance, the date of incorporation was Apr. 23, 1839. Several years later the name was shortened to "Crane Iron Company."

37 Thomas, 904–905. The agreement between Hazard and Thomas is printed in full in *ibid.*, 905–906.

38 W. R. Johnson, 34–38, styles the hot blast apparatus of Baughman, Guiteau & Company as "at first defective" and in general criticizes their machinery.

want of foundry-facilities was one of the greatest difficulties encountered."[39]

Much of the machinery was made in Britain and was shipped to Pennsylvania. According to Richard Richardson, before Hazard left Wales he "ordered such machinery as was necessary to be made for the company, under the direction of George Crane, the inventor."[40] Later, Samuel Thomas disputed this, claiming credit for the machinery for his father and went on to say: "The blowing-machinery was constructed at the Soho Works, England, and the hot-blasts at Yniscedwin from the same patterns as used there, under the supervision of John Clee, the assistant superintendent, who succeeded my father in the management of the works, while the fire-brick came from the Stourbridge works, England."[41]

David Thomas, his wife, and three sons, arrived at Allentown July 9, 1839. For almost a year thereafter the Welshman was engaged in building the first furnace of the Lehigh Crane Iron Company at a spot near Allentown on the Lehigh River, to which the name Craneville was given, but which was soon changed to the present name of Catasauqua.

Meanwhile, some other owners of blast furnaces and ironmasters in the United States were working to develop an anthracite process. Before the Lehigh Crane Iron Company succeeded in getting its first furnace into blast, a furnace called the "Pioneer" began making anthracite iron at Pottsville. Burd Patterson was the owner. In 1837 he had persuaded William Lyman of Boston to come and build an anthracite furnace using a hot blast. Lyman completed the furnace in the summer of 1839. On October 26 of that year Benjamin Perry, a Welshman with previous experience in the use of hard coal in Wales, put it into blast. David Thomas was present on that occasion. According to one authority, "Thomas Chambers stated (1846) that Mr. Lyman made no use of Mr. Crane's experience, and yet his success was complete and perfect in his prize-blast of ninety days' (October 19, 1839–January 17, 1840) continuance at Pottsville. The feat was almost incredible in an inferior furnace, with a weak blast."[42]

39 Thomas, 912, 914.
40 Richardson, 102.
41 Thomas, 927.
42 Pearse, 235.

Lyman won the $5,000 offered by Biddle and his associates, receiving his award at a banquet held in January, 1840. On this occasion, Biddle compared "the effect of hot-blast on the ores and coal which would not yield their treasure to a cold blast to that of the sun on the traveler, who only wrapped himself the closer against the cold wind, but could not resist the sunshine." In happy vein, he toasted "Old Pennsylvania: Her sons, like her soil, a rough outside, but solid stuff within; plenty of coal to warm her friends; plenty of iron to cool her enemies."[43]

Before Thomas put his first furnace into blast, Benjamin Perry also succeeded in starting two anthracite furnaces. One was the Roaring Creek Furnace in Montour County, Pennsylvania, blown in May 18, 1840. The other was the Columbia Furnace at Danville, Pennsylvania, which began making iron July 2, 1840. On June 17, 1840, William Firmstone blew in an anthracite furnace at Phoenixville, Pennsylvania, using ovens designed and built by Guiteau. Another of the early furnaces was called the Danville. It was owned by Biddle, Chambers & Company. Built in Montour County in 1839, it started smelting iron ore in April of the following year.

On the Fourth of July, 1840, David Thomas put his furnace into blast. Although not the first, it was the best of the early anthracite furnaces. Whereas the others soon shut down, this one endured. Except for a brief period in 1841, when it was flooded by the Lehigh River, it produced iron continuously until 1879, when it was torn down.

[43] *Ibid.*, 235–236. See also Joseph H. Zerbey, *History of Pottsville and Schuylkill County, Pennsylvania* (Pottsville, 1936), V, 2091. The gold medal offered by the Franklin Institute was, apparently, never awarded. In 1839 the Institute gave a silver medal to J. C. Bryant & Company, for a "specimen of Iron smelted with Anthracite." *J.F.I.*, XXVII (1839), 302. The judging committee did not feel that it could decide on the quality of the pig iron thus produced. The furnace of this company is not among the anthracite furnaces described by W. R. Johnson and Firmstone as operating before 1841.

Several patents were granted for anthracite furnaces which were apparently never built. George E. Sellers of Upper Darby Township, Delaware County, Pa., and Simeon Broadmeadow of New York City both received such patents. The patent of neither mentions specifically the hot blast. Both attempted to solve the problem of getting the blast to penetrate the mass of anthracite-ore-flux by shortening the stack of the furnace and thus reducing the weight resting on the burning fuel. *J.F.I.*, XXV (1838), 45–46, 56–57. Also, Joseph Lyon of Pottsville patented a fuel consisting of a mixture of powdered anthracite and clay to which he gave the name "Clay-Coals", to be used in smelting iron ores. *Ibid.*, 333–334.

Why did this furnace succeed when the other early anthracite furnaces in the United States had failed? The answer is not to be found only in the use of the hot blast, for all of the anthracite furnaces built in 1839 and 1840 used that. The reason lies in the superior construction of Thomas' furnace. According to Firmstone, with it "commenced the era of higher and larger furnaces and better blast machinery, with consequent improvements in yield and quality of iron produced."[44] The operation at Catasauqua became the principal model which other ironmasters sought to copy and to improve on.

With the blowing-in of the first of the Lehigh Crane Iron Company's furnaces this story of the development of the process for making anthracite iron ends. It was by then the standard process in the anthracite district of Wales, although it had apparently not yet been successfully used in France.[45] It spread rapidly in the United States. While neither Geissenhainer nor his heirs attempted to enforce the initial patent, Crane compelled British ironmasters to pay royalties to him. After buying Geissenhainer's patent he patented several improvements on it in the United States, but on the advice of Roberts he did not enter into litigation to enforce them.[46] Thus there was no effective legal obstacle to copying the basic process. The number of anthracite furnaces in the United States increased from six in 1840 to about forty in 1846.[47] According to Chandler, "By 1844 anthracite was the cheapest iron ever made in America."[48] In 1860 the domestic production of iron stood at 821,000 tons, almost five times the level of production in 1830. Anthracite iron accounted for the largest part of the increase. In

44 Firmstone, 155.

45 Daubrée, 259–263. Daubrée noted that Crane's hot blast supplied air at a pressure of 2½ pounds per cubic inch at 620° F., and stated that this was insufficient to overcome the density of the anthracite mass in the French furnaces. He blamed the failure on the difference in behavior of the coal, saying that the anthracite of Wales "does not decrepitate so violently as that from the neighbourhood of the Alps." On the other hand, by 1836 the hot blast was being extensively used in France with coke or charcoal as a fuel. A. Guenyveau, "Report on the Use of the Hot Air Blast in Iron Furnaces and Foundries," *Annales des Mines*, VII, reprinted in *J.F.I.*, XXI (1836), 62–66, 135–139, 354–359.

46 Roberts, "Obituary of George Crane," 216.

47 Thomas, 916.

48 Chandler, 164.

1860 about fifty-seven per cent of all iron in the United States was made by anthracite or a combination of anthracite and coke.[49]

Who, if anyone, was principally responsible for the process? Writers narrating the story of its development have attributed principal credit to various persons. John B. Pearse seems to give it to Benjamin B. Howell;[50] Sylvester K. Stevens, former State Historian of Pennsylvania, accords Frederick Geissenhainer credit for being the first to produce pig iron using anthracite coal as a fuel;[51] Samuel Thomas gives principal credit to his father and quotes extensively from a narrative by Solomon Roberts in an attempt to prove his point.[52] Ironically, Roberts in another place stated that "Mr. Crane is undoubtedly entitled to the honor of being the first to establish the smelting of iron with anthracite coal."[53]

David Thomas is sometimes referred to as the pioneer or father of the anthracite industry in America.[54] But, if this title is at all deserved, it must be both for what he did after July 4, 1840, as well as for what he did before that date. He remained for years as superintendent of the highly successful Crane Iron Company, building its other furnaces, and then, in 1854, together with persons and capital drawn mostly from Bethlehem and Easton, he founded his own company—the Thomas Iron Company, a few miles north of Catasauqua at a place called Hokendauqua. This venture was also successful and outlasted the life of its founder by many decades. Thomas became the first President of the American Institute of Mining Engineers and lived to be the oldest ironmaster in length of service in the United States. His sons followed him in the business

49 Temin, 266, 268. Also, in fiscal year 1860 the United States imported 71,000 tons of pig iron. *Ibid.*, 281.

50 Pearse, 243.

51 Sylvester K. Stevens, "A Century of Industry in Pennsylvania," *Pennsylvania History*, XXII (1955), 53.

52 "Mr. Crane has often received the credit of this useful discovery. With all due respect to his memory, I must state that he was in no sense of the word a mechanic or a technical man, but a shrewd business man, with a faculty for recognizing the merits and promoting the commercial utilization of the inventions of others." Thomas, 926.

53 Roberts, "Obituary of George Crane," 216.

54 Thomas, 902; Swank, *Iron In All Ages*, 273; Howard M. Jenkins, ed., *Pennsylvania Colonial and Federal* (Philadelphia, 1903), III, 381.

of making iron, and at least one, Samuel, took pains to perpetuate his fame.[55]

In fairness to all, however, it seems best to withhold the accolade of "principal contributor" from any. The articulation of the process for making anthracite iron was social in character. It involved essential contributions from many people—the operators at Vizille, Neilson, Howell, Crane, Thomas, Geissenhainer, Lyman, Perry, Guiteau—these and others put pieces of the puzzle in place. The process was not so much a single invention as it was a new arrangement of old methods, to which some improvements and a few innovations were added. The sparks of genius flickered in a number of people.

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[55] Thomas, 927; *The Thomas Iron Company* (memorial volume published by the Company on the occasion of its fiftieth anniversary, 1904), 25–29.