American Iron, 1607-1900

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Until the 1830s Americans, with their abundant forests, had not seen much advantage in using innovations, such as smelting with coke or iron puddling, that the British needed to avoid paying the high price of fuel wood in England. In the 1860s, however, they recognized that the new European steelmaking techniques, such as the puddling and pneumatic processes, could be immediately useful in the American economy. Each steelmaking entrepreneur then had to decide which of the new processes to select. As they made their decisions, they conducted expensive experiments with German steel, steel puddling, pneumatic (Bessemer) steelmaking, and the open hearth process. Some thought they had ore particularly suited to steelmaking. Many still believed particular resources to be the key to metallurgical success and overlooked the need for adequate, if not superior, skills.

In previous decades American artisans had achieved great success with the mechanical arts as they developed techniques of mass production. However, artisans could not see and study metallurgical processes the way they could the operation of a machine. They experimented at their furnaces and drew on their accumulated experience. Then, when they had mastered a technique, they found it hard to explain to others why a particular method or material worked while another, apparently similar, one did not. Consequently, inexperienced inventors and investors could easily believe in the rich promise of a particular ore or a new process and then find that converting it into a commercial operation making a reliable product at a competitive cost.
was a task for which they had neither the temperament nor the resources. Even Bessemer would not have succeeded if he had not had both plenty of money and technical help from others. Most American metallurgical innovators—unlike the financiers who eventually organized large steel companies using already proven methods—had little reward for their efforts.

PNEUMATIC STEELMAKING

William Kelly began experiments with pneumatic refining and fining of pig iron at the forge and blast furnace he managed near Eddyville, Kentucky, in 1847. He intended to speed production of wrought iron. Instead, his 1857 patent on fining iron proved useful to a group of American entrepreneurs in their attempt to make pneumatic steel without paying royalties to Bessemer.

William Kelly was a young haberdasher when he met Mildred Gracy of Eddyville, Kentucky, and to be better able to court her, searched for a business opportunity in her home town. He found it in ironworks, and with his brother he purchased Suwanee Furnace and Union Forge in 1846. After the Kellys rebuilt the forge in 1854, they had two refinery and ten finery hearths, and a steam hammer. Their forgemen made about 1,000 tons of blooms per year from pig iron. William Kelly managed the furnace and forge; his brother handled the finances.

Kelly watched the forgemen at the refinery and finery hearths as an observer unfamiliar with the subtleties of making high-quality wrought iron, but one with some knowledge of the chemical changes taking place in the forge fires. He recognized that he could save fuel if his forgemen took liquid iron from the blast furnace, refined it, and passed it to the finers while still liquid. His first idea was to do both the refining and fining by blowing air into liquid pig iron in a blast furnace; he designed a trial furnace for this purpose in 1847. He intended to make a loup that he could consolidate under the forge hammer, thereby combining the work of the blast furnace, refinery, and finery in one vessel. He did not succeed with this scheme and put the project aside.

Kelly returned to his experiments in 1851. He simplified his earlier plan by placing a brick-lined chamber with a tuyere at its bottom adjacent to the Suwanee blast furnace. He ran liquid pig iron into the chamber, turned on the air blast, and made metal that he later described as “refined” or “run-out metal.” He did not need the coke fuel used in the refinery because he began with liquid rather than solid pig and eliminated the heat lost through the refinery doors. He said that he sometimes made malleable metal, so he evidently had difficulty controlling the reaction in the refinery vessel. When he built another refinery vessel at Suwanee Furnace, he could make as much refined metal as the refinery at his forge did. However, he would have had to haul the refined metal to his Union Forge, some miles away, for conversion to wrought iron.

Kelly may not have appreciated that finery forges competed
with puddling works by using a labor-intensive process that al­
lowed forgemen to make a superior grade of iron. Forgemasters
recovered their higher labor and fuel costs in the high price
their product brought. Kelly’s refinery saved fuel at the sacrifice
of close process control. Had Kelly’s new refinery been an eco­
nomically useful device, it would certainly have been adopted
by American makers of wrought iron, who exchanged informa­
tion freely, were trying all kinds of new ideas at this time, and
were anxious to reduce fuel consumption.

Henry Bessemer, another entrepreneur with no experience
in ferrous metallurgy, began experiments on pneumatic pro­
cessing of liquid pig iron with the intention of making steel
rather than Kelly’s run-out metal. When Kelly learned of Bes­
semer’s U.S. patent on the pneumatic process, he recognized the
similarity between the enclosed vessel he had used to make
run-out metal and Bessemer’s stationary converter for making
steel. Kelly claimed prior invention, produced witnesses who had
seen his experiments in 1847 and 1851, and was issued Patent
No. 17,628 (23 June 1857) for “Improvement in the Manufacture
of Iron” by blowing air into liquid pig iron contained in an en­
closed vessel where the heat released sufficed to keep the alloy
molten. In an initial show of interest in the pneumatic process
by an American ironmaster, Daniel J. Morrell arranged for Kelly
to use facilities at the Cambria Iron Works for trials. The record
of his experiments at Cambria is based on the recollections of
witnesses set down years after the events. Kelly made at least
two trials between 1857 and 1859 that were spectacular enough
to be remembered by Cambria employees. He did not mention
these trials in his letter to James Swank, who was writing an am­
bitious history of the iron industry, and the attempts probably
resulted in nothing useful.

By 1859 Bessemer had his pneumatic steelmaking process in
regular operation. Steelmakers in Sheffield melted pig iron in a
cupola, poured it into the converter, and blew air through it to
remove the silicon and most of the carbon (Fig. 10-1). William
Durfee started building a pneumatic converter at Wyandotte,
Michigan, in 1862 without a license from Bessemer for either the
process or the converter design, while his cousin, Zoheth Dur­
fee, was attempting to negotiate for patent rights. Meanwhile,
John A. Griswold and John F. Winslow sent Alexander Holley to
England in 1863 to obtain rights to Bessemer’s patents. Durfee
failed with Bessemer, while Holley succeeded. However, Dur­
fee, after two years of experimentation, made the first Ameri­
can pneumatic-process steel in September 1864 at Wyandotte.
Through bad management the Wyandotte group made little fur­
ther progress, and Durfee left in June 1865. Holley started build­
ing a converter plant for Griswold and Winslow at Troy in Janu­
ary 1864 and successfully made steel in February 1865. Next,
the Pennsylvania Steel Company of Harrisburg took a license
for a Bessemer converter and made Holley the chief engineer.
10-1. Bessemer patented this tilting converter for carrying out his pneumatic steelmaking process. He lined the vessel with refractory brick and fitted ports at the bottom connected to an air compressor. Artisans tilted the converter back, poured in liquid pig iron, turned on the air blast, and tilted the vessel upright. Air blowing through the metal burned the silicon and carbon out of the pig and released enough heat to keep the metal molten. When conversion was complete, the operator tilted the vessel forward, shut off the air, and poured the liquid steel into ingot molds. (From Ferdinand Kohn, *Iron and Steel Manufacture* [London: William Mackenzie, 1869], pl. 25, facing p. 78)

The company began construction of the works late in 1866 and was soon in regular production. Other investors then rapidly expanded Bessemer steel capacity in the United States (Fig. 10-2).  

When Morrell, Zoheth Durfee, and the American industrialist and financier Eber Ward failed to get American rights to Bessemer’s patents, they took renewed interest in Kelly. Morrell had Kelly make some additional experiments at Cambria in 1862 with a tilting converter of Bessemer’s design that the Cambria company purchased abroad, probably in England.  

Again, there is no record of useful results. Since Holley had secured the rights to Bessemer’s patents for a rival group, the value of Kelly to the Cambria entrepreneurs was not in further progress that Kelly might make, but rather in the possibility of using his patent to thwart the investors who had hired Holley. The patent owners created most of the Kelly legend while trying to secure commercial advantage over their rivals; others later embellished the legend uncritically and with growing fervor.

The only records Kelly left of his experiments are his patent and a letter he wrote many years later for Swank. The other documentary evidence of the experiments at Eddyville comes from the testimony of seventeen witnesses who gave statements
As the air blast burned carbon out of the molten pig iron in a Bessemer converter, it formed a long, luminous flame at the converter mouth, as seen in this undated photograph. A nineteenth-century blower had no instruments to indicate the progress of the conversion reactions; instead, he controlled the process by his interpretation of the appearance of the flame.

(Courtesy of Robert Vogel)

for the interference proceedings that led to Kelly’s patent. All the witnesses confirm that Kelly experimented with blowing air into liquid pig iron in enclosed vessels first in 1847 at Union Forge and again in 1851 at Suwanee Furnace, and that his intention was to make wrought iron (the product the Kelly Company was selling). He actually made run-out metal (white cast iron) that was sometimes sufficiently decarburized to solidify in the vessel.

After Bessemer’s demonstration that steel could be made pneumatically, Kelly wrote a patent claim asserting that his process could be used to make run-out metal and implying that it could be used to fully decarburize iron, even though this had not been demonstrated in his experiments. Kelly claimed in his patent specification that “the prevailing opinion among iron-workers [was] that a blast of cold air driven into a body of liquid iron would chill it.” This was a fabrication. None of the seventeen witnesses expressed surprise that the iron in Kelly’s vessel remained liquid. The forgemen would have known from their own observations that the air blast in the refinery or finery fire caused pig iron to get hotter. Other Americans had already ob-
served and reported that iron containing silicon and carbon could be heated by blowing air on it. John S. Gustin obtained Patent No. 2,743 (2 August 1842) for an air blast directed on the metal in a puddling furnace to accelerate refining. Gustin instructed the puddler to remelt the solid metal formed on the hearth by placing it in the air blast. Members of the press and the public may have been surprised, but forgemen were well acquainted with the effect of air on hot pig iron. The patent commissioner overlooked the inconsistency between Kelly’s patent claim (that he could make carbon-free iron in the liquid state) and the evidence brought forward (that he made run-out metal or wrought iron) in the interference proceedings. The Kelly story is an example of how entrepreneurs reconstructed the substance of patents for financial advantage and thereby created legends about invention.\textsuperscript{14}

**PUDDLED STEEL**

While Holley was adapting the Bessemer process to American conditions, another group of Americans tried making puddled steel, a technique German experimenters had developed by 1850. A puddler could make steel if he could stop the boil before he had removed all of the carbon in the iron. He found this difficult to do unless he could slow the rate of removal of carbon. Ironmasters who wanted to make puddled steel reduced the oxidizing power of the furnace slag by substituting manganese oxide for some of the iron oxide. They had the puddler use a smoky, reducing atmosphere in the furnace at the end of the boil.\textsuperscript{15} With this technique a puddler spent nearly double the usual time completing a heat and used correspondingly more fuel. Puddled steel, like wrought iron, contained particles of slag that could not be completely removed by subsequent hammering, piling, and rolling. Until Sidney Thomas developed the basic Bessemer process, Europeans, who had few sources of low-phosphorus ore, practiced steel puddling because they could convert pig containing more phosphorus than the original Bessemer process would tolerate.\textsuperscript{16} Some American ironmasters attempted steel puddling, but most failed to master it. Among those who failed were the proprietors of the Shepaug Steel Mining Company (later the American Silver Steel Company).

In 1817 Benjamin Silliman reported that he had seen “steel ore” in Roxbury, Connecticut, like that used by the famous Styrian steelmakers in Austria.\textsuperscript{17} A decade after Alexander’s attempt at Airdrie to smelt ore he thought identical to that he had used in Scotland (see chapter 9), a group of Connecticut entrepreneurs, believing they had the equivalent of Styrian ore, tried to transfer Austrian steelmaking to America. In 1865 they began building an integrated steelworks, probably the first in America.\textsuperscript{18} Yale professors G. J. Brush (the metallurgist) and J. D. Dana (the famous geologist) advised the Roxbury proprietors on smelting and steelmaking. Artisans opened a mine and built a
railway to deliver ore, charcoal kilns, roasting ovens, a blast furnace, and the steelworks. The proprietors expressed their confidence in the enterprise by sparing no expense, as in sheathing their blast furnace with ashlar masonry. They adopted the then novel elliptical hearth as well as a waste-heat recovery system to generate steam for the blowing engine.

Archaeometallurgists found through studies of slag and metal artifacts that the Austrian foreman and his artisans failed to make steel with the Roxbury ore. The proprietors then shifted their efforts to puddling steel and hired William Durfee, who had recently made the first pneumatic steel in America, as their superintendent. By the time they discovered their ore was not really similar to that in Styria, and before Durfee and the artisans had mastered steel puddling, the proprietors had exhausted their capital and credit. In 1868 they abandoned their steel-puddling furnaces. A reorganized company continued to make pig iron and then failed after botching an attempt to convert the furnace to hot blast.

The artisans at Roxbury did not have the skills and information they needed to deal with the chemical differences between American and Austrian ores that had appeared to be similar. Other Americans had trouble with direct transfer of new processes that depended on control of chemical reactions, as when Park Bros. and Company in Pittsburgh failed in an attempt to set up Siemens’s direct-reduction process, then operating successfully in England.

OPEN HEARTH STEEL

While Americans were learning the Bessemer process and experimenting with steel puddling, Europeans developed another new steelmaking technique. William Siemens of Hanover, Germany, went to England in 1842 and with his brothers Werner, Frederick, and Karl built regenerative furnaces. Glassworks operators began using them in 1861. William began experimental steelmaking in 1865 and by 1867 was making open hearth steel from pig and ore. Siemens melted pig iron on the hearth of a reverberatory furnace and used ore and an oxidizing flame to eliminate the carbon, silicon, and manganese in the pig, as was done in puddling, but with a temperature high enough to keep the furnace contents molten. Because the metal remained liquid, the melter could adjust its composition to the carbon content he wanted, thereby making steel. Siemens used silica brick and a sand bottom in his furnace, and steelmakers called his method the acid open hearth process. Later steelmakers used magnesite brick for the hearth so that they could charge limestone to eliminate phosphorus from the iron. They called this the basic open hearth process (Fig. 10-3). Because the purifying reaction was not the only source of heat, as in a Bessemer converter, open hearth furnace operators could maintain closer
control of the steelmaking reactions than they could in a converter. Emile and Pierre Martin built an open hearth furnace at Sireuil, France, in 1863, and by 1867 they made steel by adding wrought iron to molten pig iron. By adjusting the proportions of pig and wrought iron scrap in their furnace charge, they controlled the composition of the resulting steel. Abram Hewitt obtained a license for the Martins’ process in 1867 and managed to make some steel with it at Trenton. However, his artisans had difficulty holding the temperature of the furnace between the melting point of steel and that of the clay firebrick then available for furnace lining. Consequently, Hewitt was unable to make the process a commercial success. Three years later artisans at the Bay State Iron Works of South Boston overcame these problems and had an open hearth steel furnace producing by 1870. American steelmakers started using it on a large scale after the Cambria works built an open hearth plant in 1878 (Fig. 10-4).
As steelmakers adopted the new steelmaking processes, they also began building integrated works where they could transfer hot metal from their blast furnaces to their converters or open hearth furnaces, thereby making iron smelting an adjunct to steelmaking. Initially, however, they increased the demand for charcoal-smelted pig iron and wrought iron made by puddling. Holley had used charcoal pig from Crown Point, New York, in his initial Bessemer steelmaking at Troy in 1865, and in their first decade converter operators preferred charcoal-smelted pig. In 1871 and 1872 the Pennsylvania Steel Company purchased for its converters more than 17,000 tons of pig made in the two charcoal-fired blast furnaces in Fayette, Michigan. Steelmakers using the Martin open hearth process bought wrought iron to mix with the pig. They used puddled iron (puddling could remove 90 percent of the phosphorus in pig iron) and experi-
mented with iron made by the Krupp pig-washing and Siemens direct-reduction processes.25

Competition from cheap steel also forced rolling mill proprietors to improve the quality of their product. Railway superintendents in the 1870s discovered that rails made of Bessemer steel could give much better service than iron ones. Then, as they gained experience, they learned there could be great variation in the endurance of different steel rails. Chemical analyses of the steel failed to reveal the cause.26 Lacking means of controlling the microstructure of their steel, the railmakers could not maintain uniform quality. This helped proprietors of rolling mills that could make high-quality iron rails retain a share of the market for twenty years after the introduction of steel. The superintendent of the Reading Railroad had discovered in 1857 that, if properly rerolled, old iron rails would give years of good service. Because he also found it difficult to get mills to follow his specifications for the rerolling process, he had the Reading build its own mill in 1868. Artisans there rolled rails from piles made of two-thirds old iron and one-third newly puddled iron. They improved the endurance of their rails by incorporating iron hardened with phosphorus in the pile, forming a wear-resistant railhead backed up by tougher, low-phosphorus iron. These rails gave better service than many of the early steel rails.27 Managers of the Reading rail mill also experimented with rolling steel heads onto iron rails with the Wheeler process for making “iron-clad steel.” An iron covering was supposed to protect the steel from decarburization during rolling. However, at the temperature needed to weld the pile, the steel began to melt and often broke through the thin iron cover. Following another plan, artisans at the New Jersey Steel and Iron Company of Trenton successfully rolled iron rails with heads made of puddled steel.28

By 1883, however, Bessemer steelmakers had improved the uniformity of their rails and reduced their price enough to induce railway superintendents to abandon iron rail in mainline service. Between 1871 and 1881 rolling mill proprietors tripled their output of wrought iron, and they continued to gradually increase it through 1890. In Pittsburgh thirty of sixty-three iron and steel plants still made wrought iron in 1894, and there were 1,050 single puddling furnaces in the city, with more in the environs (Fig. 10-5). The Sable rolling mill, built in 1845, had thirty-four puddling furnaces in 1874, and in 1900 it still had a capacity of 22,500 tons of merchant bars per year.29 Although ironmakers had enlarged their production, steelmakers had far outstripped them. The percentage of the total metal production contributed by puddling works and finery forges therefore shrank.30

By 1867 artisans and managers at American ironworks had been building up a store of metallurgical knowledge by trial and by experience for more than 150 years. Through the decades before the Civil War they had worked with particular technological
exuberance. In the absence of any discipline imposed by science, they often went astray. Nevertheless they became technologically informed and adept. With their knowledge and industry, they matched, and sometimes surpassed, their overseas rivals.

After 1867 professional scientists and engineers gradually diminished the mystery surrounding specific natural resources and metallurgical processes. Accordingly, Americans found it harder to believe that their national greatness derived from the superior endowments of their continent. Instead, patriotic writers turned to inflating the reputations of American inventors and entrepreneurs, as Benjamin Silliman and E. W. Blake did when they so enlarged upon Eli Whitney’s genuine accomplishments that later historians could easily demolish the legend they had created. The owners of Kelly’s patent protected its value by re-

10-5. The proprietors of this unidentified puddling works and rolling mill near Pittsburgh, unlike the Cambria managers, did not convert to steelmaking. In the late nineteenth century, as seen in this undated photograph, they received coal and pig iron (stacked in the yard next to the track) directly by rail. The square stacks fitted with dampers show the location of the puddling furnaces; boilers for the steam engines that drove the rolling mill used the round, damperless stacks at right. (Courtesy of Robert Vogel)
defining what Kelly actually did. Then, nationalistic partisans abetted by Kelly descendants took the story on further flights of fancy in their patriotic zeal.

Those who made American inventors and entrepreneurs into industrial heroes inevitably diminished recognition of the skills and informal knowledge of the artisans who actually made metallurgical and manufacturing techniques work. As American politicians and businessmen, increasingly removed from personal experience of industrial work, came to believe the stories about heroic inventors, they began to see artisans simply as workers rather than as partners in the difficult task of executing metallurgical technique. Union and business leaders, in their quest for political and economic power, lost interest in the intellectual content of work and were willing to confine artisans’ creativity with rigid work rules and bureaucratic control of the shop floor. As they did these things, they put in place the forces that would later bring about the demise of the great American steelworks.