In their final task, ironworkers shaped the metal they made into the forms their customers wanted. They hammered or rolled wrought iron or steel into bars or plates sized to buyers’ specifications. Blast furnace proprietors, who in the eighteenth century had often cast their metal directly into finished products, increasingly left this work to specialist founders as the nineteenth century progressed. Instead, they dispatched their product as pigs.

Makers of wrought iron could use the slow, heavy blows of the helve hammer to shape a rough billet. As did steelmakers, they turned to tilt hammers to make smoothly finished bars. Millwrights built a tilt hammer with a lighter wooden beam than they would use for a helve. Cams on a rotating drum lifted and released the beam (Fig. 8-1). By using a large number of cams or rapid rotation of the drum, the millwright designed the hammer to strike about 400 blows per minute. He often used an additional wooden beam to act as a spring to accelerate the hammer on its downward stroke, thereby increasing the force of its blow. A skilled hammerman drew the work back and forth under the rapid blows while flipping it from side to edge. He could shape a long bar to a cross section so nearly uniform that it appeared to have been rolled. For heavier tasks, such as making iron axles for railway cars, artisans preferred steam hammers because they could precisely regulate the force of each blow (Fig. 8-2). Because large steam hammers could deliver heavier blows than any helve or tilt hammer, ironmasters increasingly adopted them as they undertook larger forgings for railways and marine en-
The Lowell Machine Shop in Massachusetts offered to supply the Harpers Ferry Armory in Virginia with tilt hammers of this pattern in 1855. A belt from overhead shafting to the large pulley drove the hammer. The wooden spring at the back of the hammer beam accelerated the downward motion of the hammer head to increase the force of each blow. Artisans used tilt hammers, which delivered up to 400 blows per minute, to shape hot metal into finished products. (Courtesy of Harpers Ferry National Historical Park)

In the nineteenth century, they found that hydraulic presses, which applied steadily increasing force rather than sharp blows, were even more effective for this work.

Power-driven hammers mimicked the work of a smith with a hand hammer. A rolling mill shaped metal by an entirely different principle. The motion of the two rolls turning toward each other squeezed the metal and caused it to flow over the surfaces of the rolls in their direction of rotation, extruding it out of the gap between them. This could make a smooth, uniform finish on the rolled bar. Silversmiths and goldsmiths used small sets of rolls turned by hand cranks to work precious metals. Ironmasters needed heavier equipment: they drove their rolls with water power or steam engines.¹

Through the eighteenth century American ironmakers used small rolling mills like the one at Saugus to convert hammered bars into plates that they could pass through slitting rolls to make nail rods. After 1810, when Isaac Pennock rolled plate with rolls 4 feet long, ironmasters built larger, stronger mills to do the work previously done with helve and tilt hammers.² They sometimes found their water-power systems inadequate: the artisans at the Lukens mill, who rolled the first American boiler plate in 1824, had to climb on their undershot wheel and tread with the buckets to keep the mill from stalling.³ (If the mill stopped
8-2. To shape large forgings, artisans used a steam hammer like the one seen in this undated photograph probably taken before 1870. The hammer driver manipulated valves to admit steam to the cylinder at the top of the hammer frame to lift the hammer head and then drive it downward. He had precise control of the time and strength of each hammer stroke. Hammer drivers liked to ask visitors to place a pocket watch on the anvil. The driver would then shoot the hammer head down, stopping it a fraction of an inch from the watch face. (Courtesy of the Smithsonian Institution)
Jewlers used this looping mill in Cumberland, Maryland, to make long, thin iron rod that could later be drawn into wire, as seen in this 1920s photograph. The roller at the left is putting a red-hot billet through the initial roll passes to make a bar. To the right, a roller has looped a bar emerging from one pass through the next pass. The rollers worked on a floor made of cast iron plates. (Courtesy of the Smithsonian Institution)

Later, most proprietors turned to engines powered with steam from waste-heat boilers over their puddling furnaces. By reversing the engine, rollers could pass bars alternately back and forth through the mill, thereby reducing the time and heat they lost if the catcher had to return the bar over the top roll between each pass through the mill.

Americans did not favor reversing mills as much as the British, and often built three-high mills instead. The rolls in such mills turned continuously, and the artisans passed the work forward through the lower pass and back through the upper. To make a shape like a rail, they used rolls with a succession of grooves that would form the iron to the desired shape. However, rollers found it difficult to make round bars this way because of the large number of finishing passes they needed. Mill designers solved this problem with a guide that fixed the orientation of the bar with hot metal in it, unequal heating would crack the rolls.)

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Successive passes through the Cumberland looping mill elongated the red-hot iron bar until it covered much of the mill floor, as in this 1920s photograph. F. W. Harbord and J. W. Hall described the process in their book, The Metallurgy of Steel (vol. 2: Mechanical Treatment, 4th ed. [London: Griffin, 1911], p. 799): “To watch the progress of the fiery serpent, with its life-like wriggles, in its course through the mill is a fascinating sight, but, for an unwary sightseer, a dangerous one. It is easy to be caught in the toils, and seriously if not fatally injured, and in the event of a serious breakage in the mill, the workmen to avoid being lassoed by the hot loops, usually clear out till the mill has stopped.” (Courtesy of the Smithsonian Institution)

as it entered one oval pass. Gradually, mill designers adopted guides for other shapes, and guide mill came to mean any mill fitted with a device for holding work in the correct orientation. Artisans found iron and steel softer and easier to form when hot. However, when they tried to hot-roll a long bar, it would cool off between passes through the rolls. Yet once it was longer than their furnace, they could not reheat it. In the mid-nineteenth century, European engineers devised the looping mill to solve this problem: the catcher grasped the bar emerging from one pass, looped it around himself, and inserted it in
the next pass. As each pass through the mill elongated the bar, the loops on the mill floor got longer. However, the time saved between passes coupled with the mechanical work done by the rolls helped keep the iron at the hot working temperature (Figs. 8-3, 8-4). Washburn and Moen of Worcester, Massachusetts, initiated looping-mill technique in America in 1877 with a mill installed to prepare bars to be drawn into telegraph wire.4

Metalworkers used cold rolling when they wanted to shape iron to exact dimensions and have the surface free of the oxide scale that adhered to it after hot forming. The cold metal hardened with each successive pass through the rolls. If the iron became too hard to work further, the roller could anneal it by heating it to a bright red heat followed by slow cooling. After cleaning off the scale formed during the anneal, he could then roll the softened metal until it became hard again. To successfully cold-roll iron, artisans needed rigid mills driven by powerful engines. In 1860 Bernard Louth of Pittsburgh developed a technique for cold-rolling bar that millwrights could use for line shafting, and in 1864 he devised a three-high mill in which the center roll was smaller than the other two. This reduced the power required to drive the mill.5

ROLLING RAILS AND BEAMS

When Americans began building railways, they spiked iron straps to the tops of wooden stringers to make their rails. Any ironmaster with a merchant mill could roll the straps, often called railroad iron. The proprietors of the Delaware and Hudson railway learned one limitation of this design in 1829, when their first locomotive, the Stourbridge Lion, crushed the wooden rails on its initial run.6 Later, as American travelers rode in the lightly constructed cars that could be pulled on strap-iron rails, they discovered how easily the car wheels could drive a “snake head,” a loosened strap, upward into their midst.

Robert L. Stevens had designed the T-shaped rail in 1830 while on a trip to England to buy materials for the Camden and Amboy Railroad. At that time, no one had been able to roll a wrought iron beam with flanges on it, and English rolling mill proprietors did not think a T-rail could be made. Eventually, Stevens persuaded Guest, Lewis, and Company in Wales to undertake the task. After many difficulties with split and twisted rails, they made a supply of 3½-inch-high rail weighing 35 pounds per yard for the Camden and Amboy. American railway builders had to buy rails from British mills until 1844, when artisans at the Mount Savage works in Maryland began rolling U-shaped wrought iron rail (Fig. 8-5). The Montour Works in Danville, Pennsylvania, successfully made T-shaped rail the next year. Both used pig iron smelted with mineral coal and converted to wrought iron in coal-fired puddling furnaces.

When Peter Cooper moved his ironworks out of New York
Artisans at the Mount Savage Iron Company in Mount Savage, Maryland, rolled this wrought iron U-shaped railroad rail about 1844. They did not get the thickness quite the same on the two sides. The section has been polished and treated with a reagent that reveals the distribution of phosphorus in the iron. Dark spots are slag particles; bright bands are phosphorus-rich metal. The shape of these bands shows how the iron flowed as it passed through the rolls. The amounts of slag and phosphorus (determined by microprobe analysis) are within the range commonly present in good-quality wrought iron. (Photograph by William Sacco)

City in 1845, where its smoke and noise had become a nuisance, he was making wire-bars and wire. Cooper secured a contract from the Camden and Amboy for rails to be made at his new Trenton Iron Works, managed by his son Edward and Abram Hewitt. This rail had a bulb-over-flange section 4½ inches deep and weighed 64 pounds per yard. The Trenton works continued to make this rail for four years. Early in 1849 William Cook, the chief engineer of the Camden and Amboy, ordered rails 7 inches deep. He wanted the stronger joints that could be made with deeper splice bars. Cooper and Hewitt undertook the project. The rollers at Trenton found that their piles of wrought iron often split at the welds as they ran through successive passes. In addition, the rolls tore off the flanges as the rails emerged from the mill. By December, when their specially made, chilled-iron rolls broke, they had completed only 150 of the 4,000 tons of rail Cook had ordered. Because of the money they had already lost on the 7-inch-rail project and a flood of British imports that forced the price of rail down, Cooper and Hewitt abandoned rail making. They sold off part of their rail-making machinery. Some other mill—no one has discovered which—rolled the twenty-seven miles of heavy rail for the track the Camden and Amboy had in place six years later. Cooper and Hewitt diversified their product line by making bar, shapes, and wire for suspension bridges.7

In 1852 Peter Cooper needed wrought iron floor beams that could span up to 18 feet for his new Cooper Union building. He asked William Borrow, who had designed the mill for the 7-inch rail at the Trenton works, to roll 7-inch-deep wrought iron beams. Borrow found it difficult to convert Cooper’s ideas to practice. He built a universal mill (one with both vertical and horizontal rolls; see Figure 8-6) that also had lifting tables and drive rolls to handle the bars and spent a year getting it to work. In the meantime the Trenton Iron Works supplied composite beams, made by riveting channel sections together, for the New York Assay Office. By midsummer 1854 Borrow had the universal mill operating and rolled the 7-inch beams for the Cooper Union building.8 The cross sections of specimens of the 1854 Cooper Union beams and the 1849 Camden and Amboy rail are nearly identical.9 Engineers knew well before 1853 that the T-rail section was not an efficient shape for a floor beam; when made of wrought iron, it should have had a symmetrical I shape.10 In fact, Cooper had designed an 8-inch-deep, true I-beam by August 1854, and after Borrow died in October 1854, Charles Hewitt, Abram’s son, modified the Trenton mill to make I-section beams. We are left to wonder if Cooper had Borrow work two years on a mill intended to roll an appropriately shaped floor beam, or if the managers of the Trenton works, attempting to reenter the heavy rail market, supplied Peter Cooper with rails for beams and later found a stronger market for true I-beams. Whatever
A universal rolling mill had both vertical (b) and horizontal (a) power-driven rolls. William Borrow designed a universal mill at the Trenton ironworks in 1852 to make floor beams for the Cooper Union building in New York City. After modification by Charles Hewitt, the mill was successfully used to roll I-beams. (From Bruno Kerl, Handbuch der metallurgischen Hüttenkunde, 2nd ed. [Freiberg: Engelhardt, 1855], 3: pl. VII)

In 1857 John Fritz at the Cambria Iron Works in Johnstown, Pennsylvania, adapted the design of the three-high mill to rolling rail. His hanging guides stripped the rails free of the rolls as they emerged from each pass. (In mills without Fritz’s guides, the rail often wrapped itself around the rolls, bringing work to a stop until the resulting mess could be cleared.) These guides, along with Fritz’s power-driven feed rolls, allowed artisans to run rail back and forth through the rolls rapidly and greatly improved their productivity.

**RECYCLING WROUGHT IRON**

American rolling mills developed an increasingly large business recycling wrought iron from old structures and machines as the nineteenth century advanced. Smiths had long known how to recycle discarded wrought iron by forging it into new shapes. They would weld up small pieces when they needed something larger than the scraps they had at hand. Artisans at rolling mills drew on this experience when they cut up, bundled, reheated, and re-rolled scrap into rails and merchant iron. They also recycled the
iron oxide scale that broke off hot metal passing through their rolls by sending it to the puddlers to use as an oxidizing agent.

Smiths faced a more difficult task in recycling steel. They could not weld small scraps of steel together to make large pieces nearly as easily as they could weld wrought iron. Unless they could reshape a scrap piece of hard steel on a grindstone, they had to anneal it, forge it to the desired shape, and reharden it. Machinists who could grind cutting tools out of worn-out files did not need to attempt heat treating. However, when a gunsmith wanted to convert an old sword blade into lock springs, he had to be careful to avoid decarburizing the metal while annealing and then rehardening it to the correct temper. Many woodworkers retain the tradition of making cutting tools from old files today; machinists now prefer high-speed steel.

Managers of factories where artisans cut and shaped iron often went to considerable trouble to recycle their scrap. The superintendent of the Harpers Ferry Armory in Virginia started a recycling program soon after the armorers began making muskets. In September 1818 he contracted for a “Puddling furnace for welding the borings and scrap iron of the Armory.”13 Superintendent Stubblefield reported in early 1820, “In the last year we purchased bar and band iron in the amount of $25,000 and also completed our puddling Furnace and Forge and made 60 tons of bar Iron, out of borings, trimmings of the [musket] barrels.”14 The price of new iron suitable for arms making was about $160 per long ton,15 so $25,000 would have bought about 156 tons of gun iron. Hence, the reworked scrap made up about a quarter of the gun iron used at the armory that year. Armory managers kept an emphasis upon recycling. In 1836 the chief of ordnance wrote, “A forge at this Armory is much wanted to work up scraps, old gun barrels, borings and turnings . . . It is estimated that . . . about three pounds of good iron may be made from the borings and turnings of each musket. The scrap iron at the armory, if sold at public auction, will not command more than two cents per pound; but if worked up into bars, it will be equal in value to three or four cents per pound.” In July 1836 Congress appropriated $5,000 “for the erection of a forge and fixtures for working up scrap iron into bars.” This was a substantial brick and stone building with a slate roof.16

Managers of private metal-working factories probably made similar efforts to recycle. Nevertheless, the most common artifacts archaeologists find at the sites of private armories, such as those of Eli Whitney or Simeon North, are worn-out files and misshapen wrought iron parts. Despite the vigilance of their foremen, armorers often followed the old custom of pitching spoiled work and damaged tools out a shop window into the mill race to get them out of sight.

War and the obsolescence of old machinery put increasingly large amounts of scrap iron on the market as the nineteenth cen-
tury progressed. When the Tredegar Iron Works in Richmond, Virginia, first sold wrought iron made in its rolling mill, railroads and other users were returning relatively little scrap. Thus, in 1844 Tredegar artisans puddled 2,463 tons of wrought iron and rolled 2,244 tons of finished product: they did not augment the output of their puddling furnaces by rerolling scrap. After 1865, however, ironmasters could easily purchase worn-out railroad equipment and surplus ordnance. Tredegar managers began making large purchases of old cannon and rail. They built a roll train for breaking down old rails. A specification for rails from the Richmond, Fredericksburg, and Potomac Railroad in 1867 shows how Tredegar artisans used scrap in making finished wrought iron products: the piles for rolling into rails were to be made up of two-fifths each new puddled iron and old rails, and one-fifth tough scrap iron. The old rails were to be heated and rolled into plates. The puddled iron was to be placed on the top of the pile and the plates made from the old rails on the bottom.

By 1875 the Tredegar managers had found that they could abandon their new puddling furnaces because of the abundance of scrap offered at low prices, much of it rail and old bridge parts from railroads rebuilding their routes with steel. They brought up to twenty carloads of wrought iron scrap a week to their Richmond works for conversion into products such as rail chairs and splice bars.

**Planished Iron**

Several Russian forges in the first part of the nineteenth century made iron sheet with the fine, blued finish favored in Europe and America for covering boilers and cylinders of steam engines. Popular belief held that artisans in an isolated Siberian city made this iron by a highly profitable, secret process owned by the Russian government. Rumors asserted that “when a workman enters the service he bids farewell to family and friends . . . and is never heard from afterwards.” Several desperate attempts to steal the secret were said to have ended in death. Nevertheless, by 1871 the British metallurgist John Percy had deduced the steps in this supposedly secret process from reports of visitors to the Russian works and laboratory examination of the finished products.

In the 1840s Alan Wood began to experiment with manufacture of imitation Russian sheet iron at the Delaware Iron Works, a rolling mill established by his father on Red Clay Creek in Woodale. Within a few years he was able to get customers to buy his American Glazed Iron rather than the Russian product. Alan’s son Dewees Wood took charge of the mill at the age of eighteen and seven years later was ready to set up on his own. With his father-in-law, Dewees Wood started the McKeesport Iron Works in 1851, specializing in the manufacture of highly finished sheet iron.

About 1872 Wood developed a technique of hammering (planishing) sheet iron with large-face hammers to make a sur-
The illustration in this advertisement for Wood's planished sheet iron expressed the proprietors' feeling about the inferiority of the competing Russian product that had long dominated the market. (From F. H. Taylor, History of the Alan Wood Iron and Steel Company, 1792-1920 [Philadelphia: Alan Wood Steel Company, 1920], p. 35)

8-7. The illustration in this advertisement for Wood's planished sheet iron expressed the proprietors’ feeling about the inferiority of the competing Russian product that had long dominated the market. (From F. H. Taylor, History of the Alan Wood Iron and Steel Company, 1792-1920 [Philadelphia: Alan Wood Steel Company, 1920], p. 35)

CASTING IRON

Foundrymen melted pig iron to pour into molds shaped to the products their customers wanted. A founder could go wrong in many ways while pouring a casting. If the iron solidified before it completely filled the mold, it left a cavity (a cold shut) in the finished casting. Molten iron dissolved oxygen and other gases from the atmosphere of the furnace it was melted in. When it began to solidify in a mold, these gases bubbled up through the remaining liquid. If the bubbles did not escape, they made the casting porous. Because the iron shrank as it solidified, the founder had to make his mold somewhat larger than the finished dimensions he wanted. Additionally, metal poured so as to fill a mold began to solidify at the outside; as the remaining metal shrank, a cavity (pipe) formed in the center of the casting. Part of the foundryman's skill was his ability to design molds that minimized porosity and pipe. In a casting that was to include hollowed-out parts, like the bore of a cannon, the molders might fail properly to center the core that formed the cavity and make the casting thin on one side.

Slag could be entrapped as foundrymen poured liquid iron into the mold, and careless pouring might carry slag down into metal. Slag that stuck to the mold or the core would remain in the metal as the mold filled and make the casting defective. The founder could ameliorate this fault by designing molds to fill from the bottom rather than the top (Fig. 8-8), so as to keep the slag floating upward on the rising metal. The iron itself might contain coarse graphite flakes caused by smelting at too high a temperature. The heat-flow pattern out of a badly designed mold might result in long metal grains that collected dirt and debris between them during solidification.

Residual stresses in the solidified metal could weaken cast iron unless the founder used an appropriate mold design. In an ordinary mold, a casting solidified from the outside in. Once the outside was solid, shrinkage of the cooling metal inside caused tensile stresses that remained in the casting after it had com-
To make this mold for casting iron cannon, artisans packed sand moistened with water containing clay around a wooden pattern made in sections. The pattern was covered with cokewash (powdered charcoal moistened with clay and water). Once the mold had dried, the workers removed the pattern and dried the sections in an oven, then bolted them together and placed the completed mold in a pit surrounded by sand. To keep the casting free of slag and dirt inclusions, founders used a mold arranged so that metal entered at the bottom and flowed upward, carrying any foreign material to the top of the casting. A chamber above the muzzle, called the casting bell, provided a reservoir of liquid iron to make up for shrinkage of the metal below during solidification. After the casting had cooled, artisans sawed the bell off. This mold made a solid casting that machinists would bore out to complete the cannon. (From C.J.B. Karsten, Handbuch der Eisenhüttenkunde [Berlin: Reimer, 1841], pl. XXVI)
This cast iron bracket to support the main spindle bearings of a Robertson-designed milling machine was made in Hartford, Connecticut, about 1855. The founders who poured the casting had made inadequate provision for the escape of the gas released from the solidifying iron. Bubbles trapped in the solidifying metal made the casting porous. Dirt trapped in the bubble holes caused wear in the operation of the machine. Bubbles like these in a smaller casting could seriously degrade its strength. (National Museum of American History; photograph by Eric Long)

American founders had immense troubles casting reliable cannon (see chapter 9) and found it difficult to handle even the simpler tasks of casting frames for machine tools and structural members for buildings. American architects began using cast iron columns in the 1820s. When James Bogardus set up a foundry in 1848 to cast iron parts for complete buildings, he created a new architectural style as well as a substantial business for himself. Cast iron used to make a product such as a cooking pot or fireback did not need to be particularly strong. However, in the beams and columns of a building, it had to sustain large forces without breaking. Because cast iron was brittle, any failure of a cast iron member was likely to be catastrophic.

A few minutes before 5 P.M. on 10 January 1860, the south end of the five-story-high, brick Pemberton Mill in Lawrence, Massachusetts, fell outward without warning. The collapse then spread as fast as a person could run to the other end of the 284-foot-long structure. As the walls fell, each floor dropped on the one
Some of the 670 persons at work in the mill escaped by crawling through spaces where the fallen floors rested on the cotton-making machinery. Others were still trapped when the rescuers, working by lantern light, accidentally set the wreckage on fire. Eighty-six persons were killed and two hundred seventy-five injured.

The Essex Company, the original proprietors of Lawrence, had put up the Pemberton Mill in 1853 to a design that used wider rooms and taller windows than had been customary. Two rows of cast iron columns supported the floors. Each column rested on a flange fitted to the top of the column next below. James B. Francis, engineer and agent for the Locks and Canals Company in nearby Lowell, deduced that fracture of one of the flanges dropped the column above on the one below. Ordinarily, this would not cause the building to fall, but when he examined the debris, Francis found that the columns were full of blow holes, cold shuts, and thin places. The Eagle Iron Foundry of Boston had made bad castings, and no one had reported the defects, perhaps because the outer surfaces of the columns looked smooth. Francis believed that soundly cast columns would have withstood the impact caused by breakage of a flange.

Francis and other American engineers relied on the results of British experimental and theoretical research on the strength of cast iron beams and columns. By mid-century, they could use well-tried techniques to design metal buildings and bridges. However, builders sometimes failed to realize how often founders poured bad castings and did not provide for adequate testing and inspection of the iron structural members they used.

We have material evidence of inadequate foundry technique in parts cast for two of the earliest surviving American machine tools, a planer made by John Gage in Nashua, New Hampshire, about 1845, and a Robertson-pattern milling machine made in Hartford, Connecticut about 1855. Both frame castings are full of porosity (Fig. 8-9). In parts this big—the milling machine casting is 7 inches thick—there is enough sound metal to carry any force applied by the machine. However, a casting ¾-inch thick (as in the Pemberton columns) with porosity like this would have had little strength.