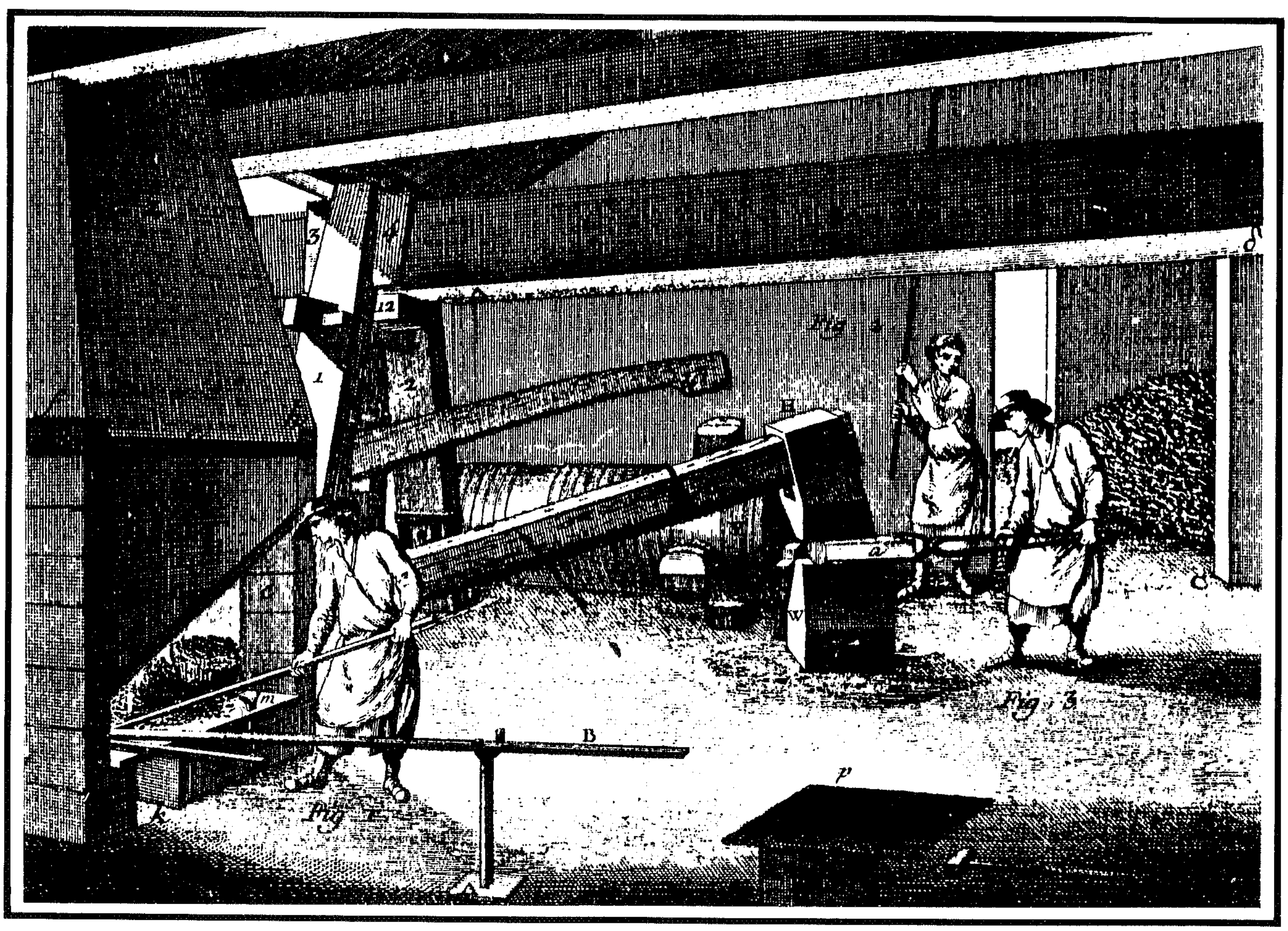
Chapter 2
Forges, Furnaces, and Foundries

In the iron business there are blast furnaces, puddling furnaces, heating furnaces, air furnaces, cupolas, and more. Each has a size, shape, and purpose. Some are associated with each other, some are not. As if to further confuse the unwary researcher, many cartographers, historians, and U.S. Census takers right down to the present insist on identifying anything connected with ironworks as a furnace, without further qualification. These include blacksmith shops, foundries, bloomeries, and even charcoal kilns and lime kilns.

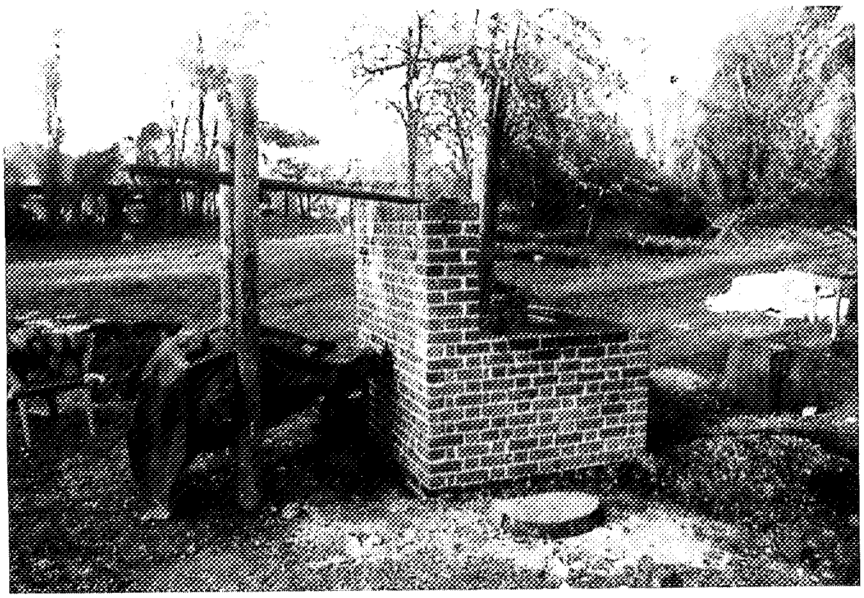
Iron was initially made in Vermont, as elsewhere, by two distinctly different processes, depending on whether the desired product was cast iron or wrought iron. Cast iron is iron that contains significant amounts of carbon and is too hard to hammer. It was molded (cast) into desired shapes such as potash kettles, tools, stove plates, machine gears, or ingots. Cast iron, also called pig iron after being molded into ingots, was made in a blast furnace, so named for the large blast of air that was needed to maintain the high temperatures within the stack. Wrought iron, on the other hand, is a relatively soft, carbon-free iron, which can be easily hammered into horseshoes, wheel rims, or plows, or drawn into rods to make nails. It was made in a bloomery forge, so named because the initial product of the forge was an approximately 100-pound (1-cwt) bar called a bloom.

The Bloomery Forge

The availability of forests to provide fuel for making charcoal did as much to dictate location of the bloomery forge site as did the site's proximity to waterpower. Bits of slag in Near



2-1. *Refining iron with a trip-hammer. Note heavy wood beam above the hammer, which the hammer "bounced" against while being lifted upward, thrusting the hammer down on the anvil with more force than if merely dropped at its height (Diderot 1763: plate 96).*



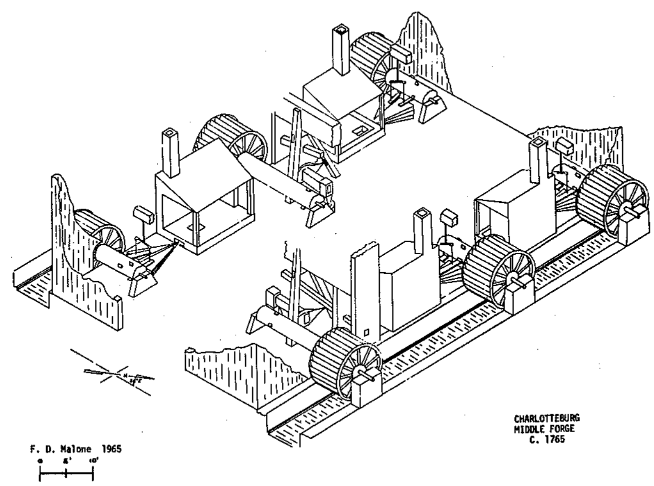
2-2. *A working reconstruction of an 18th-century bloomery forge at Colonial Williamsburg, Virginia.*

Eastern deserts betray an ancient catastrophic loss of local forests for making charcoal, at a time when the primitive methods of iron making consumed 70 pounds of charcoal for every pound of iron produced (Fleming, July/Aug. 1983:66).

Contrary to popular thought, unlimited hardwood forests were not everywhere available in the American Colonies to supply charcoal. The expensively high ratio of charcoal consumption to iron bar production caused many to consider bloomery forges as wasteful. One of these areas was Pennsylvania, where few bloomeries existed. There the blast furnace came into use instead from almost the birth of this frontier industry. The reverse was true in New England, where bloomeries thrived (Bining 1973:65). Colonial New England iron was therefore made primarily in bloomeries (Pearse 1876:101). Vermont was no exception; there were many more bloomeries than blast furnaces.

Many of the early New England ironworks contained "complete works"—both blast furnace and bloomeries—rather than just one type of forge. These New England works were generally categorized as follows: (1) *smelting furnaces* reduced crushed rock-bearing ore into pigs, with unlimited charcoal supply; (2) *refinery forges* imported pig iron from New York, Pennsylvania, and Maryland furnaces and converted it into bar iron; (3) *bloomery forges* reduced directly from bog ore (without an intermediary furnace operation) into blooms—much inferior to those refined from pigs; (4) *"bog ore"* furnaces reduced bog ore and mainly cast hollowware (Bining 1973:28).

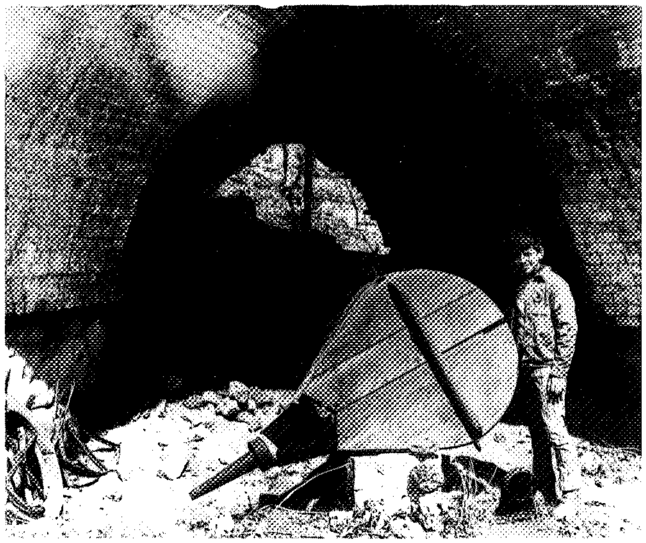
Few records dealing with the operations of forges in colonial America have survived but it is assumed the forge procedures and design in Vermont followed the English pattern. Generally, the English forge had two hearths (called fires in the 1780s and 1790s) to each trip-hammer. Plans of the forge at the 17th-century ironworks at Saugus, Massachusetts, contained this ratio. The 1765 forge at Charlotteburg, New Jersey, had two sets of this 2-to-1 hearth–to–trip-hammer arrangement, each



2-3. *Ground plan of a bloomery forge at Charlotteburg, New Jersey, about 1765; typical in both layout of apparatus and area as those built by Ira Allen in Vermont during the 1780s (Lenik 1974:10).*

set using about 2,000 square feet of floor space (Lenik 1974:10). Ira Allen contracted for a forge at Tinmouth in 1791 with two fires. A year later he contracted for another forge in Shelburne measuring 50 by 40 feet, or 2,000 square feet (Wilbur vol. 2 1928:6, 27). Matthew Lyon sold his "two south fires together with a hammer, anvil, and coal house" at Fair Haven in 1794 (Adams 1870:142). It seems, therefore, that Vermont's earliest bloomeries, at least, followed somewhat in the pattern of English and colonial American bloomeries.

Vermont bloomeries in the early 1800s were the latest improved version of the old Catalan forge (Overman 1850:245). No longer a small cup-shaped device, it had evolved to a 6- to 8-foot-square stonework table called the hearth, with a place for the fire 24 to 30 inches square, recessed 15 to 18 inches

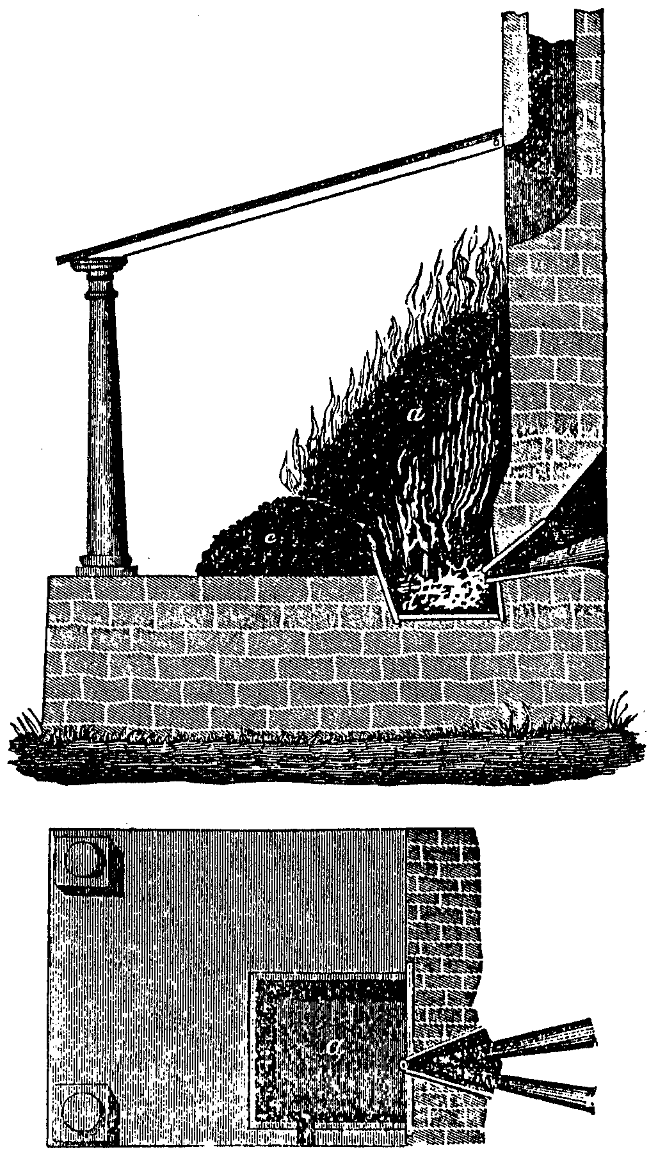


2-4. *Wood and leather bellows, such as this one with an iron tuyere attached, provided forced draft for many early bloomery forges.*

deep into one corner of the hearth. The hearth was 3 to 4 feet high. Through the back wall was an iron nozzle called the tuyere, which directed the preheated draft that was provided by the wooden bellows and waterwheel. These were early predecessors to the Champlain Forge, which reduced magnetic ores. The Lake Champlain region, both the Vermont and New York sides, was regarded industry-wide as containing the best-known deposits of the time.

To reduce the ore in a bloomery, first the hearth was lined with charcoal, then coarse iron ore placed against the wall of the hearth opposite the tuyere, the fire set, and the draft gently directed against the ore. Charcoal and ore were added as the process continued, 400 pounds of ore being a common charge. Charcoal was piled 2 to 3 feet high against the back wall above the hearth. After 1½ to 2 hours the charge was reduced to a hot (but not red-hot) mass, pasty in consistency, like taffy or cold molasses. It was the skill and experience of the bloomer that made the critical difference whether the soft iron mass could be separated from enough charcoal and non-iron elements to result in a bloom of marketable value. Poor iron, with too high a ratio of non-iron elements remaining in the product, resembled no more than one large chunk of slag. The resulting bloom was therefore subject to considerable variation, depending on whether the bloomer considered the economy of charcoal or ore the object. By manipulating the tuyere to save charcoal he obtained a small yield of iron; or, he obtained more iron by burning more charcoal.

Good bloomers worked the iron mass in the hearth with long iron tools, slowly applying moderate draft, and turning and folding the charge (much like a baker kneading dough). The bloomer's job was to concentrate the iron within the charge into a coherent ball of iron, working out pieces of stone and non-iron material. Some of the non-iron material might melt and run out of the charge as droplets of slag, but usually the charge looked like one large mass of debris, except to the eye of the expert bloomer. When he judged the time had come, the bloomer separated the last significant parts of the slag from the charge and lifted what had now become a bloom out of the hearth with heavy, long-handled iron tongs. If the bloom was no larger than a basketball in size, it may have weighed about 100 pounds (not including the weight of the tongs) and could be lifted out by a single bloomer. But if the hearth capacity was larger, the bloom might weigh up to 500 pounds. That size bloom required lifting by two or more workers with specially large tongs that were sometimes connected waist-high by chains to an overhead support beam. The ironworkers could then swivel the bloom up and out of the hearth to an adjacent anvil where the bloom was worked on by a trip-hammer to



2-5. *Vertical section of bloomery fire (top); plan at hearth level (bottom). Hearth at point "a" (Overman 1850:246).*

squeeze out the non-iron particles, returned to the hearth for further heating, then underwent repeated hammering. The process eventually shaped the bloom into a long, thick bar, which could be rolled into smaller bars and cut into individual 1-cwt pieces (merchant iron). Waste material left in the hearth, although much of it contained iron, was cleaned out and discarded. The hearth was recharged before it cooled and the process repeated.

The bloomery process obviously wasted much good iron, especially at bloomeries that operated before 1800, when American bloomers had not fully developed the necessary skills and hearths had not incorporated the latest technology. The British made sure the American Colonies did not have access to the latest developments from Europe. Slag from many early bloomeries contained so much reworkable iron that some of the slag heaps were later "mined" and remelted.

Slag from many early- to mid-19th-century Vermont bloomery sites is likewise dark and heavy, loaded with wasted iron. Not shiny and light in weight like slag from blast furnaces, bloomery slag is dull-looking, appearing like something from outer space. Hefting a piece in one hand while holding a similar-size rock in the other will immediately betray the difference in weight, the heavier being the slag.

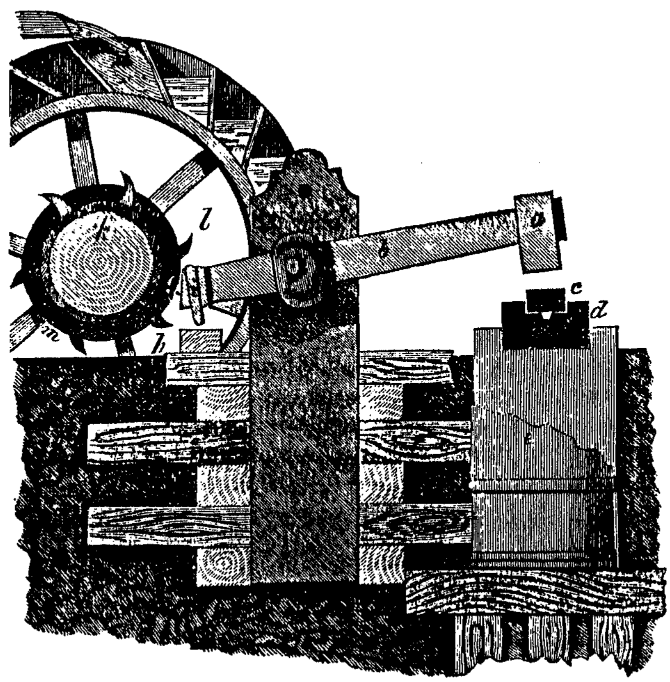
Despite later improvements, the bloomery process remained an apparently inefficient one. Yet it remained popular because the bloomery forge required a much smaller initial investment of money and labor than that of building a blast furnace. Whereas the blast furnace, once fired, had to remain in continual day-and-night operation, month after month, the bloomery cycle ended with each final removal of the bloom from the hearth. The bloomery consumed much less fuel and time to come to temperature as compared to the large blast furnace, which took days to slowly bring up to operating temperature. The bloomery could more easily respond to fluctuations in the supply of ore and fuel, and to demands of the market. And since the domestic needs of blacksmiths who were making horseshoes and door hinges could be better met by the direct ore-reduction process of the bloomery, these small ironworks tucked away in mountain hollows became more significant contributors to the market needs of early Vermont than did the blast furnace.

On an average, it took 4 tons of ore and 300 bushels of charcoal to make a ton of iron. In Vermont bloomeries, where the rich magnetic ores were worked, a ton of iron in the 1840s cost about $40 to make. An ironworker earned an average of $10 per ton (Overman 1850:247-248).

There are numerous references to trip-hammers and trip-hammer shops throughout town and county histories. Trip-hammers were large, ponderous, and noisy hammers that might have been associated with a forge, but could also have been involved in other activities, including welding, plating, hammering edges on axes and knives, or stamping out small pieces of copper, iron, bronze, or leather for various mechanical, decorative, or architectural needs. Stamping did not require much hammering force and as such, the hammers were quite small, on the order of 10- to 40-pound hammerheads and anvils. They were all waterpowered, but being small operations, could have been set up in modest shops near any small streams.

Most trip-hammers were associated with blacksmith shops or small foundries. Hammers usually did not involve any furnace beyond a small charcoal hearth to heat metal, which made it easier to plate, edge, or stamp. Welding required an intense heat, enough to bring the metal to a cherry-red brightness before hammering, requiring a larger, bellows-driven heating furnace. Small welds, such as for wagon wheel rims, could be done by the blacksmith's rhythmical hammer. Larger welds for repairing cracked or broken castings were relegated to the trip-hammer at the forge. Both were noisy and scattered many sparks, much to the amusement of spectators.

The hammers used at the forge had hammerheads weighing from 50 to 400 pounds. For drawing small-diameter iron, such as for nail rod, a hammerhead of 50 pounds was sufficient.



2-6. *Tilt hammer and foundation pilings (left) and helve ring (center). The helve ring served as the strong fulcrum on which the full weight of the helve rested (Overman 1850:335).*

Forging 60- to 100-pound blooms required a hammerhead of 300 to 400 pounds. These heads were made of strong-quality cast iron and were secured to the business end of the helve by wooden wedges. The other end of the helve was acted on by the waterwheel (Overman 1850:336-339).

In the usual arrangement, a cam wheel driven by the waterwheel struck forcibly downward on the helve, which, pivoting on a horizontal pin near its middle, raised the hammerhead end. The closer the pivot pin was located to the cam wheel end of the helve, the higher the hammerhead would be raised (much like adjusting a seesaw), and thus more striking force on the anvil would be obtained. But then a more powerful waterwheel was required (putting the heavier person at the short end of the seesaw), due to the additional torque now added to the hammer. Hickory or oak was most commonly used for making the helve.

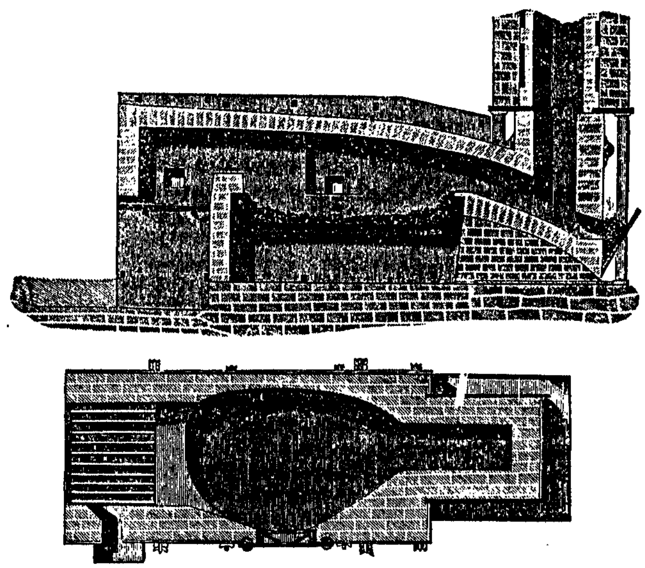
The anvil, upon which the hammer worked the iron, equaled the hammerhead in weight. It was attached to the cut end of a 4-foot-diameter log that extended lengthwise 6 to 8 feet into the ground. Under that, a platform of pilings secured the anvil to a stable platform. At many forge sites long since abandoned or destroyed by fire, the location of the anvil is still marked by its deeply buried foundation. With that located, the rest of the forge remains can be approximated and found.

The cam wheel did not merely raise the hammerhead to let it drop to the anvil. When striking its end of the helve, it caused the opposite (bottom) edge of the helve to bounce off a large piece of timber. This bounce imparted to the hammerhead the effect of a recoil and dramatically increased its striking force on the anvil. The faster the hammering speed (either by increasing the rotational speed of the waterwheel or by additional cams on the cam wheel), the greater the hammering force due to increased recoil action.

Hammers of this type were called German forge hammers, but they were commonly known in Vermont as trip-hammers or tilt hammers, from the actions of the mechanisms. A variation of the forge hammer that was more common in Europe had the cam wheel raising the hammerhead at that end, and was known as the T-hammer. By the 1840s, when most water-driven hammers were being replaced by steam hammers, bloomeries in Vermont were still utilizing the cheap and abundant water resources of the state. Only in foundries and heavy machine shops did steam, and later hydraulic, hammers make their appearance.

The process of hammering blooms was known in some sectors of the industry as shingling. It was usually used more in terms of hammering to remove (or squeeze out) solid bits of impurities such as slag, small stones, or unburned charcoal, rather than hammering the bloom into a uniformly shaped bar. A type of hammerhead with a beveled face called a squeezer was sometimes employed for shingling. An "iron and shingle mill," therefore, did not refer to the manufacture of house shingles.

Another process of producing wrought iron was to refine pig iron from the blast furnace and convert it in the puddling furnace. Refining meant cleansing the pig iron of most of its carbon and other impurities. It was called a puddling furnace because the pig iron was melted in a reverberatory-shaped chamber and worked in "puddles" into pasty balls, similar to the bloomery process. The puddling process took advantage of a major difference between wrought and cast iron: how their carbon content inversely affected their respective melting points. Cast iron, with a higher carbon content, melted at a lower temperature, about 2,100° F, whereas practically carbon-free wrought iron melted at about 2,500°F (Schuhmann 1906). The heat in the puddling furnace was maintained high enough to melt the pig iron, but just short of the melting point of wrought iron. Additionally, by burning charcoal in one hearth and drawing the hot flaming gases over and through an adjoining hearth containing the pig iron, the iron was melted and its carbon burned away. Physical separation of the iron and charcoal in this horizontal-type furnace prevented charcoal carbon from replacing burned-away carbon. In the foundry, this separation-type furnace was known as an air furnace.



2-7. *Vertical section (above) and ground plan (below) of puddling furnace, showing the fire chamber and grate (left), hearth (center), and chimney (right). The puddler worked the iron through the door at the center, top view; and bottom, lower view (Overman 1850:264-265).*

Puddlers stirred the molten iron with long iron rods that reached into the furnace through little holes in its side walls. The stirring action continuously brought higher-carbon iron from below the surface to be exposed to the carbon-consuming flames. As the carbon content of the iron was reduced, and therefore its melting point dropped, the iron commenced to congeal (come to nature). Lumps of this purified iron were removed from the furnace and worked at the hammer much like the bloom of the bloomery process. The puddling furnace product, however, was much more pure than that of the bloomery. The resultant iron bars hammered from puddled iron were called puddle bars or muck bars. They were cut into pieces 2 to 4 feet long, piled in stacks weighing upward to a ton, reheated in another furnace specially designed for this purpose (called a heating furnace), and each piece was finally rolled into merchant bars.

With the development and proliferation of puddling furnaces, a controversy arose regarding the quality of wrought iron made by the direct method—the bloomery—and the indirect method—puddled pig iron from the blast furnace. In the 1850s, when the two operations were operating neck-in-neck for supremacy, the consensus was in favor of the bloomery. One reason was that bloomeries produced in smaller quantities. This was an age when small quantity was still considered superior to large; only 25 years later the theme would switch to "big is better." The puddling furnace, which was consuming much more charcoal per ton of merchant bar, would evolve into an efficient process capable of turning out a most superior wrought iron from the most questionable grades of pig iron.

One significant improvement to the Catalan forge was made

2-8. *Interior view of the forge at Jay, New York, in 1888. Man in the right foreground is lying in a charcoal basket (courtesy Adirondack Museum).*

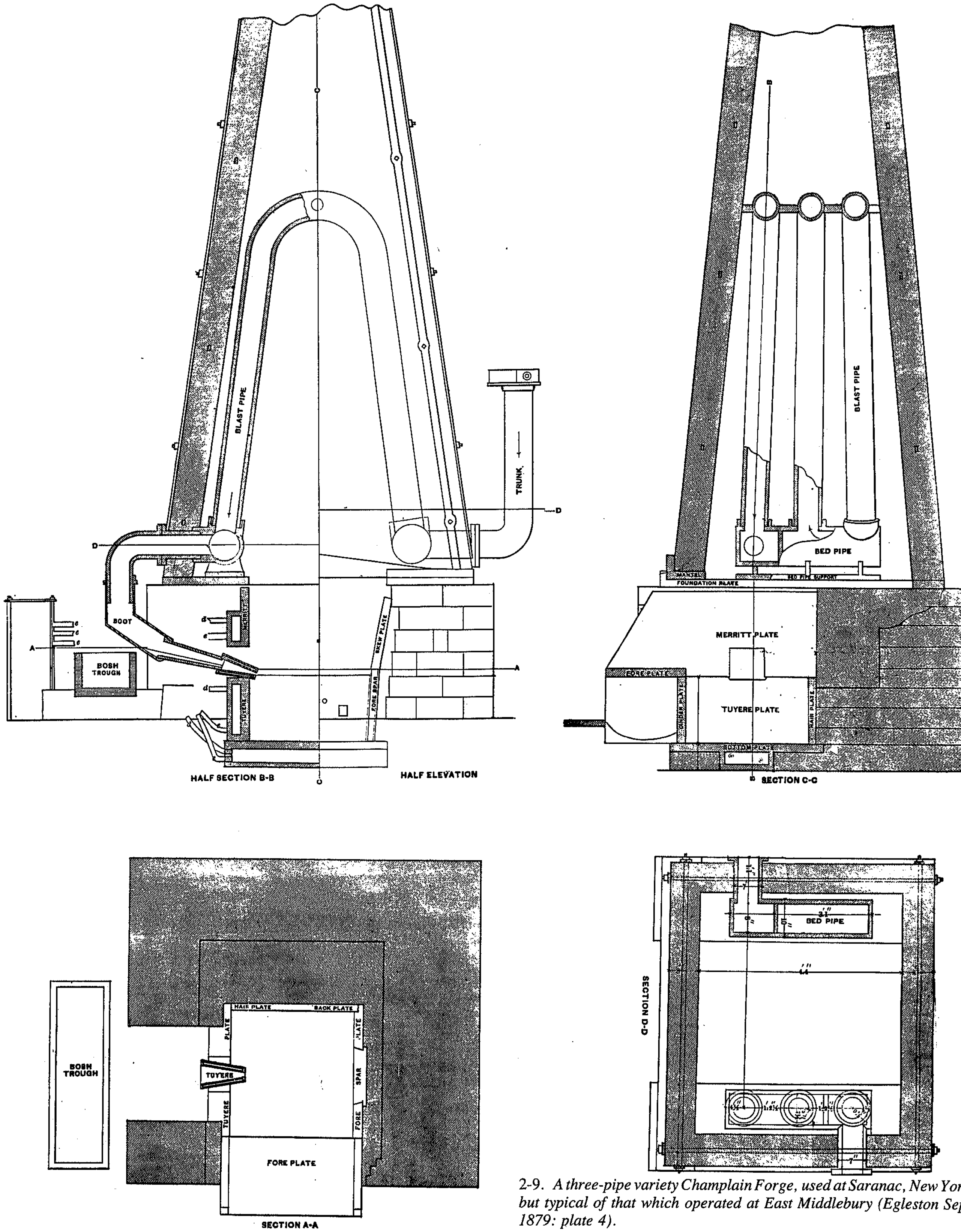
in the Adirondack bloomeries during the early 19th century. It consisted of preheating the blast, which was never done with the earliest Catalan forges (Swank 1892:107). The improvement seems to have been copied at the Fair Haven Iron Works; an 1866 description of the bloomeries includes three arched pipes for preheating the blast above each bloomery hearth (Neilson 1866:227). Since it was an American improvement, it became known as the American Bloomery, although in the New York and New England area it was called the Champlain Forge (Egleston Sept. 1879:515). "The Catalan Forge in this country took the form of the Champlain Forge, which had the blast heated by the waste flames from the forge. These waste flames heated a coil through which the blast was blown, thereby cutting down the fuel requirement. The Champlain Forge, of considerable importance in the development of the early iron industry in the northern Appalachian areas, was capable of producing an iron with an almost complete absence of phosphorus and sulfur" (Kirk and Othmer vol. 8 1952:25).

Physical details of the Champlain Forge were described in 1879 as follows:

> The furnace in which the ore is reduced and the bloom is made consists of a series of cast-iron plates, 2 to 3 inches in thickness, securely fastened together, forming a rectangular opening, which, at the bottom, varies from 24 to 30 inches, at right angles to the tuyere, and 27 to 32 inches parallel to it. On the back side, parallel to the tuyere, it is 28 to 36 inches high. On the front this plate is cut down to from 15 to 19 inches, to make a place for a small platform, or shelf, called a fore plate. The bellows space, where the operation of reduction is carried on, is thus rectangular in shape, and is called the firebox. Its walls are usually vertical, except the fore and skew plates, which are generally inclined, but sometimes they are made to incline outward at the rate of 1 inch in 7.
>
> Each one of the plates forming the sides of the furnace had a name and a special duty. They are sometimes made of more than one piece, and are not always of exactly the same shape, nor are they always put together in exactly the same way in different works, but the variations are not very essential. Their size varies also with capacity of the furnace, but their office is the same in all. Those plates most exposed to the direct action of the fire are usually cast with holes in them, into which pieces, called repair pieces, are made to fit, so that they can easily be removed and replaced when worn out (Egleston Sept. 1879:518-519).

Another contemporary report described the hearth area varying from 27 by 30 inches to 28 by 32 inches, with the height from 20 to 25 inches above the tuyeres and 8 to 14 inches below:

> In the East Middlebury forges this bottom plate is 4 inches thick and has within it a hollow space of 4 inches. The side plates, which slope gently inward in descending, and rest on ledges on the bottom-plate, are 1¼ inches thick. A water box, measuring 12 by 8 inches, is let into the twyer-plate [*sic*], and a stream of cold water circulates through this box and through the bottom plate, as well as around the twyer. The length of the hearth, from the twyer plate to that opposite, is 24½ inches, and the breadth from front to rear is 29 inches. The twyer enters 12 inches above the bottom, and is inclined downwards at such an angle that the blast would strike the middle of the hearth. The opening of the twyer has the form of the segment of a circle, and is 1 inch high by 1¾ inches wide. In front of the furnace, at 16 inches from the bottom, is placed a flat iron hearth, 18 inches wide. The side plate beneath it is provided with a tap hole, through which the melted slag or cinder may be drawn off from time to time. The iron plates used in the construction of these furnaces last for 2 years.
>
> At East Middlebury . . . the estimated consumption of charcoal was 270 bushels to the ton of blooms, a result which is the mean of the figures obtained at the New Russia [N.Y.] forges. Some of the ores here used contain a little phosphate of lime, and it was observed that when too hot a blast was used, although the production of metal was rapid, the iron from these ores was hot-short, while with the cold blast, formerly employed, the iron, although pro-



2-9. A three-pipe variety Champlain Forge, used at Saranac, New York, but typical of that which operated at East Middlebury (Egleston Sept. 1879: plate 4).

duced more slowly, was never hot-short. The force of the blast at these forges was equal to 1¾ pounds and even 2 pounds to the inch. Mr. Pearson, the director of the East Middlebury forges, made, in the autumn of 1867, experiments on several tons of the iron sands from Seven Islands [Sept-Îles, Québec] and succeeded in obtaining from them about ⅗ths of their weight of good iron. He, however, found it necessary in order to treat these fine sands, to reduce very much the force of the blast. . . . It appears to be from ignorance of this fact, that the bloomers of New York had always rejected the fine sandy ore separated during the process of washing, as being unsuited for treatment in the bloomery fire (Hunt 1870:277-280).

Tools required at a typical Champlain Forge (Egleston Sept. 1879:536) were:

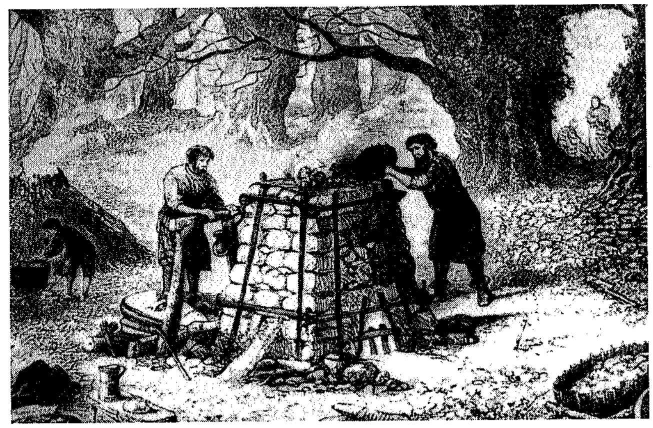
Bloom tongs	Foss hook	Sledge, 3 pound
Turn-bat	Cinder bar	Hammer, 1½ pound
Billet tongs	Tapping bar	Fore bar
Ore shovel	Furgen	Anvil
Fire shovel	Wringer	Piggin

The U.S. Census of 1860 recorded three bloomery forges still operating in Vermont, the only report of such forges yet in operation throughout New England. The bloomeries reported an output of 1,400 tons of blooms. Neilson's 1866 report notes, however, that Vermont did not become the solitary producer of blooms until 1864, the last year that the bloomery fires ran at the Franklin Forge, New Hampshire. The only other bloomery then in New England was at Falls Village, Connecticut, which by that time had not run for some years (Neilson 1866:232-236). Vermont bloomeries were replaced by larger specialized operations such as the National Horse Nail Company at Vergennes. Some of the smaller forges continued supplying local blacksmith and foundry needs until cheaper puddled iron from outside the state closed them down. In the post-Civil War period bloomeries continued at East Middlebury, Fair Haven, and Salisbury. By the time the East Middlebury bloomery closed in 1890, the significance of Vermont's superior Lake Champlain magnetic ores had already passed into history (Swank 1892:113).

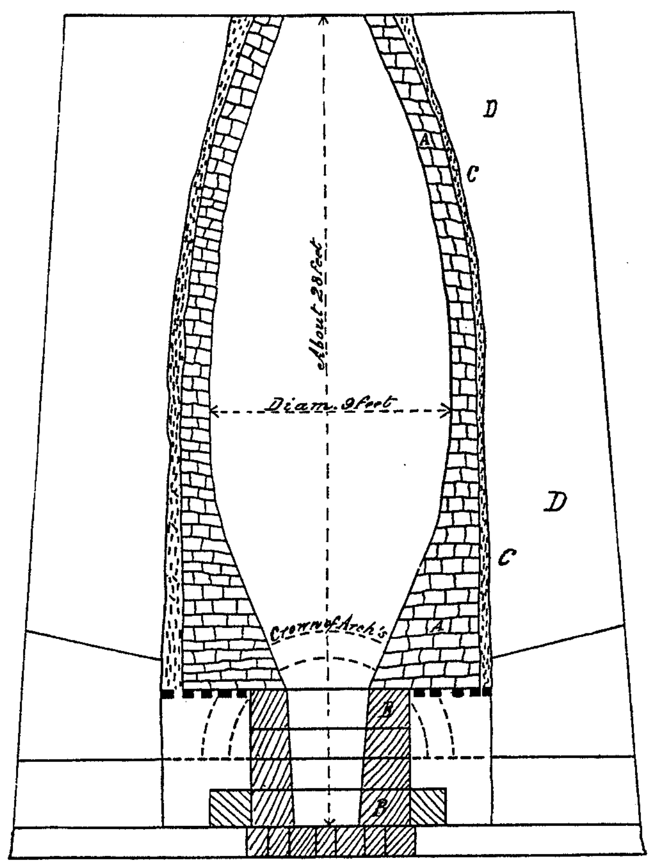
The Blast Furnace

The early 19th-century blast furnace structure, or stack, was generally 25 to 30 feet square at its base and 30 to 40 feet high. The outer walls were made of hard stone masonry and were either vertical or slightly sloping inward as they rose upward so that the top flat area was less than the base area. Rather than having the fuel and ore carried up steps and ramps alongside the stack, the furnace was built beside an embankment, with a stone or wooden bridge laid from the bank to the top of the furnace. Across this bridge, workers known as bridgemen carried ore and fuel in wheelbarrows, emptying them into the furnace through an opening at the top.

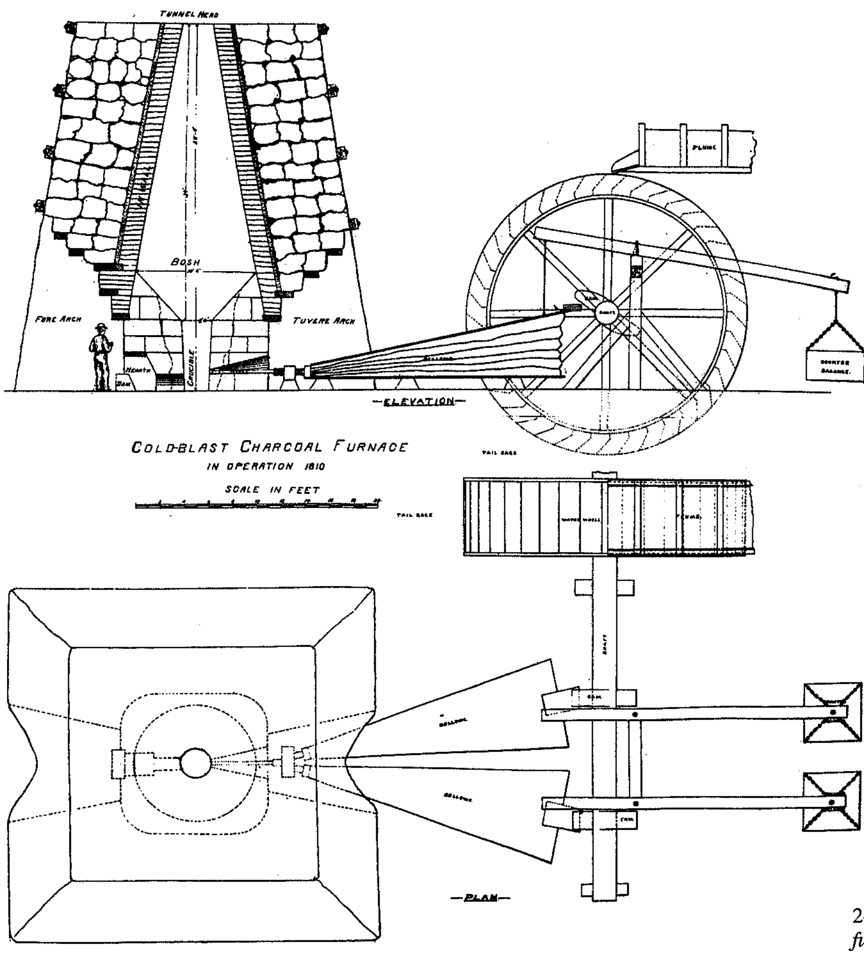
The construction of such a heavy structure required very special attention to the foundation and to the nature of the ground on which it was to be built. Poor ground preparation could result in the stack shifting under the combined weight of the structure plus its load of molten iron. The effect could be a fatal rupture of the blast furnace itself.



2-10. *Typical pocket, or "testing" furnace, for testing the ore before investing in a full-size blast furnace stack. Note the foot-operated bellows at left (Fisher 1949:18).*



2-11. *Inside configuration of a late-18th-century furnace showing the rough nature of the stone bosh lining (*Salisbury Iron *1878:4).*



2-12. *Plan of a ca.-1810 cold-blast charcoal furnace showing side view (above) and top view (below) through the furnace.*

During the 1780–1810 period when Vermont was experiencing its first large influx of settlers, the iron industry nationwide still consisted of a large number of relatively small furnace and forge operations. The only major blast furnaces near Vermont in that period were situated in the vicinity of Salisbury, Connecticut. The quality of the iron demanded at that time was so poor in comparison to only a half-century later that the skills for smelting iron were not yet complex. A shrewd entrepreneur with some industrial acumen and idle capital could easily afford to speculate on the construction of a small blast furnace to "test" local ores (Fisher 1949:18). If it succeeded in producing an acceptable-quality iron, he could rebuild a larger, more efficient furnace, or reap a tidy profit through the sale of the proven site. If the furnace failed, abandonment meant the loss of a small investment and he was free to tend to other speculative ventures. Such small furnaces might have been the so-called "pocket furnaces" at Weybridge, New Haven, and Tinmouth before 1800.

The first settlers to Vermont found the land well-watered with streams, meaning an abundance of good mill sites for grinding grain and sawing wood. They also found the soil of the valley bottoms to be wet and heavy (Lamson 1922:115). This might have resulted in good farming, but would not do for the manufacture of iron. Damp ground was cold ground, and therefore drained much heat away from the bottom of the furnace hearth. Field research has found that a number of Vermont furnaces built during that early period had been constructed on ground so damp that in springtime it was actually soggy. Some were only 10 to 15 feet from good-running streams, and the bases of these furnaces barely a foot above stream level. Others, somewhat farther from the stream but still on the same level, must also have been close to the local water table. Such furnace sites have been found in Troy, Tinmouth, Clarendon, New Haven, Orwell, and Bennington. At one of the Tinmouth sites the telltale of a cold hearth was found in the form of heavy chunks of black slag. Might these small, poorly located furnaces have been the results of some speculators' poor judgment?

The problems of building a blast furnace on damp ground were recognized by the 1840s, as instructed by Overman:

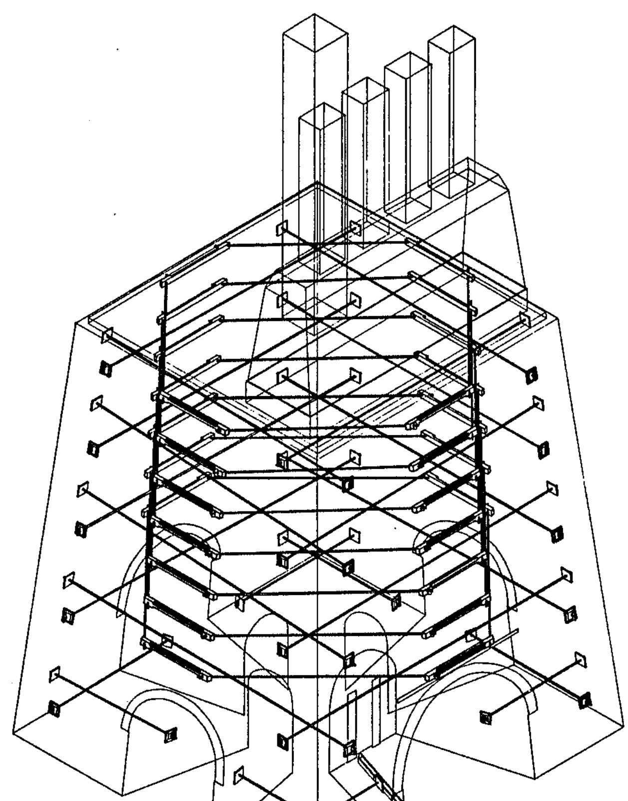
> A furnace should be located on a dry spot, free from springs and water of any kind, and not exposed to floods after heavy rains. The ground should be then excavated, until the bottom is sufficiently solid to bear the heavy weight of the stack. The foundation should be at least 1 foot larger

in each direction than the base of the furnace; that is to say, if the furnace is 30 feet at the base, the foundation ought to be 32 feet square. Any kind of hard, large stones may be used to fill the excavation. No mortar should be used in the stone work. We should be careful to leave some channels through which rain or spring water in case it should penetrate the foundation, may flow off. Such a drain should be carefully walled up and covered. The cavities or channels for the blast pipes are to be placed level with the ground; and the four pillars of the furnace then laid out (Overman 1850:153-154).

To hold the stack's masonry together and to protect it from shifting due to expansion when in blast and contraction when out of blast, pairs of horizontal iron rods or flat iron straps, called binders, were embedded into opposite and diagonal sides of the stack. Early furnaces used binders made of timber. The binders were connected near their ends by horizontal bars that

2-14. *A study of binders and keys at the mid-19th-century Pittsford stack, showing pairs of diagonal binders protruding from the wall and keyed securely to horizontal iron plates.*

2-13. *A unique binder assembly found among collapsed furnace debris at East Bennington. Note the key through the end of the spike (the other end of the spike is headed). Pairs of these binders were laid at right angles to each other in the corners of the stack to strengthen the walls.*



2-15. *An "X-ray" isometric view of the reinforcement binders of a mid-19th-century blast furnace (Bowie, John R., HAER, NPS 1978:8-13).*

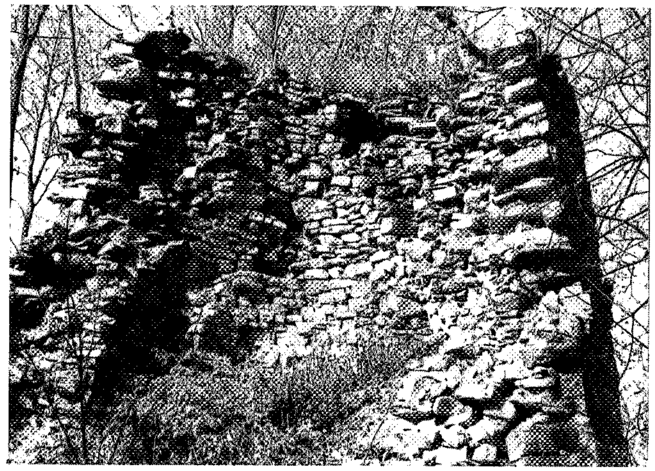
laid up against the furnace wall. Through these bars, the slotted end of the binder protruded. A heavy iron wedge in the slot held the entire arrangement of binders together. "The strongest and most secure binders are wrought iron bars, 3 inches wide, and ¾ inch thick. They can be rolled in one length, and should be 2 feet longer than the actual length across the stack; each end of such a binder is to be bent round to form an eye. . . . A flat bar of the same dimensions as the binder is pushed through this eye; and sufficient room is left for a key or wedge . . . the eye is formed by simply bending the bar round, and by riveting it in two places. A slight welding heat may be applied to the joint. There should be 5 binders on each side of the furnace, making 20 binders in all; as well as 8 bars reaching from the top to the lowest binder" (Overman 1850:157).

The eight bars reaching from the top to the lowest binder were laid against the wall horizontally, giving an impression of ladder rungs laying upward against the wall, rising from just above the arch to the top of the stack. Binders with slotted ends are visible at the standing blast furnace ruins at Bennington and Forest Dale; iron binders with horizontal bars at Pittsford; and remains of binders, wedges, and end plates (instead of horizontal bars) among the debris of the partially collapsed furnace at Troy. In the breakdown of the west stack at Bennington are binders that look like 2-foot-long, small iron ladders: 2-inch-thick bars bent in a U-shape, one end slotted and the other end pinned. These binders were laid flat and totally within the stonework, as no parts of them are visible sticking out through the wall.

One of the most visual characteristics of an iron-smelting blast furnace is the arrangement of the arches. These were a functional part of the furnace design and were built during the construction of the furnace proper. Early furnaces were built with only one or two arches, such as those at Bennington, East Dorset, and West Haven. The Tyson furnace at Plymouth had three arches. But the final design was four arches, one in each of the four sides, as at Forest Dale. Even New Hampshire's eight-sided blast furnace at Franconia has only four arches. One arch was usually larger than the other three to give ironworkers room to work the hearth. This was called the work arch. The other three arches provided access to the tuyeres and were thus called tuyere arches. A typical blast furnace 30 feet square at the base had a work arch 14 feet wide and tuyere arches 10 feet wide. The work arch reduced in width to 5 or 6 feet at the hearth; the tuyere arches to about 3 feet.

The arches of earlier furnaces were built of stone, as at Bennington, East Dorset, and Forest Dale. Stone arches, however, were prone to cracking, and as happened from time to time, the intense heat within the hearth would cause the blast to work its way out of the hearth and throw stones in every direction inside the work arch. The solution was to use hard-burned bricks that were strong and durable. At least one course of stonework above the brick-lined arch was also arched so as to relieve some of the pressure on the brickwork. The Pittsford furnace arch is brick-lined but there is no attached course of stone above.

The stone wall areas that made up the corners of the furnace adjacent to the arches were called the pillars. Almost any kind of hard building stone, such as granite or even slate, could be used to build the pillars, which were laid solid. Limestone was a poor furnace construction material. By 1850 it became the practice to mortar the stones into place, although none of the standing and collapsed furnace ruins found in Vermont show positive evidence of any outside walls being mortared or cemented (excluding mortared brick arches). The only blast furnace built in Vermont after 1850 was Henry Burden's 1863 stack at Shaftsbury, which unfortunately was completely razed sometime before 1900. Vermont blast furnaces were evenly laid with a structural balance of large and small stone, with shimming and chinking where necessary. The stacks generally maintained dressed walls, square corners, and fine symmetrical appearances considering the available working materials.



2-16. *View into the partially collapsed ruin of the 1823 stack at East Bennington, exposing three distinct inner design details: the outside walls (left and right), a small surviving section of bosh lining (lower center), and rock fill between the bosh and outer walls.*

When the construction of the pillars reached about 7 feet high, construction of the arches commenced. Horizontal channels were left in the pillars and walls above to allow the binders to be pushed through after the furnace was built. Wood scaffolding surrounded the stack and gave the masons a place to stand. As the stack rose, the scaffolding followed it upward. Furnaces made of relatively small fieldstones were built by handing or hand-hoisting the stones up a scaffold and setting them into place. Those stacks made of massive blocks (ashlar) required a boom and winch to raise the stone. Such derricks were used in quarries throughout the state to hoist granite, slate, and marble, and similar devices were probably used to build the furnace walls.

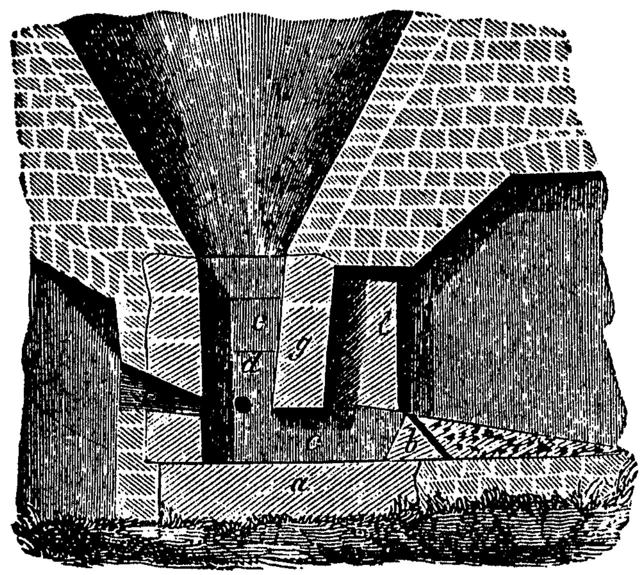
Little pre-1850 furnace construction information is available, but techniques of working with heavy stones were widely known. Castles and stone bridges and aqueducts had long since been built in Europe. In New England, stone was used in house and barn foundations, root cellars, churches, bridge and road abutments, dams, canals, sea wall and dock facilities, and many 18th- and 19th-century forts in the Champlain Valley. The derrick was positioned on a platform at the ironworks site to build the furnace stack and wheel pit, plus associated retaining walls and abutments. Afterward, the derrick was disassembled and removed.

Assuming the typical blast furnace was 35 feet high, its rising walls were tapered inward such that the 35-foot-square dimension at the base reduced to about 15 feet square at the top. This resulted in a wall that sloped inward about 2½ inches per vertical foot.

Coincident with the building of the arches, the rough inner wall was laid up. This inner wall was laid vertical for 5 feet before contracting inward about 1½ inches per foot to the top, allowing for the configuration of the bosh. An internal cross-section view of the furnace would show the bosh looking much like an egg standing on its fatter end, about 9 to 10 feet in

2-17. *Massive breakdown of the Forest Dale stack conveniently exposed the in-wall and furnace lining for study, but also accelerated further deterioration in 1990.*

diameter at the widest. The bosh lining was mortared with fire clay; the lining was firebrick. The space between the bosh lining and the inner wall was about a foot wide and was filled with stone fragments. Remains of a few early Vermont furnaces show linings made of red sandstone rather than firebrick. These are in sites at Tinmouth, Troy, Clarendon, and Dorset. No rough inner wall was found at any of these sites. At the Forest Dale furnace, firebricks were found that were made at Troy, New York, and at Brandon. Complementing the number of stove foundries in Troy at that time, the making of firebrick there was a big business. Firebricks made at Troy are common and have been found at many blast furnace (and lime kiln) sites throughout New York and New England.

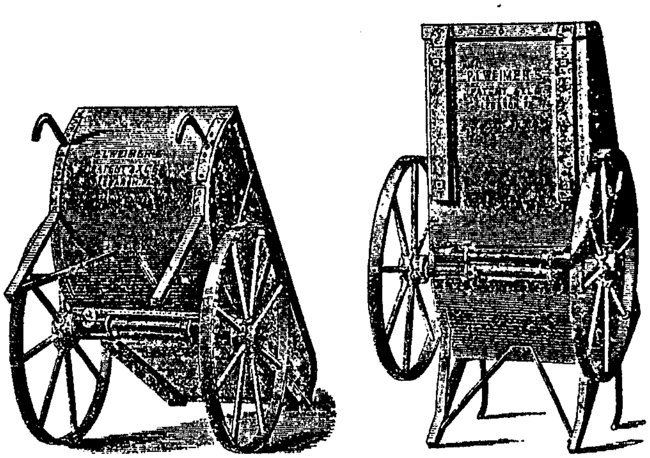


2-18. *Arrangement of hearthstones: The bottom stone was bedded in fire clay and sand, tipping a bit downward toward the front of the hearth (right). Two sidestones were backed by the backstone, through which tuyere holes were cut before the stones were imbedded. The timpstone (tymph) overlapped both sidestones and extended below them. The damstone, a small triangular stone shown on the bottom stone and forming part of the forehearth, was usually laid after the furnace was completely dried and ready for blast. The tymph and damstone were sometimes faced with cast-iron plates to protect them from slag that would be apt to stick to stone and brick (Overman 1850:159).*

Directly below the bosh was the hearth, lined similar to the bosh, into which the molten iron and slag would eventually collect. The hearth, also known as the crucible, was about 2 feet square with walls 2 to 3 feet thick, flaring outward a little in its 4- to 5-foot height. It was extremely heavy when filled with molten iron and was therefore supported on a strong foundation. The top part of the bosh was called the shaft. It increased in diameter from about 3 feet at the top opening to about 10 feet at the center of the bosh. The top opening was the charge hole and was lined with curbstone, usually granite. The charge hole at the top of the Forest Dale stack is further protected by a cast-iron ring and plate.

A high-roof wooden structure called the casting shed was built against the opening of the work arch to protect the delicate and dangerous casting operations from wind and rain. The high roof allowed space for heat thrown off by the molten iron to rise and escape out the roof-top monitors. The casting shed also provided clearance for hoists and cranes that moved ladles of molten iron and finished ingots (pigs).

The three solid ingredients in the iron-making process of the blast furnace were the iron ore, charcoal, and limestone. These ingredients were prepared and mixed in ratios required to obtain iron of desired quality. Each "batch" of mixed ingredients dumped into the furnace was known as the charge, thus the naming of the charge hole at the top of the stack. The limestone in the charge acted as a flux, chemically uniting with various impurities in the iron ore under the influence of the high temperature inside the stack. The proper mix of limestone depended on the estimated quantity of impurities in the iron ore. Some furnaces averaged 6 percent limestone mixture to the ore, others as high as 10 percent. As the crushed limestone descended into the stack, it heated and released carbonic acid, which rose out the top of the stack along with other stack gases. The burned lime continued its descent and combined with silica that was present in the iron ore. Without the lime, the siliceous materials would not fuse and flow freely. With proper quantities of lime, the silica and other mineral constituents of ore and ash united to form a liquid slag that separated out to float atop the dense molten iron (Campbell 1907:43-44).



2-19. *Charging barrows in which ore, fuel, and limestone were manually pushed from the measuring house to the top of the furnace, then dumped into it* (Annual Report of . . . Pennsylvania *1894:66ff*).

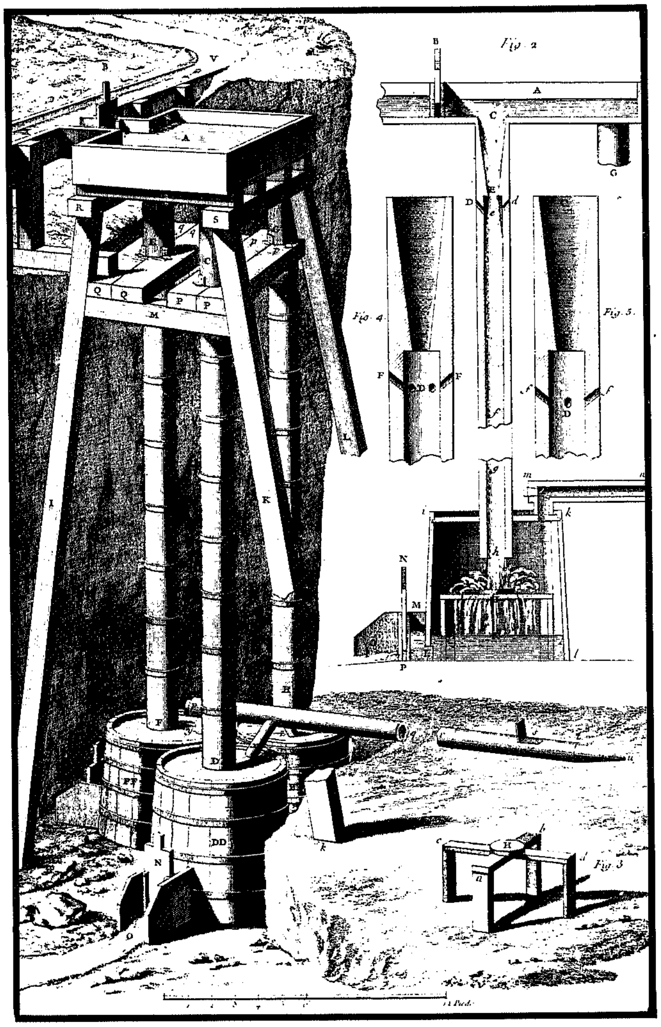
The molten iron, meanwhile, collected in a growing puddle at the bottom of the hearth. As more and more iron collected in the hearth, more slag formed, requiring the ironworker to periodically open the higher of two tapholes in the hearth. Opening the higher hole allowed the slag to run out and provide space in the hearth for more molten iron to accumulate. Slag was commercially a waste by-product of the blast furnace operation, although an analysis of cooled slag by the ironmaster told him many things about the quality of the iron he was making. The color of slag was not always a safe criterion of the quality of work being done in the furnace. Gray slag, for example, might contain as much wasted iron as green or black slag. But as a general rule, gray slag did prove somewhat better. A furnace in good condition would produce a highly glazed green slag. Perfectly gray, white, black, or olive-green slag was not a good indicator (Overman 1850:203). After being allowed to cool and solidify, the slag was broken up and carted away to be discarded, usually some distance from the immediate working area. Years later, many large slag heaps were "discovered" and used as filler in asphalt that today covers many roads in the vicinity of old ironworks.

In the early 20th century, a process was developed by which high-pressure air was blown through molten slag from steel furnaces, creating a fibrous material generally known as rock wool. This material, a forerunner of fiberglass, was used to make a fireproof building insulation. Rock wool was also made from limestone and siliceous rock.

When it was determined that enough molten iron had formed in the hearth, usually because iron was now running out the upper taphole along with slag, the lower taphole was opened and the iron ran out to the molds. There was a large, flat-edge stone called the tymph located inside the hearth. The tymph's bottom, flat edge was level with the bottom of and just behind this lower taphole. By forcing the molten iron to flow under it before passing out the taphole, the tymph stone served a dual function. It prevented hot stack gases from escaping though the taphole and splattering molten iron about the casting area, and at the same time, it blocked most of the slag that was still in the hearth and floating on the iron from running out with the iron.

The molten iron flowed out of the hearth into a central trough, where remaining slag and oxidized scum were skimmed off by ironworkers with special tools. The iron flowed from a central trough into smaller lateral troughs around it, all dug into the molding sand on the casting floor. Early ironworkers saw in the arrangement of the large central trough connected by small runners to smaller troughs a resemblance to a sow with suckling piglets around her. The heavier central casting thereafter became known as the sow and the small castings became the pigs. To this day, the general expression "pig iron" remains for the casting product of the blast furnace process.

2-20. *Casting pigs in sand at the base of a mid-19th-century blast furnace. Note that the casting area is within a building that protects the workers and castings from weather (Chapin 1860:156).*



2-21. *The trompe, in which falling water draws in air (upper right). The aerated water falls into a box and the froth gives up the trapped air, which is coaxed out the end of the horizontal pipe (Diderot 1763: plate 88).*

Draft, also called blast, fanned the charge to temperatures that accomplished reduction of the ore. It was usually supplied by bellows in early times, although a device called a trompe came into use also. The trompe is said to have been invented in Italy in 1640, its use confined at that time to some charcoal furnaces and Catalan forges in Spain, Italy, Germany, and France. It was also known as the water-blast and was used in some southern states, but also in the Adirondack Mountains of New York (Allen 1983:86). Vermonter Allen Penfield from Pittsford employed a trompe (he called it a troupe) at his forge at Crown Point in 1828 (Allen 1967:4).

The trompe was essentially a 5- by 2½- by 1½-foot-deep wooden box, nearly immersed in a stream directly under the flume. Water rushed straight down off the end of the flume through an 8-inch-square, 10- to 20-foot-long wood pipe. Air was sucked in through small holes in the side of this pipe by the action of the falling water and was trapped in the box below. In this box, water escaped out a hole in the bottom while the air was forced out a hole near the top of the box. The pressure of the collected air given up by the bubbling froth moved the air along. Although a blast provided by the trompe was very uniform as compared to the pulsating bellows, it required huge amounts of water that might be put to better use driving water-wheel/bellows machinery. The blast was also cold and damp. Its main advantage was that it was easily and cheaply constructed—ideal for a quick speculative forge or small blast furnace.

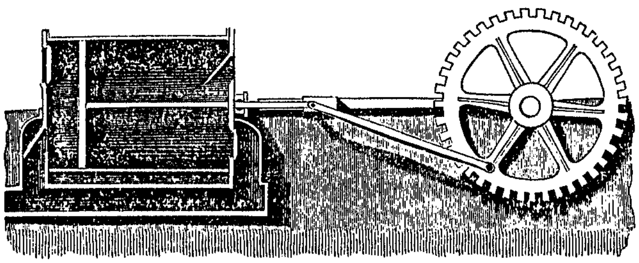
Bellows resembled common household fireplace bellows except that by the era of Vermont ironworks, they had grown to 22 feet long and 4 feet wide. Bellows date back to antiquity when slaves, standing on a pair of bellows often made of goatskin, shifted their weight so as to repeatedly step on one, then the other. This is depicted on the walls of an Egyptian tomb that dates to about 1500 BC, showing a small furnace and bellows nearby (see figure 1-1).

Waterwheels and their associated shafts, controls, and cams were developed to near perfection by the 18th century. Through innovation and experimentation, waterpower systems in New England were transformed into highly efficient sources of power. They took advantage of good running streams and powered all types of mills well after the adoption of steam power in the more industrialized parts of the United States. Cut from hardwood, usually oak, the waterwheel was carefully assembled and balanced. The shaft was cut from the tallest and straightest tree in the local forest, shaved to about 2 feet in diameter, and notched to the wheel. Waterwheels were connected to operate trip-hammers, shears, rollers, rock and ore crushers, and other devices in addition to bellows and air cylinders (blowing tubs) for bloomeries and furnaces.

The blast usually had a pressure of ½ pound per square inch. It was introduced into the hearth through a tuyere that measured 2 to 3 inches in diameter. Some tuyeres were double-walled so water could circulate through them, preventing them from melting. Early furnaces had one tuyere; later furnaces had as many as five or more for even distribution of the blast. While passing upward through the burning charge, the oxygen in the blast combined with the carbon in the charcoal to form carbon dioxide and produced very high temperatures. The hot, oxygen-hungry carbon above this combustion zone reduced the carbon dioxide to carbon monoxide and in turn reduced the iron from its ore. Hot gases vented out the top of the furnace through a flue, which protected the bridgemen from the noxious fumes. The gases usually burned on reaching the outside air above the furnace, resulting in the flaming top that was typical of early furnaces: "A translucent flame interspaced with flowing sparks rose and fell from the open trunnel head [*sic*] in harmony with the pulsations of the blast. By day it was suspended over the furnace top like a mystical oriflame, and at night it served as a beacon, lighting up the countryside" (Peters 1921:7). Patrick E. Mooney of Pittsford, in 1953 the sole surviving workman of the Pittsford furnace, remarked how the furnace sent up flame-colored gases, lighting the yard enough to read a newspaper. Sometimes it attracted people to the scene who thought a fire was raging out of control (McWhorter "Mooney" *Rutland Herald* Oct. 2, 1953:68).

The flame at the top of the furnace told the ironmaster a number of things. If the flame was dark and heavy, it indicated that the furnace was cooling and the charge was probably too heavy. A light, smoky flame throwing off white fumes indicated too much limestone, or that the charge might be too light. An almost invisible, lively flame at the top indicated a healthy state inside the furnace (Overman 1850:204-205).

As the years passed and furnace designs improved, the need for an increased volume of blast forced ironmasters to turn to other devices to replace the outdated bellows. One such device was the 1550 invention of a German organ builder, later adapted to an industrial use. The machine looked so much like a pair of tubs that from the beginning it was called blowing tubs. The machine was made of two main cylinders (the tubs) with pistons connected by linkages to the waterwheel. Air was pumped from the cylinders into a smaller chamber called an equalizer (windbox), which contained a horizontal, free-riding weighted piston that maintained a steady blast at uniform pressure.



2-22. *Horizontal iron cylinder blast machine, such as operated at Forest Dale. Note double-acting valves (Overman 1850:399).*

While designing the Monkton Iron Company blast furnace at Vergennes in 1808, Bradbury and Perkins considered cylinders of wood, but they had to settle on conventional leather bellows—wooden cylinders were still so new, no one was found who knew how to make them (Seaburg and Paterson 1971:203).

During a 1974 inspection of the remains of two 19th-century blast furnaces deep in the Adirondack Mountains of New York, many pieces of blast machinery were found, reflecting the state of the technology of the two sites. Near the collapsed ruins of an 1844 blast furnace (which might have been built on the foundation of an earlier 1838 furnace), pieces of wooden cylinders and their 6-foot-long piston rods with wood heads were found half-buried in dense undergrowth alongside the upper reaches of the Hudson River. The cylinders were made of laminated wood. The piston heads had a strip of leather nailed around the edge to reduce air leakage while pumping air to the furnace. Many pieces of gears, thick iron plates, and unidentified castings were also found in the vicinity. About a mile downstream and adjacent to the standing ruin of an 1854 furnace are four 46-inch-diameter cast-iron cylinders with heavy piston rods that could be adjusted to provide 36- to 66-inch strokes. Each cylinder is about the size of a 500-gallon fuel oil tank.

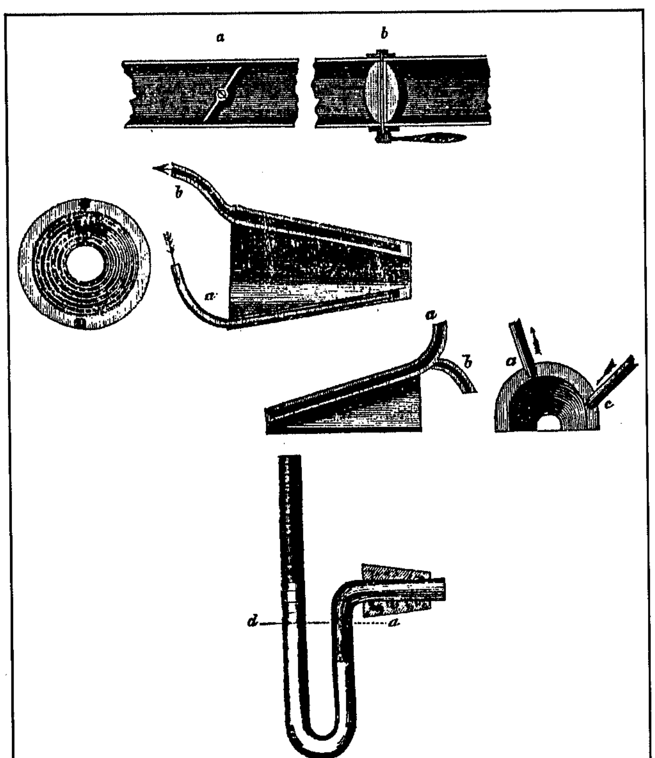
The accepted year for the appearance of blowing tubs in the Northeast is 1835 (Harte 1935:42), indicating the advanced state of thinking at Vergennes. Conant's furnace at Brandon was enlarged in 1839 with two 6½-foot-diameter blowing tubs, the earliest recorded use of the device in Vermont (Lesley 1858:76). The cylinder heads were double-acting (air pumped

2-23. *Ca.-1915 view of waterwheel, blast machinery, and heating ovens (top of the furnace) at Forest Dale (courtesy Vermont Division for Historic Preservation).*

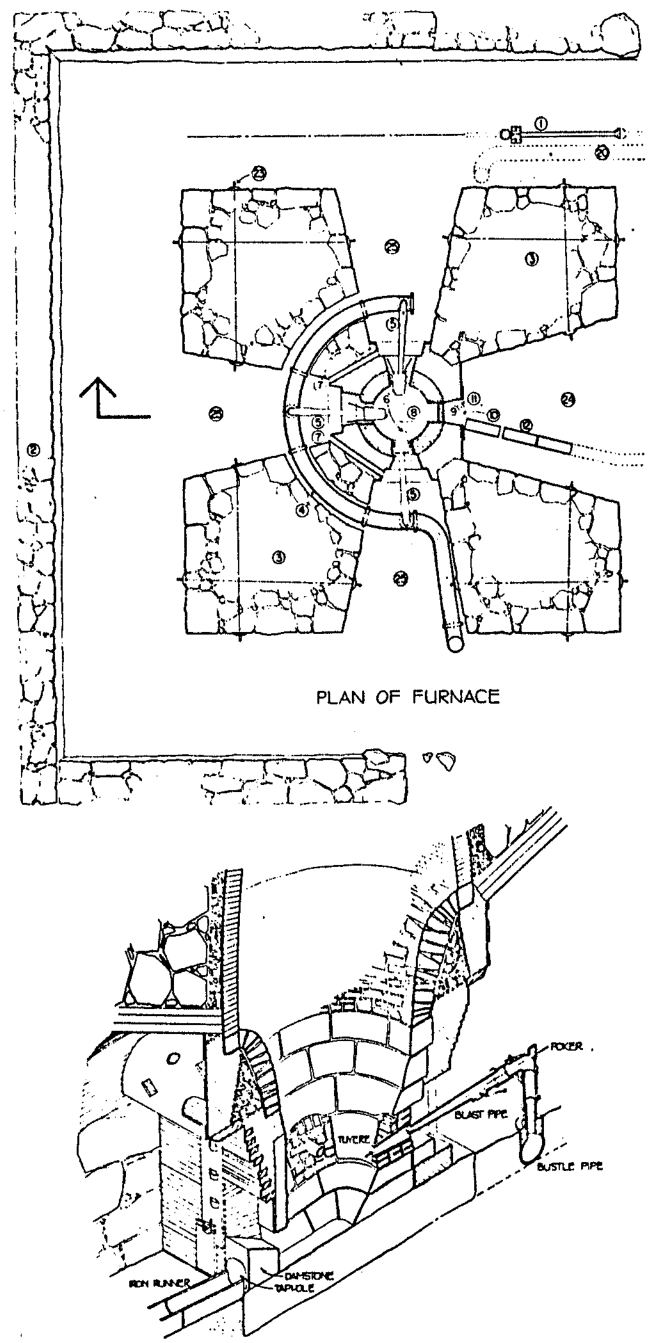
with each in-and-out stroke of the piston), with both inlets and outlets closed by wood flap valves on leather hinges. The pistons were made airtight by a packing of narrow leather strips on the riding edges. Although graphite and lard were common lubricants, many residents 2 miles from the furnace would swear that on a still night the furnace was right next door. Some older residents of Tyson used to claim that when in blast, the creaking and groaning of the bellows machinery at the furnace could be heard 3 miles away, contributing in part to the name of nearby Echo Lake (Hubbard 1922:51).

Replacement of wooden cylinders with those made of iron started in the 1850s. Operation of the iron cylinders was the same as the wooden, but much quieter. They were less prone to leaking due to warped wood parts, and had better-balanced parts. They could be made to run vertically or horizontally, with the former found to work better when driven by steam engine, the latter by waterpower. Blast furnaces throughout most of New England were so large by the 1850s that they were generating enough waste heat to run small steam boilers, but Vermont's well-watered countryside continued to power its blast machines. As recently as the early 1900s a large water-wheel connected to a pair of iron cylinders could be seen at Forest Dale. Today, only the empty wheel pit and blast machine mounts remain, next to the silent, decaying furnace stack.

Another improvement was the hot blast, first introduced by James Neilson in England in 1828. Furnaces were previously blown with unheated outside air. During winter, the cold outside air had a bad effect on both the homogeneous temperature inside the stack and the desired uniform consistency of the



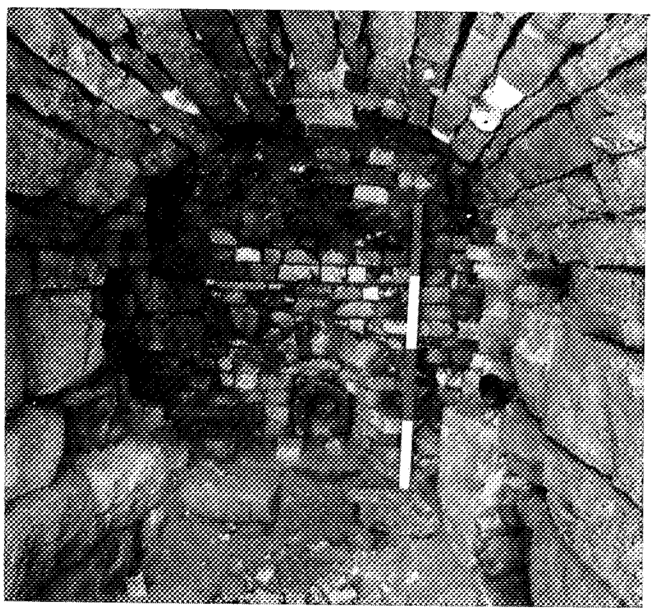
2-24. *Pressure of the air blast was regulated by use of trundle valves (top) before being fed into the tuyeres (middle). Tuyeres were made round (left) or flat (right), the latter so as to support the nozzle, but the former the most common. Both tuyeres contained hollow jackets through which water circulated (a and b) to prevent the nozzles from melting. A manometer (bottom) measured blast pressures as near to the tuyere as possible (Overman 1850:419, 423-424).*



2-25. *Blast was distributed to the tuyeres around the base of the furnace by a bustle, or "belly" pipe (Richards, B. A., and Bowie, J. R., HAER, NPS 1978:4-13, 13-13).*

smelted iron. The preheated blast not only solved most of these problems but also reduced the amount of fuel required to smelt the ore. The blast could be heated by pumping it through pipes that were either laid over an independently located fire or run over the top of the furnace. The latter, utilizing the hot waste gases of the furnace, required no extra fuel. It was the most efficient and became the accepted technique.

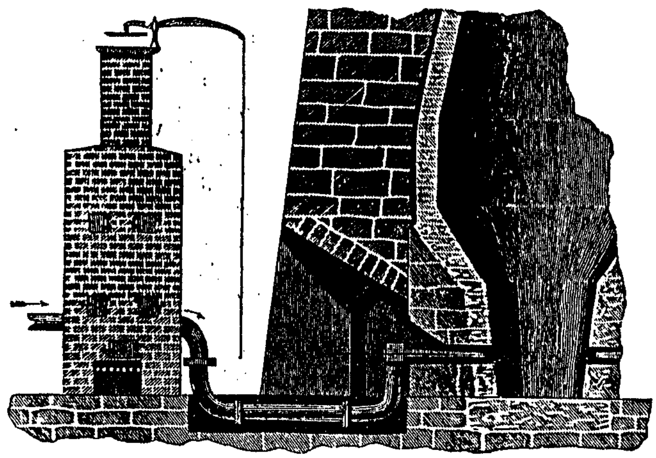
In practice, hot blast was created in a brick-type chamber called an oven, located at the top of the furnace stack. The cold blast was received from the blast cylinders, which were on the ground near the waterwheel, and pumped through many round pipes inside the oven. Inside the oven, some of the furnace waste gases that had been diverted into the chamber passed around the outside of these round pipes. Because cold air expands when heated, the pipes were quite large—up to 5 feet in diameter. The hot gases entered the oven at the bottom of one end, played through the rows of pipes, and, somewhat cooler, exhausted out a chimney near the top of the opposite end.



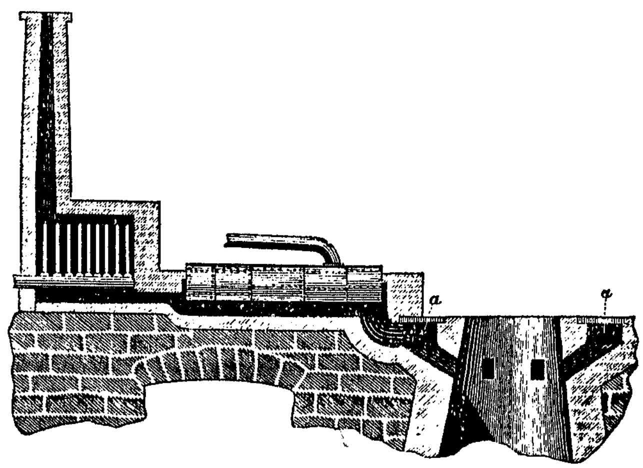
2-26. *Broken end of a bustle pipe (right) and the tuyere (center) at the Forest Dale furnace (courtesy Vermont Division for Historic Preservation).*

The pressure from the blast machine forced the heated air out of the oven and down a pipe to the tuyeres. This vertical pipe was built inside the furnace wall to insulate the hot blast from the cooler outside air. The hot blast was applied to a series of tuyeres around the widest part of the bosh by means of a circular pipe called the bustle pipe. Where a "T" connected the bustle pipe to a tuyere, a small round piece of isinglass (mica) was mounted into the pipe so the ironmaster could look directly through the inside of the tuyeres to inspect the red-hot interior of the blast furnace.

Historical consensus credits Oxford Furnace in New Jersey with the distinction of the first practical application of hot blast in the United States, in 1834 (Temin 1964:59; Swank 1892:326). But a hot-blast system was introduced at Bennington the year before (Hodge May 12, 1849:290). Perhaps one of those crumbling furnace ruins at Furnace Grove at East Bennington qualifies as a national industrial monument?



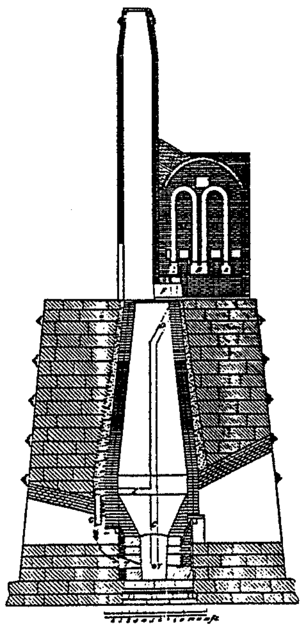
2-27. *Although not as efficient as utilizing waste furnace gas, one method of preheating blast was to pass it through a small, independently heated stove beside the stack (Overman 1850:432).*



2-28. *Tapping the hot exhaust gas just below the top of the furnace did not interfere with top doors and charge-measuring devices (Overman 1850:450).*

Initial hot blasts in New England were about 250° F with 900° F being the upper limit. The Forest Dale furnace preheated blast at 600° F in ovens that were still visible at the top of the furnace in the early 1900s.

When all worked well within the furnace, the charge moved its way down the throat of the furnace at a steady rate. The bridgemen charging the furnace top paced their efforts by the steady descent of the charge. But when they found themselves catching up too quickly, it was the sign that something was

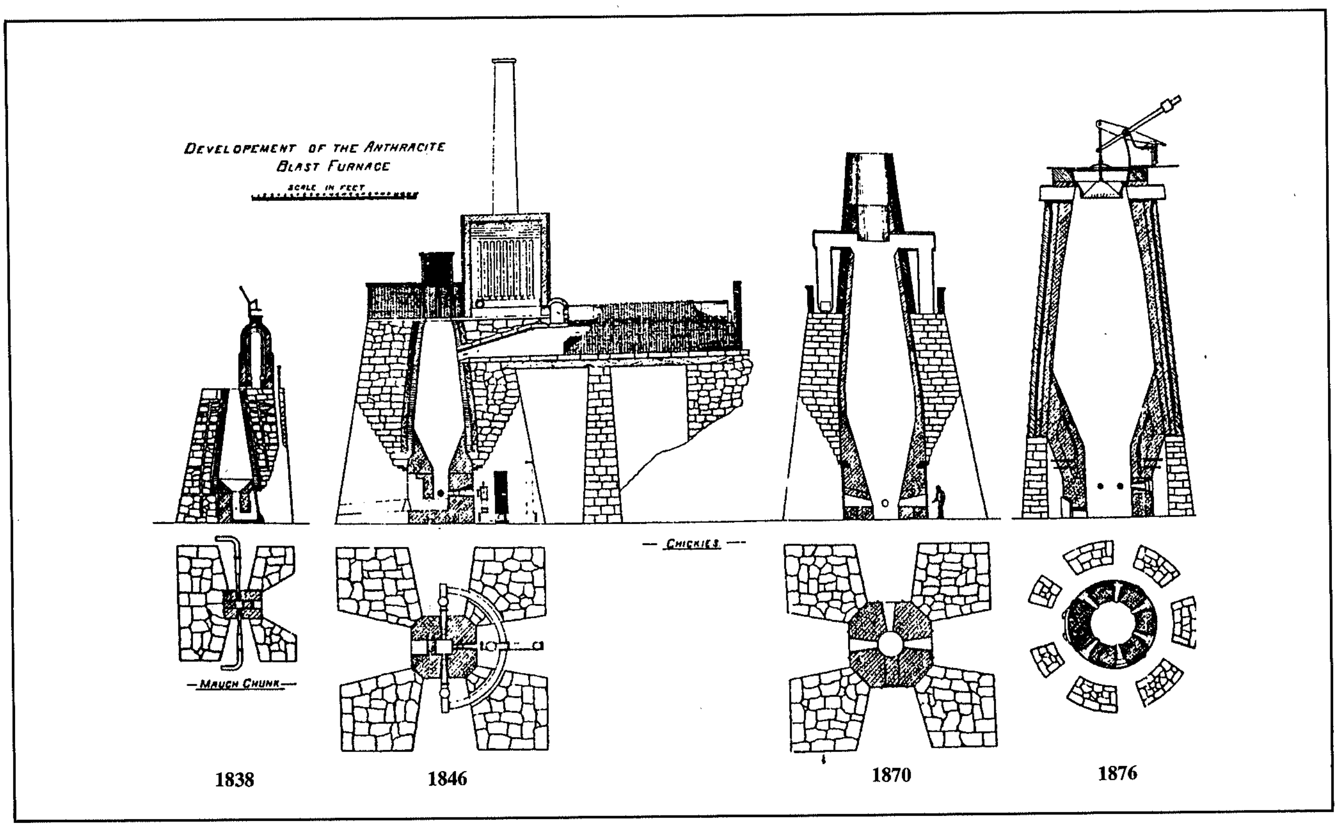


2-29. *Cross-section of a typical mid-19th-century blast furnace showing the top heating ovens, the downer pipe, and bustle pipe feeding hot blast to the tuyeres near the bottom of the hearth. This is probably what the furnaces at Pittsford and Forest Dale looked like in their final days of operation (*Salisbury Iron *1878:7).*

amiss somewhere inside the furnace. A stuck charge usually was budged loose by turning the blast on and off a number of times in quick succession. If that did not unstick things, a bridgeman probed inside the furnace with a long iron rod. In the meantime, fuel was no longer descending to the bottom of the furnace and the furnace was starting to cool. The result could solidify everything in the hearth and in the furnace, requiring the expensive process of opening a furnace wall to remove the "frozen" charge. If probing at the top did not move things along, then more drastic actions were called for. Both tapholes were opened and slag and iron were run out of the hearth. Part of the forehearth was removed and iron rods probed up to the charge to dislodge the stoppage. Some ironworks were known to have small cannon for just such an emergency. After removing part of the hearth, small solid shot was fired upward into the charge (Harte 1935:61-63).

The problem was caused by large pieces of ore, charcoal, or limestone, which should not have been charged into the furnace in the first place. These pieces expanded when nearing the lower, hotter end of the bosh and sometimes wedged the charge by forming a bridge, or arching, across the inside of the bosh. The charge below this bridge continued to move downward, but everything above stopped. In the frenzied battle

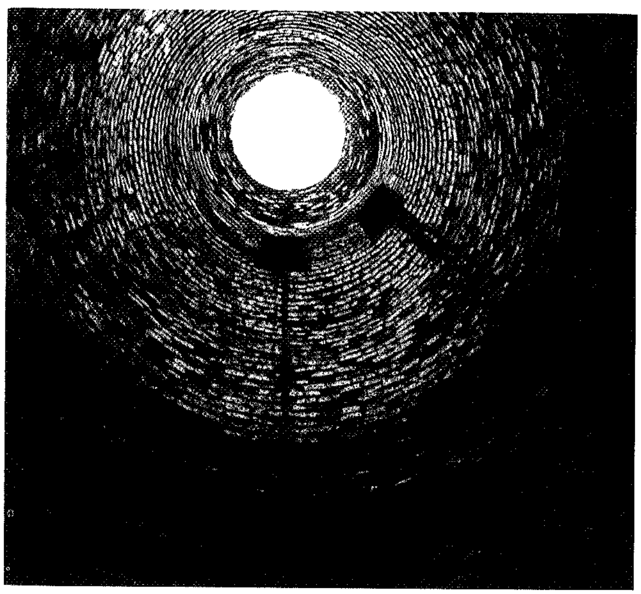
2-30. *This evolution of Pennsylvania's anthracite-fueled blast furnace also shows the relative scale in size of Vermont's early, small blast furnaces compared to later 19th-century furnaces* (Annual Report of . . . Pennsylvania *1894:50ff*).



against time to save the stack, many a bosh wall was inadvertently ruptured, spilling the molten slag and iron, turning the casting shed into a miniature volcanic eruption and fatally injuring many ironworkers.

The efficiency of the blast furnace was defined in terms of how much charcoal was needed to make a ton of iron. Tyson Furnace consumed 150 bushels of charcoal per ton of iron made by cold blast but only 100 bushels by warm blast (Hodge May 19, 1849:306). In the New York–New England area, the average blast furnace consumed 120 to 130 bushels per ton of iron (Overman 1850:168). This confirms earlier statements about the apparent wastefulness of bloomery forges, which consumed about 300 bushels of charcoal per ton of blooms. But it also took additional charcoal to puddle pig iron into wrought iron. What primarily regulated consumption of charcoal in the furnace was the design of the stack. In the 1840–1850 period, an optimum furnace height was about 35 feet. Shorter stacks consumed charcoal excessively; taller stacks strained the blast. In the race to increase production some ironmasters pushed their shorter furnaces to produce beyond their natural limit rather then invest some capital to rebuild their older stacks up to "modern" 35-foot heights. A furnace that readily produced 35 to 40 tons a week could be coaxed to 50 or 60 tons. But when the consumption of charcoal outran the increase in iron output, the point of diminishing returns was exceeded.

The development and improvement of the cupola furnace at the foundry allowed cast iron to be remelted in a separate furnace and run into molds for casting operations. The importance of the cupola furnace was that it relieved the blast furnace of the job of direct casting, and allowed it to concentrate on just casting pig iron. The cupola did its casting in a foundry built either next to the blast furnace, or remote from it near markets and transportation. Other pig iron was shipped to the puddling furnace where it was refined.



2-31. *View up the inside of the Forest Dale stack in 1990, showing the two side openings near the top where some of the hot exhaust gases were drawn into the blast heating ovens (courtesy Vermont Division for Historic Preservation).*

The advantage of Vermont's seemingly limitless streams to run its mills with cheap waterpower was balanced by Vermont winters, one characteristic of which is the numbing cold that froze millstreams solid for months at a time. But even before a solid freeze, ice formation and expansion did much damage to wooden sluice gates, raceways, and the waterwheel. When the time came, the last heat was drawn from the furnace, the sluice gates closed, the waterwheel slowed to a halt, and quiet once again returned to the countryside. As soon as the furnace interior had cooled, it was inspected for wear and damage. A decision was made whether to daub up the firebrick or replace the entire lining. Clinkers were coaxed out of the hearth with heavy iron scrapers, wheezing blast pipes repaired, and badly burned tuyeres replaced. There was time to patch leaks in the roof of the casting shed, replace broken windows, and make some new tools for next year. There was also time to balance the past season's profit margin against needs for improvements to the furnace hardware as the technical state of the iron-making business moved onward. The furnace owners and partners considered how the convening session of the Congress might affect the future prices of iron, costs of fuel, and the economy of the industry in general. And, after reflecting on all that, it was no wonder that so many Vermont ironworks failed to reopen the following spring.

Early Vermont Foundry Operations

Some early Vermont iron-making industries were set up so that many products that were later made in a foundry had earlier been cast right at the blast furnace. By the early 19th century, however, iron making was a blast furnace function and iron working was done solely at the foundry. In some cases, the foundry was built next to the blast furnace stack, such as at Pittsford and Tyson. Usually, the foundry was located a distance from the blast furnace, and might even have been operated by another company.

Two distinctly different kinds of furnaces, the cupola furnace (the cupola) and the air furnace, were used in the foundry to melt and work the pig iron. Which was used depended on a number of variables.

The cupola furnace was the more convenient, economical, and most generally used. It resembled a brick tower, 3 to 10 feet wide and about one story tall, or tall enough to rise as a chimney through the roof of the foundry. A late-19th-century cupola was made with a steel jacket and a firebrick lining. Charging was done through an iron door, 6 to 10 feet from the bottom, through which pieces of pig iron and coke (or charcoal) were introduced. The cupola worked much like a blast furnace, but with some significant differences.

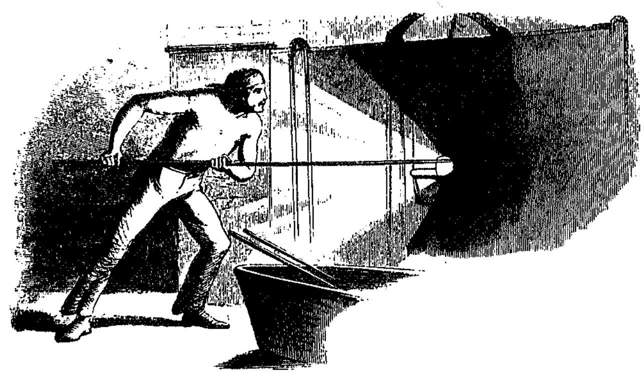
The cupola was started by laying a bed of charcoal and scrap wood on the bottom, igniting it, and as the fire burned, adding more fuel—charcoal, coke, or coal. The time required to heat the cupola and firebrick was generally one to two hours. Tuyeres and natural draft up the tall chimney initially kept the fires going; when charging commenced, only tuyeres provided draft.

Iron was then fed into the cupola through the charging door in as small pieces as practical for the diameter of the cupola. The quantity of iron fed was dependent on the size of the cupola; the larger the diameter, the more iron. A 5-foot-wide cupola could be charged with about three tons of iron.

It took six to eight tons of coke or five to seven tons of hard coal to melt a ton of iron. Too much or too little fuel affected the quality of the iron. In cases where inferior iron (burned or dirty) was used, the charge included a flux of limestone, feldspar, or magnesia; the amount depended on the quality of the iron—worse iron required more flux to carry the impurities off as slag. But over-fluxing could attack the cupola lining and lead to premature shutdown of the cupola. The flux was added (called "slagging out") in egg-size pieces and mixed well with the iron, only after the cupola was filled to the charging door or the iron had been melting for about 30 minutes. Slag was tapped from the slag hole, located just below the tuyeres (so that the slag did not interfere with the blast). The slag hole was placed in the wall about opposite from the spout that allowed the molten iron to flow from the bottom of the cupola.

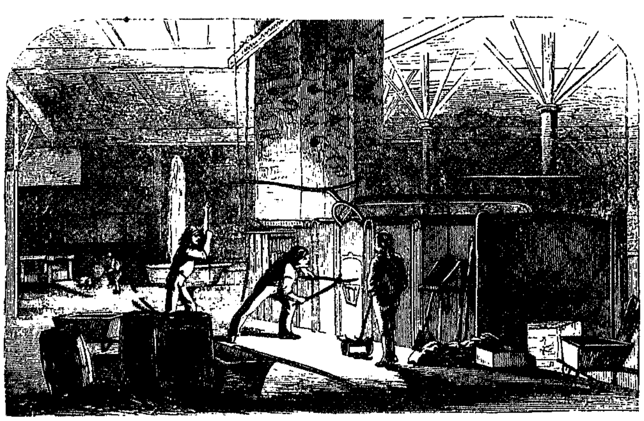
Tapping the cupola was the most dangerous part of the operation, requiring a number of tools for tapping and handling the ladles. The tapping bar was forced into the taphole to loosen the plug, and the molten iron burst out and down the spout. The iron ran directly into a mold or a ladle. The ladle, depending on its size, was hand-carried or crane-assisted to the molds. The taphole was closed with another tool, the stopping bod, which stopped up the hole with a clay plug. It took much skill to prevent the flowing iron from pushing the clay off the end of the tool, or from continuing to flow around the plug and splattering onto the floor (and the workmen). Once flowing, molten iron was not easy to stop.

The air furnace was a variation of the puddling furnace, in which the fuel and iron did not come in physical contact. It received its name from its use of natural convection rather than blast or forced air draft as used in the cupola. Air furnaces were used where melting required great purity and strength.

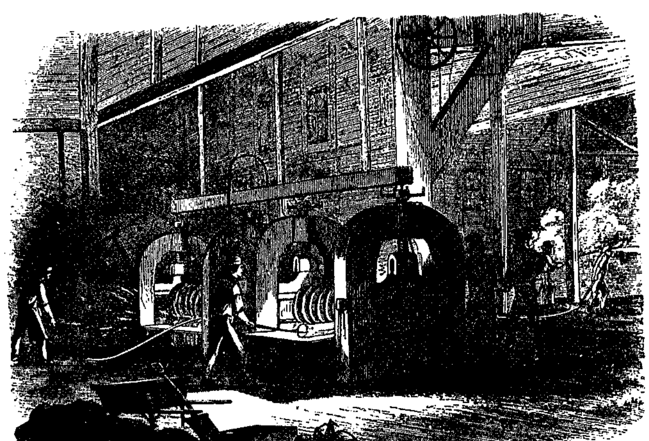


2-32. *The puddler working the iron through a small hole in the side wall of the puddling furnace (Chapin 1860:159).*

2-34. *Transporting a red-hot bloom from the puddling furnace to the hammer, where the bloom was worked into a manageable shape (Chapin 1860:159).*



2-33. *At the puddling furnace, where cast iron from the blast furnace was converted into wrought iron, the puddler removes a bloom with a large tongs (Chapin 1860:158).*

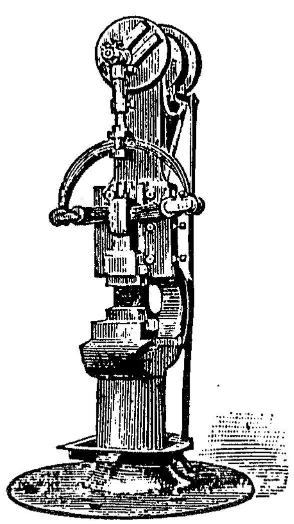


2-35. *After the hammer-shaped piece of wrought iron was squeezed into a rough iron bar, it was successively passed through smaller pairs of rollers, eventually formed into long, flat iron plate ready for shearing and stamping into nails (Chapin 1860:160).*

Larger pieces of scrap iron could be melted in the air furnace, and the greatest casting strength could be obtained with the air furnace because the iron could gain the highest percentage carbon with the lowest percentage sulfur.

The air furnace was generally a rectangular box, 6 to 8 feet long, 3 to 5 feet wide, and 4 to 6 feet high. It looked more like a furnace laid on its side, since the process here was more horizontal than vertical. The foundation under the furnace had to be very strong to hold up under the heavy weight and the stresses involved in the operation. It also required a much greater amount of skill to operate, and up to 12 percent of the iron was usually lost through oxidation.

2-36. *Casting at the Gray Foundry at Poultney in 1956 (courtesy Richard S. Allen).*



2-37. *A ca.-1880 power hammer, looking very much like those used in Trow & Holden at Barre in 1980 to forge stone-working chisels (Naujoks and Fabel 1939:10).*

One end of the furnace contained a grate on which the fuel was piled. A foot-high bridge separated the grate from the hearth, which was the middle section of the furnace. Chunks of pig iron were laid in the hearth, fed through a side door. The entire inside of the furnace was lined with firebrick. A spout was located at the lowest point of the hearth to draw off the molten iron. Other small holes in the walls were either peepholes or permitted tools to sample the molten iron. At the back end was a brick chimney, 30 to 80 feet high, sufficient to provide draft and draw air into the front (grate) end.

The air furnace required 5 to 6 hours burning before it could be charged with iron. The bars of pig iron were piled crisscross so the hot gases could be drawn between and around them and up the chimney.

Typical of Vermont's larger 19th-century foundries was the Burlington Manufacturing Company, whose rolling mill contained three trains of rollers, four heating furnaces, and a hammer in one large 75- by 155-foot wooden building. The adjoining nail shop was built of brick and housed 46 nail and spike machines. The entire works was run by four steam engines and had the capacity of making 6,000 tons of iron products a year (see chapter 4, CH-IW06).

Products made at early Vermont foundries varied with time and demand. During the early years of settling and clearing lands, the common foundry products were nearly the same as that of the blast furnace: merchant bars for the commercial trade, hand tools, parts for waterwheel systems, iron stock for blacksmiths to fashion into horseshoes, hinges, and soft nails, and also something called hollowware—pots that were used for making potash.

Potash Kettles

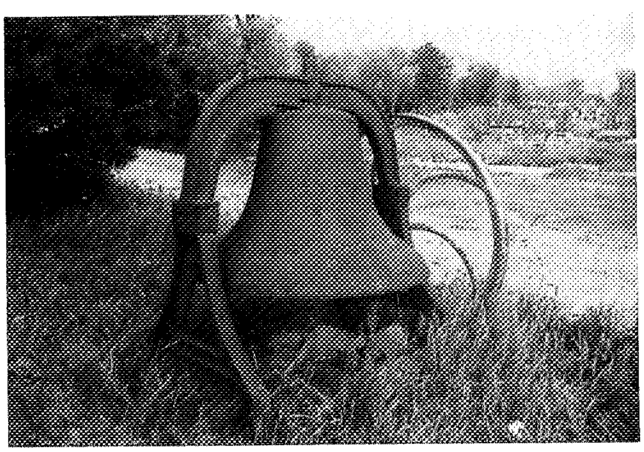
Although potash was used to some lesser degree in making glass, most everyone asked will respond that it was a part of the early process of making soap. And so it was. But as Dorothy Canfield Fisher pointed out: "the amount of potash you came across in old account books and commerce reports couldn't have been for making soap to wash with. Enough was sent out of Vermont every year to wash the clothes and faces of humanity all round the globe ten times a day . . . in a manner of speaking. In 1791, three hundred tons of potash were produced in one Vermont county alone. That's six hundred thousand pounds and that year two million pounds were exported from the whole state" (Fisher 1953:164).

The answer to the apparent puzzling need for such huge amounts of potash was found thousands of miles across the Atlantic in the woolen mills of England. As part of the process of converting wool from its original scratchy texture to fine soft cloth, the wool had to be finished. The process was called fulling and involved treating the raw wool with fullers soap. The chief ingredient in this soap was potash, and tons were needed every year by the English mills to finish the wool. But with the restrictions on cutting trees in England for anything except naval construction, potash had to be imported, and the seemingly endless forests of the American Colonies answered the question of supply. To further encourage the importation of potash from the colonies, starting in 1756 all potash from America was imported duty-free (Fisher 1953:163-184).

2-38. *A large heavy-duty cast-iron caldron, abandoned near one of Vermont's more remote blast furnace sites.*

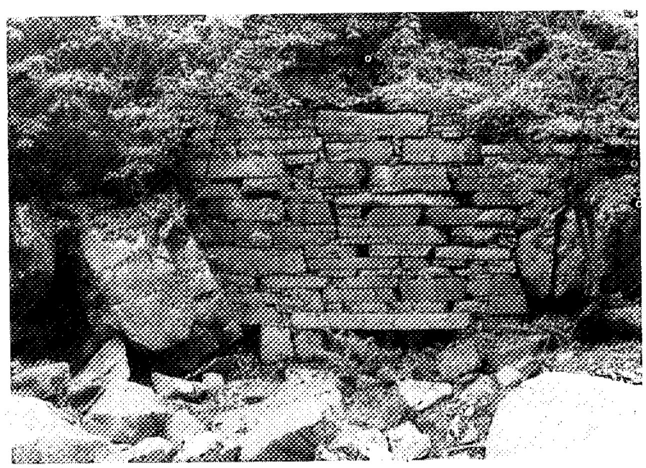
The process for making potash was quite simple, and the chief ingredient, wood, was a by-product of settlers clearing their land. Essentially, logs and branches were burned and their ash collected in a trough. Water was poured on the ashes and drained through them into a large cast-iron pot. This solution was boiled until the salts—the potash (also called pearl ash)—crystallized at the bottom of the pot. Instructions for making potash were written and printed in England and sent to the colonies where they were eagerly studied. All the raw materials were here, all one needed was the patience to endure the time-consuming process . . . and a large cast-iron pot.

These pots—called hollowware, potash kettles, or caldrons in advertisements and books of the time—were usually made right at the furnace by direct casting into a mold. The typical potash kettle weighed 400 to 1,000 pounds, measured 40 to 60 inches across, and had walls 1 to 2 inches thick. Some were cast upside-down, resulting in a weak bottom that rapidly burned out during the boiling process; the better pots were cast open side up, a more difficult molding operation but one that produced a pot whose bottom was the strongest side (Miller 1980:187-208).



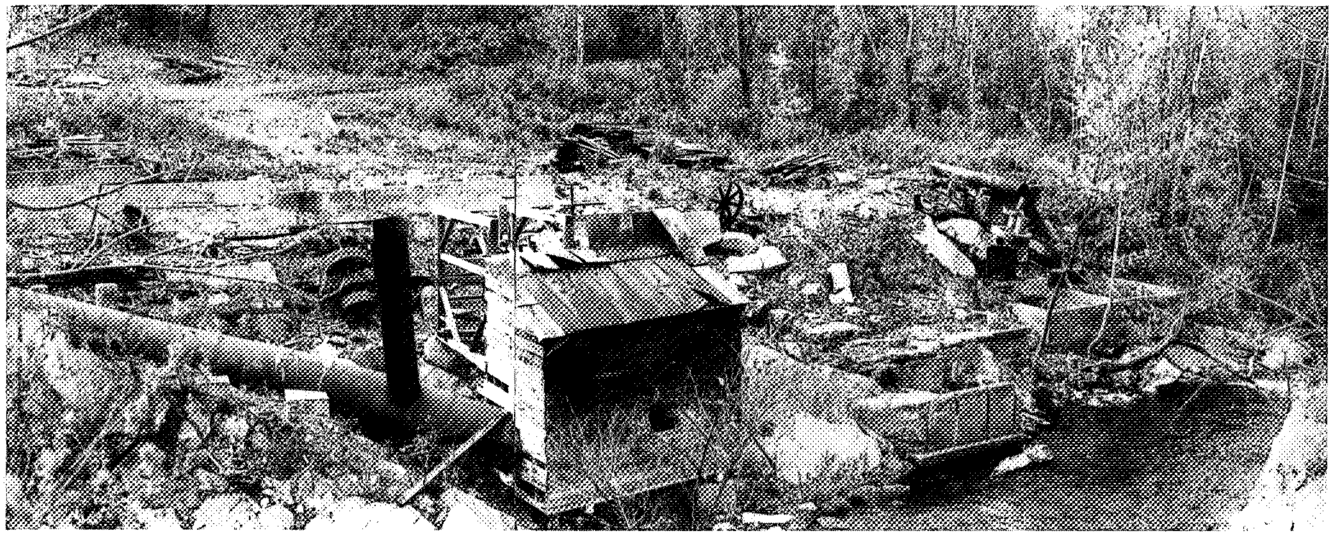
2-39. *Too heavy to be moved, this large cast-iron bell sits outside a former antique shop in West Rutland.*

By 1790, with frontiers being pushed forward and forests cleared at a furious rate, potash exports from the United States had tripled that of 1770. In Vermont, where potash production was in full swing, the first award of the newly created U.S. Patent Office was in recognition of an improved potash-making process. Samuel Hopkins of Pittsford was awarded U.S. Patent Number 1, signed by George Washington (Paynter 1990:18-22). An illustration of the device is in *Pittsford: Now and Then* (Pittsford Historical Society 1980:93). Not only were more and more individual Vermonters taking advantage of the potash "boom," but large-scale commercial potash industries came into existence. They were called potasheries (also asheries). Potash Bay at Addison on Lake Champlain was the site of one such potash mill. The business in turn generated the demand for good quality, heavy-duty cast-iron kettles. In response, blast furnaces up and down Vermont turned out the kettles day and night. At Sheldon, potash kettles were so good that customers came 200 miles to choose among 45-, 69-, and 90-gallon kettles. So many people waited their turn to buy kettles hot from the mold that Sheldon pots were called Sheldon Currency.



2-40. *Remains of the waterpower system for a foundry and plow factory along the New Haven River below a washed-out dam, two miles east of Bristol village. This imposing feature housed a turbine; the inlet at the top and outlet at the bottom.*

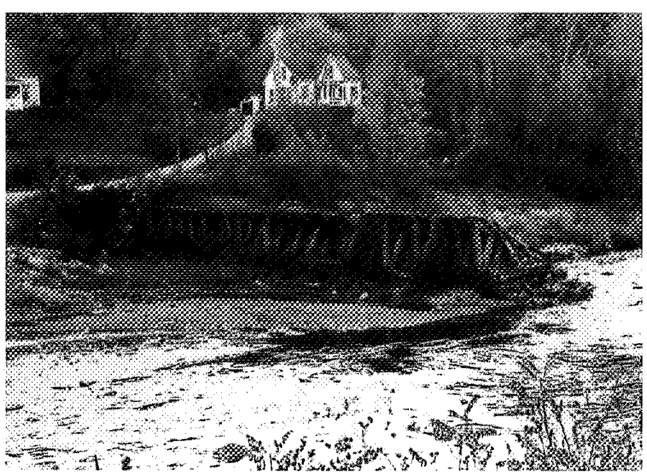
Just as the ironworks had fully geared up for kettle production in the early 1800s, potash demand suddenly dropped off. Europeans had discovered that sodium could replace potash and could be made much more cheaply from the vast European salt deposits. In addition, the threat of renewed war between England and the United States resulted in a trade embargo that cut severely into potash exports. Although Vermonters managed to smuggle potash into Canada during the embargo, by 1810 the demand had peaked. The Monkton Iron Company at Vergennes was finally getting its troublesome blast furnace to work by then, but cast its first batch of kettles too late. So much



2-41. *Ruins of a waterpower system in the Mad River at Warren, showing the dam (lower right), machinery scattered about, and the penstock that conveyed the water (left) to a mill.*

hollowware was being made throughout Vermont that the rapidly declining potash market became saturated with kettles. They were piling up unsold at furnaces in Pittsford and Bennington. And with the end of the War of 1812, the potash demand ended. Those ironworks whose mainstay had been potash kettle production found themselves out of business. A few works continued making kettles for other domestic needs, such as Pittsford, where a ca.-1831 advertisement listed kettles from 7½ to 15½ inches in diameter priced from 20¢ to $2. But the kettle business remained a shadow of the former potash kettle frenzy.

Cast-iron caldrons and kettles can still be seen throughout Vermont performing new, non-potash functions. Some water cattle and chickens in barnyards; others provide extra-large pots for frontyard plants. Many more are in museums and in front of town halls and churches. At least one large, heavy cast-iron kettle lies partially hidden in the undergrowth of a remote Vermont blast furnace ruin, too heavy to be dragged away.



2-42. *Although many mill dams were made of stone, others, such as this washed-out artifact in the Ottauquechee River at Bridgewater, were made of wood with a stone base.*

2-43. *A relic of Manchester Center's more industrial days lying in the brook in 1981, just downstream of the marble bridge. The turbine disappeared a few years later.*