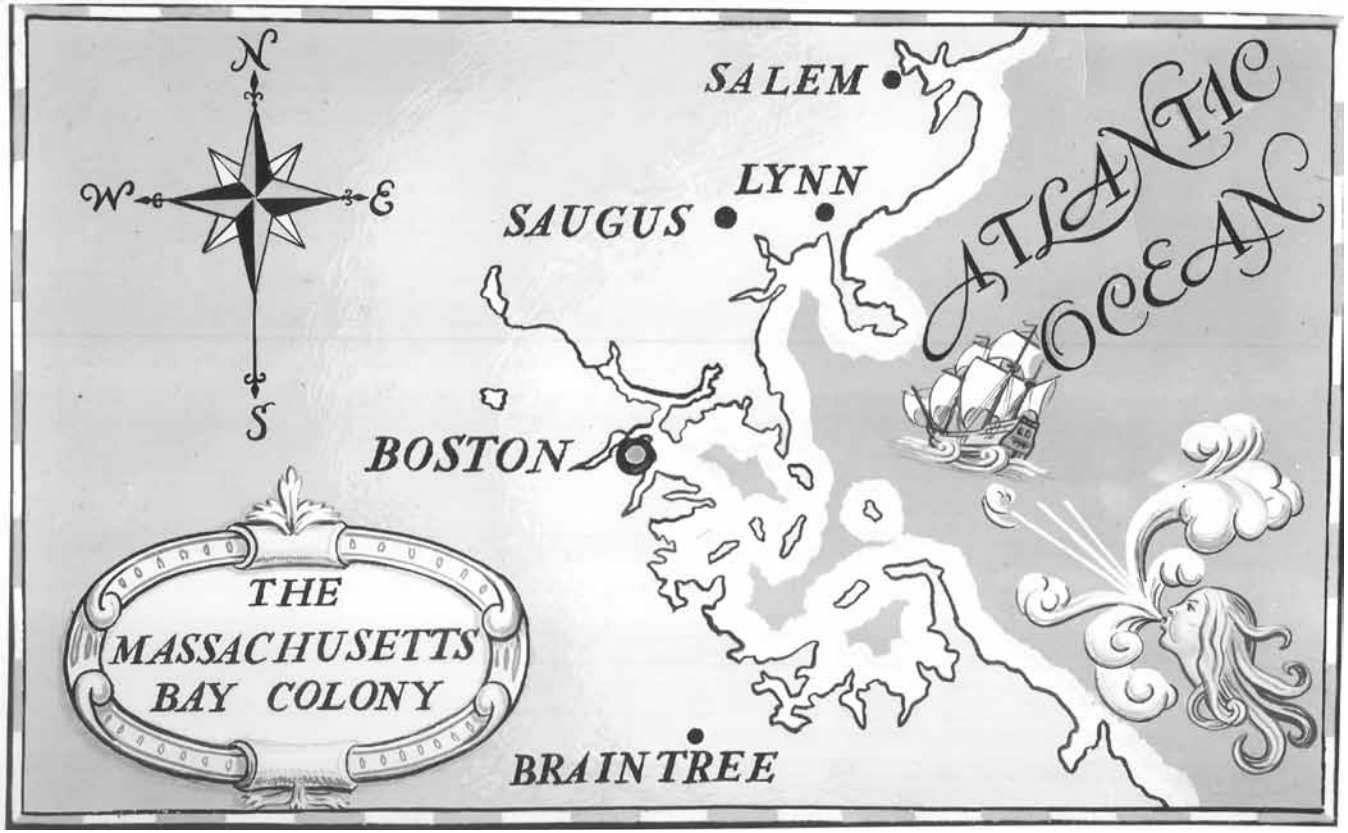

1.1 Map illustrating the location of Braintree, Lynn, and Saugus from a filmstrip produced for the First Ironworks Association. (Image by John Lencicki and Lee Sherman.)

CHAPTER ONE

The History Behind the Iron Works Industry

William A. Griswold

Of all the industries that have contributed to the development of the modern world, few have had as great an impact and lasting effect on society as the iron industry. For millennia, people in various places around the world have used iron to engineer and advance technological change, to solidify social and economic relationships, and to wage war. The effect of iron upon our modern world is so pervasive that life is almost unimaginable without it.

The American entry into the iron industry began early in the colonial period. Early attempts were made at Falling Creek, Virginia (ca. 1621–1622), and at Braintree, Massachusetts (c. 1644–1647), before they were begun at a site known as Hammersmith in what was then Lynn, Massachusetts. What made Hammersmith special was that it was the first site to successfully implement the full range of iron production and refinement at one facility producing cast iron, refined bars, and nails. It was established by a consortium of English and colonial investors, the same ones that had set up the earlier Braintree operation. Hammersmith, now commemorated at the Saugus Iron Works National Historic Site, has been partially reconstructed to educate visitors about colonial iron production and refinement.

This chapter provides readers with background to better understand the following chapters on Hammersmith and Roland Robbins' archeological excavations at the site. Information on iron production, including discussions on ingredients, techniques of manufacture, and spatial layout, are presented to illustrate just how complex the Saugus Iron Works really was and what a truly industrial undertaking it represented.

The Europeans who settled in North America from 1607 onward could apply their metallurgical skills to ore, wood fuel, and water-power resources far more abundant than those they had known at home. A few decades after John Winthrop Jr. started his Saugus, Massachusetts, ironworks in 1641, many colonies had smiths, founders, or smelters among their inhabitants. By 1770 the American colonies had made themselves the world's third largest iron producer.

Robert Gordon, *American Iron 1607–1900,* p. 1.

From Bloomeries to Coal-Fired Furnaces: A Brief Historical Review of Iron Technologies

For many years now, archeologists and historians alike have used an evolutionary framework to describe the development of civilizations based on the utilization of different metals. The Chalcolithic, Bronze, and Iron ages are used to classify civilizations based on the predominant type of metal used. The earliest, the Chalcolithic Age, is a term given to an era in which people developed and used copper and copper tools. Following the Chalcolithic is the Bronze Age, named for its dominant metal, an alloy of tin and copper. Finally, during the Iron Age, people developed and manufactured a metal that, in many cases, was far superior to either bronze or copper for making tools. In addition to providing an evolutionary

scheme of development, these terms also reflect the technological complexity required for their namesakes' manufacture; copper is the easiest to manufacture, followed by bronze and then iron.

The technology necessary to manufacture iron has existed for several millennia. While certainly not the dominant form of metal, several iron objects have been dated to contexts prior to the traditional beginning date for the Iron Age in parts of the world.[1] For most of its period of manufacture, iron has traditionally been made in bloomeries. A bloomery is a "furnace in which iron ore is reduced directly to solid iron and liquid slag with charcoal fuel."[2] The key distinction of bloomeries is that they never produce liquid iron. For thousands of years, people produced iron in relatively small quantities using bloomeries. Indeed, the Romans manufactured all of their iron in bloomeries. Some liquid iron had been produced in the earlier bloomeries, but had been discarded because it lacked the desirable ductile qualities.[3]

Beginning sometime during the middle of the second millennium A.D., after uses had been found for cast products, a new manufacturing process known as smelting was introduced.[4] Iron smelting, using a charcoal blast furnace, actually converted the iron into a liquid that could be molded into given shapes as it cooled. This technology represented a significant step forward in the complexity of iron production. While blast furnaces produced much larger amounts of iron, they required greater amounts of raw materials, continuous operation and maintenance while functioning, a more complex division of labor, and a significant investment of capital. The conversion from bloomeries to charcoal blast furnaces did not happen overnight, but took years to complete. Manufacture by bloomery and by blast furnace coexisted for some time, with production largely determined by demand. Once the conversion to charcoal blast furnaces had been completed, most producers lost the incentive to make relatively small quantities of iron for immediate needs with limited sales. Instead, these smaller-scale technologies were replaced by truly industrial operations, years before the coming of the noted industrial age.

The charcoal blast furnace was not the end of the story of the technological development of the iron industry. The charcoal furnaces, as with the bloomeries that preceded them, saw their age of glory come and go. Coked coal replaced charcoal as the primary fuel type for smelting iron in the early eighteenth century after Abraham Darby's successful substitution and steel later replaced iron when Henry Bessemer introduced the process for manufacturing steel that now bears his name.[5] Numerous other technological improvements have been made in the manufacture of iron and steel through the years since Bessemer. While it might be a stretch to say that the production and refinement of iron is the most important technological development in history, the development of the iron-making industry certainly has helped to shape the world we live in.

The story of even so seemingly prosaic a thing as the establishment of the early iron industry in America is in itself an epic. What a lot of persuading, what long and perilous journeys it often required, to get capital for mining and manufacturing of iron in those first hard years in the colonies! What an adventure, what a gamble it was to set them up in the wilderness! And how often the industries were built up only to be totally destroyed, as in that first Virginia venture, or to be abandoned because the ore gave out, or the capital gave out, or the home government legislated against them. Here was a fitting task for heroes.

Albert Sonn, *Early American Wrought Iron,* Vol. III, p. 3.

Essential Elements for Successfully Smelting Iron

When scouting for an area in which to establish a new iron-smelting facility, early ironmasters asked themselves many questions. Did the area have suitable topography for construction of a furnace and

1.2 Workers casting iron. (Photograph 1460 by Richard Merrill, 1958.)

charging bridge? Was there a good and plentiful supply of water? Were the surrounding landforms suitable for constructing water-control features, i.e., dams, canals, headraces, waterwheels, tailraces, penstocks, etc.? Were there plentiful raw materials available in the area, i.e., iron-bearing ore deposits, fluxes, and wood for making charcoal? How close could these supplies be procured if local supplies ran out? Could supplies be brought to the site easily? Could the finished product be transshipped easily and cheaply to markets or refineries? Was there an available labor supply?

Since the establishment of a smelting facility involved considerably larger-scale manufacturing than a bloomery, investors were usually involved to some extent and the answer to many of these questions then became a matter of economics. Theoretically, a company could always get supplies to a facility, produce marketable goods, and then ship them out to markets. The key was to be able to do so and turn a profit. There was a certain economic cutoff at which a corporation produced and shipped a marketable product and yet lost money and failed to remain in business. Therefore, iron-making sites were chosen very selectively. The better the selection process, the more likely that the company would turn a profit. Profit, however, was never a forgone conclusion for these early iron-making ventures, no matter how suitable the location.

We have no record of [Saugus ironmaster Richard] Leader's search for a new and better site. He must have engaged in much the same kind of location surveying that Winthrop and his men had carried out, tracking down reports of ore deposits, checking on availability of water power, pondering the relative merits of wilderness and settled regions, and keeping an eye open for prospects of sales and transportation of finished products. Ten miles north of Boston, on the banks of the Saugus River, in that section of old Lynn which is now Saugus, he found a spot which had been overlooked in Winthrop's survey but which clearly had distinct advantages.

E. Neal Hartley, *Ironworks on the Saugus*, p. 123.

Suitable topography was very important for the establishment of an iron-smelting facility. Special landforms, usually a hollow or a valley, were needed to construct a blast furnace so that a charging bridge from an elevated ridge or plateau could reach the top of the furnace structure. Likewise, a facility needed a pond, dam, spillway, and canals to channel water to the furnace and finery. Some of these features could be constructed, especially the water-control and water-delivery systems. However, in most cases the ironmaster sought natural landforms for the site to limit the amount of labor necessary to create the facility. The construction of an iron-production facility already represented a huge investment of time and money and the ironmaster and the investors wanted to limit the amount of work needed to get the facility built and operational.

A plentiful supply of water was essential. In most cases, a river or stream supplied the water. To control for seasonal variation in the water and to ensure an uninterrupted flow of the correct amount of water for months on end, several water-control features had to be created. These included a dam, or a series of dams, spillway(s), canal(s) (variously known as a headrace, flume, and channel), gates, waterwheels and wheel pits, and tailraces. Extraordinary care was used in the construction of the entire water-distribution system. Dams were built for permanency; spillways, headraces, waterwheels, waterwheel pits, and tailraces were constructed out of wood or other durable materials. The dam, or bay as the English call it, served to impound the water. Depending on the location and the topography, this dam and the subsequently created pond could be quite large. Usually, water from a river or stream was diverted through a canal from the river to the pond. Depending on the setting, some sort of water-control device, such as a gate, was usually placed along the canal or in the river or stream to control the amount of water being

1.3 Exploring a new environment. (Image 2219 by John Lencicki and Lee Sherman.)

diverted into the pond. The dam could fail if too much water accumulated in the pond, so most systems had a spillway to allow water to be released rather than overfill a pond. Breaches still occurred, however, often with devastating results.

Once contained, the water had to be channeled from the pond to the furnace, forge, and other buildings and features that required waterpower to operate. In most instances, a headrace was built from the dam to the buildings requiring waterpower, with a gate or two along the way to regulate the water flow. The penetrations in the dam were usually the weakest point in the water-control and -distribution system. If water was allowed to migrate outside of the various features, the whole system could fail. Provided that the canal was set up correctly and diligently monitored, it would provide enough water to power the facility without interruption for months. Once the water entered the headrace from the pond, it flowed to the waterwheel. When additional water was required, the gates could be opened or flashboards could be added to the dam to raise the level of the pond. When less water was needed, the gates could be closed or the flashboards taken away.

There are three types of waterwheels: the overshot, undershot, and breast wheels. The overshot wheel, as its name implies, was powered by water that was delivered to the top of the wheel. Water fell from the headrace into buckets that were integrally attached to the circumference of the wheel and gravity pulled down the filled buckets to make the wheel turn. At the bottom of the wheel, the water was dumped out of the buckets and was carried away through the tailrace. The water could then either be diverted to another waterwheel or allowed to return to the river or stream of origin. While more expensive to construct because it required a dam and an elevated headrace, an overshot wheel was much more efficient and could deliver approximately twice the power as an undershot wheel.[6]

An undershot wheel delivered water to the bottom of the wheel. The force of the water pushed the flat blades and turned the wheel. The water was then returned to the river or stream from which it was originally drawn. The undershot wheel did not need a headrace to work, but it was much less efficient and provided much less power than the overshot wheel.[7] Water struck the breast wheel midway along its circumference, horizontal to the shaft axis. This wheel can be thought of as something in between the overshot and undershot wheels, in both design and efficiency.

Once a furnace was fired up, the inside of the furnace cured, and iron production begun, it could not be interrupted without great expense. If a furnace was blown out or extinguished, it had to be rebuilt, causing a one-or two-month delay before high-quality iron could again be made. Therefore, it was imperative that the iron-smelting production process not be disrupted. Once begun, smelting operations were continued twenty-four hours a day, seven days a week, for much of the year. If a dam were breached, a headrace system collapsed, a gate failed, or a waterwheel broke, it often represented a great expense in lost manufacturing capacity.

No documentary data on wheel construction have survived. In recent excavations, however, a fair portion of the furnace wheel and essentially all of the pit in which it turned were found intact. The craftsmanship of some colonial wheelwright is abundantly plain in the excavated specimen. The dimensions and type of the other wheels are not definitely known, although it is clear, both from general archeological evidence and from their known or assumed functions, that all were quite large, that one was an undershot, the others overshot or pitch-back.

E. Neal Hartley, *Ironworks on the Saugus,* p. 183.

1.4 The reconstructed overshot waterwheels at the Saugus Iron Works slitting mill. (Photograph 1419b by Richard Merrill, 1957.)

The location of raw materials, iron ore in this case, was another consideration when ironmasters selected the location of an ironworks facility. The ore was usually heavy and was used in large quantities. To cut expenses, it needed to be available within close proximity to the processing facility. A limited supply of local ore created a problem with the Braintree facility; the supply of ore ran out and caused the facility to shut down.[8]

Diderot's eighteenth-century *L'Éncyclopédi*é identifies several ore mining methods. Most were likely used for thousands of years prior to their discussion in *L'Éncyclopédi*é. Mining approaches included shaft mining, a very dangerous method requiring deep excavation into the earth; strip mining of ore-bearing deposits, a much less dangerous technique than shaft mining; and what appears to be a form of wet dredging of ores.[9]

Once the raw ore had been obtained, it had to be washed and in some cases allowed to age. Washing of the ore was necessary to remove material that could not be smelted. Adding too many impurities to the furnace would cause a number of problems, from producing poor-quality iron to creating bears, or blockages, in the furnace that required it to be blown out. Workers separated as many impurities from the raw ore as possible before it was added to the furnace. *L'Éncyclopédi*é documents several methods used to purify the ore, including basket washing, basin washing and water-powered agitation.[10]

Washing, whereby the ore was cleansed from earth and clay, was still practiced in the seventeenth and eighteenth centuries in parts of Britain. Another method was weathering: the ore dug up at the mine was left in a heap and exposed to the weather for a considerable time. At Rievaulx, in Yorkshire, it was the rule as early as 1541 that the ore, after it had been "gathered", was exposed to the weather for at least half a year so that it could lose its earthy parts, otherwise "ther will be much losse in cariage" of it to the smelting place.

H. R. Schubert, *History of the British Iron and Steel Industry from c. 450 B.C. to A.D. 1775*, pp. 215-216.

Mining of the flux was done in much the same fashion as the raw ore. Flux, when added to the iron ore and charcoal in the furnace, helped to separate impurities into slag and promoted the efficient smelting of the iron. Limestone was one of the most common flux agents used in the production of iron. Other flux agents included coral and gabbro, a dense igneous rock. The Saugus Iron Works used gabbro obtained in Nahant, Massachusetts.[11] Because fluxes were used in smaller percentages than either iron ore or charcoal, their ready availability was not as important. A supply would likely have to be transported to the site by horse-drawn cart or by boat.

Early blast furnaces required large amounts of charcoal to fuel the smelting process. Charcoal was created by the incomplete combustion of wood. Collection and seasoning of wood involved considerable time and forethought. At a typical ironworking site, more people participated in wood chopping for the production of charcoal than any other task.[12] Because wood chopping was not a specialized skill, farmers would often do it during the non-agricultural months, generally November to April.[13] Wood required seasoning before it could be converted into charcoal. In the seventeenth-century, this involved stacking the wood to allow the air to circulate, which prevented the growth of mold. The minimum period for seasoning was half a year, during which time the wood lost much of its sap and became more compact.[14]

After the wood had seasoned it was converted into charcoal, which was a specialized process performed by a collier. The collier oversaw the whole charcoal-production process. The seasoned wood

1.5 Costumed interpreters working in the blast furnace. (Photograph 1215 by Richard Merrill, 1954.)

was stacked in a domed pile around a central pole on a large cleared area, usually thirty to fifty feet in diameter.[15] This pile typically contained several layers of wood stacked at various levels approximately twelve feet high. The stack was then covered with leaves and charcoal dust, with several ventilation holes poked through the covering around the base.[16] The pile was ignited and the collier, with the help of his assistants, allowed the wood to burn enough to produce charcoal but not so much that it became ash. In some cases, the pile required additional leaves and coal dust to limit combustion or additional ventilation holes to encourage combustion. The collier was extremely knowledgeable about his craft and would tend the burning pile night and day for two weeks until the process had been completed.[17] The collier then would allow the pile to cool before opening it and removing the charcoal. The charcoal was loaded onto wagons or carts and transported to the furnace or forge. Because the charcoal was easily ignited, it was usually stored in a covered structure near the furnace that protected it from sparks.

Pale blue smoke from the vents meant the pit was burning evenly. Heavy white smoke meant a poorly charring pit, usually from too much draft which caused too fast a burning. Blue smoke spiraling quickly indicated an opening.

Susannah Wilson Brody, *The History of Dowlin Forge*, p. 72.

When making charcoal, colliers selected certain features.[18] Broadleaved trees were preferred because of their higher carbon content and because they gave greater heat than coniferous trees.[19] The size of the charcoal was also a major consideration. Charcoal larger than about five to six centimeters in diameter was more easily reduced to dust when transported or crushed to dust by the furnace charge.[20] Charcoal dust was undesirable because it lowered furnace efficiency. Historically it was either given a very low price or discarded.[21] This served as an incentive to conduct cyclic coppicing or fresh cutting stump growth, in England.[22] Coppicing ensured the regrowth of trees without planting and allowed the selection of smaller-diameter wood for conversion to charcoal.

The fragility of charcoal and the cost of transporting it limited the catchment area for ironworks, at least in Britain, to between three and five miles.[23] According to one study, a five-mile radius covers about 50,000 acres; a big blast furnace and finery could work indefinitely and refine 530 tons of bar iron with about 13,000 acres of woodland.[24] The charcoal needs of the ironmasters, coupled with the charcoal needed for other industries like glass works, potteries, and shipbuilding, necessitated the maintenance of adequate forests; the seemingly endless woodlands of the New World offered a secure resource base compared to England's rapidly declining forests.

Typical Organization of Ironworks Sites

There is no evidence to suggest that early iron-making sites followed a planned organizational layout. However, almost by definition, ironworking sites required certain primary structures and activity areas and other areas relating directly to iron smelting or iron fining or to housing workers, animals, and supplies. Another way to look at the organization of ironworking sites is to break them down into smaller areas or building groups that supported the ironworks (industrial) and those that supported the workers

1.6 Basket of charcoal. (Photograph 1534 by Richard Merrill, unknown date.)

and their families and possessions (domestic). Some overlap in these categories occurred; for example, horses and oxen served both the industrial and domestic sectors.

Industrial Core

The industrial core can be defined as those buildings, structures, or features necessary for the production and fining of the iron. This would include buildings like the blast furnace, finery, chafery, warehouse, and charcoal house, raw material storage piles, curing areas, canals (headraces and tailraces), ponds, dams, spillways, waterwheels, wheel pits, stables, cart and wagon storage areas or buildings, slitting mills, blacksmith's shop, casting shed, roads, boats, etc. All of these would have related directly to the production of cast- or wrought-iron products.

The principal structure for an iron-smelting facility was the blast furnace. Diderot's *L'Éncyclopédi*é describes a blast furnace as "a stomach which demands feeding steadily, regularly, and endlessly."[25] The analogy to a stomach is a useful one; if the furnace was overfed or fed foods not to its liking, a wide variety of things could happen, ranging from producing poor quality iron to causing a fiery explosion. Once it began eating, the furnace required not only food that it liked, but also around-the-clock feedings. The furnace tenders had to be especially careful to give the furnace what it needed and to quickly treat the symptoms if it showed any signs of illness.

In principal, a seventeenth-century blast furnace was a relatively simple system. Ore, flux, and charcoal were added to the top of the furnace through an aperture. This load would move down though a large chamber where the heat produced by the charcoal, enhanced by regular, forced blasts of air from a bellows, would melt the iron ore. The liquid iron would flow down the furnace, pulled by gravity into a collection chamber. The slag, or impurities from the ore, floated on top of the liquid iron and could be skimmed off at regular intervals. Once enough liquid iron had accumulated in the collection chamber, the tap hole would be opened and liquid iron would rush out to fill whatever casts or molds the ironcasters had prepared. At times, this type of iron was used make firebacks for fireplaces or was dipped and poured into castings. In most cases, however, this melted iron was used to make iron pigs and/or sows.[26] Pigs and sows are the casts of elongated bulk quantities of liquid iron intended for the finery. They are described as such because of their resemblance to a mother pig suckling piglets.

While the smelting process sounds relatively simple, it involved great danger and many things could go wrong. The tuyère, or pipe that directed the bellows blast into the furnace, might get clogged. Additionally clogs might form in the furnace itself, the furnace lining could crack, ingredients might be added in the wrong proportion, or water might come in contact with the liquid iron, all of which might have potentially lethal consequences. Workers had no defense against the danger of explosion. *L'Éncyclopédi*é notes that for "workmen and plant alike, eruptions are the most terrible danger. They bring death to

Comparison of Ardingly with the only other Wealden forge excavated, at Chingley, reveals the same basic elements on both sites, i.e. power hammer, hearths, and water-channels; what varies is the way in which these elements are arranged. At both forges, the anvil base consisted of a section of tree trunk, but at Chingley it was braced by radial beams, whereas at Ardingly, the tree trunk was held in place by three external beams forming an open triangle.

At both forges, there were two approximately parallel water-channels. At Chingley, one channel supplied power, via different wheels, for the hammer and chafery hearth; a second channel provided power for the finery. At Ardingly, both hearths were operated from the same channel, the hammer by a wheel in the other channel.

Owen Bedwin, "The Excavation of Ardingly Fulling Mill and Forge, 1975-76", *Post-Medieval Archaeology* 10 (1976), p. 50.

1.7 Reconstructed collier's hut from Hopewell Furnace National Historic Site. A structure like this would have sheltered the collier when the charcoaling process was underway. (Photograph by William Griswold, 2004.)

those nearby and spread fire far and wide. In a sudden explosion, a furnace will throw up all its contents, molten and solid. It becomes a volcano vomiting flaming fragments from every opening."[27]

The furnace had to be shut down and rebuilt only once or twice a year under normal conditions. Otherwise, it ran night and day, seven days a week, for months on end. In 1550, furnaces typically ran for 25 continuous weeks. By 1646, Sir James Hope reported that Barden furnace normally ran for 45 continuous weeks. Improvements in the smelting process and the use of better materials for hearth construction allowed for longer periods of operation.[28]

Because the blast furnace operated continuously, it required a large labor force. While worker's shifts seem long by twenty-first-century standards, replacement crews were needed every day, week in and week out, while the furnace was in blast. Shift work in some form or fashion would have been required to keep the furnace in blast. This represents a quantum step toward industrialization, one that would have been foreign to most agriculturally based societies around the world. This change served as a harbinger of the industrialization that materialized more than a century later.

*L'Éncyclopédi*é indicates that the furnace was replenished with a charge as soon as the old charge had settled enough to make room. The new charge consisted of about 230 pounds of charcoal, 500 pounds of ore, 50 pounds of limestone, and 20 pounds of argillaceous earth as a lubricant. These ingredients were added in a particular order and ration: three baskets of charcoal, half a basket of limestone, and two more of charcoal were added to give the surface a tilt angle of approximately 30°; to this were added ten baskets of ore. The tilt was necessary to prevent the crushing of the fragile charcoal and to prevent the ore from going straight through the center.[29] "A single charge would move through the blast in 12 to 14 hours," according to *L'Éncyclopédi*é, "and in a good week the furnace would produce 6 or 7 tons of pig iron."[30]

Before the charge was fed into the furnace, the interior had to be well heated in order to get rid of all moisture which might evaporate from the walls. This was termed "seasoning the furnace". It was particularly necessary because of the open top aperture through which rain and snow might fall. According to the available evidence the preliminary heating took from three to eight days, mostly from three to four. The fuel used was charcoal, sometimes with an admixture of peat, or, very frequently, of mineral coal.

H. R. Schubert, *History of the British Iron and Steel Industry from c. 450 B.C. to A.D. 1775*, p. 234.

The casting house was usually adjacent to, if not integral to, the blast furnace. In the casting house workers cast sows along with a variety of other products like firebacks, kettles, pans, and andirons. These items were cast either in the fine sand that lined the floor of the house or in specially prepared molds. While the liquid iron ran through troughs in the sand to form the sows, it had to be ladled into the various ceramic or sand mold shapes. The sand was moistened with water, but could not be too wet or the gases generated by the liquid iron and water would bubble up through the iron rather than through the sand.[31]

Output from blast furnaces varied from place to place. It was dependent upon the percentage of iron in the ore being smelted, the type of charcoal being used, and the size of the furnace itself. Schubert indicates in his book, ***History of the British Iron and Steel Industry from c. 450 B.C. to A.D. 1775***, that output increased from about one ton in twenty-four hours to two to three tons in the same period from

1.8 Blast furnace charging hole. (Photograph 629 by Richard Merrill, 1952.)

the second half of the sixteenth to the mid-seventeenth century.[32] These figures are likely similar for ironworks outside of Britain, especially America where the materials were much more abundant than in England.

Pig iron produced directly from the furnace was brittle because of its relatively high carbon content. To be useful for tools or nails, the carbon content of the metal had to be reduced. A forge (finery and chafery) was not necessarily an integral component of a blast furnace operation. A furnace was really a special operation, because it required tending around the clock, by numerous people, and required a dedicated water flow to power the bellows. It could produce a product (sows or pigs) that could then be sold to various forges for refining. A finery or forge was not nearly as demanding an operation as a furnace. It required many fewer people to run, did not necessarily need around-the-clock attention, and could utilize less stable water sources. For these reasons forges could exist independently of furnaces, purchasing sows for refining. In the finery, the metal sows and pigs were remelted, which burned off more of the carbon, and collected into a loop at the base of the forge; a loop was a mass of partially refined iron. This loop was hammered (by hand and by power) into a bloom, which was then reheated in the chafery hearth and trip hammered, gradually drawing it out into an anchony (dumbbell) and finally into a long bar that could be sold directly to blacksmiths or other metal crafters. The process of refining created flexible and durable wrought iron.

Seventeenth-century colonists brought the fining process to America. A finer melted pig iron in a small hearth containing a charcoal fire blown with a strong air blast. The air oxidized the carbon and silicon in the pig. As did a bloomer, a finer made a loup, a mass of solid iron particles and liquid slag, in the bottom of his hearth. He hammered the loup to consolidate the metal and expel the slag.

Robert Gordon, *American Iron 1607–1900*, p. 125.

In addition to the furnace, casting house, and finery and chafery, ironworks required numerous other buildings or features. A warehouse or storehouse was needed to store the sows, castings, and wrought-iron bars if the facility had a forge. This warehouse was located near a water body if the goods were to be moved by water or by a road if the goods were to be moved overland. It was much less expensive to ship materials by boat than by wagon.

Charcoal would have been housed in a roofed structure to protect it from moisture and fire. The charcoal house would have been large enough to store the huge amount of charcoal needed to supply the furnace and forge. In some cases, the iron ore was also allowed to season in large open-air piles. Whether a seasoning process was involved or not, ironworking sites would have had large numbers of iron ore and flux stockpiles, located close to the charging hole of the furnace. It is highly unlikely that the iron ore or the flux would have come to the site in the sizes needed for the smelting operation. Therefore, facilities were needed to refine the raw materials for the furnace. Logistically, the most appropriate place for such a refining facility would be between the raw material stockpiles and the furnace.

If the raw materials were being transported to the site overland and/or finished products were shipped by horse and wagon, good roads were needed. These roads would have needed to be passable at all times while the blast furnace was in operation. Roads to the site itself and from the charcoal collection points in the wooded areas beyond the site would also have been necessary. A stable would also have

1.9 Costumed interpreter working at forge hammer. (Photograph 1216 by Richard Merrill, 1954.)

been required to house the teams of horses or oxen needed to bring in supplies and ship the finished products. In addition, the horses or oxen would have required pasturage in the warm months and hay or other food in the cold months. If the iron ore, flux, or finished goods were being transported by boat, a dock or wharf would have been necessary. Depending on the size of the operation and the organization of the site, several docks may have been required.

Other structures may also have been found in or around ironworking sites. A blacksmith's shop or work area would have been a likely subsidiary structure, as would a pottery for making molds for the casting products and a carpenter's shop to produce the wooden machinery and buildings. Rolling and slitting mills, where iron was rolled into sheets and then cut into strips, and, later, stamping mills, where slag and cinders were crushed to be resmelted, have also been identified on many ironworking sites.

In addition, dozens of people would have been involved in the ironworking operation: laborers and colliers to chop the wood and to turn it into charcoal; miners to dig up the ore and flux and to process it into usable materials; wagon masters and boatmen to move raw materials to the site and the finished products to market; shipwrights and carpenters to build and maintain the boats, wagons, buildings, dams, races, and equipment at the site; animal handlers to care for the horses and oxen that drew the carts for the raw materials and manufactured products; ironworkers to charge the furnace and smelt, cast, and refine the iron; and accountants and overseers to control and track the production and operation of the facility. Such a complex facility could not operate independently of a settlement that provided the necessities of life. Given its complexity, the seventeenth-century ironworks truly amounted to an industrial operation.

Independence in economic terms meant the creation in New England of native manufactures which could supply the goods hitherto obtainable only in Europe. The settlers needed a great variety of English manufactures, almost all of which were made exclusively of iron or cloth. Cargoes unloaded on the Boston wharves were comprised mainly of iron pots, pans, weapons, and farming and building equipment, side by side with bolts of cloth and piles of stockings, coats, and blankets. If these commodities could be produced in New England, lesser needs such as pottery, leather goods, gunpowder, and salt would present no serious problem. It was the large-scale production of iron and cloth that independence demanded.

Bernard Bailyn, *The New England Merchants in the Seventeenth Century,* p. 61.

Domestic Core

An extraordinary number of people were required to maintain the industrial operation at a blast furnace. These people, in turn, required numerous buildings, structures, and activity areas for their own maintenance. Buildings and structures like houses or quarters, outhouses, barns, animal pens, grazing or feeding areas, churches, schools, and stores were needed to support the vast array of laborers. Unfortunately, in most of the historical and archeological studies to date, the investigation of the industrial core has far overshadowed the study of the domestic areas.

Worker housing would have been an important component of domestic life at an industrialized facility in the recently settled New World. Workers were paid based on the specialization required for their jobs. While professionalization was still rare, differences in wages were clearly evident. Ultimately, this meant that status differences were manifest in salaries and probably in housing. Both married and single men would have worked at the site. Single men likely earned less money than married men and many may have been indentured, especially in the New World. In certain cases, slaves or war captives also worked at industrial facilities. Worker housing, at least initially, was probably owned by the ironworks, but some

1.10 Fred Bonsal and J. Sanger Attwill with reproductions of some of the final products from Saugus. (Photograph 1302 by Richard Merrill, unknown date.)

individuals may have earned enough money to purchase property. Farmers who chopped wood for the colliers may have even owned large tracts of land. Women would have maintained the domestic sector while the men worked in the various ironworking operations.

Areas for the production of foods and the care of animals also would have been required. Barns would have been necessary to house various farm animals like horses, cows, pigs, and chickens. While many of these animals would have been allowed to graze in the warmer months, they needed stored feed in the winter; some animals required feed throughout the entire year.

While some of the needs of the workers and their families could have been met within the community, other needs had to be procured from outside. This meant either interacting with a local village or settlement or having the goods shipped to the ironworks complex. For early industrial experiments like Hammersmith, no doubt some of both were necessary to support the domestic core.

In presently available data no less than 185 men can be identified as having worked for wages or under indenture in, or resided at, or been paid for services to, the ironworks at Lynn and Braintree over the whole span of their operations. Of these, only about one in five was a real ironworker. It is not easy, indeed, to distinguish even among vocational specializations. The neighboring farmers, in addition to the general chores they handled normally, occasionally took on jobs which usually fell to the regular ironworks employees. The latter, particularly in times of plant shutdown, often joined them in the forests, at the mine pits, and in the work of carting and hauling. Even in the activities connected with ironmaking proper, there was little specialization. Many of the workers were Jacks-of-all-trades, worthy sires of a long Yankee strain of specialists in versatility.

E. Neal Hartley, *Ironworks on the Saugus,* pp. 187-188.

The Iron Industry of Britain

Saugus Iron Works was a direct descendent of the English ironworks of the period. Centuries of ironworking technological development had taken place in Britain prior to its export to the American continent. An examination of the English ironworks of the seventeenth century and their antecedents sets the stage for the story of the transplantation of the iron industry to the colonies.

Iron smelting in England seems to have been introduced from France as early as the late fifteenth century. During this time, there was an apparent population movement from France and the technological change from bloomery to blast furnace may have occurred as a result of this migration.[33] The industry had grown with such speed as to raise an alarm in the middle of the sixteenth century because the landscape was being deforested quickly as timber was converted into charcoal. As mentioned above, the deforestation in England provided an impetus for colonizing the New World, where vast quantities of timber had been reported.[34]

As with the introduction of many new technologies, the blast furnace did not immediately replace the bloomery. Bloomeries survived in the Barnsley and Sheffield areas until the second quarter of the seventeenth century. [35] Archeologists Crossley and Ashurst comment in their excavation report on Rockley Smithies, a sixteenth- and seventeenth-century water-powered bloomery, that

> there was considerable variation between the main iron-producing areas of Britain. In the Weald of south-east England the first blast furnace was built at Newbridge, Sussex, in 1496, and no bloomeries are known after one referred to in 1606 at Haslemere, Surrey, which itself appears to be an exceptional survival. In the West Midlands the Pagets' furnace at Cannock was

1.11 Image of a settler's cabin. (Image 2240 by John Lencicki and Lee Sherman.)

> in operation in 1567, although the Willoughbys built a bloomery in the 1570s and did not adopt the blast furnace on their lands until the 1590s. In South Yorkshire the overlap between the two processes occupies a still later period; the Earl of Shrewsbury's furnace, the first in the Sheffield region, was built in 1587, yet the Barnby bloomery operated until the 1650s, perhaps a decade after the abandonment of Rockley.[36]

Crossley and Ashurst go on to make the argument that the slow adoption of the new technology was directly related to the scale of production, market forces, and setbacks with the new technology. Not only would the early ironmaster have to sell a much larger volume of iron, 150–200 tons produced from a blast furnace compared with the 30 tons from a bloomery, but he would also have had to deal with technological problems inherent with the furnace shaft design and logistical problems of amassing enough raw materials to last a lengthy smelt.[37] These factors worked against the immediate and universal adoption of the new blast furnace technology.

In areas distant from London, such as the Midlands and Yorkshire, the demand for iron could be met by the available technology.[38] However, around London, where the population was rapidly expanding, landowners and ironmasters were more willing to accept the investment risk associated with the increased output of a blast furnace.[39] Not only would the burgeoning London population have use for the iron, the iron and iron products also could be shipped to other areas of the world undergoing development and colonization.

The Crown also affected the demand for iron, especially during wartime. Several ironworking facilities were more or less controlled by the Crown during wars. The English government required cannon and iron ordnance during wars and production from the new blast furnaces was tuned to meet the demand. In times of peace, many of the ironworks relied on the needs of merchants and the export trade. [40] While the sale of cannons or armaments beyond the Crown's needs was expressly forbidden, it may have been attractive to some black market operators.

Schubert and others have demonstrated from primary sources that the forests of England were being quickly depleted of timber by the growing ironworks industry.[41] In 1548, a commission bemoaned the damage being inflicted on the timber industries by the ironmasters. If allowed to continue, the commission reported, there would not be enough timber to build "houses, water mills or windmills, bridges, sluices, ships, crayers, boats, and especially for the King's Majesty's towns and pieces on the other side the sea." The report goes on to note that the continued depletion of timber for charcoal jeopardized the production of "gunstocks, wheels, arrows, pipes, hogheads, barrels, buckets, sieves, saddletrees, 'dossers,' bellows, showles, 'skopets,' bowls, dishes, bills, spears, morrispikes with such like necessaries."[42] Numerous other wooden products and constructions were also mentioned in the report, including the building of piers and jutties.[43] References by the commission also included a case from the Forest of

A growing population in the Mother Country cried out for more and more iron. A charcoal timber shortage had pushed the English iron industry from its ancient centers to ever more remote areas. It had been carried to Ireland and to Scotland, where in certain cases even the ore had to be imported from remote places and much of the finished and weighty product carried back to English markets. The reaching out of far-sighted capitalists to New England thus seems to be little more than an extension of an already well-established trend of economic imperialism fed by the lure of high profits in a generally favorable business situation.

E. Neal Hartley, *Ironworks on the Saugus,* p. 82.

1.12 Casting crucibles. (Photograph 1533 by Richard Merrill, unknown date.)

South Frith in the Weald, where in 1553 the ironworks were allowed access to the land for production of charcoal. An inquiry held in January 1571 noted that the area then was barren. Another example cited by the commission concerned the Cannock wood in Staffordshire. Evidently, Sir Fowke Grevills clear-cut these woods to produce charcoal for what was once Lord Paget's ironworks.[44] Arguing against Schubert, other scholars note that a lack of charcoal, even though severe in some areas, did not lead directly to the demise of the charcoal furnace.[45] Regardless of whether the forests were being managed for charcoal production, they were clearly highly in demand. This is one reason why financiers agreed to undertake the transplantation of the industry to America in the middle of the next century. The New World offered what seemed like an endless supply of timber for the production of charcoal.

Archeological Investigations

In addition to research on historical ironworks, there has also been a great deal of archeological excavation done on English ironworks sites, especially in the Weald. Some of the more important ironworking sites in England to be excavated have included Ardingly Forge (sixteenth and seventeenth centuries), Batsford (sixteenth century), Panningridge (sixteenth and early seventeenth century?), Pippingford (late-seventeenth to early eighteenth century?), Rockley Smithies (bloomery, sixteenth and seventeenth centuries), Dyfi furnace (mid-eighteenth to early nineteenth centuries), Maynard's Gate (sixteenth and seventeenth centuries), Cowden (sixteenth through eighteenth centuries), and Chingley (sixteenth to early eighteenth century).[46] Most of these excavations were conducted in the 1960s, 1970s, and 1980s by two scholars, Owen Bedwin and David Crossley. These excavations in general have taught us much about blast furnaces, waterflow and distribution systems, manufacturing processes, English ironmasters, gun casting, and more. As a result of the archeological labors of these scholars, a great deal is currently known about charcoal iron smelting in England around the time the Saugus Iron Works was in production. Archeological work on these English ironworks has essentially stopped for now, due to preservation concerns.

Few of the latest generation of charcoal blast furnaces have escaped the attentions of excavators in recent years. As the later development of the charcoal blast furnace is now generally well understood and the excavation of further examples is not a high priority for research purposes (see *Society for Post-Medieval Archaeology* 1988, 5), the preservation of those which are untouched is crucial. It is important to ensure that the fragile below ground remains of these structures are protected as thoroughly as the standing buildings and to safeguard a substantial archeological reserve for future generations.[47]

The excavation reports on these sites, which record the discoveries made through archeological investigations, are invaluable as a comparative tool. In later chapters, parallels will be made between these English sites and the Saugus Iron Works discoveries. In many cases these English excavations help us to better understand the Saugus materials.