Colonial America's Pre-Industrial Age of Wood and Water

From the Collections at Historic Bethlehem [PA]

More than 200 years ago, Moravian settlers created a community with an integrated industrial area along the Monocacy Creek in Bethlehem, Pennsylvania. Greatly admired throughout the colonies, the industrial site bustled with activity. Today, Bethlehem's Colonial Industrial Quarter, which covers 10 acres, is the largest and most diverse pre-Industrial Revolution technology site under restoration in the Commonwealth--if not the nation.

To understand the impact of pre-Industrial Revolution technology, we must first come to an understanding of what technology is. Simply defined, technology is "a system based on the application of knowledge, manifested in physical objects and organizational forms, for the attainment of specific goals" (R. Volti). Thus, technology can consist not only of tools such as hammers and saws, but also the knowledge of how to make and use those tools and the broader system of which they are a part. For example, a grist mill involves a power source, transmission gearing, stone grinding wheels, barrels, a building to house it all, and, of course, some sort of distribution system for the final product, or the goal, which is flour. Ultimately, technology is a human endeavor and cannot exist outside its human context. Technology is thus embedded in society--it is shaped and influenced by human values, aspirations, and goals as filtered through political, social, and economic institutions. In turn, technology impacts those very same goals and values and the society that holds them.

For many people, the word technology conjures up images of large-scale industrialization. The Lowell textile mills in the early 19th century, the steel mills of Pittsburgh and Bethlehem, or today's Silicon Valley come easily to mind. But of course industrialization did not spring out of nowhere. It was, and is, a process, one that is hard to date, extending over a long period of time, involving a steady accumulation of knowledge and technical innovation. To understand that process and to understand how we got to where we are today, we need to understand that which came before--the pre-industrial age. In doing so we can better understand the importance of early Bethlehem and its own industry and how it fits into the history of how we do things.

It would be erroneous to think that there was no technology in the pre-Industrial Revolution age. Ships brought colonists and supplies to the new world. Shipbuilders had the technical knowledge to build and sail these vessels and they had navigational aids such as the compass and charts to help them find their way. The colonists brought with them hand tools, plows, domesticated animals, clothing, and firearms--items which comprised a technical system.

Most, if not all, of these tools and products were "handmade" in contrast to being produced by extensive machines. In this context, however, "handmade" did not always imply that the items were more "natural" or "better" than objects produced in a factory with the help of machines. All products require some sort of "natural" resource and utilize human skill. It is also important to remember that there were a lot of inferior artisans producing sub-standard goods, which is one reason why industrialization was so widely and readily accepted.

The colonial economy was based on the four F's--furs, fish, farms, and forests. In all of these areas technology played an important role. However, only a relatively small percentage of the colonists engaged in crafts and trades or artisanal work--perhaps 10 to 18% depending on the time period and the location. By far the largest percentage of Americans were involved in agriculture.

Another way to characterize the colonial economy and its technology is to call it an age of wood and water. In general the colonists substituted that which was plentiful for that which was scarce. Thus, wood and water were used lavishly while the soil was often exploited. Labor was scarce and thus expensive. In many ways the colonial period was an environment of abundance and the use and misuse of this abundance would shape long-term values.

Wood

Wood was an important product. First, there were many chemicals in wood which could be used successfully. The tannin in tree bark was used for the tanning process. Potash, heated ashes left from burning trees cleared off the land, was potassium nitrate used in the making of soap and glass. If potash was heated further the resultant pearl ash, almost pure potassium, could be obtained and used in the dying and shrinking of cloth.

Second, wood produced pitch, tar and resin for use as naval stores. Trees were felled to be used in ship-building--the largest trees were used for masts, while the smaller ones were used for spars.

Third, wood in the forms of boards, clapboards, shingles and barrel staves was used to support everyday life. Houses, containers like piggins and barrels, dishes, spoons, bowls, furniture, and coffins were made of wood. Wood was so important that it became an important colonial export especially to the Caribbean.

Fourth, wood was the major form of fuel as a heat source. The average colonial family used 30-40 cords per year, the equivalent of one acre of woods, to heat their homes and to cook their meals.

Finally, wood was the material most available and most easily shaped. Thus it could be used to make a wide variety of manufactured goods and even small machines such as lathes and printing presses were almost entirely constructed out of wood.

Because of America's extensive reliance on wood, it is not surprising that one of the first commercial buildings to be set up in a new town was a sawmill--often before the erection of a grist mill. Colonial Bethlehem had both a sawmill and a grist mill very early in its history. The establishment of sawmills revealed some differences between the colonies and England. England had turned quite early (by the 17th century) to coal because of wood shortages. In the colonies, wood was plentiful and almost "free for the asking." At the same time, labor in America was expensive because it was scarce. Thus, waterpowered sawmills appeared quite early in America as a technical solution to an ecological and human power problem. Many of these early sawmills were built and operated by men who were not English, due to a lack of familiarity and skill level that the English colonists had with this technology. The first colonial sawmill was erected by the Dutch in New Amsterdam in the 1620s. The first English sawmill was built in Maine in 1623 or 1624 and the first sawmill was erected in Pennsylvania in 1662. By 1700 there were about 70 waterpowered sawmills in New England and 100 years later there were 250.

The first patent in America for a mechanical invention was issued in 1646 for improvements in a sawmill. This suggests that people were constantly working on improvements even if they were not making radical changes. The typical saw was an up and down sash saw. The problem with it was that it had a very thick blade, 3/8" to 1/2" thick. This blade chewed up a lot of wood into sawdust. But it was fast and saved labor which was more important than trying to save wood. A sawmill with one man, perhaps assisted by a boy, could produce 1,000 ft. of pine boards in one day. It was five times more efficient than two-hand sawyers who could produce a dozen boards per day on the average.

Eventually circular and band saws with much thinner blades replaced sash saws but only when the metallurgical knowledge to improve the technology of blades could occur and the price of labor rose high enough to make it economical. The circular saw first appeared in America in 1814 but it only used small blades for the next 30 years because of the limits of metallurgy. The band saw was patented in 1869.

Waterpower

The colonial period was not only an age of wood but also of water. Water was the major means of transportation but it was also an important source of power. One of the indications of the process of industrialization is the replacement of animate (human and animal) power with inanimate power sources. Waterpower was the first common form, usually used to turn a mechanical wheel of one variety or another. Waterpowered mills ultimately paved the way for demonstrating the benefits of machinery and mechanical power. Windpowered mills were also employed in some areas, usually to grind grain. The two most common and important mills were sawmills as mentioned and gristmills. Other mills included fulling mills for pounding and shrinking cloth, paper mills, oil mills, tanning mills, and carding mills. The number of waterpowered mills actually increased until just before the Civil War and many were still in use in the early 1900s. This use illustrates a point that there can be several different types of technology in place at one time and all of them can be economically viable at the same time. Just because something new came on the technological scene did not mean that it was immediately and widely adopted.

The development of mills was the first step in freeing agricultural people from the drudgery of rural life. Colonial farmers often traveled up to 50 miles to get grain ground into flour. The long trip to the mill was offset by the fact that it saved them the labor of grinding by hand.

Mills were so important that communities often offered inducements such as free mill sites and adjoining land, limited monopoly rights, tax exemptions, exemptions from military duty, and even outright money gifts. Mills helped to attract settlers to a town and increased land value. Mills were often built before schools and churches. Colonial settlers sometimes perceived the lack of a mill as "a serious evil" that was "inconsistent with civilized life."

The use of waterpowered technology in colonial America was derived directly from the Old World. Waterwheels, while often thought of as the key element, were only one part of a whole system that was needed. Generally, a good mill site needed to have a dam and millpond to impound water for dry periods and to regulate flow; a millrace to carry water to the wheel itself; a sluice with a gate called a penstock to put the water onto the wheel; and a tailrace to carry off the spent water.

There are four major types of prime movers or waterwheels. The tub wheel was the most primitive. It is like a turbine with a vertical shaft set horizontally in a stream. The tub wheel was usually small, simple, and relatively inexpensive. It was used in rural locations primarily for grinding grain because grindstones could easily be attached to the shaft. The three other types of wheels were vertical wheels and were undershot, breast, or overshot, depending on the height of the water used to power them.

In the undershot wheel the force of the water hit the paddles directly, with most of the wheel out of the water. Power depended largely on the flow of the water, which could be quite fast, but the wheel did not require a high head, or height of water. This was the type of wheel used in Bethlehem's waterworks and oil mill. It produced about 3-4 horsepower and utilized 15-30% of the water's energy.

An overshot wheel required the most head or height of water, perhaps more than 10'. It was the most efficient kind of wheel utilizing 50-70% of the water's energy. This wheel produced only slightly more horsepower than the undershot wheel, generally in the 4-5 horsepower range but not greater than 10. The weight of the falling water, as well as the velocity with which it struck the paddles or buckets as it flowed over the top of the wheel, determined the amount of power the wheel could produce.

The breast wheel was a wheel that was half submerged. The water hit the paddles in the middle utilizing a curved, wooden wall around that portion of the wheel to keep the water on the paddles. Breast wheels could be very efficient but they were also most difficult to build and hence not widely used in the colonial period. There is some evidence that the 1743 and 1752 grist mills in Bethlehem used breast wheels. In general, however, breast wheels became much more common after the emergence of factories.

Colonial mills were usually built by millwrights, or sometimes clever carpenters, with the help of blacksmiths to construct the few metal parts such as bands on the wheel shafts and the gudgeons on the shaft ends. Most of the mill parts were wooden, however, including the gearing although sometimes leather belting was used to transfer power to the application. Millwrights had to decide what type of wheel was best suited to a given location, what size it should be, how to design the paddles or buckets, where and how to build the dam and raceways, and what gearing was necessary to power the mill itself. Then the millwright oversaw the construction. Thus millwrights might well combine the skills of carpenter, joiner, mason, stonecutter, blacksmith, wheelwright, and surveyor.

Millers, the men who ran the mills, were also multi-talented. They often owned the mill site as well as the mill. They had to have a good knowledge of the trade itself and be able to maintain the equipment once it was constructed and put in place. Millers' fees were not small. Usually they asked one quarter of the lumber sawn or grain ground. Apparently there were few disputes about such fees, suggesting the important role that these mills played in everyday life. Thus, despite the noise, the waster, and the pollution created by colonial mills, both millers and millwrights were valued citizens. The US Census for 1840 lists 23,700 gristmills, 31,650 sawmills, 2,600 fulling mills, and 8,200 tanneries. This amounted to more than 6,000 mills or one mill for every 245 people at a time when the absolute use of waterpower peaked in the United States.

Iron Production

Despite America's basic reliance on wood, the colonists still needed some metals, especially iron for items such as cookware, firearms and swords, horse shoes, and the edges on tools. Iron was hard to manufacture and expensive to produce in the 17th century but by the mid-18th century iron was the third leading colonial export behind wheat and timber.

In the early years of the colonial period, iron was produced in bloomery forges--a hearth in which raw iron ore was combined with charcoal and heated. The oxygen in the iron combined with the carbon in the charcoal--giving off carbon dioxide and thereby reducing the iron oxide. These forges never got hot enough to really melt the iron, which ended up as a black pasty substance called a "bloom," hence the name of the forge. The black color also gives us the name of "blacksmith.” The bloom was full of impurities which had to be pounded out by a blacksmith on an anvil.

To produce larger quantities of better quality iron, larger blast furnaces were developed in America as they had been in England. Perhaps 25' tall, the blast furnace was loaded at the top with a measured charge of iron ore--often broken up by water-powered hammers--and charcoal and limestone used as a flux to help separate the impurities in the iron ore. The blast furnace was operated at a higher temperature, accelerated by air blasted by water-powered bellows, into tubes at the base of the furnace, which melted the ore. The slag--limestone flux and impurities--was lighter and floated to the surface where they could be drawn off. Then the heavier iron could be drawn off through the removal of a plug in the hearth at the base of the furnace. The molten iron often was allowed to run out into a series of shallow troughs, or molds on the floor. These molds resembled a litter of pigs nursing from the sow, hence the name "pig iron." The pig iron was also known as "cast iron" because it could be cast or poured directly into molds to produce kettles or stove plates, for example. The problem with cast iron was that it was fairly brittle with about 4% carbon content absorbed from the charcoal fuel. Therefore it would only be used where there was little stress, such as in stove plates which were produced in the Hopewell Furnace, PA area. Much of Bethlehem's iron supply came from the Durham Furnace in Bucks County.

A stronger material was wrought iron. Pig iron was reheated in separate forges and then pounded or hammered to drive off the remaining carbon particles and impurities and to create and align a tough fibrous structure containing essentially no carbon. The resulting "bar iron" was then sold directly to blacksmiths for turning into specific products such as iron plates, nails, and locks.

To produce steel in the small quantities used for blades in cutting implements such as saws and razors, wrought iron was reheated to a molten state in clay pots with measured amounts of charcoal to reintroduce just the right amount of carbon content--perhaps up to 1%. The blade of the implement was then dredged in this molten liquid so that a fine layer of steel covered the wrought iron. This process was very difficult and expensive to produce.

Part of the problem in making iron was that no one really understood the chemical processes involved and the work was mostly trial and error. In addition iron-making was different from many other crafts and trades practiced in colonial America. It required large capital investments in land and equipment and few artisans could ever expect to own their own facility. It had to be located fairly near to the sources of raw materials--iron ore, forests for the charcoal, and limestone, although the latter was needed in smaller quantities and was fairly widespread in terms of availability. Transportation for the finished goods was often an issue as well.

Iron ore deposits were located in a variety of places but Pennsylvania, southern New Jersey, and part of New England had good supplies in rural areas close to the needed forest lands. It took about 4.5 cords of wood to produce a ton of iron ore. One acre of trees produced 30-40 cords of wood, or 6.5-8.5 tons of iron per acre. A typical iron furnace might utilize 5-6,000 cords of wood or 125-200 acres of woodland per year to produce 1-2,000 tons of iron per year (the equivalent of what a modern furnace produces in a few hours). Iron-making required only one bushel of limestone for every 10-20 bushels of ore depending on the purity of the ore, so that was not as big a problem. Because of the land required, most iron-producing facilities were located in rural areas and had to be largely self-sufficient, producing their own food and providing housing for ironworkers and their families. They were isolated, the work was hard, and although wages were not that bad, labor was scarce and turnover was high. Many iron plantations were located on navigable rivers which facilitated the transport of the pigs, bar iron, and finished products. In fact, proximity to transportation was often the difference between a charcoal furnace being able to continue producing iron after coke furnaces became widely used.

By the time of the American Revolution, there were as many furnaces and forges in America as there were in England and Wales producing almost as much pig iron, although less finished goods. By 1775, America was producing about 1/7 of the world's total iron. In the 1770s Pennsylvania alone had some 20 blast furnaces.

Pre-Industrial BuildingTechniques

Wood was also important in providing housing in colonial America. Although in some places in the early years the log cabin, a Scandinavian import, was used, stone and brick over a timber frame were the most common materials used to build dwellings and public buildings. The timber frame included the use of heavy solid beams called girts connected with mortise (the hole) and tenon (the protrusion) joints held together with wooden pegs. This construction method was used in part because of the relative lack of and high cost of nails. In fact unused buildings were sometimes burned down to get at the nails if they had been used. The heavy walls were usually laid out and put together on the ground and then raised with a team of laborers, usually neighbors, who would help each other to build houses and barns.

Once the walls were erected some material was needed to fill in between the posts. Sometimes this filler was brick or more likely a lathing of woven branches covered over with plaster known as "wattle and daub." This "stucco" did not provide enough protection for people or for the lathing itself especially in the cold of New England winters. Therefore the colonists developed clapboards (overlapping wood siding) and shingles using wood that was relatively abundant and cheap. Producing clapboards and shingles was at first done by hand but was eventually mechanized.

Other housing adaptations included large fireplaces, low ceilings, and few windows--all done for warmth especially in New England and because glass was also expensive. It was not until the latter part of the 18th century that Franklin's cast iron stove was widely adopted--a tremendous heating efficiency improvement. Remember also that the Moravians in Bethlehem were using tile stoves from their middle-European roots to heat their choir houses and work spaces. All used wood for the fuel, a fairly abundant and inexpensive item throughout much of the colonial era.

Where did developments in building techniques lead? Inventions that facilitated the exploitation of abundant lumber supplies were likely to be profitable. Thus in the late pre-industrial period, the 1790s, there were 23 patents issued for nail-making machinery, for if the cost of nails could be reduced, so could the cost of building. Jacob Perkins developed a waterpowered machine in 1795 that could produce 200,000 nails per day, which helped reduce the cost of nails by almost 90% by 1840. This reduced the cost of using wood for building and paved the way for the "balloon frame" housing of the 1830s, the type of wood frame building used today. In balloon frame building, the whole frame, not just a few posts and beams, carries the weight. The advantage is lighter-weight: 2" x 4"s can be substituted for the massive beams. This lighter frame is nailed together, reducing the time-consuming skill of mortising and tenoning, and therefore reducing the number of people necessary to handle the building process overall. The balloon frame is then covered by clapboards. An American innovation, the balloon frame was cost-effective, using less labor and less skill, and still took advantage of available wood; it thus became a logical extension of timber framing.

Relationship of Colonial American Workers to Technology

What was the colonial worker's relationship to the technology just reviewed? While the typical colonist was still a fanner or farm worker, that did not mean that he or she did not deal with technology. It only meant that the individual was not an artisan or a craftsperson. Farmers tried to be reasonably self-sufficient, but usually out of necessity and not out of some great vision or ideology. They sold one cash crop to exchange or buy items that they could not produce themselves like guns and gunpowder, sugar, salt, glass, ironware, and books. They also tended to be the proverbial "jacks of all trades and masters of none," especially if they lived away from the sea coast or rivers for transportation or from more heavily populated urban areas. If some farmers were particularly good at a task like shoemaking or coopering, for example, they might use these skills to augment their livelihood, especially if they lived near a village or an urban market.

It must be remembered that only 15-18% of the colonists were artisans or craftsmen. Generally they centered their activity around towns and cities because that is where the concentration of people provided them with a ready market for their specialized trades. In 1690, the total population of the 5 largest colonial cities was only 19,000--Boston, New York, Philadelphia, Charleston, and Baltimore. By 1776 this figure had risen to 108,000.

Even in the cities, most craft operations were carried out in small shops, often family-owned and located in the family home. Skills were passed along via the apprenticeship system in which young boys exchanged their labor for a period of 4-7 years in return for learning a trade and support for daily living. They then became journeymen and could work for other masters as they saw fit, earning a wage in return. Eventually, after they had acquired enough capital, they could set up their own operation somewhere.

There was usually a shortage of skilled labor in early America, however. This was due in large part to the abundance of cheap land. It was often easier and more profitable for a young man to go into agriculture than to learn a trade, especially in areas where the markets were small and unstable. Importing master craftsmen from Europe was difficult because most were already well-established and reasonably well-paid and, therefore, had no real financial need to emigrate and start over. Even if such craftsmen did move, they often found the availability of cheap land extremely attractive, or if they settled in less urban areas, they found it a necessity, especially in the early years, to turn to agriculture to survive and to support themselves. What was true for the master craftsman was even more applicable for journeymen or even indentured servants who often ran away soon after they arrived, lured by the attraction of cheap land. The shortage of skilled labor also meant that crafts in general were slow to develop and the colonies generally imported about half of the manufactured goods they needed. This shortage also accounts for the frequent community advertisements soliciting and offering inducements to artisans whose specific skills were needed.

In general, colonial craftsmen made the whole product from beginning to end, although in some crafts like shoemaking and textile production, there may have been some division of tasks in the early stages of production, especially in the slightly larger shops. Craftsmen were also responsible for selling the items themselves so they usually only produced work that was contracted for. Only later did some artisans begin to venture to produce items on speculation for a yet unfound market. This activity most likely occurred during a slack time to keep the apprentices busy.

The general scope of colonial production was very human in scale. The schedule often varied with the season, the number of orders, and the ability to obtain raw materials--it was definitely not clock- or machine-based. The scale of production was also generally small. It is also important to remember that not all craft work was necessarily good. A lot of artisans made inferior items. One reason we may think of handcrafted products as being of higher quality than machine-made products is that primarily the better pieces have lasted through the years and been handed down through generations of people.

Because of the small number of artisans and the limited specialization, the pace of technological change was very slow. Colonial Americans transferred and adopted the European techniques with which they were familiar and generally tended to make few changes. There are a number of reasons for this. First, English mercantile theory viewed the colonies as sources of raw materials to be used by craftsmen in England. They, in turn, would provide finished goods for markets in the colonies. Thus, English legislation passed to regulate the economy of the colonies did not encourage manufacturing there and often prohibited it because it would have prompted unwelcome competition. For example, the colonies were prohibited from producing finished iron products but colonial furnaces were allowed to produce bar and pig iron. Textile production was also especially hampered in the colonies.

Second, the density of artisans in the colonies was too low to encourage technological change. When large numbers of artisans work together, they have the ability to share information and develop new techniques and solutions to common problems in their work. This interaction helps improve technology, tools, and production processes.

Finally, different crafts interact with each other. The weaver needed a loom builder and the printer needed a joiner to make him a press, for example. In the absence of these mutually reinforcing trades, craftsmen had little ability or desire to improve, nor was there very much competition which also leads to technical improvement.

Nonetheless, colonial artisans did accomplish a great deal, laying the foundations technically and economically for the industrial revolution which would follow. Some even produced fine examples of silverware, furniture, and clocks. These technical skills, whether they were from millwrights, ironmasters, or carpenters, would be necessary for the new nation to have as it expanded across the continent and began to compete on its own terms with the nations of Europe in the 19th century.