TECHNOLOGY 3: IRON AND STEEL PRODUCTION TO 1945.

Iron is produced by melting iron ore and removing impurities. Steel is simply a purer form of iron with lower carbon content. Since ancient times, iron was made using charcoal as a fuel, but with wood becoming scarce in England by the eighteenth century Abraham Darby (1677-1717) pioneered the alternative of using coke (which is made by baking coal to drive off impurities and gases in order to produce a hotter burning fuel). His innovation (1709) was in widespread use by the 1760s. The following series of processes were carried out separate firms until the about the 1860s and 1870s when innovations in steel making permitted their integration within the same plant. (Boyce & Ville, Box 6.1 pp. 165-6 explains why Andrew Carnegie developed integrated iron and steel works.)

1. <u>IRON MAKING</u>: Since the eighteenth century iron has been produced in a vertical shaft furnace, called a blast furnace. (It resembles a wide metal pipe, lined with refractory brick to protect it from the heat, standing on end with a closed bottom and an open top into which raw materials are dropped.) Iron ore, coke, and limestone are charged into the top of the furnace; limestone acts as a fluxing agent, that is impurities adhere to it and are removed leaving a purer iron. Air is pumped into the bottom of the blast furnace to intensify the heat and speed up the melting process. (In 1776, John Wilkinson [1728-1808] pioneered the use of steam engines to pump the air –previously water-driven bellows had been used-, and in 1829 James Neilson (1792-1865) introduced pre-heated air, or a "hot blast" in order to raise productivity further.) The air pressure suspends the materials in the furnace and as they melt a bath of molten metal appears at the bottom of the furnace. As the limestone attracts impurities, a "slag" forms and floats on top of the molten iron. At intervals the slag is drawn off through holes in the side of the furnace and discarded. Similarly, the iron is drawn off, or "tapped", and poured into moulds made of heat resistant material. Known at this stage as "pig iron", the metal cools and hardens and is then removed from the moulds. The large blocks of cold iron are called "ingots" or "pigs".

   During the nineteenth century, blast pressures and furnace size increased to boost productivity and economise on coke. Edward Cowper (nd) patented the regenerative stove in 1857; this device burned gas emitted from the top of the blast furnace, and later from coke ovens, to heat the air being pumped into the blast furnace. This example of recycling gas reduced fuel use by 17-8% and increased the furnace temperature to 700 degrees Centigrade. In the late 19th century the largest blast furnaces produced 100 tons per day; a century later they produced 1600 tons in twenty-four hours.

   2. <u>PUDDLING:</u> The pig iron drawn from blast furnaces in the nineteenth century had a relatively high carbon content which made it brittle and suitable only for casting (pouring into sand moulds to create shaped pieces of iron). It fractured easily when hammered in forges. To reduce the carbon content and make the iron more malleable, it was reheated in a shallow coal-fired furnace, stirred manually but later mechanically, and subjected to oxygen in order to burn out carbon. The resulting product, called wrought iron, could be easily rolled or hammered into finished shapes like rails, plates, or beams.

2. STEEL MAKING: In the 1850s and 1860s, experiments paved the way for the mass production of steel. Previously, steel had been made in small quantities for very specialized uses like tools and cutlery. It was refined in crucibles and was extremely expensive. Several inventors developed processes for refining iron by reducing carbon and other unwanted chemicals to produce steel, which was stronger and lighter than wrought iron.

   Modern steel making processes can be differentiated in terms of the underlying chemistry and according to the principles on which the production process is based. Chemically, there are two types of process 1. acid steel making where the material has a low ph reading, and 2. basic steel which has a high ph. The two principles behind the actual process can be called 1. pneumatic which involves the use of air pressure, and 2. the regenerative principle which refers to the regeneration, or "rebirth", of heat by passing hot gases to and from brick lined chambers to heat cold air. Different processes evolved using all four variables –acid, basic, pneumatic, and regeneration- in four different combinations.

   Let us examine the breakthroughs in steel making during the late nineteenth century.

   A. Pneumatic/acid or Bessemer process: In 1856, Henry Bessemer (later Sir Henry, 1813-98) patented the idea of blowing air through molten iron to drive off impurities. He built a pear shaped vessel, or "converter" lined with bricks and blew air in through holes, or "tuyeres", in its bottom. (Converters were sometimes stationary, but more commonly they could be tilted: down to take the charge of pig iron, upward for the "blow", and finally down again to draw off the slag and to pour out, or "tap" the finished steel.) When the air was blown into the converter a truly volcanic reaction erupted: a blast of flame projected from the mouth of the vessel for 12-15 minutes and then died down after the impurities were eliminated. This process only worked well using pig iron made from iron ores that had low phosphorus content. Indeed, Bessemer used high grade Swedish iron in his experiments and was baffled because the process did not make good steel when he tried other types of pig iron. Nor did the Bessemer process work when it used pig iron that had high levels of sulphur (often this element was absorbed by the iron from coke used in firing the blast furnace). The latter problem was solved by adding spiegeleisen, which contains manganese, after the initial volcanic blowing process was completed. This additional stage in the production process was called the "after blow". The rapidity of the Bessmer process presented difficulties in controlling the quality and chemical composition of the steel. It produced steel that had high tensile strength (it could withstand shock) but relatively low ductility (it was difficult to draw or bend without breaking). However, the speed of the process and the fact that it used molten pig iron made it possible to accelerate production and encouraged the integration of iron and steel making within the same plant and thus save fuel. (See Boyce & Ville, Box 6.1 pp. 165-6 to see how Carnegie exploited economies of scale and speed by building integrated iron and steel works.) The pig iron was not allowed to cool in ingot form, but rather was charged molten into the converter. Bessemer's process was widely adopted in the 1860s. It is interesting to note that, much like kiln firing in the pottery industry (see Technology 2 Box on this web site), tacit knowledge was vital to the operation of the process. A skilled worker had to learn how to determine when the steel was finished by observing the colour of the flame emitted by the converter.

B. Regenerative/acid or Siemens-Martin process: Charles William Siemens (later Sir Charles, 1823-83), German-born but British by citizenship, invented a regenerative process for making steel in 1868 after ten years of experimentation. (The Martin family was a French licensee who helped to perfect the process.) Instead of using a vessel-like converter, Siemens build a rectangular chamber lined with bricks; this was called an open-hearth furnace because one end could be opened up to charge materials and draw out the finished steel. Initially, Siemens heated the furnace using hot gases produced by burning coke in a separate chamber. However, impurities entered the steel and to perfect his process, he had to develop the gas producer, which burned coke and filtered the hot gas. The gas was stored in brick chambers on either side of the open-hearth furnace and was blown across the top of the metal from side to side. In this way the impurities were burned off or fused with fluxing agents to produce a slag.

   In contrast to the Bessemer process, Siemen's furnace, which was stationary, was charged with cold pig iron and a small quantity of iron ore. Steel scrap was also used; indeed some firms specialized in producing steel in open-hearth furnaces charged solely with steel scrap. Later, the practice of charging hot pig iron into the furnaces came into widespread use. The Siemens-Martin process was slow – it took between seven and twelve hours to complete a "heat" instead of the mere 30 minutes or so for the Bessemer method. However, its very slowness was an advantage: quality could be controlled with much greater precision and the process yielded a superior grade of steel highly suitable for ship plates. Moreover, Siemen's method generated higher yields of steel – the volcanic reaction of the Bessemer converter wasted steel by spewing some of it out of the top of the vessel. The open-hearth process spread rapidly after 1870. By combining it with hot metal practice and using several Siemens furnaces, companies could make the overall process nearly continuous and suitable for integrated plants. Some firms, like South Durham Steel & Iron in the North of England, bought pig iron on the market and converted it into steel using the open-hearth method; these firms were called "re-melters".

C. Pneumatic/basic or Thomas-Gilchrist process: As we have noted, Bessemer's process did not work when using pig iron made from ore that was high in phosphorus. In 1878, two Englishmen, Sydney Thomas (1850-85) and Percy Gilchrist (1851-1935) overcame this problem by lining the Bessemer converter with bricks made of basic materials, and by using lime as a fluxing agent to absorb unwanted elements into the slag. The process also reduced the level of sulphur. It made it possible to produce steel from low-grade ores and low-grade coke. The Thomas-Gilchrist method was not adopted in the United States, which had good ore supplies, and was not extensively used in Britain. However, steel makers in Continental Europe, where low grade ores were plentiful, employed it widely. By 1890, just 400,000 tons of Thomas-Gilchrist steel were being produced annually in Britain, compared with 2 million tons in Europe. After 1904, the development of basic open-hearth technology caused a shift away from the basic-pneumatic process.

D. Regenerative/basic process: A number of individuals and companies experimented with Siemens furnaces to develop a basic regenerative process. Essentially, the operation was the same as the acid process described above, except that the open-hearth furnace was lined with bricks made of basic materials and lime was used for fluxing. Thus, the basic regenerative process applied the lessons learned by Thomas and Gilchrist to open-hearth technology. One problem that had to be overcome, however, was to cope with the large amount of slag processed. (Excessive slag absorbed heat and slowed production thereby undermining its commercial viability.) This difficulty was solved by using an open-hearth furnace that could be tilted to draw off the slag at frequent intervals. Benjamin Talbot (1864-1947), a Briton who worked in the United States for many years before returning home to help develop the Cargo Fleet Iron Company's new integrated works (see Boyce & Ville, Document 6.3, p. 174) devised a tilting furnace to tap molten steel and slag alternatively and thus make basic open-hearth steel making a nearly continuous process. With the superior quality control, high yields, and scrap using capability of the Siemens-Martin technology, the basic version was adopted in the North of England where poor-quality ores were abundant, and throughout Continental Europe, where it displaced the Thomas-Gilchrist method from 1904 onwards. The basic open-hearth became the dominant method used throughout the United States, where by 1954 it accounted for 85% of total output.

3. ROLLING: Before the development of the continuous caster in the 1980s, finished steel was poured, or "teemed", into moulds and allowed to cool. The ingots of steel were then removed from the mould by a ram. In the late nineteenth century, steel ingots were often sold to firms that specialized in rolling steel. However, as fully integrated plants proliferated, increasingly the ingots were processed in mills adjacent to the steel shop. In these facilities, ingots were placed in "soaking pits", or brick lined chambers fired by gas, where they were reheated. ("Soaking" also improved the consistency of the metal and brought its surface and internal areas to a uniform temperature.) The ingots –now at 2150 –2450 degree Fahrenheit- were then removed from the soaking pits by crane and placed onto a "roughing" or "cogging" mill (sometimes also called "blooming" or slabbing" mills) to undergo primary rolling. At this point, the ingot was between five and ten tons in weight, and somewhat rectangular in shape. In the roughing mill, it was pressed between huge rolls (one on top and another below), made of high-grade cast steel and cooled by water spray, to adopt one of three basic shapes. If compressed into a bloom, the ingot emerged from the mill as a long piece of steel of between 6 inches by 6 inches to 12 inches by 12 inches with square or slightly square corners. Billets were also long pieces of steel with square or slightly square corners, but they ranged from between 2 inches by 2 inches up to 5 by 5

inches in width. Slabs emerged from the mill with rounded corners and were 2 - 6 inches thick and 24 to 60 inches wide. The primary rolling consisted of passing the ingot backwards and forwards through a single set of rollers until the desired shape was achieved, but more advanced mills pushed the ingot through a series of rolls that gradually reduced it to the required dimensions. The resulting bloom, billet or slab was then allowed to cool. Again, these shapes –called "semi-finished" steel- were sometimes sold to other firms that specialized in rolling final products, but within integrated facilities they were placed in another soaking pit and rolled in an adjacent mill.

4. Finishing: The re-heated "semi-finished" steel underwent further rolling to form its final shape. Blooms were formed into rails, girders, or bars by being passed through a series of rolls which progressively reduced them to the final shape desired. The smaller billets were likewise run through a series of rolls to emerge as small girders or bars, or they were rolled into long round forms that were rolled further to make steel wire. Slabs were rolled into heavy steel plates used for boiler making or shipbuilding. Plates were and are still 0.18 inch of more in thickness, and between 6 and 48 inches wide. Initially, they were produced by reversing mills which passed a slab backward and forwards through a single set of rolls. Later, a series of rolls were used to gradually reduce the slab. Slabs could also be rolled into sheet steel that is flat and much thinner than plate and can be rolled up into coils. While undergoing all of these processes, the steel became progressively longer and the speed of rolling increased dramatically. Today, modern mills roll white-hot steel at 60 miles per hour!

These are the fundamentals of mass iron and steel making as the technology developed from the late nineteenth century until 1945. During this period, incremental improvements in metallurgy, melting, and rolling practice unfolded continuously. Developments in specialty steel making will be considered in a separate Technology Box. The electric arc steel furnace was pioneered at the turn of the twentieth century, but it will discussed in another Technology Box which charts path breaking innovations that occurred after World War 2 (also see Boyce & Ville, Box 8.3, pp. 250-1).

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Further reading:

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