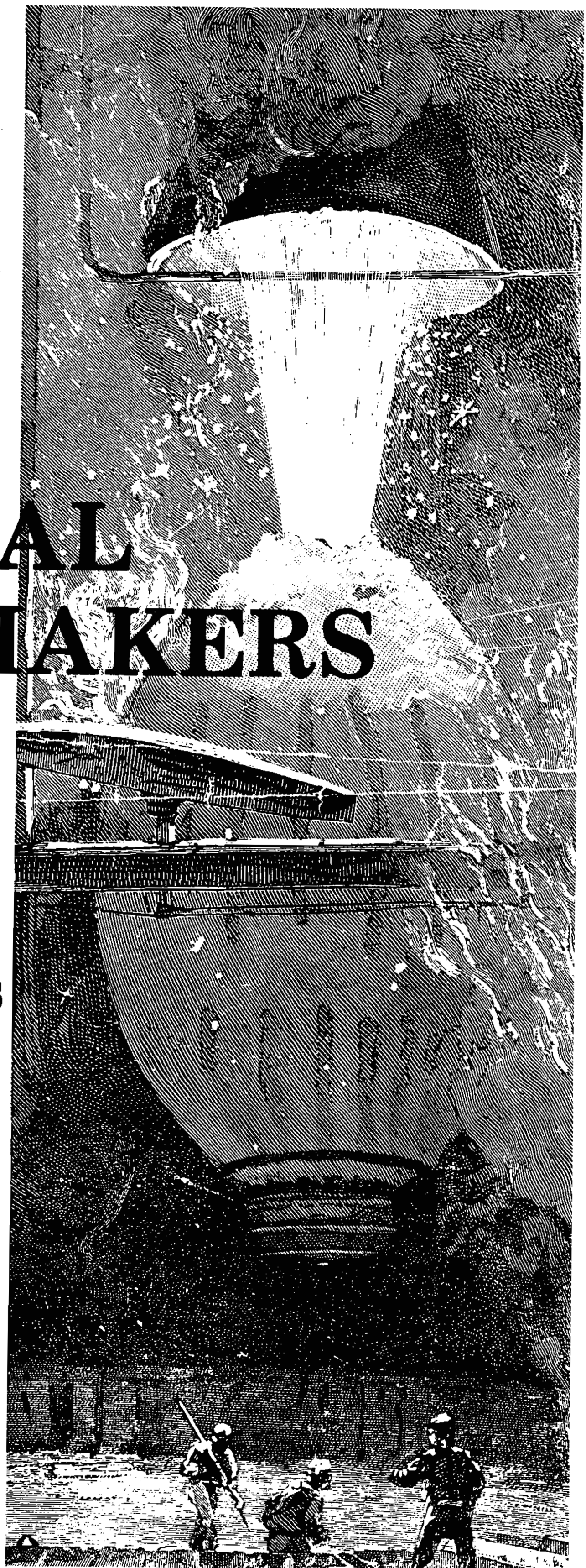
THE ORIGINAL STEELMAKERS



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THE ORIGINAL STEELMAKERS

by John R. Stubbles

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PREFACE

This monograph is a tribute to the men who developed tonnage steelmaking over three decades in the mid-nineteenth century. Now that a hundred years have passed, it is easier to put their accomplishments in perspective, setting the record straight where appropriate. The protagonists have been written about many times as individuals, but there have been few attempts either to trace their careers in parallel or to portray them as real human beings against their historical background. This approach adds another dimension to a fascinating technological story.

PART I: INNOVATION

"...and there is no new thing under the sun" - Ecclesiastes 1:9.

A Slice of Time

The year is 1848. Henry Bessemer is 35 years old, a family man and a successful inventor, moving easily in that London social set which is on the lower fringe of the aristocracy. It is not his fault that people are willing to pay exorbitant prices for his "gold paint," produced from bronze by a secret mechanical grinding process over which he has had a monopoly for five years. Yet, in all fairness, Henry does have a flair for inventing and improving processes involving mechanical equipment, despite his limited technical training. The "gold paint" process has made him wealthy, but no significant income ever came from his patents on electroplating, imitation velvet, or sugar manufacture. At the moment he is working excitedly--as always--on a technique to improve the manufacture of glass. If he can gravity feed the viscous mass from his reverberatory furnace directly to the rolls below, he believes he can produce the world's first continuous sheet of glass. The seed for the concept of continuously casting steel has unwittingly been sown.

Down in rural Gloucestershire, Robert Mushet accidentally acquires a metallic alloy from Prussia. Because of its reflective crystalline facets, it is called spiegeleisen, or looking-glass iron. It contains: 86 percent iron, 8 percent manganese, and 5 percent carbon. He orders twelve tons for his mini-crucible steelworks at Coleford (Figure 1), recalling the long discussions between his father, David, and Josiah Heath on the benefits that manganese confers on steel, although neither resolved that metallurgical mystery. He speculates that Prussia's reputation for quality steel probably hinges on the availability of spiegeleisen.

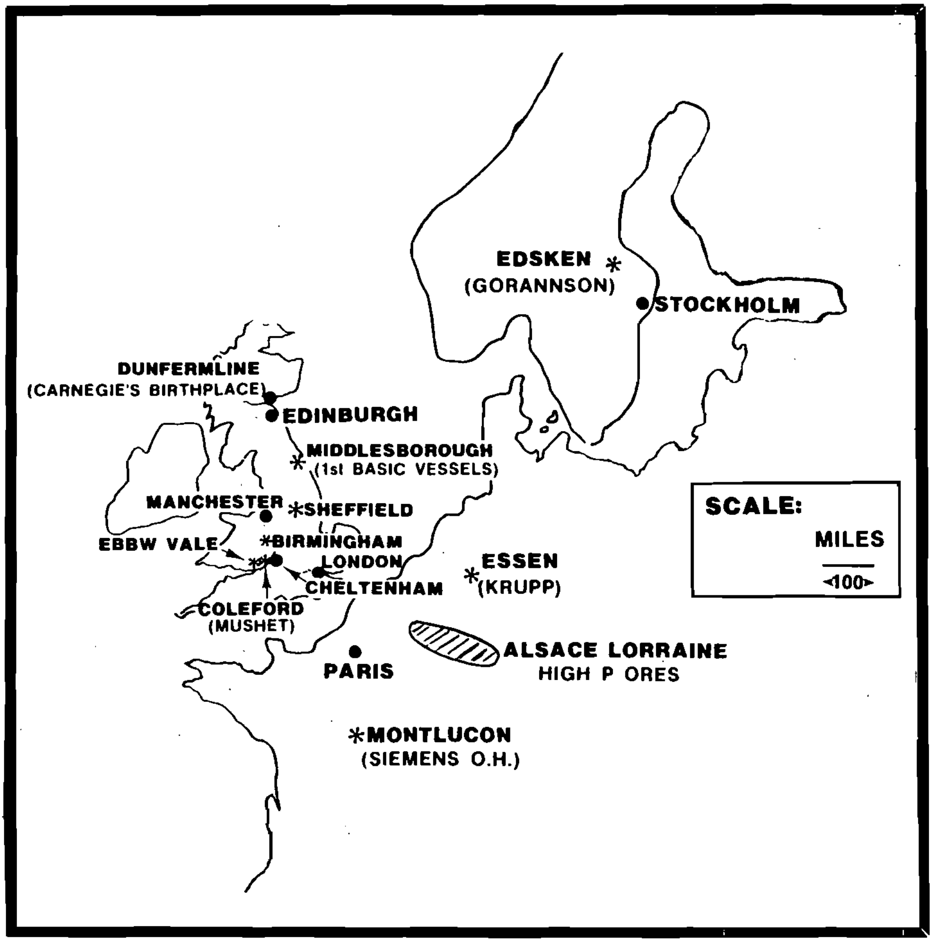


Fig. 1 - European steelmaking, 1850-1890.

Carl Wilhelm Siemens has just been granted a British patent for a regenerative condenser on a steam engine and is a disciple of the school of physicists who have developed the new dynamic theory of heat. Educated in Germany as an engineer, he now finds himself, at the age of 25, working in Manchester, where James Joule is trying to quantify the relationship between heat energy and work. His elder brother, Werner, is the driving force in the family and has just started a joint venture with Halske in Germany. But Wilhelm is interested more in mechanical and thermal than electrical energy.

Apparently, none of these men are involved in the social unrest which is sweeping Europe in the wake of the great potato and corn famines of the forties. In England, the working-class Chartist movement has exploded again--why shouldn't there be universal suffrage and voting by ballot? In France, the monarchy of Louise Phillipe has been overthrown and visions of the Second Empire are in the air. Curiously enough, this occurs on the very day (February 24, 1848) that the matriarch, Therese Krupp, finally decides to step down and hand over the Krupp industrial "empire" to her colorless son, Alfred, who is such an Anglophile that he has changed his name from Alfried. Little did the new French Emperor, Napoleon III, realize the ultimate significance of that act. Later in 1848 the firm of Krupp is saved from financial disaster by an order from Russia for a spoon factory.

Far to the north in Dunfermline, Scotland, the proud Carnegie family is caught in the economic depression and, without food or work, decides to emigrate to the United States. Their 800 ton sailing ship leaves the Clyde on May 17, but it is another ten weeks before their nightmarish journey ends in grimy Pittsburgh, where damage from the downtown fire of 1845 is still visible. Andy is only thirteen, but impish and street-smart.

In Eddyville, Kentucky, William Kelly is having second thoughts about the iron works which he and his brother John have recently purchased. It was a smart move to marry pretty Mildred Gracy, the daughter of a wealthy local businessman. If only his father-in-law would get off his back, maybe he could check out the unusual observations he has recently made. Perhaps he did need less wood to run the ironworks.

Finally, the restless Alexander Holley, at age sixteen, is fascinated by the mechanical world and by locomotives in particular, much to the chagrin of his father and overly pious stepmother. His interest in the classics is close to zero and yet they are required for entrance to nearby Yale, the family university. His father is mortified by reports of the poor scholastic progress and antisocial behavior of his high-spirited son. Another change of high school is clearly necessary. Fortunately, an understanding principal at the new school and the introduction of an applied science curriculum at Brown University in 1850 permit Holley to pursue the career of his choice.

Little did these seven men realize that within thirty years, through their diverse roles in the development of tonnage steelmaking, the world would be changed permanently. A brief description of the iron industry of 1848 is in order so that we can fully appreciate their accomplishments.

The Ironmaking Scene

By the mid-nineteenth century, the art of making cast iron had been practiced in Europe for over 500 years. Prior to the Revolutionary War, iron production in Britain was restricted due to a shortage of wood for fuel. There was legislation against deforestation, but the iron-masters were reluctant to use the alternative fuel, sulfurous coke, which produced brittle "hot short" iron. In the Colonies, with their abundant forests providing sulfur-free charcoal, "iron plantations" flourished, and production exceeded that of the mother country. London sought to control this embarrassing development by the unenforceable Iron Act of 1750. Without a strong domestic iron industry, the Colonies would probably have lost the war, and expansion across the continent would have been much slower.

The liquid iron from the blast furnace solidified into a material of limited engineering value and variable properties. The solid iron was neither ductile nor shock-resistant because flakes of weak graphite (pure carbon) precipitated from the carbon-saturated iron (about 3.5 percent-C) upon cooling. It was unsuitable for either horseshoes or swords.

But because of its relatively low melting point, it could be cast directly into useful items (cooking pots, grids, Franklin stoves) for the local community, or channeled into a layout in the sand of the cast-house floor which resembled a sow feeding her piglets. The terms "sow" and "pig" stuck. It was very significant that pig iron (the small pieces) could be broken from the sow and remelted in furnaces located away from the blast furnace, because this extended the industry geographically. Thus, each village could have a "smithy" but did not need a blast furnace.

So the problem was clearly defined. How could remelted liquid pig iron be converted into ductile iron? No one in the iron industry understood iron-carbon metallurgy, however. The academic German chemist Karsten postulated in the 1820's that carbon could appear in iron as graphite, or in solution, or as a carbide--he guessed FeC_2, Fe_2C_3, FeC, and Fe_2C--everything but Fe_3C, which was not separated and identified until the 1880's. The first simplified iron-carbon phase diagram was published in 1900. The first analytical test for carbon was finally developed in Sweden by Professor Eggertz in 1862. It was colorimetic, and required the solution of 0.1 grams of iron in nitric acid at $80 \pm 5\,°C$. This took three hours and was hardly an "on-line" test. No, the iron-masters had never heard of these ideas in 1848; but they had a job to do and their only protection was to stick rigidly to jealously guarded recipes handed down by past masters. Over the centuries, a mentality had been established in the industry which resisted innovation to an unreasonable extent.

The iron-master knew that fluid remelted "pig" eventually became pasty as it was worked in either a "puddling" furnace or charcoal "finery" and could only be handled as red-hot 100 pound "blobs." These could be removed from the furnace, squeezed to remove some of the slaggy material ("shingled") and finally hammered into a desired shape or rolled into bars in a grooved mill. We now know that the oxidizing atmosphere in the furnace plus some "cinder" (iron-oxide rich slag) decarburized the molten "pig," thereby raising its melting point. In 1848, no working finery or forge could reach the temperature necessary to melt low-carbon iron. The ironmakers did not understand the problem, nor could they measure any temperatures. Although this wrought iron was full of slaggy stringers, it was at least ductile and technically it was "soft" steel. By reheating the solidified iron with charcoal, it could be recarburized (the "cementation process") to make stronger blister steel, which sometimes exhibited amazing ductility when quenched in a liquid and then reheated or tempered. This is how swords became legends. It was even possible to melt small batches of blister steel from the cementation process in sealed crucibles which were heated in beds of charcoal. This ancient process, which was "rediscovered" by Huntsman in England in 1740 so he could make better watch springs, took several hours and consumed about two tons of charcoal per ton of steel. This was the only cast, homogeneous steel which was available in 1848 in either Britain or the U.S., and it was expensive. Both muscle power and furnace capabilities restricted lot sizes to about 100 pounds. At its peak in the 1830's, steelmaking capacity for the entire United States was only 2,000 tons annually and much of this was "blister" steel. Crucible steel produced by the Garrard brothers in Cincinnati in the 1830's was very expensive. McCormick used it for his new reaper and Deere for his plough-share. By 1840, however, U.S. steel production was virtually dead, thanks to an unsympathetic Congress and cheap imports from England. To counteract cheap pig iron imports, the U.S. charcoal furnaces on the frontier moved further west to new forest lands, while the substitution of anthracite for charcoal and the introduction of the hot air blast reduced fuel costs dramatically and kept the Eastern furnaces in Pennsylvania competitive. By 1850, over 600,000 tons of pig iron were being produced annually in the U.S., about half of which was laboriously converted to ductile bar products. Domestic steel, however, was still a rare commodity. In England in 1848, crucible steel was selling for over 50 pound sterling per ton, an excessive price relative to the 8 pound sterling per ton for the cost of the basic raw material, namely premium Swedish iron made from charcoal. As long as the production rate for steel was measured in pounds per hour, steel would remain expensive.

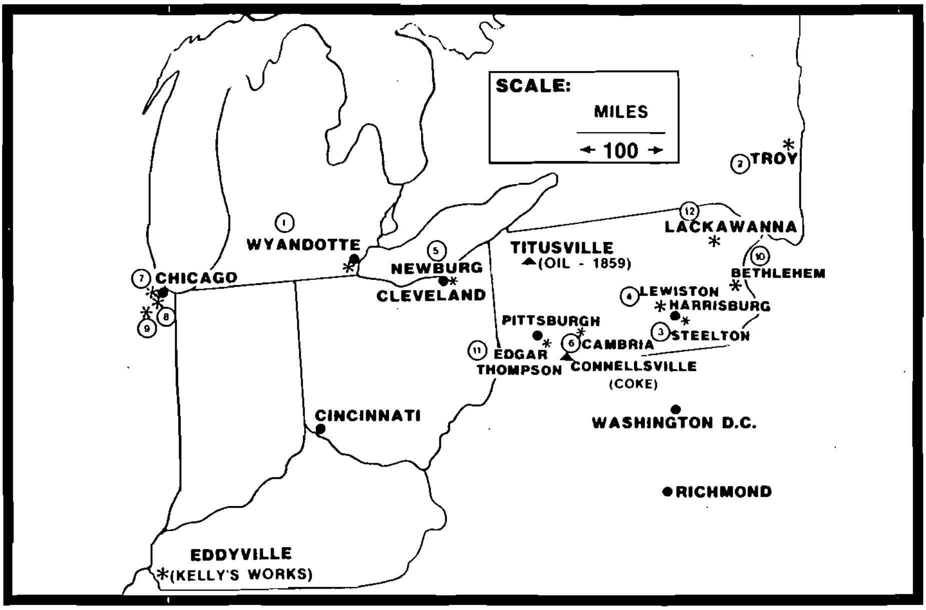
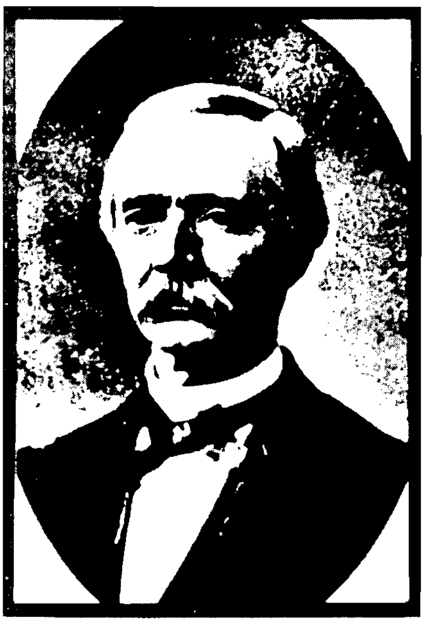


Fig. 2 - Early U.S. steel plants, 1864-1875.

Eddyville

The Kelly brothers ran a wholesale dry goods business in the 1840's. They were essentially brokers for commodities like tea and muslin. Their father was well off and the boys received the best education that Pittsburgh had to offer. This could not have included any metallurgical training, for there was none to be had in the world, let alone in Pittsburgh, which was a small trading town with a population of less than 20,000 when William Kelly lived there as a young man. Whiskey, not iron, was the commodity people treasured. To be sure, there were some small ironworks and forges around the town, but it could not yet lay claim to the title "Iron City." Paddle wheel steamer traffic on the Ohio River thrashed regularly between Pittsburgh and Cincinnati (Figure 2). The latter was a bustling trading center nicknamed "Porkopolis," after its huge meat-packing industry. The Ohio was the superhighway of the day, continuing south to New Orleans and the Caribbean with several natural embarkation points to the west--the California gold rush was a year away, gold having already been discovered. The eastern seaboard was separated from the Midwest by the Allegheny Mountains. These were impassable by road, and the Pennsylvania Railroad did not complete its continuous leg from Philadelphia to Pittsburgh until 1854. (Andy Carnegie was by now a valued assistant to the superintendent of the Pittsburgh area P.R.R. and to become superintendent himself five years later, a consequential association with the world of steel). Water traffic to the Great Lakes and New York went by canal, originating west of Pittsburgh at Beaver and running to Cleveland through Akron.



William Kelly, 1811-1888

William Kelly covered the Ohio Valley as a salesman, but fell in love with Mildred Gracy, who was a tender sixteen, on a trip to Nashville. He discovered that her hometown was in his territory at Eddyville, downstream from Cincinnati via the Ohio and Cumberland Rivers, and lost no time cultivating her affluent father. Kelly was impressed by the busy Cobb furnace and ironworks near Eddyville--there was unquestionably a demand for iron. He saw trees for charcoal, rocks of surface hematite ore lying everywhere, water for power and transportation; in short, he recognized a business opportunity which would permit him to stay with his beloved. He even persuaded his future father-in-law to back him financially. So the Kelly brothers purchased the Cobb furnace in 1846, along with 14,000 acres of land. They had no manufacturing experience whatsoever.

Did Cobb know that the surface ore was running out? Did he know that the plentiful subsurface ore was flinty and virtually unsmeltable? Did he see that the wood supply feeding the ironworks was dwindling fast and that relocation was inevitable? Was he tired of having his slaves escape across "the border" to friendly Illinois? Or was he simply an old man glad to hand over a thriving business to younger men? William was the operating manager and he quickly realized the magnitude of his problems, with the wood shortage looming largest. The ironworks consumed prodigious quantities of wood, which was converted to charcoal by heating it in the absence of air in large sod-covered piles. The resulting fuel was used for roasting and smelting the ore and refining the "pigs" to malleable bar iron. Let's put Kelly's 1847 "energy crisis" into a perspective we can appreciate.

Each week the small ironworks consumed a football field of virgin forest to produce a few tons of pig iron and convert some of it to ductile bar iron. The cord of wood (4 ft. × 4 ft. × 8 ft.) that we buy "to see us through the winter" would have been consumed as charcoal in a matter of hours. Smelting alone with a cold blast required about 4,000 pounds (200 "bushels") of charcoal/ton iron. The forge consumed a little less; and charcoal fines were used to roast the ore piles. Labor was needed primarily to produce the fuel rather than iron. The Kellys were not very enthusiastic about black slave labor and through a tea broker in Cincinnati arranged to have ten Chinese coolies imported. (This was probably a "first," and if U.S.-Chinese relations had not soured in that year, the program would have been expanded. Indeed, in 1854 over 13,000 coolies were hired to build the transcontinental railroad.) One suspects that the desperate Kelly made the observation that a forced draft of air playing on some molten pig iron in his "finery" fire heated rather than cooled the metal. But Kelly had a business to run and creditors to satisfy. Clearly, because of deforestation, a new blast furnace had to be built. A site was selected about seven miles downstream from Eddyville, closer to virgin forest land. Kelly apparently abandoned his early experiments until the Suwannee furnace was completed in 1851. And the name Suwannee? Stephen Foster had just moved from Cincinnati to Pittsburgh and his second "hit" song was--you've guessed it! Maybe it was a favorite with Mildred; or maybe the Gracy's owned a summer home down in Florida on that river.

Kelly has left no drawings, sketches or notes to describe his early experiments in 1847. He was clearly discouraged by his workers, customers, and creditors. If Kelly himself had been confident about his concepts, surely he would have found some way to resume experimentation during the four years prior to 1851. It is not clear what he had in mind when he did resume experimentation at the new furnace site. One assumes that the iron works operated normally, i.e., iron from the charcoal blast furnace was cast into "pigs" which were then remelted in a run-out furnace or "melting finery." The liquid produced from this was either cast directly into a product or fed to charcoal fineries. In both operations, tuyeres blew air to burn charcoal to create heat--in one case to melt the pig, in the other to keep the iron molten while it was decarburized by the cinder (oxidizing slag) and air-blast. Eventually the mass of iron "came to nature" (became pasty) and the lower carbon product could be forged. In England, the puddling process had long ago superseded the charcoal finery, the primary difference being the separation of the fuel from the charge, which permitted sulfurous coal to be used. Puddling furnaces foreshadowed the open hearth, where the charge is exposed to a hot flame and not mixed with the fuel.

It seems that the run-out furnaces served not only to remelt the pig iron but to desiliconize and partially decarburize it. The liquid product could then be run to the charcoal finery for further decarburization. Kelly seems to have realized that he could take liquid pig iron and expose it to air in a vessel to refine it, thus by-passing the fuel-hungry run-out furnaces and saving time as well. The real unknown is the extent of the refining, and Kelly's recollections on this point leave us in some doubt. He says that he "could make refined iron, suitable for any charcoal forge fire," and "when the blast was continued for a longer period, the iron would occasionally be somewhat malleable." Why not always? The key here seems to be that a variable blast coupled with inconsistent ore chemistry resulted in variable silicon, manganese and phosphorus levels in the iron. Furthermore, the rate of heat loss in the process would have exceeded

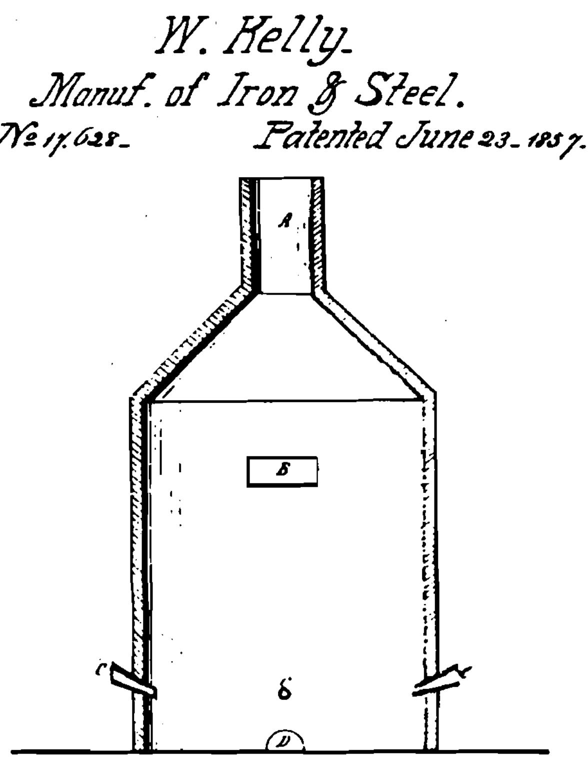


Fig. 3 - Kelly's sketch of his original furnace, 1857.

the rate of exothermic heat generation, which is why the mass always came to nature. Low pressure air (5 psi) blown through a single one-inch diameter tuyere could not have removed much carbon and silicon from a one ton charge even with extended blowing. It is perhaps significant that Kelly's process was referred to as "air-boiling;" of the 17 witnesses who testified on Kelly's behalf when a patent was being sought in 1857, only one, William Soden, refers to the boiling phenomenon at all. Clearly, the process was not dramatic visually. Kelly admits failure with respect to making consistent malleable iron in one step, but he did eliminate the remelting or run-out furnaces, and thus made a major step towards improving the efficiency and cost of converting pig-iron into a malleable product.

With a stronger air blast and some encouragement, Kelly rather than Bessemer, might have become the acknowledged father of tonnage steelmaking. The only drawing of his air-boiling furnace (Figure 3) does not inspire confidence in his process, while his after-the-fact recollections diminish his credibility. If only he had kept a diary! Kelly's experimentation continued for several years after 1851 and it was during this period that steelmaking captured Bessemer's interest. Let's return to England to see how that happened.

Bessemer

Henry Bessemer, 1813-1898

The year that Kelly lit his new furnace was the year of the Great Exhibition at the Crystal Palace in London. It was natural for Bessemer to participate since he had contributed significantly to improving several manufacturing processes in the previous decade. The novel plate glass concept was demonstrated and sold in 1849 for 6,000 pounds sterling. It was probably worth much more. Meanwhile, the income from "gold paint" kept rolling in (this was an unpatented secret process). Bessemer was from now on very conscious of the commercial aspect of his developments, even though he would initially be smitten by his enthusiasm for engineering a better way to do things. A chance acquaintance with a Jamaican sugar plantation owner led to a machine which squeezed the juices from cane more efficiently and doubled the yield. For this Bessemer received a medal from Prince Albert. Between 1849 and 1853, he accelerated the development of the glass and sugar cane industries with thirteen very practical patents.

But now the storm clouds of war were looming. The political reasons behind the Crimean War are complex and do not concern us. Russia was eventually goaded into action in 1853 by Turkey, which was backed by Britain and France. War was officially declared on March 27, 1854. The war was famous for Florence Nightingale and her nursing, and the charge of the light brigade led by Lord Cardigan, after whom the sweater is named. Russia's stance in the European power struggle was permanently changed. And patriotic Henry Bessemer was stimulated in 1853 to invent an elongated projectile, which rotated itself in a smooth-bore rifle or cannon and thus did not require a rifled bore. Only as recently as 1849, Captain Minie of France had developed a practicable elongated "bullet" for a rifled bore.

In December 1854, Bessemer and Lord Hay were hobnobbing in Paris with French royalty. Unlike the British War Office, Napolean III was interested in the new projectile and encouraged Bessemer to experiment with the smooth bore cast iron cannon at Vincennes. Captain Minie himself witnessed the successful experiments, but later, over hot spiced wine, remarked to Bessemer that "unless he had something better to make our guns of," the projectiles could not be used safely. That was the spark, the challenge that Bessemer needed. His demon urged him to improve the quality of iron. By his own admission, he had "little to unlearn" about iron metallurgy. Nevertheless, his first patent was filed less than a month later on January 10, 1855, and the early experiments were directed at diluting molten "pig" with "blister steel" in his reverberatory furnace at Baxter House.

Bessemer, like Kelly, wrote down his reminiscences later in life, but there is still uncertainty with respect to what actually encouraged him to pursue air injection into molten pig iron. Bessemer says that shells of decarburized iron were left on the bank of his reverberatory furnace and from this he inferred that air decarburized iron. However, he had no analytical tools or microscopes to tell him that the shells were decarburized and it is likely that they would in fact have been iron oxide shells. I prefer the account of his brother-in-law, W. Allen (an 1890 Bessemer medalist) who was Bessemer's assistant. One day, the iron wouldn't melt very easily because of a poor air draft, so (presumably) to supplement the air supply, another blast of air was directed by a tuyere into the furnace and onto a portion of metal which had already melted. In a few minutes "the whole pig was in a beautiful fluid condition," much to everyone's surprise. Bessemer was quick to react and draw his first wrong conclusion. Air was fuel. Experiments and patents followed in rapid succession throughout 1855. First, a static 20 pound top-blown crucible, surrounded by white-hot charcoal (Figure 4); later, a movable bottom-blown converter, with 700 pounds of pig iron converted to malleable iron autogenously in 30 minutes. What a scale-up! Steel production could leap from pounds per day to tons per hour. Mr. Rennie, a friend and prominent member of the British Association, was so excited after a demonstration "blow" that he invited Bessemer to present a paper "next Tuesday" to the mechanical section of the Association. Surely Bessemer had a rough draft up his sleeve! His

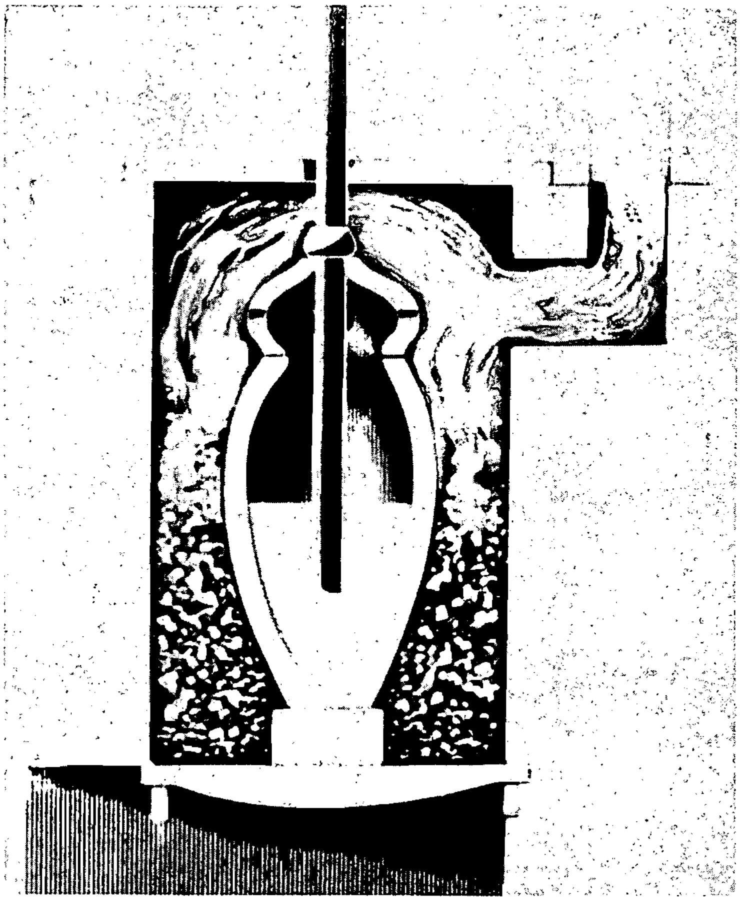


Fig. 4 - Bessemer's experimental crucible, 1855.

key patent was No. 356, dated February 12, 1856, so he had probably been looking for some months for an opportunity to go public. His 3,000 word paper "On the Manufacture of Malleable Iron and Steel Without Fuel" was presented at Cheltenham on a Monday, as it turned out, and the full text appeared the following Thursday on the front page of the London "Times" a unique distinction to this day for a technical paper.

The paper is a fascinating blend of highly practical suggestions for recovering iron shot from slag, remelting scrap, and producing a range of steels, and gives graphic descriptions of the fiery blow, with emphasis on the conversion scale-up to match the output of the "giant" blast furnaces of the day. The chemistry reflects the times. It is stated that the "mechanically mixed carbon" is oxidized before the "chymically (sic) combined" carbon. The "sulphur" is driven off as "sulphurous acid gas." Little did he foresee how this last statement would haunt him. But Bessemer the engineer had achieved what Kelly had not, namely, he had blown his iron vigorously enough so that the rate of generation of chemical heat within the molten mass far outstripped the rate of heat loss from the crucible. He was able to produce a melt of low-carbon iron, i.e. steel, rather than have it "come to nature." His cast product sometimes had outstanding mechanical properties relative to cast and wrought iron and it was produced at an incredible speed.

He could never have foreseen how difficult the development of his process was to be. Nor, apparently, was he aware that another engineer in London was working on the same problem from an entirely different angle.

William Siemens, 1823-1883

Of all the innovators, only Charles William Siemens can truly claim to have been a scientist. His interests ranged in depth across many engineering fields and his papers are models of lucidity. His elder brother, Werner, had founded the Siemens Company in Germany in 1847 and William became his London agent in 1852. England provided better protection for patents than Germany, and this carried enough weight to induce Siemens, an aspiring inventor to settle there permanently. He became a British citizen in 1859; only then did Carl Wilhelm officially become Charles William. The theme that pervades his papers and scientific lectures is energy conservation. Whereas Werner was innovative in the field of electrical energy, William seemed to be attracted to the field of thermal energy. These were exciting days, for Joule had only recently (1846) demonstrated the equivalence of mechanical work and heat. The caloric theory of heat as a substance was dead, gone to oblivion with phlogiston. Siemens was an eager disciple of the new school of dynamic heat theorists, and was anxious to explain the inefficiency of steam engines, which he calculated to be about 7 percent. He was able to rationalize the failure of Stirlings "air engine" in 1845 and through the application of the new heat theory he devised a regenerative condenser to conserve wasted heat and thus increase steam engine efficiency. The patent was granted in 1848, but it proved difficult to apply in practice. And also in that year, James Beaumont Nielson was belatedly recognized by the Royal Society for his idea of preheating the air blast to blast furnaces, which reduced coke rates by up to 30 percent. Siemens could hardly have been unaware of this award, interested as he was in heat and energy conservation, and it may have diverted his attention from steam engines to metallurgical furnaces. His younger brother Frederick joined him in London in 1852, and together they worked on the thermal efficiency of both engines and furnaces. In fact it is Frederick's name alone which appears on the 1856 patent (December 2), No. 2861, entitled "Improved Arrangements of Furnaces, which Improvements are Applicable in All Cases Where Great Heat is Required."

In retrospect, the regenerative idea, born out of the steam engine work, was simple. The hot gases from the furnace are diverted through a stack of bricks which captures some of their sensible heat. A system of valves and dampers then allows gas flow to be reversed and the air for combustion is now preheated by passing through the hot bricks (Figure 5). The net result is that flame temperatures were achieved which had never before been reached. Indeed, the temperatures were so high that the bricks in the furnace chamber tended to melt.

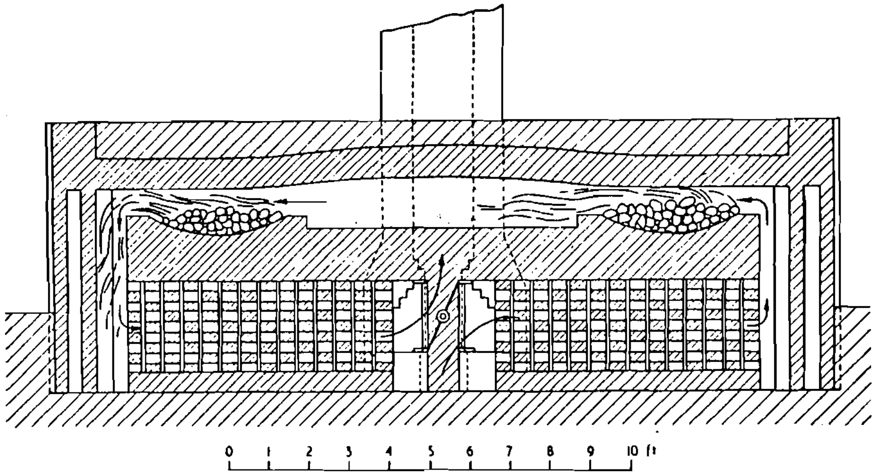


Fig. 5 - Siemens regenerative furnace, 1857.

One wonders why William's name did not appear on the 1856 patent along with Frederick's. Nevertheless, the two of them initially developed the concept and in June 1857 William addressed the Institution of Mechanical Engineers and described two working installations, the one in Sheffield for reheating bars of iron and steel and the other a puddling furnace in Bolton, north of Manchester. Siemens was able to demonstrate that fuel consumption in puddling furnaces could be reduced by as much as 75 percent. Despite this, the English ironmasters were slow to adopt the new furnace.

Frustrated by the problems of furnace design and the poor quality of the refractories, Frederick returned to Germany. He applied the regenerative technology to the German glass industry, where lower temperatures were required, and revolutionized it. William remained in England to develop the process for the iron and steel industry; the concept of a new steelmaking technique had not really crossed his mind yet, but he knew he had an efficient high temperature furnace probably capable of melting any iron-based material.

The End of the Beginning

By 1856, the innovative phase is over. Kelly, isolated in Eddyville and without either encouragement or technical assistance, has improved the efficiency of converting pig iron into ductile iron. His "air-boiling" process is locally well known, but "Crazy Kelly" has no imitators. His business survives, barely. He produces cast-iron pots for sugar boiling in the south, and ductile iron for the steamship business on the Ohio River.

Bessemer can blow cold air through molten pig iron to exothermically decarburize it and generate sufficient heat in his converter to exceed the melting point of low-carbon steel. He has "gone public" at Cheltenham. By fall, the stage is set for the commerical development of his process, with 27,000 pounds sterling in licenses having been sold in August.

Siemens can absorb some of the heat from furnace waste gases in brick regenerators and then, by reversing the air flow, use this stored heat to preheat the combustion air, thus creating very high flame temperatures over the hearth of the furnace chamber.

Carnegie by this time has become the indispensable assistant to Tom Scott, General Superintendent of the Pennsylvania Railroad, and lives in Altoona, Pennsylvania. He is only 21, and on a trip to Ohio chances to meet a Mr. Woodruff, the inventor of the sleeping car. His sharp mind sees the potential of this idea and on his $50/month salary he makes the first of many successful investments. Philadelphia and Pittsburgh are now linked directly by rail, and the funicular cars needed to scale the Alleghenies are no longer needed.

Krupp continues to expand his works at Essen. Back in 1851 at the Crystal Palace exhibition, Exhibit No. 649 is listed as the world's largest steel ingot, weighing 4,300 pounds and poured by Alfred's regimented "Kruppianer" from 98 separate crucibles of steel. But shipment is delayed and in desperation a small shiny steel cannon--a six pounder--is prepared as an alternative exhibit. And even though the ingot does arrive in time, the cannon becomes the talk of the exhibition, eclipsing the award-winning but prosaic reaper of McCormick.

Krupp thus begins to manufacture cannons as a sideline to seamless steel railroad tires, the staple product of Essen after 1853, and later, the symbol for Krupp Steel. He flatters Czars, Emperors, and Kings in the hope of obtaining lucrative orders for cannons, but is disappointed. At the Paris Fair in 1855, he astounds the world by exhibiting a 10,000 pound ingot, still made from small lots of crucible steel but fractured to show its internal integrity. He also exhibits a new steel cannon, now a 12 pounder. He captures the interest of Napoleon III, for the cannon is 200 pounds lighter than the same cannon made of bronze, and performs admirably at the Vincennes testing ground, where Bessemer's special projectiles were tested only the winter before. But the order from France never materializes. The generals advise Napoleon not to buy steel cannons, a decision they were to regret fifteen years later, when thousands of Krupp's monstrous shells, fired from a distance of three miles, rain down on Paris to destroy the Second Empire.

PART II: DEVELOPMENT

"The Fog of Discouragement" - *E. Morison*

Problems

The experimental developments patented by Bessemer and Siemens in 1856 promised two solutions to the problem which ironmasters had wrestled with for centuries, namely, how to keep molten iron from becoming pasty or "coming to nature" during decarburization. Siemens solution was physical: develop a higher flame temperature above the hearth so that even low-carbon wrought iron could be melted. This process was, as Dr. Percy noted in 1864, founded on "truly philosophical (i.e., scientific) principles" and was a rational extension of puddling. Even ironmasters could understand the intent if not the principle.

But Bessemer's process was like a blinding flash of light in the darkness. How could cold air injected into molten pig iron raise it to white heat? Those who had witnessed the process were astounded by the pyrotechnics. There was an element of magic here, perhaps even the work of the devil! Few chemists were available to explain what actually happened during a "blow"; the results had to speak for themselves. The Cheltenham exposure had been gratifying after the initial scoffing and ridicule. Although Bessemer got "good press," his classic paper was eventually excluded from the bound proceedings of the British Association because a controversy developed. Within a few weeks of his lecture, his licensees were back, angrily demanding their money plus additional costs. To quote Bessemer, "the results of the trials were most disastrous." What happened?

And then there were patent problems on both sides of the Atlantic. Mr. Brown, manager of the Ebbw Vale plant in Wales, at that time one of the largest iron works in the world, sought to buy Bessemer's patents outright for 50,000 pounds sterling. "I'll make you see the matter differently yet" was Mr. Brown's parting shot after Bessemer refused to sell. Tied in with the Ebbw Vale group was Robert Mushet, who claimed that his manganese alloy was the salvation of the Bessemer process. We shall examine the validity of this technical claim and the impact of the attendant legal hassles on the development of tonnage steelmaking in both Europe and America.

Finally, there were the actual engineering developments and the building of steel plants based on Bessemer's process. We shall renew our acquaintance with Alexander Holley, whose accomplishments have been in the shadows far too long, and meet a Swedish iron works manager, Goran Goransson, who was the first man to operate the Bessemer process on a commercial scale. Without question, the Bessemer story is more interesting and complex than that of Siemens' in both human and technical terms, and we shall therefore give it precedence. Let us return to Baxter House in London, the scene of Bessemer's original triumphs, to see first how he handled his technical problems.

Progress

To Henry Bessemer in 1855, all pig iron was the same. His initial experimental batch was gray Blaenavon iron. Although no analyses of this were made then or are available now, we must assume that it was a low-sulfur charcoal iron fortuitously low in phosphorus. He thus avoided both "hot shortness" and "cold shortness." Furthermore, the iron must have been high enough in manganese for the residual manganese to take care of the dissolved oxygen in the steel after the blow. If any one of these conditions had not been met, Bessemer would not have produced the ductile product he was able to exhibit at Cheltenham. His licencees however were producing steel full of blowholes and brittle when both hot and cold.

After this debacle, Bessemer sought the help of three eminent scientists. Percy, a professor at the Royal School of Mines was one of them, and phosphorus was his "thing." Not surprisingly, this element was identified correctly as one of the culprits. But all efforts to remove it by oxidation proved fruitless--and the person who would eventually solve the problem was then a seven year old boy!

As we have just noted, in addition to being "cold short" because of phosphorus, i.e., brittle when cold, the steel was full of blowholes. Despite this awful product, Bessemer knew he was onto something big from a process standpoint. He set aside a 10,000 pounds sterling trust fund for his wife, prepared if necessary to commit all his resources to this project. Then he decided to go back to square one and duplicate his original experiments by importing Swedish charcoal iron, known to be low in phosphorus and sulfur. His new material was also high in manganese. Once again, Bessemer produced ductile steel of various carbon contents. And once again, he was lucky without knowing it, for not all Swedish iron was high in manganese; he was still completely unaware of the key role played by that element.

Bessemer breathed a sigh of relief but he still needed a viable process to convert English iron made from sulfurous coke and frequently, but not always, high phosphorus ores. In other words, the raw material restraints on his process were so stringent that it was worthless as far as the English ironmasters were concerned. Enter Mr. Robert Mushet, self-appointed metallurgical sage who, only five weeks after the Cheltenham address, applied for a patent which went a long way towards solving all but the phosphorus problem.

Mushet

Robert Mushet, 1811-1891

Mushet's ace was that glittering triple alloy of iron, carbon, and manganese, spiegeleisen, which he had purchased back in 1848. In the intervening years he had no doubt explored the benefits conferred by this alloy on crucible steel and confirmed the opinions of his father and Josiah Heath. We now know that the alloy deoxidizes the steel, thus making it free of blowholes. It also ties up the sulfur as high-melting-point iron-manganese sulfides.

Mushet's mini-steelworks lay midway between Cheltenham and Ebbw Vale (Figure 1). Mr. Brown stopped by on his way back to Wales after the Bessemer paper to show samples of Bessemer steel to Mushet, who was an occasional consultant for Ebbw Vale. When the samples were fractured, blowholes were revealed. It was clear to Mushet that spiegeleisen would solve a problem which Bessemer was still unaware of at this time. After a few weeks of experimentation with blown metal from Ebbw Vale, Mushet filed for Patent 2218 (September 22, 1856) on the use of this triple alloy as an additive after the blow.

He had also been convinced by Ebbw Vale management that they held a patent which outranked Bessemer's and that by sharing interests, a fortune was in store for all of them. The offer was tempting, for Bessemer was clearly in trouble by then, not only with blowholes but with sulfur and phosphorus. Mushet's sympathies would have been with the old ironmasters, gleefully rubbing their hands at the downfall of Henry, who was wealthy, successful, and an outsider to the iron trade. Mushet succumbed. There were more cooperative experiments at Ebbw Vale in late 1856, although Mushet claims never to have entered any ironworks other than his own at Coleford. A formal contract with Mushet was never executed in fact, and he regarded his patent as "wholly my own," although he felt honor-bound to the Ebbw Vale group.

Consequently, when Bessemer finally approached him, Mushet refused to share his secret. Bessemer's reaction was typical. He was an avid reader, and soon became aware of the beneficial effect of manganese on steel through Dr. Ure's "Dictionary of Arts, Manufactures, and Mining." Bessemer's earliest work on electroplating had been referenced by Dr. Ure and a personal friendship had developed over the years between the two men. No doubt they discussed the mysterious manganese question, although neither knew why the element was beneficial. Bessemer not only repudiated and ignored Mushet's patent, which, as he said, "only pointed out to me some rights which I already possessed," but went on to develop his own manganese alloy, with a much higher Mn/C ratio than spiegeleisen. This permitted soft, i.e. low-carbon, steel to be produced, and was a significant breakthrough by Bessemer.

Having failed to buy Bessemer's patents, the Ebbw Vale management apparently decided to go on the offensive and attack Bessemer for infringement. They pinned their hopes primarily on John Martien's U.K. patent 2082.

Martien came from the U.S., where he had been manager of a special puddling furnace patented by James Renton in December 1851 and operated in New Jersey until about 1855. Fine hematite ore and coal in a 1:3 ratio were charged to a vertical chimney located at one end of the puddling hearth and heated externally by the exiting hot furnace gases. Direct reduction occurred, and the sticky mass was gravity fed onto the hearth for further reheating and working. A second furnace of this kind was built in Cincinnati between 1851 and 1854.

Martien next appears in Ebbw Vale presumably trying to duplicate or improve upon the Renton process. Renton had no U.K. patent and was therefore not protected. This venture does not appear to have been successful, but in September 1855--remember that Bessemer was well into his experimental work but had not yet obtained his key patent--Martien was issued U.K. patent No. 2082. It was sealed on March 11, 1855, and owned by the Ebbw Vale Iron Company. Martien claimed to "purify" liquid iron by using air or steam blown through the metal as it ran down the trough from the blast furnace. According to his patent, "the use of a refinery furnace should be dispensed with." But wait a minute! Surely this was exactly Kelly's idea. Martien was a travelling man, and an active manager in the United States when Kelly was experimenting at Eddyville after completion of the Suwannee blast furnace in 1851. It is more than likely that he was aware of "Crazy Kelly's" experiments and may even have visited the works; there was a Renton furnace in Cincinnati, not far away. Is it possible that Martien stole both the Renton and Kelly concepts and sold them to the Ebbw Vale management?

Late in 1855, George Parry, the operating manager at Ebbw Vale, decided to try a variant of Martien's idea. The sub-hearth of a reverberatory furnace was laid with a number of perforated 1-inch diameter pipes so that 80 to 100 jets of air could be blown up into the charge. The pipes were carefully covered with clay, the hearth burned in, the plugs protecting the perforations pulled out, and the air blast turned on. Three thousand pounds of liquid pig iron were then poured into the furnace.

If the metal had not run into the road after the initial vigorous action, the course of history might have been changed. But the Ebbw Vale management was unwilling to repeat this bold experiment. Had Parry proceeded without incident, however, his heat losses would have been so high that the metal would have undoubtedly "come to nature" as usual. Furthermore, his hearth construction was impractical, and the chemical problems involving sulfur, phosphorus, and manganese would have surfaced sooner or later.

Ebbw Vale continued to fight Bessemer, but Mushet's patent ran out in 1859 due to inadvertent nonrenewal of the patent fee. A final showdown came in 1861, by which time Bessemer had his process under control. Ebbw Vale was licensed to make Bessemer steel, while Bessemer bought outright the Martien patent and a variation by Parry for 30,000 pounds sterling.

The Ebbw Vale group never appreciated the weakness of Martien's purification patent. Carpmael, Bessemer's own patent agent and a "leading man" in the field, had advised Martien when drafting his patent that it was restricted to the treatment of iron flowing in a gutter. This was sharp practice by Carpmael, since he presumably knew he was protecting Bessemer's experimental work, which was based on a "receptacle." Thus, Carpmael may be the real villain of this story while Martien and Mushet simply appear as naive technical people manipulated by lawyers and businessmen. So ended the legal struggle in the U.K. The activities of the Ebbw Vale group put the Mushet-Bessemer controversy in a different light. Bessemer would have solved his problems sooner had he been able to work with Mushet, but he solved them anyway. Mushet, for his part, remains an enigmatic, dour character, a technican rather than a scientist or a businessman. He was treated rather shabbily by the Ebbw Vale management, and one suspects that even Bessemer's anger was directed more against them than Mushet himself. When Mushet fell on hard times, Bessemer came to his assistance with an annuity of 300 pounds sterling a year, not enough to acknolwedge the validity of Mushet's claims but token compensation. Bessemer also supported the award of the Bessemer Medal to Mushet in 1876.

Martien may have been "terminated" after the failure of both the Renton process and the "purification" experiment, or he may have exited gracefully on his own accord. He returned to the States to secure an American patent for his iron refining processes and remained there for at least two years. The patent saga crossed the Atlantic.

Interference

Bessemer's Cheltenham address was published by "Scientific American" on September 13, 1856, only three days before Martien filed for a U.S. patent on his air-refining process (No. 16690, granted February 24, 1857). Mushet filed separately for a U.S. patent on his triple alloy. The correspondence in the technical journals on Martien's prior claim over Bessemer provoked Kelly to surface again with a letter explaining his activities at Eddyville since 1851. Bessemer was granted three U.S. patents in November 1856 and Kelly began interference proceedings two months later. Did Kelly know there were three patents? He was awarded an interference only against Bessemer's U.K. 2321 patent (October 17, 1855) entitled "Improvements in the Manufacture of Cast Steel" and related to forcing air or steam or both into molten iron..."until the metal is rendered malleable." This preceded Bessemer's key patents of December 1855 (vessel design and operation) and February 1856 (blowing without fuel). The October patent was clearly issued before Bessemer himself understood what he was doing. As he soon found out, air and steam behaved differently, the latter being strongly endothermic and cooling the melt.

In July 1857, Kelly nevertheless received an interference against Bessemer's first patent for the process of blowing air into liquid iron. The sketch of his vessel is unimpressive (Figure 3), and his workers were not very enthusiastic supporters at the hearings. Martien supported Kelly's prior claim in writing--the subsequent status of his own patent remains unclear--and this puzzling character then disappears from our story. It was a poor decision by the patent lawyer, but there were few people available to give him sound technical advice. Bessemer still had his patents on machinery (U.S. patent No. 16082) and for making steel (No. 16083), while Mushet had his triple alloy patent (No. 17389). The stage was set for further complications. Despite the correspondence and technical reports, Kelly still seemed unaware of what Bessemer had accomplished, namely the high speed production of cast steel from liquid iron in one step. And despite his victory on the patent issue, he had other problems.

Cambria

It was the collapse of a small insurance company in Ohio that triggered the world-wide financial panic in late 1857. Speculation in U.S. land and railroads had been rampant and sooner or later the bubble had to burst. Kelly was one of the victims; his ironworks went bankrupt. To raise some cash and protect himself against creditors, he sold his patent to his father for the nominal sum of $1,000. He then attempted to interest several prominent ironmasters in his idea. One of these was Dan Morrell, manager of the Cambria Ironworks in Johnstown, Pennsylvania (Figure 2). He was curious enough to give Kelly an opportunity to "blow some pig." Two experiments at least took place at Cambria in 1858. The first was a disaster, since the strong air blast ejected the iron from the converter--"Kelly's Fireworks" were good for a laugh for years afterwards in the Johnstown area. But on the second day, a heat was "successfully blown." Kelly hammered the ejected globules until they were no longer brittle, then stopped the blow, turned down the vessel, and hammered out a sample of malleable iron on a nearby anvil. If things went this well, some of the puddlers standing around must have swallowed hard. Did they sabotage further experiments? Did the management worry about the fact that Kelly's movable converter unquestionably infringed on Bessemer's machinery patent? Were there problems with phosphorus from the Pennsylvania ores which resulted in unusable "cold short" steel?

The Cambria works was exceptionally innovative. They had hot blast stoves for their three blast furnaces (run by only one blowing engine) in the mid-fifties, well before Cowper's patent. They had an unheard-of three-high mill. Cambria spawned several great ironmakers during these years. If Kelly had really been convincing, Morrell would surely have continued his support; perhaps the economic risk that year was simply too great. But he did not forget the concept of pneumatic steelmaking. Kelly, however, was "retired" by 1860 at the age of 50, seemingly lacking both the stamina and vision of Bessemer. But the patriotic American press wouldn't let his process die, and wondered in 1861 why the Kelly process to manufacture steel was not being used in America as the Bessemer process was being used in Europe.

What, in fact, had been accomplished over there since 1857?

Goransson

Goran Goransson, 1819-1900

Bessemer obtained a Swedish patent in July 1856, and Goran Goransson, head of the ironmaking firm of Elfstrand and Company, bought one-fifth of the rights to this patent for 2,000 pounds sterling. This included the right to manufacture up to 500 tons of steel a year at Edsken (Figure 1), where the charcoal blast furnace was located, for a royalty of two shillings per ton! At this time, not one ton of Bessemer steel had ever been produced commercially. The first 1,000 pounds sterling was paid in the summer of 1857, but Elfstrand and Company were affected by the same financial panic as the Suwanee Ironworks and went bankrupt in December 1857. It was a very deep global depression which fortunately lasted for only a few months. Nevertheless, the administrators of the Elfstrand estate decided to pay the second installment of 1,000 pounds sterling at the end of 1857. The original tilting converter shiped over to Edsken by Bessemer was clumsy to operate, so the next two converters were fixed. Personnel from Jernkontoret, the Swedish equivalent of today's AISI, were sent to monitor and help with the experiments in early 1858. They soon recognized the need for harder blowing, the need to avoid iron made from high-sulfur ores, and the advantage of using iron produced from manganiferous ores for making soft steel. Most of the ores used at Edsken were very low in manganese, and one consequence of this was that rising or "rimming" ingots were made for the first time in mid-1858. The date of July 18 is accepted as the inception of regular Bessemer ingot production at a steady level of about 15 tons/week. Bessemer and Goransson communicated indirectly through an intermediary, C.J. Leffler, who lost the confidence of both. Goransson eventually discouraged Leffler's visits to Edsken, having failed to be impressed by his "expertise," while Bessemer complained to Leffler that he needed to know more about the work in Sweden, which seemed to be proceeding far more successfully than at Baxter House. Bessemer constantly refers to Mr. "Urenson," not Mr. Goransson, in his letters, an indication that they were not very close friends. "Have you tried manganese in any way?" he asks innocently. The Swedish records and works were open to anyone, but Bessemer suffered from acute sea sickness all his life and hated to cross the sea. For this reason alone, it is unlikely that he spied on Kelly as has been claimed. Goransson, however, did visit Sheffield in late 1858 and, with Bessemer, watched several Edsken ingots forged very successfully, some of the steel eventually becoming razor blades. Bessemer was so impressed that he ordered 100 tons of pig iron from Edsken for the new steelworks he was building in Sheffield (which started production in 1859). He also sent Goransson (directly) a letter and a sketch of his new pear-shaped tilting converter, which eventually became the model for all subsequent converters.

While Goransson had been succeeding in 1858, Bessemer had been in serious trouble. Apart from raw material problems, i.e., obtaining the right pig iron, Bessemer did not know how to control the end-point of his process. There were no carbon-oxygen-manganese equilibrium data available to anyone. At one time, he was reduced to granulating his blown metal, sorting it into "carbon qualities," and remelting in crucibles, clearly an absurd, retrograde step from a commercial standpoint. Goransson would stop his blow based on the malleability of ejected globules. He cannot claim to have realized that a better answer to making steel of various carbon contents in the absence of analytical controls was to blow "soft" and then recarburize. By mid-1859, however, Bessemer's own converters were in successful operation in "enemy" territory in Sheffield. His debt to Goransson was enormous. He read a paper in May 1859 to the Institution of Civil Engineers which brought everyone up to date on the developments since 1856--the revised vessel design, higher blowing rates, the manganese additives, and the admission that phosphoric iron could not be handled. There was continued activity in Sweden, while France had a converter in 1856. And in one of the ironies of history, the Bessemer process had been tested in the U.S. in the fourth quarter of 1856 only weeks after the Cheltenham address. The man responsible was Abraham Hewitt, and the operator was Peter Cooper, manager of the Trenton Ironworks in New Jersey. The trials were not successful and reports from England were even less encouraging. Hewitt decided to drop the licensing negotiations with Bessemer. Ten years later he realized that he had been premature in his judgement. In 1866, as a result of this experience, he introduced the first open hearth furnace to the U.S.

The Open Hearth

The slow development of the acid Bessemer process--neither sulfur nor phosphorus could be removed from the pig iron during the "blow"--was paralleled by the development of the open hearth. However, unlike Bessemer, Siemens had no demon to drive him and was not exclusively concerned with the iron and steel industry. A few plants had attempted to apply the "regenerative" principle with mixed success, but one suspects that in the period between 1856, the year of the patent, and 1860, all attention in the iron industry was focused on whether or not Bessemer could get his process to work. One newfangled idea at a time was enough!

In this interim, Siemens became involved with Cowper in designing hot blast stoves for preheating the air blast for blast furnaces. He also tried to apply his idea to puddling furnaces, but the difficulty in adapting them was that the air flow was always in one direction because there was only one fuel location relative to the working hearth.

Maintenance and control of temperature with a solid fuel like coke was also difficult. Siemens' answer was to develop a separate gas producer, i.e., to burn the solid fuel away from the hearth to generate gas and then preheat both the gas and the air prior to combustion by passing them through regenerators. In this way, he could burn the air/gas mixture at either end of the hearth, and thus, by 1861, the firing concept for the modern open hearth furnace was in place. But Siemens was an energy engineer, not an ironmaster, and his new hot flame principle was adaptable to any high temperature manufacturing process. In January 1862, he described regenerative gas furnaces in use in glassworks, brick and pottery kilns, and in various metalworking operations, including puddling and crucible furnaces. Bessemer now had a working converter in Sheffield and, except for phosphorus removal, had a revolutionery steelmaking process under control and in the public eye. Siemens had a less exciting evolutionary process. In 1862 Charles Attwood asked Siemens to design him an open hearth, regenerative furnace to melt pig-iron--preferably our old friend "spiegeleisen"--with puddled iron. His patent (No. 1473, May 18, 1862) was very weak. Steel was melted, but Attwood preferred to return to crucible steelmaking. This was uncharacteristic of Attwood, who was an active proponent of new technology and, incidentally, a founding member of the British Iron and Steel Institute in 1869.

Eventually, however, it was the French who got the process off dead center, and did for Siemens what Goransson did for Bessemer. Many of the French ores were high in phosphorus, so Bessemer's process had a limited appeal in that country; the regenerative process by itself did nothing for phosphorus or sulfur removal, but it was flexible with respect to any combination of ferrous charge materials, and therefore phosphorus problems could be alleviated by either material selection, dilution, or both.

Siemens spoke and wrote fluent French. One of his closest friends was Louis Le Chatelier, a top-level French government engineer and father of the more famous "equilibrium" Le Chatelier, Henri. Early in 1863, Louis approached Siemens with a proposal for an open hearth to be built for Boignes, Rombourg and Cie, using blast furnace gas as a fuel and various combinations of raw materials. An English patent (No. 708, March 16, 1863) was obtained. A furnace was designed by Nehse and built at Montlucon, but the refractories--roof and hearth--failed miserably. The trials were abandoned. Nehse had also been employed in 1862-1863 by Siemens to build a furnace for the Martins family of Sireuil. It happened that the nearby quarries yielded almost pure silica which, when made into brick, would withstand steelmaking temperatures. Steel was melted on April 23, 1863. Pierre-Emile and Emile Martins then independently proceeded to develop a process based on mixing liquid pig iron with scrap wrought iron, an approach which their countryman Reaumur had advocated back in 1722. (Reaumur, known best to us for his temperature scale, was in fact a remarkable ferrous metallurgist, years ahead of his time). Without consulting either Le Chatelier or Siemens, the Martins' took out an Engligh patent (No. 2031, August 15, 1864), which was rather "bad form," but their process did succeed commercially and their aggressive attitude forced Siemens to intensify his own commercial developments in England. He built a furnace in Birmingham in 1865.

Siemens, now the learned engineering businessman, had little in common with the provincial ironmasters at Sireuil, and the coolness between them prevented joint developments. Yet in Europe, the process has always been called the Siemens-Martins, whereas in the U.S. the name open hearth has persisted. Unlike the Bessemer process, there were fewer chemical problems with this slow refining method where the charge could be watched and sampled periodically. But to this day, the conventional open hearth process is only possible because of a phenomenon that no one appreciated for many years, namely, the carbon "boil." No chemical engineer would design a process where the small amount of high-temperature heat available from the flame must be transferred through a slag that is a poor thermal conductor to a shallow steel bath in a furnace that seems designed to maximize heat losses. Only the spontaneous unplanned nucleation of carbon monoxide bubbles on the hearth of the furnace provides enough bath stirring to promote slag/metal reactions and to facilitate heat transfer from gas to slag to steel in order to avoid freezing or "skulling" on the hearth. The absence of the necessary conditions (i.e., dissolved carbon and oxygen) leading to this boil no doubt discouraged many open hearth pioneers.

Troy and Wyandotte

Back in the U.S., two groups of investors had reacted to the suggestion by the American press that the Kelly process be "exhumed." The group at Wyandotte near Detroit was headed by Eber Ward, who owned an ironworks there. In 1862, Dan Morrell from Cambria joined them, Zoheth Durfee was sent to England to buy the Bessemer patents, and his cousin

William Durfee was hired to erect a plant --without ever having seen one. They travelled a hard road. The Bessemer negotiations failed, but they did secure the American rights to Mushet's patent. Kelly's patent now belonged to his sisters, since Kelly senior had died in 1861 without changing his will. After interminable negotiations, the Kelly Pneumatic Process Company was formed, with Kelly's sisters joining the group--but not Kelly--as well as Mushet and two of Mushet's friends. Incredibly, William Durfee was ready to make steel by the summer of 1864, and even conceived and built the first steelworks laboratory, later destroyed by a "syndicate of sin." In the early days of September, the first tons of "Bessemer" steel were produced in the U.S., (Figure 6) clearly in violation of Bessemer's machinery patents, and before the Mushet rights had actually been obtained (October 1864).

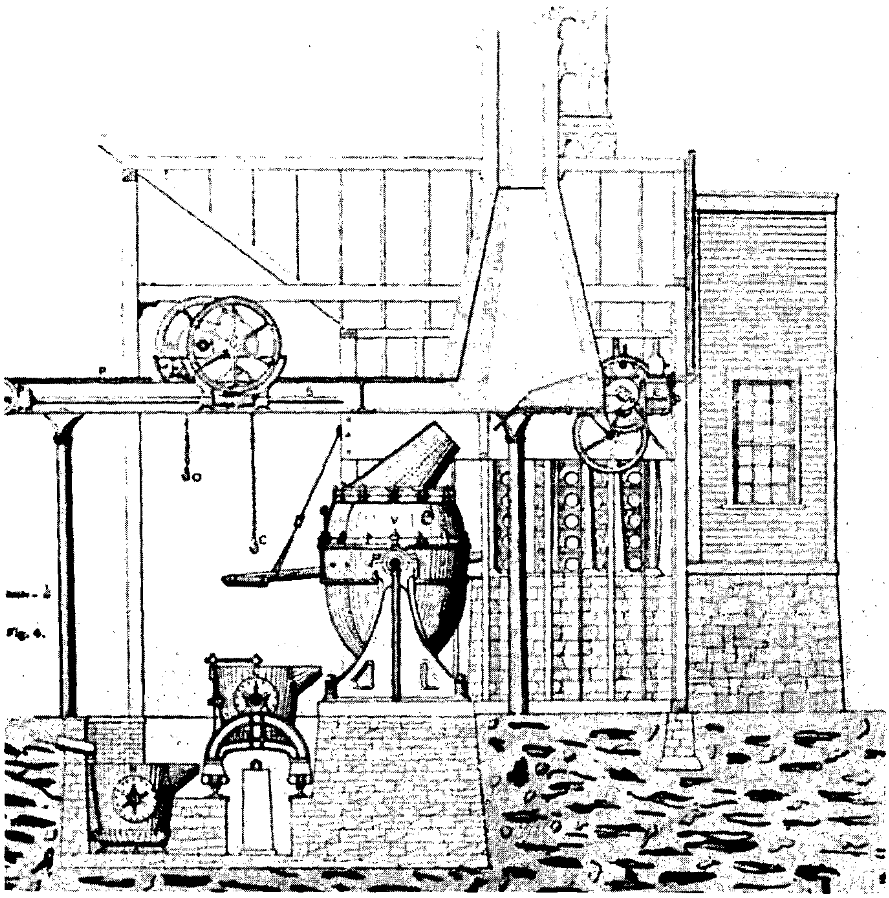
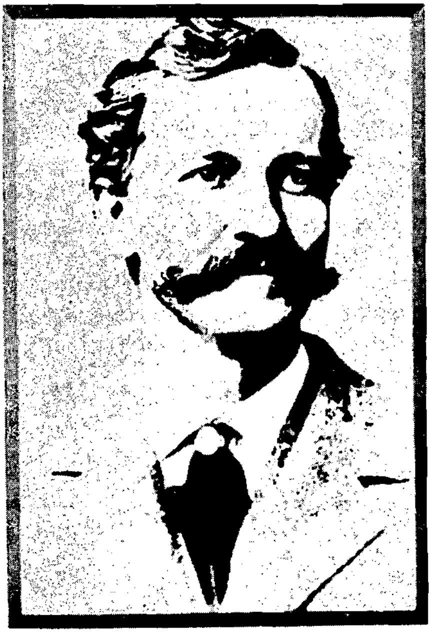


Fig. 6 - The original Wyandotte plant, 1863.



Alexander Holley, 1832-1882

In the intervening years between his student days at Brown and his involvement in the construction of the Troy Bessemer plant, Alexander Holley never lost his boyish enthusiasm for massive mechanical devices, such as locomotives and ships. He was a good technical writer and observer, was never afraid to get his hands dirty--indeed, seemed to relish it--and had a winning personality which made him very popular on both sides of the Atlantic. Yet the sad fact remains that although his engineering competence was widely recognized, he never found regular employment, and was constantly seeking commissions and consulting jobs to make ends meet. One of these commissions was to study European armaments for Edwin Stevens. But in his European travels Holley had seen Bessemer's Sheffield plant in operation and couldn't forget it. Eventually he made contact with Griswold and Winslow, two wealthy ironmasters in Troy. They were prepared to back Holley, since the need for a Bessemer steel plant in the U.S. was becoming apparent. In late 1862 Holley returned to England to secure the exclusive American rights to the Bessemer process. Instead, he returned to the U.S. early in 1864 with a license to produce Bessemer steel on a royalty basis and the option to purchase the American rights within three years. After months of frustration and a second trip to Sheffield, the first Bessemer steel was produced at Troy on February 16, 1865 (Figure 7). The patent rights were purchased in July. To generate the air blast, a steam engine replaced the water wheel in early 1866.

On his trips to Sheffield in the early 1860's, Holley was unfortunately not aware that a local geologist named Henry Sorby had just developed a microscopic technique for examining opaque sections of polished iron, steel and meteorites. For the first time, iron was seen from a new perspective. But who cared! Clearly the work had no relevance to iron and steelmaking. Someone had already chided Sorby about his early geological work: "Man does not look at mountains with microscopes." So the diffident petrographer returned quietly to his private world of rock sections and botanic specimens. Not for another twenty years (1882) could he be persuaded to present a paper (the first) on the microscopic structure of iron and steel.

Meanwhile back in the U.S., Holley found that the U.S. patent held by Mushet and the Wyandotte company could not be circumvented. The situation was ridiculous. Neither side could move because of the patent

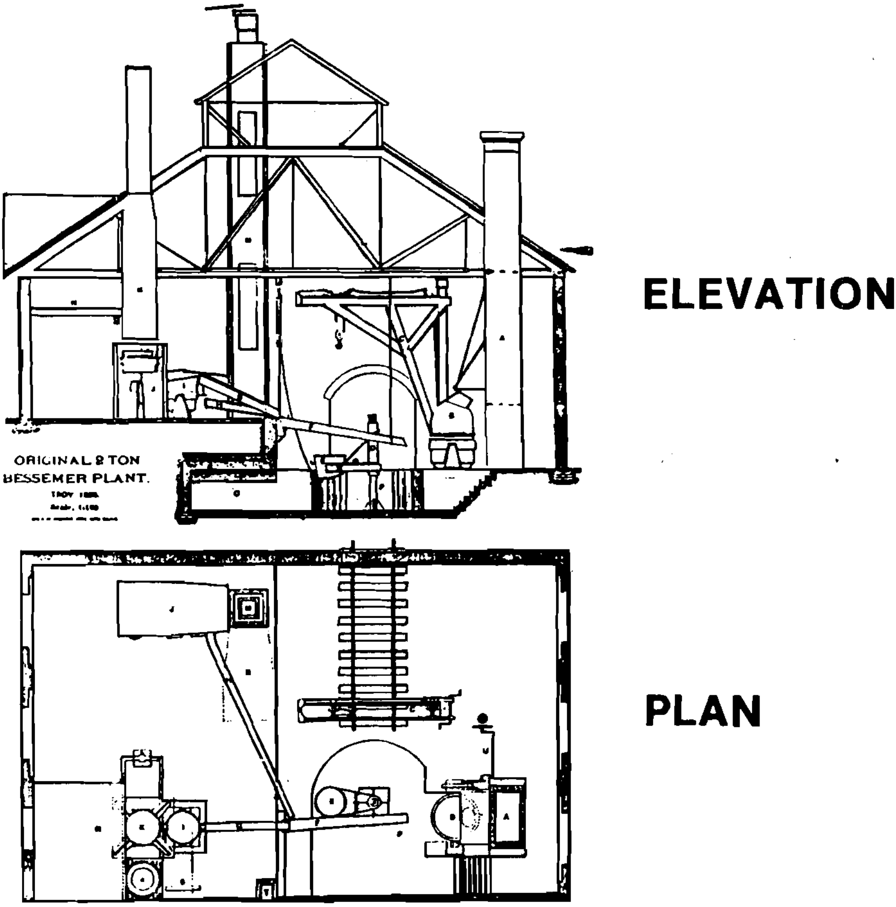


Fig. 7 - Drawings of Holley's plant at Troy, 1865.

holdings, but with the end of the Civil War men of vision saw steel as a vital material for the "new" nation. Some Pennsylvania investors got together with the Wyandotte and Troy groups to hammer out a deal so that all three groups could make Bessemer steel without patent infringements.

The Kelly Company got the short end of the stick, but Morrell finally got a real converter to play with, Holley had the manganese additive, and construction began in May 1866 on the first pneumatic steelworks in Pennsylvania at Steel Works (later Steelton) near Harrisburg. The key investor was J. Edgar Thompson, president of the Pennsylvania Railroad and father figure to Andy Carnegie. Holley's role in the whole endeavor cannot be underestimated; and Griswold had enough faith in Holley's technical ability to underwrite an even larger plant at Troy in 1866 which incorporated many novel designs in the converter shop.

Turning Point

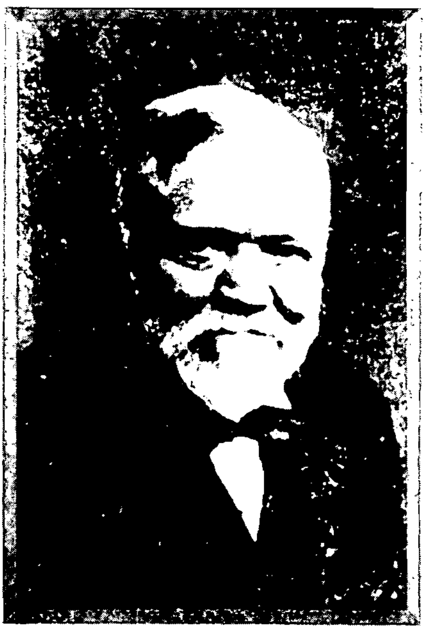
The development phase of tonnage steelmaking ends in the mid-1860's. The acid Bessemer process was comfortably established in several European countries, and two U.S. plants, Troy and Wyandotte, were ready to operate commercially. In 1865, ingots from the latter were rolled in Chicago into the first American steel rails. The limitations of Bessemer's process were well publicized and Krupp should have known that his Prussian ores were laced with phosphorus. Yet he siezed the opportunity to obtain a license from Bessemer through his London agent Alfred Longsdon. Krupp was soon receiving reports of broken steel tires and fractured cannons from all over the world - "cold shortness" had caught up with him. He was also in political trouble with the Prussian authorities for supplying cannon to both sides in the short Prussian-Austrian war of 1866. Krupp beccame a nervous wreck and went into lonely exile for a year. But by 1867 he was pleased to accept know-how on the open hearth process from Siemens, who referred to him as "our leading industrialist," perhaps forgetting that he (Siemens) was now a British citizen. Siemens had been unable to obtain a Prussian patent because the lawyers argued that the principle of his regenerative furnace had been employed in a fourteenth century abbey at Marienburg in Prussia!

Post-Civil War America was ready for steel. Railroads would bind together a nation torn apart by war, criss-crossing the giant North-South river systems and mountain ranges to create a transportation network which stimulated industrial growth. No one was better prepared to exploit these opportunities than Carnegie. Through both luck and judgement, he was also able to bring together and stimulate people who could make things happen. The spotlight also falls on that legendary operator "Wild" Bill Jones, who established the tonnage philosophy in American steelmaking, and the engineering genius of Alexander Holley, who had the vision to see beyond converter shops to fully integrated steel plants. The combined talents of these individuals catapulted the American steel industry into a world leadership role within a decade.

PART III: COMMERCIALIZATION

"Settle in Oxford and get a thorough education making the acquaintance of literary men" - two year goal of the 33-year-old Carnegie, written to himself in 1868.

Carnegie


Andrew Carnegie, 1835-1919

The first shot of the Civil War was fired on April 12, 1861. Within days the Confederates had nearly encircled Washington D.C.; the Union was full of bravado but very disorganized. It was Carnegie's crew that rebuilt and cleared the tracks from Philadelphia. Andy himself rode the cab of the first troop train to break through from the north. He and his mentor, Tom Scott, had been drafted to Washington in April 1861 to establish railroad and telegraph lines for the Union armies, then rallying to the northern journalistic battle cry of "On to Richmond." The phrase had a popular ring to it, and Richmond became the ultimate target for the North, even though there was no military logic behind it. Carnegie, now 25 and Superintendent of the PRR - Western Division, was a staunch Republican, but saw no conflict between his Chartist liberal background and his opportunistic brand of Capitalism. He identified with Lincoln, another self-made man. He hated the Southern planters as much as the Tory aristocracy in Britain. His practical background in laying track and operating telegraphs was of enormous value to the Union forces in those early days. But a case of sunstroke led to an inside war office job, where he frequently met Lincoln. When the super-organizer General McClellan took over the Union armies from McDowell, Carnegie didn't like what he saw. He asked to be transferred back to Pittsburgh in the fall of 1861. The sunstroke attack still bothered him, and was to do so for the rest of his life. That is why he spent most summers in Europe.

Carnegie became busily involved again in the Pittsburgh industrial scene, investing wisely in oil and bridges. The Titusville drilling of 1859 had led to some "gushers" further south near Oil City by 1861. Oil, sold originally as a medicine (a "Natural Remedy" for $2 a bottle) was now being refined in Pittsburgh for use as an illuminant to replace the expensive and fast disappearing whale oil. To Carnegie, however, the bridge business was a better bet; he foresaw the end of wooden bridges and a post-war boom in railroad building. He encouraged two close and competent friends, John Piper and Aaron Shiffler, to form a bridge-building company. Carnegie himself took a one-fifth interest for $1,250 (1862).

Nor was he a stranger to the world of iron and steel, even in the early sixties. He and his boyhood friend Tom Miller, another railroad man, had invested in the Freedom Iron Company (1861) to produce iron rails. Miller was also involved with the Kloman Brothers and Henry Phipps in a forging company which produced the finest railroad axles in Pittsburgh. It was a rift between Miller and Phipps and the financial involvement of his younger brother Tom in this enterprise that brought Andrew Carnegie into the picture--as a mediator rather than an investor. For a while Carnegie was able to keep the peace, but even he finally became disgusted at the treatment of his friend Tom Miller and, in 1864, they formed the Cyclops Iron Company, which also involved the bridge company. No sooner had this rival company to Kloman and Phipps appeared on the Pittsburgh scene than merger talks were in the air, engineered by the Carnegie brothers. In 1865, the appropriately named Union Iron Mills became a reality. Miller, initially angered at this development and always a reluctant partner, finally sold his share in 1867. It was the end of a friendship among Andrew Carnegie, Tom Miller, and Henry Phipps which dated back to their "slabtown" days of 1848-49. Then, the three of them, persuaded by the fourteen-year-old Andy, had learned double-entry bookkeeping at evening classes. After 1867, Miller remained only a personal friend of Carnegie; Phipps, however, was his business associate until the billion dollar capitalization of U.S. Steel in 1901, a true rags to riches story for a man whose vision remained at the level of a clerk all his life.

Carnegie had resigned from the Pennsylvania Railroad on April 1, 1865, only a few days before Lee's surrender at Appomattox. His PRR salary was about $2,400 per annum; his investments returned an annual income of over $40,000.

With his Union Iron Mills to make rails, axles, and structural components for his Keystone Bridge Company, his expertise and investment in the telegraph business, his Central Transportation sleeping car company, and his contacts in the railroad business, Carnegie was ready to take advantage of the post-war industrial boom as no other man in America.

He celebrated his financial independence with a grand European tour which lasted nearly a year. One of his companions was Henry Phipps. Carnegie was an indefatigable tourist but was also always on the lookout for business contacts and ideas to rationalize his gallivanting. On this tour, he came across iron rails with steel faces, patented by Thomas Dodd, and thought he had obtained control of the U.S. patent rights. Carnegie's inability to nail down the legal issues involved was not important, for the rails proved to be a disaster in the field. That same year (1866) the Freedom Iron Company was reorganized as the Freedom Iron and Steel Company. Bessemer converters were installed, fed by charcoal iron low in sulfur but high in phosphorus. Carnegie then introduced the Webb rail, a rerolled iron rail with a steel face, but these were as unsuccessful as "Doddized" rails. Carnegie was thus an early pioneer in Bessemer steelmaking, but apparently he did not visit Bessemer during his 1865-66 tour and did not employ Holley to design his steelplant. He makes no reference to the steel rails produced in Chicago by the Wyandotte group in late 1865 when he was abroad. He was rightly concerned about the availability of low-phosphorus iron in Pennsylvania--the Lake Superior iron range had just been unmasked, but it's potential was as yet unrecognized.

Holley meanwhile had been lured from Troy to Steel Works (later Steelton) in early 1867 to serve as Chief Engineer. He now had a 100 acre site and could visualize an integrated steel plant, designed intelligently around the steel processing flow.

Steel Works had no rail mill yet, so Holley became involved with the Cambria plant, famous for Kelly's fireworks, now back under the direction of Dan Morrell. Here began the friendships with the Fritz brothers, Robert Hunt, and Bill Jones. Together, these men learned how to make steel ingots and roll them to rails in mills that they designed themselves. Steel rails were finally available commercially in the United States by 1868, six years after Bessemer's first demonstration of the durability of steel rails in London and three years after rails were rolled in north Chicago by the Wyandotte group. Another steel plant appeared in 1869--the Cleveland Rolling Mill at Newburg, Ohio--planned by Holley, who was now busy rebuilding the original Troy plant, which had been gutted by fire. In 1871 Cambria finally got its own converters, built by Fritz and Holley.

Carnegie had now set his sights on the contract to supply steel for the famous Eads bridge to span the Mississippi at St. Louis, a project which was approved by Congress in 1866. His Union Mills could supply the steel sections; Klowman had designed the first cold saw to control length. Due to a strike, he had also hired a younger roller from Prussia, who introduced the first Universal mill into America. Carnegie's old company, the PRR, was to be a principal beneficiary of the bridge and had considerable influence in the appointment of a "Keystone" man as Chief Consulting Engineer. Carnegie himself decided to visit Europe in order to sell bonds to finance the bridge. It was on this visit that he not only broke into the high finance world of the Morgans in London and the Sulzbach brothers in Frankfort but also caught Bessemer "fever." He realized that his plans for expanding his own Freedom Company were far too limited. Furthermore, abundant supplies of low phosphorus ore were now available from the Lake Superior region. No one could dissuade him from his plans upon his return from Europe, despite signs of an economic downturn. Carnegie approved a site at Braddock Field, south of Pittsburgh on the Monongahela River. The new company of Carnegie and McCandless, a longtime family friend and respected Pittsburgh businessman, was capitalized for $700,000 on November 5, 1872, with Carnegie himself contributing $250,000. Alexander Holley had offered his services that summer and became the supervisory engineer. He was now unquestionably the world's expert on Bessemer plants, having designed half a dozen. As luck would have it, Holley was able to bring along his old friend Captain Bill Jones, who had just resigned from the famous Cambria mill after Dan Morell had passed him over for promotion. Morrell did not agree with Jones' philosophy of high pay for hard work. The pieces had finally fallen into place--Carnegie with his contacts and money, Holley with his engineering expertise, and Jones with his operating experience. In retrospect, it seems as though fate played a hand in bringing together this triumvirate. Carnegie, ever the flatterer, even had tentative approval to call the works after his old boss Edgar Thomson, president of the PRR.

In 1873, as construction of the first major steelworks in Pittsburgh was about to begin, the post-war boom ended abruptly with the collapse of a major banking house. The U.S. economy ground to a halt and complete recovery was several years away. But Carnegie never faltered. He continued to build "E.T." (Edgar Thomson Works), traveling once more to London with Holley to seek financial backing. The new mill would not only contain two five-ton Bessemer converters but also two five-ton O.H. furnaces for special grades of steel. Despite Hewitt's attempt to introduce the O.H. process in 1866, it had remained a loser compared to the Bessemer process. A second blast furnace was to be built at 51st Street. The original "giant" Lucy furnace had been completed in 1872 with a 20 foot diameter bosh, and named after the wife of Carnegie's brother Tom. She was the daughter of Carnegie's business friend, William Coleman, who involved the young Carnegie in oil back in 1861 and who also selected the Braddock Field site for "E.T." By 1874 Lucy was producing 100 tons in a single day. On August 22, 1875, the first Bessemer blow occurred at "E.T.," about two months after the formation of the Bessemer Steel Association in Philadelphia. One month later, the first rail was rolled, nearly ten years after the Wyandotte trials in Chicago and twenty years after Bessemer's early patents.

As Jones whipped the new Carnegie mill into a world pacesetter, the price of American steel rails dropped and European imports consequently began to dwindle. A far reaching consequence of this was the diversion of increasing tonnages of Krupp steel into armaments as world-wide export and import patterns readjusted themselves.

Rails

The only U.S. market for steel in the 70's was the railroad (Figure 8). As "E.T." came on stream, not only did imports slow down but the era of iron rails peaked. Over 7,000 miles of track were being laid each year, with over 900,000 tons of iron and 100,000 ton of domestic steel being consumed, along with several hundred thousand tons of cheaper imported steel. By 1880, imports were starting to dry up; one million tons of domestic Bessemer steel went into rails and 400,000 tons of iron were consumed. U.S. steel production almost surpassed that of Britain. By 1884, 1.5 of 2.3 million tons of domestic steel went into rail; there were negligible imports and no rails were produced from iron. It had been a rapid transformation, all under the watchful and protective eye of the Bessemer Association. This trade association, consisting of representatives from the dozen or so operating plants, worked hand in glove with the railroads and was an effective lobbying group. Tonnages (for each mill) and prices were fixed at annual meetings. Holley was retained as the technical consultant to the group, which was not unreasonable since he had personally designed 11 of the 12 plants and was an annual visitor to Europe, where he probably received more information than he released. Holley now documented and distributed this information for the Association.

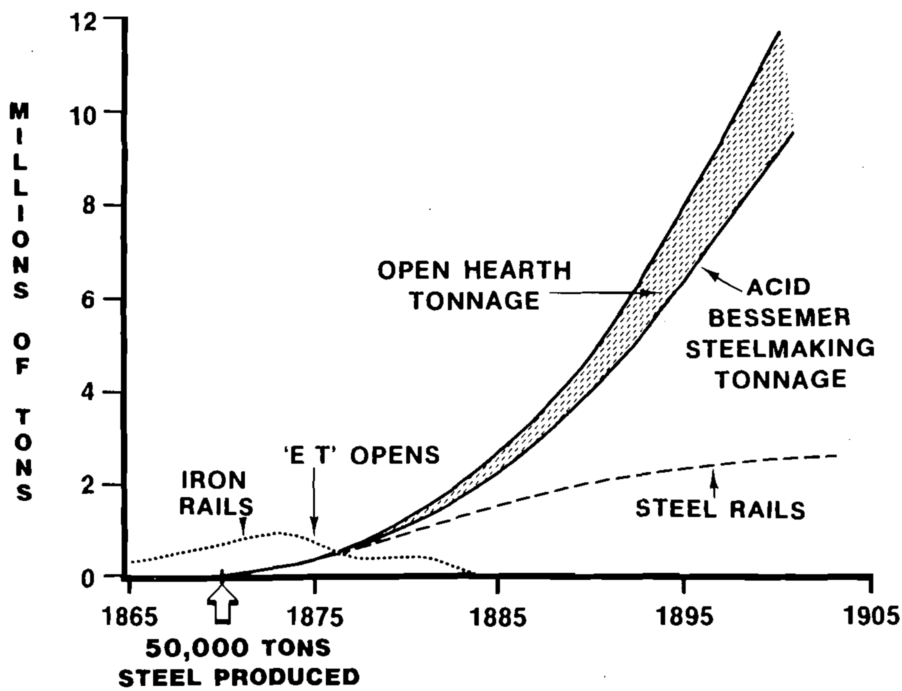


Fig. 8 - U.S. steel processes related to rail tonnages, 1865-1900.

But this obsession with rails precluded expansion into other markets. Why rock the boat? There was a comfortable tariff for protection against imports and a controlled market. Holley warned the Association that the market was limited and told it about new uses for steel, but his advice fell on deaf ears. Nor did the group heed the coming of the open hearth. Carnegie as president of "E.T." was invited to a meeting of the Association in 1876 and, when notified that his company would only get 9 percent of the business, he jumped up to claim a share "as large as the largest." Otherwise, he said, "I will withdraw and undersell you." There was no argument. Carnegie kept an eye on his competition by owning a few shares of stock in each company. He thus received their annual reports, whereas "E.T." remained a private company. Carnegie won no friends in this group, but he needed none. His mill was a world-beater; Holley and Jones were tops in their field; he had sound investments in America and good banking contacts in Europe; and the bridge business was booming. Carnegie, as a member of the committee in charge of the exhibition buildings for the 1876 Philadelphia Centennial, successfully argued for a switch from a wood framework to one made of iron and steel. Needless to say, Keystone and Union Mills got the contract! This opportunism led a few years later to a contract for the first steel- framed office building in America. Carnegie created new markets for steel as well as endorsing new technology to produce it. And as he said--"if we stand firm on quality, we must win."

Thomas

Sydney Thomas, 1850-1885

Sydney Gilchrist Thomas had intended to become a doctor, but the untimely death of his father in 1867 changed those plans. To help support the family, the 17-year-old became a clerk in a London police court. His continuing interest in science led him to attend evening classes at a London college, where he was eventually introduced to the problem of phosphorus in Bessemer steel--and the rewards which would accrue to the person who solved it. Thomas pondered possible explanations for several years before attempting any experimental work, and rightly concluded that the oxide of phosphorus did exist but was unstable in Bessemer's acid slags. Yet basic or limey slags would dissolve the silicious converter linings.

While Thomas was speculating and Carnegie was planning "E.T.," George Snelus, a chemist at the Welsh steelworks of Dowlais, was actually

Percy Gilchrist, 1851-1935

lining Bessemer converters with ground linestone and even fired magnesia. In 1872, he found that the oxide rich limey slags removed phosphorus, but not being satisfied with his results, he omitted mention of phosphorus removal in his patent on linings. Shortly thereafter, Snelus was appointed manager of a Bessemer shop in West Cumberland where, unfortunately, the local ores were free of phosphorus. Consequently, Snelus had neither the opportunity nor the incentive to pursue phosphorus removal.

By 1876 Thomas had convinced his cousin Percy Gilchrist who was a metallurgist at the Blaenavon Ironworks in Wales, to undertake some surreptitious experiments in a six-pound converter lined with limestone paste. It is a strange coincidence that Bessemer's original pig iron in 1855 was labelled Blaenavon, and was low in phoshorus! Thomas used Northamptonshire pig iron containing 1.5 percent phosphorus. A year passed, with Thomas travelling from London to Wales whenever he had a free weekend. Eventually, Mr. Martin, the General Manager of Blaenavon got wind of the experiments and offered financial support and better facilities. The bulk of the pilot scale work was continued in a 400 pound converter, and phosphorus levels under 0.5 percent were achieved, no mean feat in those days. The solution was clear to Thomas. The converter needed a basic lining and the process required a basic slag.

He filed for an English patent on November 23, 1877, his agent being the same Carpmael who represented Bessemer and Renton back in the fifties.

Thomas had not intended to discuss his work at the March 1878 meeting of the British Iron and Steel Institute. He was forced into the open, however, by Snelus, who described his 1872 experiments with limestone linings in a discussion of a paper by Lowthian Bell on dephosphorization. Thomas was dismayed at the revelations of Snelus, but he and not Snelus had the patent and the results. The pale young man asked to be recognized and took the floor. He told the august audience that he had removed phosphorus in a Bessemer converter. They were completely apathetic. They didn't question Thomas or even acknowledge his statement. They simply ignored this unknown and clearly lower class person.

Undaunted, Thomas and Gilchrist now prepared a real paper for the Paris meeting of September 1878. More frustration. Time did not permit the paper to be read, but Holley got hold of a preprint and sensed a

Windsor Richards

breakthrough in steelmaking which he signalled back to the States. Thomas also met Windsor Richards, general manager of Bolckow, Vaughn and Company at Middlesborough, and arranged for Richards and his chief metallurgist, Stead, to see some blows at Blaenavon. Richards was excited by the results and set up a pair of two-ton converters for experimentation. Percy Gilchrist resigned his post to supervise the work at Middlesborough. Lining development was the biggest problem. Eventually, highly fired ground dolomite was mixed with boiled tar (to remove moisture), and rammed linings were installed. The first official blow was April 4, 1879, and final phosphorus levels of .2 percent were hailed as a triumph. Stead, the works metallurgist, deserves credit for the subsequent idea of the afterblow during which iron oxide was generated and phosphorus levels could be decreased significantly. With the backing of a respected operator, and additional results, Thomas could now present his updated paper with confidence at the May meeting of 1879. The paper is relatively short--thirteen small pages. The discussion, however, occupies 46. The pompous Lowthian Bell did some clever talking but could not quite bring himself to publicly congratulate the young authors. Siemens was present as ex-president. Bessemer was there. And so was Carnegie, stopping off in the middle of one of his world tours. He talked about profits, flattered the British and rambled on about war and preparation for war (but didn't mention Germany).

Thomas now fought to patent his process in Germany. He studied the German language and after many continental trips won his case in 1880. Then on to the U.S. in 1881, despite poor health. This was an enjoyable trip, however, and initially he stayed with the Holley family in Brooklyn. He probably saw the partially constructed Brooklyn Bridge, which was completed in 1883. Needless to say, Keystone had the contract for its superstructure.

Thomas heard the local minister Henry Ward Beecher give a sermon--he went on for 75 minutes. He visited a dozen steel plants. And through Carnegie he sold his process rights to the Bessemer Association in May 1881 for $275,000. Carnegie took a nifty $50,000 personal commission and his companies paid no royalty fees!

Back in Europe, Thomas now turned his attention to the problem of converting high phosphorus slags into fertilizer. He had been convinced by chemists that chemical extraction of the phosphorus was necessary. From 1882 until his untimely death in 1885 at the age of 35, he was wrestling with this technical problem as well as ill-health. Perhaps it broke his heart to learn that the solution was physical not chemical. The molten slag merely had to be granulated by water quenching.

The Bessemer Association meanwhile sat on Thomas' license. Their Mesabi ores were low in phosphorus. Why encourage competition from the Southern states where high phosphorus ores existed?

Steel City

By 1877, the American economy was starting to revive after a four-year depression. "E.T." was paying off handsomely and, under the operating skills of Bill Jones, was now the world's most productive mill. Ninety percent of its product was rail, and the grid of track criss-crossing America was close to 70,000 miles long. The demise of both the domestic iron rail and the imported steel rail was imminent. Carnegie was now concerned about his lack of control over coke, a vital raw material for his voracious Lucy furnace. He wooed Henry Clay Frick, a 32-year-old entrepreneur who monopolized coke production in the Connellsville region of Pennsylvania, southeast of Braddock, and in 1881 offered him a share in the Carnegie enterprises. Carnegie thus obtained control over coke, and at the same time skillfully acquired the managerial talents of the man who was to shape the Carnegie steel empire.

This certainly more than compensated for the unpleasant departure earlier that year of William Shin, the general manager of "E.T." Shin had threatened to take Bill Jones with him. In an uncharacteristic move, Carnegie encouraged Jones to name his price to stay. Jones cared little for titles or position. He loved the mills. Cautiously, he asked Carnegie for about $15,000. Carnegie's answer was to match his salary with that of the President of the United States at $25,000. Only Carnegie knew that Jones was irreplaceable.

That same year saw Carnegie fulfill a boyhood promise to his mother. He had vowed they would return in triumph to Dunfermline one day in a coach and four. The trip was well publicized by the world press. Sydney Thomas and his sister, Lilian, dined with the group before their departure for Scotland, and were invited to join them, but Thomas declined because of his health. Upon arrival, Carnegie donated to Dunfermline the first of over 2,500 world-wide public libraries. One conspicuous absentee from the touring party was Louise Whitfield, whom the 46-year-old Carnegie was courting. Mother disapproved and as usual had her way. The marriage was delayed until 1886, a year after the death of both Margaret Carnegie and also brother Tom.

The "E.T." rail mill was so efficient by 1880 that the plant could no longer supply merchant ingots to neighboring companies. A Pittsburgh syndicate thus provided the finances for Andrew Kloman to build a mill across the river at Homestead. Kloman, who had been bought out of the original Carnegie mills cheaply when he was in dire financial straits was only too happy for the opportunity to get back at his former boss. But the combination of the depressed rail market and the antagonism of the Amalgamated Union of Iron and Steel Workers at Homestead enabled Carnegie to buy the troubled mill cheaply in 1883 within two years of start-up. Most Homestead investors took their cash and ran. Now Carnegie had two modern mills in Pittsburgh and no serious rivals. Homestead would make sections for the structural markets which Carnegie had foreseen for many years through his bridge building and centennial activities.

It was in this period that Carnegie's European trips and his association with Holley paid off yet again. He had bought the Thomas patents for the Bessemer Association in 1881, but sensed that the basic lined open hearth would be the process of the future. With experience in new O.H. operations going back to 1875 at "E.T.," he rebuilt Homestead in 1888 with four basic open hearths, and planned to install two more at "E.T." Holley himself had said "I expect to live to see the American O.H. process attend the funeral of the Bessemer process," while Carnegie wrote the following to his Board: "...I really hope that the work will not be delayed waiting for detailed plans which no one in the Board can intelligently understand. Every day's delay in building basic furnaces is just so much clear profit lost, as we are bound to be followed very soon after we get started."

Duquesne was acquired a few years later in a way which shows Carnegie at his worst. The new company was designed around the concept of rolling ingots from the soaking pit directly into finished products without intermediate heating. Carnegie saw the threat of this radical process, and before a rail was ever rolled let it be known widely among railroad purchasing agents that the steel would lack "homogeneity" and that therefore the rails would be defective. The bluff worked. Lack of orders, along with another depression and more labor troubles, permitted Carnegie--actually Frick--to buy out Duquesne for a bond issue in 1890. Curiously, the direct rolling concept was immediately and successfully introduced at Duquesne by Carnegie and copied at Homestead and "E.T." The products were presumably homogeneous.

By 1890, Pittsburgh was truly the city of steel. Jones was tragically killed in 1889 when a new "E.T." blast furnace broke out and showered the workers with incandescent materials. He hit his head when jumping out of the way and died two days later without regaining consciousness.

The Measure of a Man

Nearly one hundred years have passed since most of our protagonists died, and it is perhaps time for a subjective reassessment of their contributions to the industry and to mankind.

Kelly certainly deserves a less exalted position in steelmaking history. He was slow to act, recorded nothing and was lucky to have his patent upheld and renewed. He did not participate in the pioneering efforts at Wyandotte, even though his name was associated with the enterprise. He ignored and was ignored by his peers.

Mushet, on closer examination, also comes across as a weak man, who, despite his heritage, was afraid to get deeply involved in the world of tonnage steelmaking. He was content to vegetate in his mini-steelworks at Coleford and hide behind his pen under the pseudonym "Sideros." If he had been a real steelmaker, he would have travelled to Cheltenham--a mere 25 miles from home--to hear Bessemer. It is easy to understand Bessemer's dislike, even disdain, for him. A vain, dour, obstinate, humorless technician, he could have accelerated the development of tonnage steelmaking but, like Kelly, he backed off. Even his spiegeleisen additive was quickly cast aside for a better alternative.

William Jones, 1839-1889

Captain "Wild" Bill Jones was a legend in his time and rightfully so. He was unquestionably the driving force behind the successful operation of "E.T.," the first integrated mill in the U.S. Swashbuckling, debonair, generous, tough but fair, involved, competitive, inventive he fully earned the respect of his subordinates. If anything, he was too pro-worker for top management's liking. His men worked seven days a week, twelve hours a day, but he fought successfully for the eight-hour turn and fought against wage cuts. As he wrote to Carnegie in 1878, "low wages does not always imply cheap labor. Good wages and good workmen I know to be cheap labor." He had guarded respect for Carnegie, who could, however, manipulate Jones simply by challenging him to beat some productivity record for a token reward like a new suit or a steak dinner. He believed passionately in installing the best equipment available and maintaining it in tip-top shape. Carnegie supported this policy too. Jones was an intuitive steelmaker, however, and although he and the technically-oriented Holley were close friends, Jones believed that "chemistry will be the god damn ruin of this industry." At his funeral procession in Braddock, men wept openly for their folk hero. Yet, sadly, within a few years his eight hour turn had disappeared, and the Homestead riots of 1893 marked a low-point in U.S. labor-management relations. Besides his operating and managerial skills, and his hot metal mixer, Jones left another legacy for American steelmaking. One day at a Braddock store, he hired a slip of a lad named Schwab to drive stakes at "E.T." "Genial Charlie" became to Jones what Carnegie had been to Scott in the old P.R.R. days--indispensable. Schwab was to become a surrogate son to Carnegie, and he would go on to fashion the U.S. steel industry in the late nineteenth century.

Alfred Krupp, 1812-1887

Krupp's major technical contribution to the industry was the seamless railroad tire. One cannot deny that a touch of mechanical genius was involved here and, throughout his life, he came up with futuristic ideas. It was the tire, however, on which a dynasty was founded and which permitted Krupp to subsidize his slow-moving cannon business in the sixties. The turning point in the fortunes of this unlovable hypochondriac was the 1871 Franco-Prussian War, which made his activities indispensable to the objectives of the new Germany, the Second Reich. His persistence had paid off. Krupp controlled his far-flung workforce with an iron hand, providing social benefits for them which were far ahead of their time but in return demanding absolute loyalty. He abhorred unions; workers were property, like tools, and it paid to take limited care of them. Since the Kaiser supported Krupp's policy, attempts to organize labor were quickly suppressed, and the workforce across Germany became servile and regimented. Thus, Krupp's power extended far beyond his products. He considered his sickly son Fritz to be an inadequate successor, but Fritz would have surprised him as he successfully modernized and expanded the company. Krupp would also have been mortified to know that, despite its military muscle, the new Germany never did win a war.

Alfred Krupp died alone, never had friends and was frequently close to nervous breakdowns. Through strange circumstances, he came to wield unreasonable power. It is interesting to compare him with Carnegie.

Bessemer was primarily an inventor who loved to make money. He became a keen businessman and, because of his well protected patents, very rich. Once embroiled in the world of steel in 1854, he never entirely escaped from it, although he turned to other interests later in life. He rarely travelled outside England because of sea sickness and invested thousands of pounds in an unsuccessful venture to build a ship where the whole saloon section was on gimbals and thus, in theory, remained level as the ship tossed and turned. He built a private observatory and became interested in solar power, lenses, and diamond polishing. One challenge always seemed to lead him to the next. There is no question that "Bessemer invented Bessemer," and his process was revolutionary; it changed the course of history. A lesser man might have been discouraged by the early failures and given up. However, final world-wide commercial success of the process was due to the separate efforts of Goransson, Holley, and Thomas in sorting out the technical details. By that time, Bessemer had lost interest and was busy with other inventions. He never sought to became a real captain of industry or acquire political power like Carnegie but was content to putter around his magnificent London estate, installing gadgets and novelties to amuse his grandchildren. In his unfinished autobiography, he makes no reference whatsoever to either Kelly, who bested him in the U.S. patent court, or Goransson, to whom he owed more than anybody. What do we make of this? Surely it was not a failure of memory.

Thomas has received due recognition for his technical breakthrough, particularly in continental Europe, where most of the high phosphorus ores in the world are located and thus the "Thomas" rather than the "Bessemer" converter prevailed. One has to admire his persistence in the face of constant setbacks. Both his age and his social status precluded him from association with the engineering elite in Britain--and this would have included both Bessemer and Siemens. On the face of it, Carnegie befriended him for commercial reasons, but surely he also recognized a fellow spirit. The Holley's certainly enjoyed his company when he stayed at their home in New York in 1881, and Thomas loved American hospitality. But having known only hard times all his life, he had become parsimonious and did not approve of the ostentatious money worship of the Americans. He was probably the first philanthropic steelmaker. He died a bachelor and willed his sister to disburse his considerable estate, "doing good with discretion." For the rest of her life, Lilian skillfuly chanelled thousands of pounds into social reform organizations, the National Trust (to save historical buildings and works of art), and scholarship funds. What a shame the Thomases did not make that historic trip to Dunfermline with the Carnegie party! It would have been a wonderful memory for Lilian as she eked out a frugal existence on the 300 sterling pounds a year that her brother provided for her in his will.

In this group of early steelmakers, only Holley and Siemens had engineering degrees. Siemens managed the English operations of his brother's electrical company as well as his own Landore-Siemens O.H. Steel Company, which was producing thousands of tons per year when "E.T." came on stream. But Siemens, like Bessemer, was caught up in the general excitement over applied technology and in the 1870's devoted increasing attention to energy utilization and conservation, and the applications of electricity. In 1874 he designed a steam ship, the Faraday, for laying transatlantic cables, two years before Bell's invention of the telephone. In 1880 he reported to the Society of Telegraph Engineers that he had developed a D.C. arc furnace, which could, among other things, melt steel. But above all he served the engineering profession tirelessly, as a founder member of the British Iron and Steel Institute in 1869 (292 members), and as its president in 1878 (over 1,000 members). He was the 1875 Bessemer medalist. Throughout the 70's he was president of one technical society or another almost every year. He advocated the adoption of the metric system and the addition of the electromagnetic units the Watt and the Joule to that system. He believed energy could and should be harnessed from the sun and from the mighty Niagara Falls. His erudite scientific papers occupy three volumes and cover a variety of subjects. Siemens was knighted in 1883, but died shortly afterwards from a heart ailment. He was truly a gentleman and a scholar, a balanced man who led a full life.

Holley was no less articulate or literate. In fact, he was the cosmopolitan steelmaker, taking annual trips to Europe for the Bessemer Association, to which he reported back in detail. He drew an audience of over 1,000 to hear his lecture on Bessemer steel in 1872 at the Cooper Institute in New Jersey, and he was forever in demand as a speaker, writer, and organizer. He was a very early member of AIME in 1871, and its president in 1875, the year before he organized the metallurgical section of the Centennial Exhibition. He was the first U.S. champion of practical engineering education--the cooperative programs of today--and was as hard on the academic teachers who never faced real-world problems as he was on his steelmaking colleagues, with their "pride of ignorance." When Holley left the Pennsylvania Steel Company in 1868, the workers collected what was then the enormous sum of $500 for the construction of a perfect miniature Bessemer converter made of silver. This spontaneous expression of respect speaks volumes about the man and is a reflection of what labor-management relations could be. Holley died in New York in 1882, a year before Siemens, having seen U.S. annual steel production approach that of Britain, and certain that the basic O.H. would replace the Bessemer process. He was worn out at the age of 49. Despite his patent fees and the consulting work he did for the Bessemer Association, his estate was modest and he was concerned about the financial situation in which he would leave his family. Holley was awarded the Bessemer Medal posthumously in 1883, and his peers in the engineering societies to which he belonged contributed to the building of a memorial. It stands in Washington Square in New York City. The achievements of Holley deserve to be more widely recognized by the steel industry.

Carnegie is the last and probably the most interesting of our pioneers. His role in the steel industry has already been described, and the picture that emerges is that of an opportunistic, dynamic organizer who had an amazing capacity to select the best possible associates for any given place and time, from Piper and Jones to Holley and Frick. Unquestionably, he liked to manipulate men and make money, thus compensating psychologically for his diminutive stature and childhood poverty, respectively. But his acquisition of wealth was so easy that by the 1880's he had turned toward the acquisition of power. And always in the back of his mind was the thought that he lacked the formal education to which he had aspired as far back as 1868.

He had insinuated himself into intellectual circles in Pittsburgh at Madame Botta's in the 1870's, having been invited primarily as a curiosity, the species "homo croesus americanus." But he was surprisingly well read even then, and held his own in any discussion. His intellectual lifeline began to extend from Pittsburgh to New York to London. Within a few years, he had become a successful author by documenting his world travels. By the 1880's, with Frick running his steelworks, Carnegie was actively espousing liberal causes in Britain such as public education and the abolition of both the House of Lords and the Monarchy. His English newspaper chain proved a failure, however, and he became an embarrassment to the liberal establishment, particularly after the 1893 Homestead riots, when his ambivalent stand on labor was ridiculed. When the Amalgamated Steelworkers Union was essentially destroyed, Carnegie's image as champion of the "little man" was destroyed as well. But by then Carnegie had already written his article on "Wealth," and he was to spend his next few years as a "scientific philanthropist," disbursing his giant fortune (eventually over $300 million in his lifetime) for public benefit. It caused him many heartaches, for the disbursement satisfied no one. His donations of library buildings (but no books) and church organs are legendary. The Carnegie Trust for the Universities of Scotland, the Carnegie Institution of Washington, the Carnegie Foundation for the Advancement of Teaching, and, finally, the Carnegie Corporation of New York all provided funds and brought about changes for the better in world-wide education and the search for knowledge. His last years were spent in the abortive, and perhaps naive, cause of world peace. By this time, he had the ear of world leaders, his heroes being Teddy Roosevelt and the Kaiser. But as a private citizen rather than a diplomat, he was sometimes an embarrassing meddler. The outbreak of war in 1914 almost shattered his faith, as the 79-year-old Carnegie realized that his millions had been pitted against billions spent by Germany over several decades and that gentlemen's agreements meant nothing any longer. All he could hope for was that neutral America would be able to stop the war, and that man would see that this had to be the "war to end all wars." This typifies Carnegie. He was an eternal optimist; every setback was a new opportunity. He thrived on challenge. Among this small band of original steelmakers, Carnegie stands supreme in my opinion. He was a tough little Scot, who had come up the hard way and didn't suffer fools gladly. He had a good instinct for new technology, a good eye for detail, and enough vision to be the original marketing man of the U.S. steel industry. He used his position to distribute most of his fortune intelligently for the good of mankind, and surely the ends justified the means.

EPILOGUE

Our story is ended. In twenty years, a handful of men had taken the age-old and abundant element, iron, and made it available on a scale which staggered the imagination, and in a form which enabled man to span continents and reach for the sky. The U.S. steel industry rose from insignificance during the Civil War to become the most dominant in the world by the 1880's in terms of both tons and technology. European know-how had been bought, exploited on a grander scale and improved upon. It all happened behind a comfortable tariff wall, with sympathetic Congresses and the availability of unlimited capital. The parallel with modern Japan vis-a-vis the U.S. is striking.

With the depression of the seventies behind them and perhaps stimulated by an 1876 Centennial Exhibition which had a very international flavor, the U.S. entered a period of unparalleled industrial growth. Invention was in the air (Figure 9) and the world remained at peace. Steel and energy emerged as measures of a country's strength and vitality, and they retain that status to this day.

Our pioneers would be amazed at the present scale of the industry and the versatility of steel itself as an engineering material. At the tonnage levels which prevail even in today's depressed markets, alternative materials will only replace steel to a limited extent in the near future; the danger is from foreign steel. Iron will forever remain the most abundant and accessible metallic element in the earth's crust as well as one of the least costly to extract per unit of energy expended. Technically, its conversion into high quality steel is well understood today. A readjustment of global steel capacity and the adoption of fairer trade practices are certainly overdue. But beyond these, we need to develop new steels for new markets. Like our original steelmakers, we in the steel industry need vision and the persistence to realize that vision.

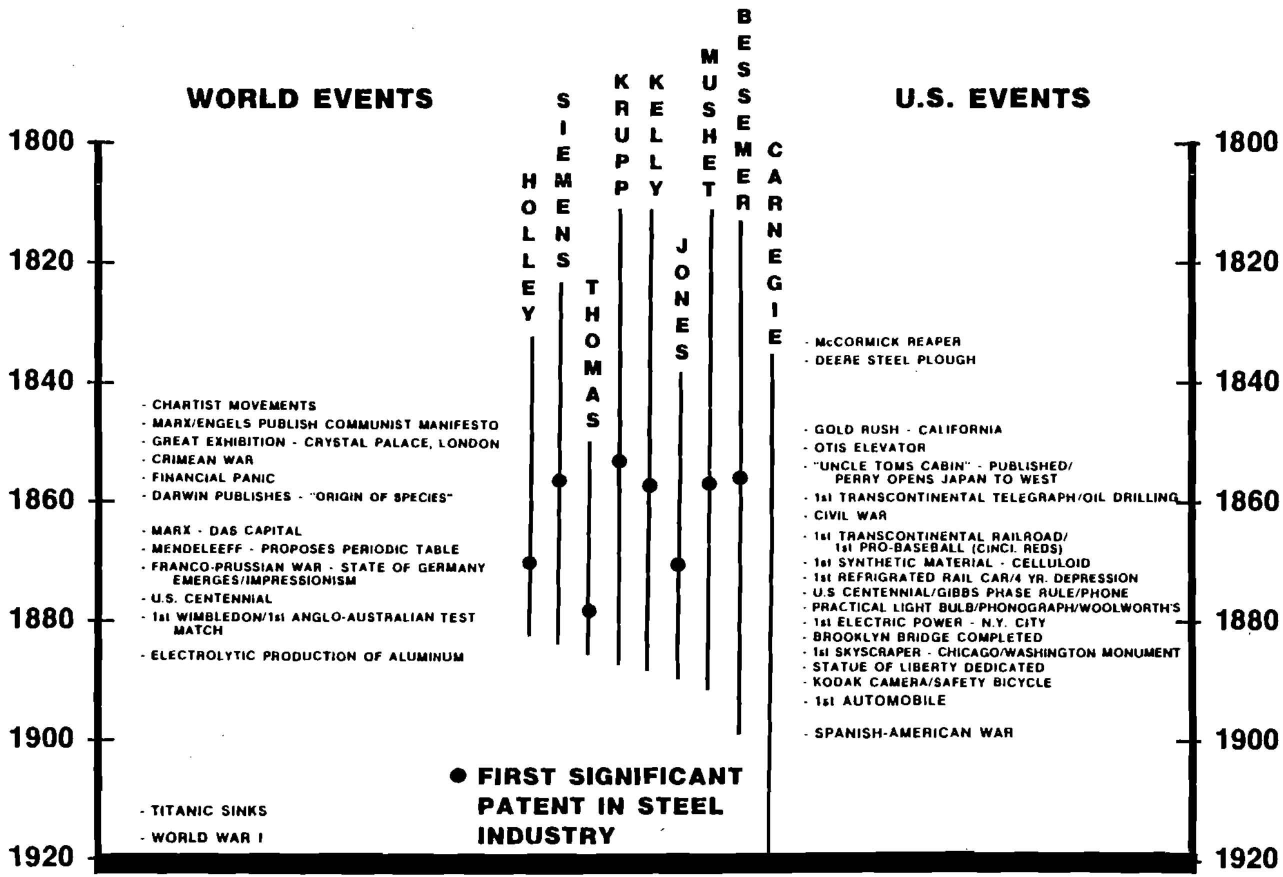


Fig. 9 - The era of the original steelmakers.

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