Innovation in Domestic Steel Production
Where Does the U.S. Stand?

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STEEL PRODUCTION has always been deeply rooted in the American experience. Pictures come to mind of coarse-featured men gazing warily at brilliant pools of molten steel. We see drab-colored cauldrons, balanced on giant hooks suspended high overhead, move slowly in the darkness with their frothing contents quenching a never-ending thirst for goods. From the superstructure of modern skyscrapers to the hulls of oceangoing supertankers, this is the stuff that holds the shape of our modern world—a dramatic reaffirmation of the industrial age. Ingrained in these images are also the symbols of national pride, prosperity, and even the will of its people. We read about it in the exploits of the Krupp armament dynasty, hear it in the musical themes of Wagner's mythical Niebelungen race, or see it in the old newsreel clips of the menacing dreadnought battleships of World War I.

BIG STEEL, THE PRIDE OF AMERICAN INDUSTRY

From its beginnings, the United States has been preoccupied with its westward movement. This expansion needed an infrastructure to tame the wilderness; wagon trails, roads, canals, inland waterways, the telegraph, and even the Pony Express were used to conquer the frontier. It was the railroad, however, that penetrated the interior, bringing in masses of immigrants and finished goods while taking out bulk quantities of raw materials, cattle, and produce. As the twentieth century dawned and the frontier vanished, the nation was rapidly building a crisscross of track and rolling stock made of steel. Steel began to give geometrical form and character to the skylines as the teeming cities grew skyward. The Navy, once constructed of wood and sail, now was recast in steel and diesel to assume the role of an emerging world power. Into this came the names of Andrew Carnegie, Henry Clay Frick, Charles Schwab, and other steel men who figured prominently among the tycoons and industrialists of the Gilded Age. It was these men who founded the dynasties in domestic steelmaking, set the stage for how business in the steel industry would be conducted, and amassed huge personal fortunes in the process.

By the mid-fifties, "Big Steel," as the leading U.S. producers became known, was king. Riding on a vast postwar consumer-spending spree, they produced a near-endless assortment of basic products, which eventually became everything from automobiles to washing machines. The war had given the U.S. steel industry a commanding lead worldwide, with production capacity far outstripping anything that Europe or Asia could muster. Bethlehem Steel, for example, churned out more steel in 1953 than the whole of Germany's rebuilt industry. Imports from Japan in 1955

Continuous casting steel mill, preparing steel ingots.

were only about one tenth of one percent of the domestic market. A mindset of limitless demand coupled with record-setting profits pervaded the industry. During this decade, domestic steel expanded its annual capacity from 100 million tons to 148 million tons. A steel industry official summarized the attitude of Big Steel as, "Our salesmen don't sell steel, they allocate it."

This confidence was personified by the colossus that Bethlehem Steel had built on the shores of the Chesapeake Bay at Sparrow's Point. By 1957, this was the single largest steel plant in the world, with an annual ingot capacity of eight million tons. The facility was tended by an army of 30,000 workers and required 640 million tons of water daily to cool the torrent of molten steel. The crowning achievement, from the prospective of Bethlehem's management, was the immense new open-hearth shop, covering two football fields. On closer look, this was actually a version of the type constructed nearly a decade earlier, albeit on a monstrous scale—a method of steelmaking that the close-knit fraternity of steel men at Bethlehem could understand and take great pride in, but that was already rapidly approaching obsolescence.

At that time the corporate culture of the major steel producers in the United States was one of isolation and inertia intent on maintaining its own sense of status and privilege. New methods of steel production that did not bring immediate and generous returns were to be avoided as too risky. To the upper ranks of management, innovation meant fine tuning tried and tested technologies, which was more a testament to their past glories than to any vision of the future. A Bethlehem official once offered this telling quote, "We don't want to invest in a facility unless it will return, on average, 20% before taxes, operating at 60-to-70% capacity." Whereas AT&T, DuPont, and General Electric, leaders in their fields, were aggressively spending enormous sums on research and development, Big Steel lagged far behind, content and complacent in its seeming dominance in national and worldwide markets. By the late fifties, however, cracks began to appear in this facade brought about by the convergence of new and powerful forces in the market place: ersatz materials to replace steel, stiff foreign competition, and radical departures in steelmaking technology.

CHALLENGES TO DOMESTIC STEELMAKING

In its time, steel had replaced, in varying degrees, wood, glass bottles, and cast iron. Yet as the new world order emerging from the ashes of World War II took shape, leaving a system of bitter political rivalries and conflicting world views, greater demand in sophistication was placed on steel. The realities of the "cold war" spurred ever more strident efforts in research, rhetoric, and resolve. This was especially true in the defense industries. An unbroken stream of military hardware followed one after the other, which either flew higher, dove deeper, shot farther, or could withstand greater impacts than their predecessors. With the launch of Sputnik in 1957 marking the beginning of the space race, pressures mounted on the technical community in still another arena of competing national interests. To complete this picture, the consumer market was growing at an enormous pace, a reaction to the restrictions placed on the country by years of war rationing. Engineers were being challenged to find newer and cheaper materials to expand the envelope of capabilities to meet all these expectations.

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In the postwar era, plastic was rapidly improving and expanding its market share. It was lightweight and could be blow-molded without machining or stamping. Backed with paperboard or other materials, items made of plastic would not dent, corrode, melt, transmit heat, or conduct electricity. Automakers, major steel customers, discovered the cost savings in switching to coated plastics. For instance, by plating plastics with a thin layer of stainless steel, manufacturers could replace metal in instrument panels, lighting displays, ventilation grills, and door locks—wherever shiny, metallic parts were needed to serve cosmetic purposes. The year 1959 also proved significant by the introduction of thermoplastics by American Cyanamid and Hercules. Products made from thermoplastics could withstand boiling water without distorting. Utensils of various sizes and shapes could now be mass produced, ushering in a new era of cheap, durable kitchenware.

Meanwhile, aluminum was beginning to make inroads into the canning market. Carefully gauging consumer needs, Alcoa, Reynolds Metals, and Kaiser Aluminum began to gnaw away at the dominance of tin-plated steel. In response to escalating costs in steel, the aluminum industry aggressively pursued and won the oil can market. This was followed by frozen orange juice containers. Eventually aluminum invaded the coveted beverage can business. Today 99% of all beer and 90% of all soft drinks are in aluminum cans.

Still another challenge that the steel industry faced was the introduction of reinforced and prestressed concrete into construction. This was "big-ticket" territory and lay close to the essence of Big Steel's symbolic might and prestige. The advantage of these innovative techniques lay in the fact that less steel was needed in the construction of short-length bridges, parking garages, and some large-scale buildings. These structures proved to be both cheaper to construct and weighed less. The axiom, once so prevalent in structural design, that steel was the only material strong enough to handle heavy loads, was being questioned in earnest.

As Big Steel had focused on increased capacity and heavy investment in outdated technology, foreign steel from Japan and Europe began to gain a small but significant share of the domestic market. In time, what had begun as a trickle soon turned into a gusher. Japan, for example, in 1955 had exported a negligible 32,000 tons into the United States. By 1967, a mere 22 years after the devastation of the war, this figure had grown a hundredfold to 4.5 million tons. By 1980, Japan accounted for 15.5% of the world's steel output compared with 14% for the United States. Experts claim that it was the enormous profits gained from its steelmaking operations that became the financial engine that drove other successful Japanese enterprises in automaking, semiconductor devices, and technical appliances. True, with low wages, modern equipment, and generous governmental support, Japan and others enjoyed a sizable advantage. Nevertheless, Japan had serious handicaps to overcome—the lack of workable iron ore deposits and its reliance on expensive coal-mining operations. To feed its growing mills, iron ore and pig iron were imported from as far away as South Africa. Even so, the bottom line for the domestic market in the U.S. was simple and direct, quality steel at low cost. Wire rod, for example, shipped 10,000 miles from Japan to New York was of comparable quality to rod from Sparrow's Point, 200 miles away, but about 15% cheaper. It was no wonder that in the early sixties, the U.S. reverted to become the world's largest importer of steel products.

Through the mid-eighties, competitive pressures from the developing industries in Taiwan, South Korea, Venezuela, Mexico, and Brazil placed further stress on domestic sales. Lured by the double-digit rates of return, banks in the United States loaned enormous sums of money to these developing nations, especially Brazil. As the freewheeling eighties succumbed to its own excesses and the specter of default loomed, financial institutions began a series of massive debt restructurings and offers of yet more credit. In a frantic effort to maintain solvency, bankers were forced to lobby for the fledging industries in these emerging economies, such as steelmaking, and thus pitted themselves squarely against the interests of the U.S. steel producers.

Through history and happenstance, domestic steel production and consumption were not evenly distributed. A patchwork of mills was concentrated along the shorelines and among river valleys in a narrow band extending from the Middle Atlantic States to the Great Lakes. Despite the awesome output of these facilities, two-thirds of the country west of the Mississippi River had to import steel. Customers in the far west and southwest, such as California and Texas, although consuming a quarter of the nation's annual output had, by the mid-fifties, less than four percent of the steel production capacity. Big Steel had little interest in the possibilities that lay ahead in servicing these expanding regions of the country and left the door wide open for its competitors.

Perhaps of all the factors that most shaped the dynamics of the postwar era in steelmaking were the significant advances in technology. These changes would shake the industry to its core, forcing an economic reckoning which would ultimately cost three quarters of the jobs in American steel, some 320,000 workers in all. The advent of the American minimill was one such advance.

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THE MINIMILL

The minimill fed on the ferrous renderings of a modern society. Ironically, the success of the minimill rested squarely on the tons of scrap steel that the integrated mill had produced at an earlier time. Unlike the older, more massive integrated steel mill that needed to be close to an ample supply of raw materials such as iron ore and coal, the minimill had to be only in the vicinity of a major metropolitan area. Integrated mills needed to chemically extract, through an elaborate and costly process, iron from the ore and subsequently steel from the crude iron. On the other hand, the minimill was already working in steel, albeit in a discarded form. Junked autos, file cabinets, refrigerators, scrapped structural steel, typewriters, old motors, and bedsprings went into the waiting furnaces of the minimill. Although each mill produced relatively small quantities of steel, perhaps 50 thousand tons annually (less than one percent of the Sparrow's Point output), they proved to be highly efficient and profitable operations. After pioneering mills such as Roanoke Electric and Florida Steel began operations in the 1950s, minimills soon sprouted in all the major population centers nationwide. At first, minimills could produce only simple products such as rod and wire, spurred on by the large demand in reinforcement bar needed for the booming interstate highway-construction market. Later, more sophisticated products such as sheet steel were attempted. Soon they became so successful that they effectively undercut foreign inroads into the rod and wire market, despite the tenacious efforts of these competitors. Their numbers swelled as the decades passed, filled by aggressive visionaries and savvy risk-takers. Nucor Corporation exemplifies the drive and hard work that eventually made the minimill into a major factor in domestic steelmaking.

The story of Nucor is a fascinating study in desperation and determination. Nuclear Corporation of America, Nucor's predecessor, had collected various business holdings over the years—a nuclear division, a steel fabrication company, and semiconductor manufacturing. The firm was even involved in paper copying and tin-can manufacturing research, which were carried out in secret. It was apparent that the company had no focus or direction, and by the mid-sixties, it was facing Chapter 11 protection. In 1966, Ken Iverson took over the reins as president. He quickly adopted the name of Nucor to replace the old, debt-ridden NCA and to quell the fears of nervous investors and uneasy creditors. He also looked into the company's future prospects. Since steel fabrication through its Vulcraft division was its only profitable entity, Iverson decided to move in this direction. Vulcraft purchased bar steel from the Big Steel companies, welded the bar into roof joists and sold the joists for use in shopping malls and high-school gymnasiums. The problem that Nucor faced was that the price for bar steel was steadily rising, squeezing the independent fabricators into ever-tighter margins of profitability. With an uncertain future in the joist business, Iverson cast about for a solution. This eventually led to the construction of a minimill in Darlington, SC. More minimills soon followed. Through quick instincts, a "no-frills" managerial style, and a philosophy of heavy investment in state-of-the-art equipment, Nucor aggressively pursued the market. The firm was just shy of one billion dollars in sales by 1988, earning itself not only a place in the *Fortune 500,* but also legendary status. By 1995, it had become the fourth-largest steelmaker in the United States.

The heart of the minimill consists of an electric-arc furnace (EAF), a continuous caster, and a hot rolling mill.

The process begins with the furnace. Ferrous atoms, due to a mismatch within the inner shells of the electron cloud surrounding the nucleus, possess a small magnetic field (actually referred to as a magnetic moment). The electric furnace imposes an external alternating magnetic field, which couples directly with each of the magnetic moments within the scrap. The iron atoms, in an attempt to maintain alignment with each other and the impressed external field, oscillate in sympathy and generate large amounts of frictional heat. Twelve-million watts of electrical power are needed to initiate the process, although this figure had reached 100 megawatts by the mid-nineties. The end result is molten steel. (The principle is similar to the conventional microwave oven that cooks through the interaction of an oscillating external electric field and the bipolar nature of the water molecules in the food.) The melt is then introduced into the continuous caster that allows the liquid to cool uniformly into a long thin tube of white hot steel. The length of this extrusion is limited by the amount of molten steel in the original batch. (We will say more about this later.) The next stage in the process is to run the plastic steel emerging from the continuous caster through the hot rolling mill, a series of rollers forcing the steel into a desired shape. Finally, the steel is post processed into the final product by any number of additional steps, such as cold rolling, coating, or annealing.

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INTEGRATED STEELMAKING BREAKTHROUGHS

The integrated mills were also caught up in technological change. Conservative in temperament and slow by nature, Big Steel at first failed to recognize and incorporate these innovations into its basic philosophy of steelmaking. To compete effectively with the domestic minimills and the foreign steel producers, Big Steel was eventually forced to capitulate and modernize. Through the sixties and seventies the industry began a massive campaign to install desperately needed state-of-the-art equipment. Unfortunately, it was a time when sagging profit margins, because of excess world-wide capacity, were lowering prices and repelling investors.

The process of integrated steelmaking is a complicated and massive undertaking, requiring large amounts of raw materials, coolants, fuels, and a developed transportation network to be economically viable. The process of refining begins in a large, sealed vessel called a blast furnace. Looking like an inverted parfait glass, this structure extends some hundred or more feet skyward and measures fifty or so feet in diameter at its widest point. Iron ore, coke, lime, and other trace ingredients are added at the top. This mix, called the charge, moves slowly downward as liquid metal and slag are drawn from the bottom—the remnants of chemical reduction. It takes 8-14 hours for the charge to descend completely. As the raw materials drop, the temperature within the blast furnace steadily rises (reaching 2,500ºF, favoring successive reactions which alter the chemical composition of the charge. Critical in supporting these reactions is outside air that is forced upward through the furnace via a series of inlet ports located near the bottom of the furnace. Pig iron, a crude form of steel, is the result. This low-quality material contains large amounts of carbon, up to 10 tons for every 250 tons of pig iron produced, as well as other impurities that diminish its strength and workability.

The next stage removes the carbon and other impurities to make steel. This had been accomplished by refining the pig iron in an open hearth furnace (OHF), a technology that had been imported from France in 1868. This process depends on the chemical interaction between slag and molten metal contained in a large, shallow bath and the surrounding air. The slag, which floats on the underlying liquid metal, exchanges impurities from the pig iron and added scrap metal with the oxygen in the air. To produce steel in sizable quantities, a large, active surface area is required. This is accommodated by an elaborate system of forced air and burning fuel injected directly and uniformly into the hearth, as well as a means of recovering and reprocessing waste gasses. The basic oxygen furnace (BOF), commercialized in Austria in 1952, radically changed this.

The BOF generates heat throughout its volume more uniformly than the open hearth furnace, albeit in smaller batches. Pure oxygen is directed through a lance directly onto the pig iron and scrap, which are placed in a relatively small enclosed containment vessel. No fuel is burned because heat is produced from the reaction of oxygen and the impurities in the iron. A large basic oxygen furnace can produce upwards of 200 tons of steel in three-quarters of an hour, compared to the typical open hearth furnace which requires four-to-five hours to prepare a 425 ton heat. The big steel producers, however, opted for the open hearth furnace. As late as 1970, such major facilities as Sparrow's Point, U.S. Steel's Fairless works outside Philadelphia, and Inland Steel in South Chicago still were using the open hearth furnace.

Continuous casting, as alluded to earlier, had been used to great advantage in the burgeoning domestic minimill sector. The caster consists of a box-shaped machine with an oscillating funnel. Molten steel introduced into the top of the funnel, through the action of the vibration, coolants, and added lubricants, emerges as a hardened, red-hot, continuous rectangular strand of steel. This is fed directly through a hot rolling mill and finally into a finishing mill. Meanwhile, the larger integrated mills cast the melt from the furnace into ingots or slabs for reheating and further processing elsewhere.

Although continuous casting had been commercialized by American inventor Irving Rossi in the early fifties, it was not fully embraced by our domestic producers for 30 years. Tentative pioneering efforts, however, were tried by U.S. Steel and Bethlehem Steel in the 1960s. Despite initial success, problems emerged which doomed these projects, in the minds of upper management, to small volume production only. The chief worry was that continuous casting required a high degree of purity and uniformity in the steel, despite processing large tonnages from the open hearth furnaces. Added to this was the ever-present danger of "breakout," a condition whereby liquid steel would rupture its hardening outer skin and spill into the interior of the caster, hopelessly freezing the operating mechanisms and possibly causing electrical fires. Interestingly, it was not long after hearing of the continuous casting trials in America that Japanese producers successfully adapted this method to their own high-volume production facilities. Using these improvements, by the early nineties, the record in Japan for nonstop casting had been set at 200,000 tons, amounting to 800 batches containing 250 tons of steel per batch. Presently 95% of all Japanese steel is continuously cast.


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Technician inspecting grain in steel on a monitor.

THE AFTERMATH

It became apparent in the 1980s that the steel industry, especially the integrated mills, would have to undergo massive restructuring. To maintain profitability, Big Steel would, by starts and fits, try various strategies. David Roderick, chairman of United States Steel, took the path of diversification. Steel and iron ore facilities were grouped together in the USX Corporation. Marathon, Texas Oil & Gas, and the U.S. Diversified Group would each also form separate units. Each "stand-alone" entity would generate its own capital resources and not be dependent upon other parts of the corporation. Bethlehem Steel, under chairman David Trautlein, began a romp through the length and breadth of the company, rooting out entrenched bureaucracy and inefficient plants. This policy was also pursued by Inland Steel. In their zeal to down-size, many steel companies such as USX, Bethlehem, and Inland took on the ire of the United Steel Workers leadership and the lasting enmity of its rank and file. One bright spot, however, was the employee stock ownership plan by which National Intergroup sold Wierton Steel Company. In 1982, Wierton was bought by its employees, a novel idea in an industry which traditionally viewed management and workers as arch-antagonists. Led by its visionary president, Robert Loughhead, the company survived and prospered, despite criticism from conservative quarters in the steel community.

This was not true of LTV Steel, formed through a merger of Jones & Laughlin and Republic in an effort to reduce duplication and increase competitiveness. For a while it was ranked as the second-largest steel producer in the country, displacing Bethlehem. Then in 1986, after running up large losses, the company filed for bankruptcy reorganization, another casualty in the disintegration of Big Steel. In the same year, Wheeling-Pittsburgh also went into bankruptcy proceedings. In contrast, National Steel emerged from these troubled times as a holding company, owning steelmaking facilities and financial institutions. To change its image, it took on the new name of National Intergroup. As part of its plan for survival, National sold off a substantial portion of its steel holdings to Nippon Kokan, a large Japanese steelmaker. Ironically, this meant that the chief foreign competitor was no longer located 10,000 miles away in Japan, but had moved next door. Other firms seeking to gain new technology and badly needed capital formed joint ventures with Japanese and Korean steel companies.

From the personal perspective, these reductions and realignments had a devastating effect on the river communities and mill towns in the heart of steel country. The typical cycles of boom and bust, which had rippled through these regions for the last century, were to some degree negated by the high wages earned by the steel workers. It became apparent, however, that this time the plant closings were to be permanent. For instance, the Mon Valley, which consisted of the Monongahela and Youghiogheny rivers and Turtle Creek, some 140 square miles in all, lost much of its steel industry. By 1987, the Monessen, Donora, Clairton, Homestead, Rankin, J&L Pittsburgh, Duquesne, and National (McKeesport) works were all closed, except for Clairton and J&L that still produced coke. A union worker once said that the big steel companies were always crying wolf; indeed, by all accounts the wolf had finally arrived.

By 1995, American steel had shed its excess annual capacity of 50 million tons through plant closures and mass layoffs, leaving behind a smaller, leaner industry. The arrogance, inaction, and confrontational style that had plagued domestic steel was replaced by a rush to survive in the highly competitive global marketplace. The momentum established in replacing old technology, which led to the introduction of the BOF, EAF, and continuous caster, continued at a steady pace. Developments in secondary metallurgy to enhance purity and conserve heat, efforts directed towards ore preparation to increase efficiencies in the blast furnace, and improved electromechanical systems that drive and automatically control rolling mill stands have led the way to a new generation in steel production.

In 1995 in a move to dispel old attitudes, several large- and small-scale manufacturers banded together under an umbrella organization called the "steel alliance." The unit hired a marketing firm, GSD&M of Austin, TX, to manage a $20 million national ad campaign to give steel new glitz. The promotion extolled the industry as well as heightened awareness in products that use steel.

SUMMARY

Although still a significant force in worldwide production, American steel can no longer boast of its early post-war dominance. In 1995, domestic producers made 103 million tons, down from the heyday of approximately 150 million tons of two decades earlier. In 1993, United States steel output ranked second, accounting for 12.2% of the world's steel, followed closely by China. Leading worldwide production is Japan at 13.7%. The global aspect of the steel industry has matured, bringing some three-dozen countries into the steelmaking business. Traditional names such as the United Kingdom, Germany, and Canada have been joined by lesser-known steel producing countries such as Venezuela, Argentina, Greece, and North Korea.

Despite its legacy of sweat, grime, and toil, the steel industry has undergone a profound change over the past several decades. In a relentless drive to reduce costs, domestic steel production has been forced, through fierce worldwide technological and competitive pressures, to modernize. The hallmark of this trend in steel production has been in the increasing reliance on high-level technology to monitor and control this process. Gone are the legions of workers who labored on a multitude of separate specialized tasks. They have been replaced by a curious mix of microprocessor chips, printed circuit boards, and video screens, which automatically and continuously sense and adjust the process parameters to create a uniformly high-quality product. Customer needs require steel manufacturers to provide small lots of diverse steel types on short notice. The introduction of the BOF, EAF, and continuous caster has allowed the steel industry to meet current world demand. Refinements to these processes continue to this day at a steady pace.

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