Mankind first began making steel using charcoal to reduce iron ore in the Iron Age, circa 2000 BCE. The early genesis of the Iron Age is attributed to the fact that iron ore is relatively common and easily acquired compared to other metals, and iron ore can be reduced easily using charcoal (carbon), at a relatively low temperature (over 450°C). At that time, semi-solid steel, produced by simply reducing iron ore, was forged to create farm implements and weapons. It was not until the mid-14th Century that liquid iron was extracted directly from iron ore. This became possible because high temperatures were reached with furnace bellows operated by waterwheels. As steel production increased, forests were destroyed in the process of securing charcoal for charcoal blast furnace. Coke was used in place of charcoal starting in the early 18th Century. In the late 18th Century, during the Industrial Revolution in England, the invention of the steam engine by James Watt enabled blasting air into the blast furnace (BF) with a machine, thus making mass production of iron possible. This coke blast furnace technology has evolved continuously for 300 years.

In the mid-19th Century, about a century after mass production of iron began in Europe with the coke blast furnace, mass production of molten steel began with the invention of the Bessemer converter (1856) by the Englishman Henry Bessemer, and the appearance of the Siemens-Martin open hearth furnace shortly thereafter.

The age of pig iron and steel

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The emergence of the blast furnace-based integrated steel mill

In the 1860s, after the Civil War, the USA underwent industrialization, transitioning from an agrarian to an industrial nation. Steel demand skyrocketed with the development of the West, and the construction of intercontinental railroads. At first, the USA was dependent on steel imports from Europe. With the rapid introduction of the Bessemer converter and the open hearth furnace, new technologies developed in Europe (England), the USA became the largest...
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Recognizing the necessity of consolidating myriad small and medium-sized steel mills in order to gain a competitive edge in steel production over Europe, JP Morgan led the merger of twelve steel companies (including Carnegie, Illinois, and Federal) in 1901 to form the United States Steel Corporation (US Steel). US Steel constructed the world’s first modern integrated steel mill, Gary Works, near Chicago. The historic opening of Gary Works was in 1908. Gary Works was equipped for seven production processes, with facilities including a sinter plant and a coke oven, starting from iron ore down to hot-rolled products, to turn iron ore into hot-rolled products. The new steel mill was revolutionary in its logical layout and rail connections between plants, its generation of electricity from gas by-product in steel production, its use of this electricity to power the steel mill, and other innovations. It was the first model for today’s BF-based integrated steel mills, which seek to improve logistics and energy efficiency between processes. Gary Works remained the largest steel works in the world until the early 1960s.

The development of new steel production technologies
While the ironmaking process has been centered on the coke blast furnace for 300 years, since its first appearance in the early 18th Century, the steel production process has made leaps and bounds in the past 160 years. The Bessemer converter, invented in 1856, utilizes the miraculous industrial process of simply blowing air through molten iron, with no external heat source, to produce molten steel in little more than ten minutes. The introduction of this process garnered considerable attention from the steel industry. However, iron resources that could be used in this process were limited, and the molten steel produced was poor in quality. For these reasons, steel production using the Bessemer converter, and the later-developed (1870) Thomas converter, was discontinued in most areas. Around this time, the S-Martin open hearth furnace appeared. Though it required an external heat source and its productivity was relatively low, it permitted a wide range of iron resources (i.e. pig iron, steel scrap), and allowed easy control of the temperature and composition of molten steel. Thus the S-Martin open hearth furnace became the predominant method of producing liquid steel for about a century, until the appearance of Basic Oxygen Steelmaking (BOF) in the 1950s.

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The age of large-scale seaside steel works

BOF and continuous casting processes developed in the early 1950s are considered as the most innovative technologies in the history of the steel industry. The two processes replaced the open hearth furnace, ingot casting, and slabbing and blooming process in integrated steel mills. In 1960s, Japan carried out the “Revamping
Plan for the Steel Industry” to restore its steel production facilities, which had been devastated during the Pacific War. Japan resolutely embraced the new technologies in its new large steel mills built at seaside locations, emerging as the world’s largest steel producer. Nippon Steel’s Oita Works, a large-scale integrated steel works that went into operation in the early 1970s, employed large-scale blast furnaces, converters, and hot-rolling facilities, and was the first in the world to adopt all continuous casting process. Oita Works constructed large-scale port facilities and established pre-processed to make sinter and coke, decreased efficiency due to batch operations between each process, and the generation of large quantities of environmental pollutants from the use of fossil fuels. In the late 1980s, major global steel companies and research institutes led research and development activities to address the disadvantages of BF-based integrated steel mills. The focus was placed mainly on developing new processes to replace the existing blast furnace in ironmaking, and improving the efficiency of the processes from continuous casting to hot-rolling.

The development of BF-based integrated steel mill
BF-based integrated steel mills consist of three major production segments: iron-making segment comprising sinter-making, coke-making, and BF processes; steel-making segment comprising BOF and continuous cast processes; and rolling segment. The integrated steel mills have many advantages such as high productivity, cost competitiveness, and the ability to produce a wide range of high-quality steel products. However, they require large-scale facility groups with complex process configurations across a large land area. Other disadvantages include their dependence on high-grade raw materials, which are pre-processed to make sinter and coke, decreased efficiency due to batch operations between each process, and the generation of large quantities of environmental pollutants from the use of fossil fuels. In the late 1980s, major global steel companies and research institutes led research and development activities to address the disadvantages of BF-based integrated steel mills. The focus was placed mainly on developing new processes to replace the existing blast furnace in ironmaking, and improving the efficiency of the processes from continuous casting to hot-rolling.

Heat flow between processes in BF-based integrated steel mill
By nature, the steel industry is high in energy consumption, and its improvement of energy efficiency is very important to increase the competitiveness of an integrated steel mill. In the ironmaking process, iron ore and coking coal are heated to 1250-1300°C to produce sinter and coke, which are cooled to room temperature before being charged into a blast furnace.

The 1300°C slabs produced in the continuous casting process are cut into fixed lengths, then cooled to room temperature before being reheated to 1200°C in a furnace at a scheduled time to be hot-rolled into finished products. Heat efficiency can be greatly improved in an integrated steel mill if the process of producing sinter and coke can be skipped in the ironmaking process, and iron ore and coking coal can be charged directly into the blast furnace to produce molten iron, and if the 1300°C slabs produced by the continuous casting process can be sent directly to the hot-rolling process without cooling.

The development of alternative process technology to BF
From the late 1980s, research projects to develop an “alternative process to BF” to resolve issues of BF-based ironmaking were carried out throughout the world, but most of them were discontinued by the late 1990s. POSCO’s FINEX is the only steel production process that was commercialized successfully as a result of these efforts, and is in operation today. POSCO initiated basic research on FINEX technology in 1992, and successfully launched a pilot plant with an annual production capacity of 600,000 tonnes in 2003. At present, two FINEX facilities are in operation at POSCO Pohang Steelworks: one plant, launched in 2007, has an annual capacity of 1.5 million tonnes, and the other plant, opened in 2014, has an annual capacity of 2 million tonnes. FINEX combines the three ironmaking processes of sintering, coke-making, and BF into one process, and allows direct use of low-grade fine ore and coal without preliminary processing. This process dramatically reduces the generation of air pollutants such as SOx, NOx,
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The changing environment of the global steel industry

Due to the stagnation of steel demand in China, global steel demand is expected to increase very slowly. Since 2000, developing countries have led an increase in global steel demand, while steel demand has been at a standstill in advanced countries. Steel demand is expanding from coastal regions to inland regions, including India, China, Middle East, and Central Asia. The attention of global steel companies is now focused on reducing greenhouse gas emissions and the tightened global regulations on air pollution. In particular, China’s new Environmental Protection Law, which went into effect in May 2015, includes strict regulations on SOx, NOx, dust, and CO₂, which are being generated in large amounts in steel mills. These regulations are expected to expedite the restructuring of steel production facilities. For reference, in the USA, strengthened environmental regulations for steel companies following the launch of the EPA in the 1970s led to the restructuring of the steel industry, for example, the replacement of blast furnaces with electric arc furnaces.

In Australia, which supplies 30% of global iron ore, production of low-grade limonite is on the rise, to replace high-grade hematite, because high-grade raw material reserves are dwindling. Due to the sudden increase in global crude steel production after 2000, steel scrap generation is expected to soar in the near future. Meanwhile, commercialization of environment-friendly and innovative ironmaking technologies is expected, enabling the use of low-grade raw materials, which are distributed over vast areas across the globe. With the development and expanded utilization of new clean energy sources, such as shale gas, steel production will depend increasingly on utilization of economically produced DRI (Direct Reduced Iron) and other virgin iron resources through EAF.

The changing environment of the global steel industry
and dust. The FINEX process unseated a conventional idea that had been fixed for 300 years, that coke is crucial in the production of molten iron.

The development of direct connection between the caster and hot rolling processes

In the conventional integrated steel mill, thick slabs produced in the continuous casting process are cut into fixed lengths and cooled, to remain on standby until the next process. This is to check slab surface quality, but is also due to a gap in productivity with the rolling process that follows. The slabs are then reheated in a furnace according to the production schedule, before going through the hot-rolling process. Issues of conventional integrated steel mills have long been discussed: the hot-rolling process. Issues of conventional continuous casting technology to refurbish the mini flat mills at POSCO Gwangyang Steelworks, directly connecting a continuous supply of thin slabs produced in a caster to a hot strip mill that rolls steel at a constant speed. In 2009, POSCO successfully commercialized the world’s first compact endless cast-rolling mill (CEM; 1.8 Mt/year). The CEM process can be summarized as follows: through a direct connection between the caster and the hot rolling process, thin slabs produced in the caster are fed continuously into the hot rolling process at a constant speed, resulting in reduced facility scale and improved productivity, energy efficiency, and product quality.

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The global steel industry and the Kondratiev cycle

World-renowned Soviet economist Kondratiev asserted early in his book The Major Economic Cycles, “Technological innovation and productivity usually last for 50-60 years.” The global steel industry seems to follow Kondratiev’s theory. With the above-mentioned Bessemer converter, an innovative technology developed in the 1850s, mass production of molten steel became possible for the first time in the history of the global steel industry. About half a century later, in the 1900s, the USA succeeded in developing technologies for integrated steel mill processes, opening the era of...
the BF-based integrated steel mill.

Another half a century later, in the 1950s, new innovative technologies of BOF steelmaking and continuous casting were developed, dramatically improving the productivity of integrated steel mills, giving rise to large-scale seaside integrated steel mill systems in the 1960s. Fifty years later, in the 2000s, POSCO developed FINEX-CEM integrated steel mill technology. I believe that this new technology has the potential to lead an age of mid-sized integrated steel mills with annual capacities of 3-4 million tonnes, meeting new demand from inland regions around the world. China has set out a restructuring plan to increase the competitiveness of the Chinese steel industry, and is forced to initiate replacement of countless outdated small and medium-sized facilities in inland regions with environment-friendly steel production facilities that can make use of raw materials produced domestically. These new facilities will supply general-purpose steel, which is in the highest demand, to the domestic market. I believe that POSCO’s FINEX-CEM technology could be a good alternative solution for restructuring the steel mills in inland regions with domestic raw materials, such as low grade iron ore and non-cooking coals.

The future direction of the steel production process

The steel production processes of the global steel industry are projected to move in the following three directions.

First, large-scale seaside integrated steelworks, the most competitive model to date, will continue to be highly competitive, taking advantage of location in economical procurement of imported raw materials by large vessels, as well as large-scale facilities and their use of high-grade raw materials for mass production of high-value-added, high-quality products.

Second, the expected increase in steel scrap availability and low-cost production of DRI using shale gas will increase the economic feasibility of procuring iron resources. With strengthened regulations related to global warming, EAF-based integrated steel mills in regions with abundant iron resources will maintain competitiveness through capital investment, focusing on production of general-purpose steel. In regions where economical procurement of virgin iron resources is possible, production of flat products will continue to increase.

Third, inland regions in China, India, and other large continent countries are at a disadvantage in logistics to procure raw materials and transport final products to end users. In these regions, simplified and compact, environment-friendly alternatives to BF, such as the FINEX-CEM integrated steel mill (3-4 Mt/year), are expected to replace outdated blast furnaces or be newly constructed. The advantages of FINEX-CEM integrated steel mill technology include its use of low-grade local raw materials, production of high-quality steel using liquid iron, and the easy supply to local customers.

Ultimately, the three steel production processes will coexist to suit varying regional conditions, which will provide the resolution for various issues.

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The Kondratiev Cycle of Steel Production Technology

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Asian Steel Watch

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