

A Comparative Analysis of Integrated Iron and Steel Companies in East Asia

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Abstract

This paper presents a comparative analysis of the production systems of the various integrated iron and steel companies in East Asia based on a generation model of production systems. Japanese companies are the leaders in the field of evolution of steel production systems. However, POSCO has established a generation 2.5 system; it is rapidly catching up to its Japanese rivals. Baosteel also has a generation 2.5 system with imported technology; it has also begun to develop its own R&D activity so that it will then have the capability to evolve. All of the Chinese integrated companies (other than Bao), and the Taiwanese company CSC are trying to improve their production systems from the second generation. CSC has adopted a unique approach to upgrading by alliances with non-automobile industries. The major finding of this research is that investment for construction and upgrading of production systems is a driving force that improves the competitiveness of integrated companies in East Asia. Additionally, we can draw some suggestions about the challenges that integrated companies in East Asia face from the perspective of international competition and system evolution.

1. Purpose of this Study

This paper presents a comparative analysis of the production systems of the various integrated iron and steel companies in East Asia.

Recently, the East Asian iron and steel industry has become a hot topic for researchers in industry studies. Some of these studies have compared the industry in one economy with another (Lee et al. eds. [2005], Kawabata [2005], H. Sato [2009]); most of these studies are conducted at an industry level, and very few comparative studies have been conducted at a company-level.

Lieberman and Kang [2008] compared the productivity of various Japanese integrated steel companies with POSCO and USX, the largest producers in South Korea and the United States. They found that the high productivity of POSCO was partly due to the high capital intensity, in comparison to the Japanese producers and USX. They suggest that there was a distortion of resource allocation at POSCO, in other words, that over investment in capital equipment was carried out. Although it is easy to see how their use of the growth accounting methodology suggested this, it is also necessary to pay attention to the specific features of the iron and steel industry wherein, to a large extent, technology is embodied in

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the capital equipment. Maintaining a consistent standard of equipment through huge capital investment might be a necessary condition for a company to remain on the stage of international competition. If this is an appropriate suggestion, then “over” investment does not amount to a distortion or biased decision ; instead, it may well reflect rational behavior. Therefore, we must conduct a more thorough investigation into the nature of the technology, equipment, and management of POSCO and other major players in the iron and steel industry.

Fujimoto et al. [2006] and Fujimoto [2009] suggested a model to explain the international division of labor in the production of an automotive steel sheet, based on the concept of “architecture.” They proposed that the process architecture adopted by most integrated steel companies in Japan was an “integral type,” while companies in South Korea and China tended to adopt a “modular type.” They regarded the division of labor as a reflection of endowment of another types of capacity rather than a difference between superior and inferior capacities. In short, a modification of Ricardian comparative advantage theory was adopted in their approach. That approach allows us to understand the diversification of production systems on an economy-by-economy basis. However, when we compare companies within the same industry, it is more realistic to set some indicators on forwardness and backwardness. In his analysis of the automobile industry, Fujimoto [1999] adopted the “evolution of manufacturing system” approach. The author thinks this approach is also suitable for a comparison of iron and steel companies.

Tanaka [2008] developed the concept of a “Japan Model,” an analytical tool that could be used to explain the similarity and variety of various integrated iron and steel production systems in East Asian economies. The “Japan Model” helped to represent an integrated multi-product mass production. The emergence of POSCO in South Korea and Baosteel in China was considered a result of the diffusion of the “Japan Model.” According to Tanaka [2008], POSCO succeeded in introducing that model to South Korea, while Baosteel adopted it imperfectly in China. Such modeling in accordance with nationality is useful if we are to understand the process through which technology is transferred abroad from Japan. However, in this model, the superiority of Japanese companies is assumed, and all other varieties of production system are regarded as derivations of the Japanese systems ; this is not a sophisticated enough approach to understand the diversification of production systems.

With this understanding of the achievements and limitations of previous studies, we must develop an analytical framework that can treat both hierarchical relations and the diversification of production systems between companies. To do this, this paper presents a generation model of production systems in the iron and steel industries.

The term “production system” has various meanings depending on the research field in which it is used. In some fields, production systems refer to the information systems that are applied to production and distribution control. In other cases, the term production system refers to the work control systems that are implemented in a factory. In this paper, the author uses a wide definition wherein, the term production system refers to the patterns of combination of production factors that are in line with the production process and the production purpose. According to this definition, production systems include production technology and production management.

On one hand, the difference between a progressive system and an obsolete one can be defined by

the differences in productivity, cost, quality, and delivery. On the other hand, some factors, including market size and features, governmental policies, working rules, corporate governance, managerial cultures, and other institutional arrangements make a diversity of production systems economy to economy, and/or company to company.

The structure of the rest of this paper is as follows : In Section 2, the framework and standard of analysis that are adopted in this paper, based on the concept of production system evolution, are presented. In Section 3, a concrete analysis of various production systems and investment behaviors is undertaken. In Section 4, the major findings and implications that emerge from this analysis are presented.

2. Evolution of Integrated Production System in Iron and Steel Industry

In iron and steel industry, there are two major types of production system. One is the integrated production system ; this system comprises three processes—iron-making, steel-making, and rolling. The major material that is used in this process is iron ore. The second type of system is the mini-mill system ; this system is comprised of two processes—steel making and rolling. The major material that is used in this system is steel scrap. Usually, the integrated system is adopted only by big businesses, because its minimum efficient scale reaches 3 million tons per annum. The mini-mill process is the most appropriate for small and medium enterprises, because its minimum efficient scale is about 300 thousand tons per annum.

This paper focuses on the integrated production system because this is the system that the major players in East Asia tend to use. Indeed, a rough estimate of the proportion of integrated production, represented by the ratio of crude steel production by basic oxygen furnace (BOF), is 83.9% in East Asia, while it is 69.8% in the world (WSA [2011a : 25]).

The process of steel production evolved over many years and underwent several stages. The first generation of integrated production system emerged in the late nineteenth century. This system allowed for the mechanized mass production of steel, although there were some limitations ; for instance, the factories in this process had to be located near to a mine or coalfield. Accordingly, when the resources became exhausted, the steelworks declined. The main products in this system were long products and ingot for forging, as the mass production of sheet steel was not required until the emergence of consumer durables. The productivity and energy efficiency of this early type of steel production were limited by the technology that was available. For example, the open-hearth furnace, which was the major furnace used for steelmaking at the time, needed a significant amount of heavy oil to fuel it. The ingot casting and slabbing/blooming process to produce semi-products also involved lengthy cooling and reheating processes ; moreover, the rolling process that was used to produce sheet products was not automated. Workers had to keep materials with pinchers and control the sheet rolling process manually.

After that, a gradual evolution of technology and systems occurred in Europe, the United States, the Soviet Union, and Japan from the 1920s to the 1970s. For example, in the 1920s in the United States,

the development of a strip mill allowed for the mechanized mass production of wide strip for automobile body panels as well as those for appliances and cans. After WWII, flat sheets became the main product category. During this period, factory locations also shifted—from close to mines to near the coast. After the war, in peacetime, most of the best materials were imported, as this was regarded as a good way to ensure the long-term operation of steelworks. BOF was developed in the 1950s in Austria. This process removed the necessity of oil fuel and promoted productive efficiency. Then, in the 1970s, the use of the continuous casting machines became widespread. They removed the ingot casting, reheating and slabbing/blooming processes to produce semi-products. It meant shortening of lead time as well as promoting energy efficiency. As a result, a second-generation integrated steel production system was established in the 1970s; it was this system that marked the arrival of a fully mechanized mass production system for steel.

From the 1950s to the 1970s, Japanese companies were at the forefront of the development of integrated steel production. A number of green-field integrated steelworks were constructed one after another. In addition, the Japanese companies developed a new type of system that was designed as a countermeasure to slow economic growth after the oil crisis in 1970s. It was based on the same major facilities as the second-generation process, but it realized flexible mass production. Integrated steel companies in Japan continuously and quickly developed and produced new steel products. For example, many kinds of galvanized sheet, high-tensile steel, and fireproof steel were developed in quick succession. Moreover, many of the Japanese steelworks developed multi-product, small-batch production management systems (Okamoto [1984], Baba and Takai [1997]), which were helped by computer control (Inoue [1992]). The processes were fine-tuned, and the integrity of the production system was reinforced (Fujimoto [2004], Fujimoto et al. [2006]). Steel products became sophisticated materials with high-technology. The author refers to this new system as generation 2.5.

It should be considered as generation 2.5 rather than generation 3, because limitation of the second generation system has not been overcome yet. It has been predicted that when this third generation does emerge, it will incorporate a post-mass production system that will bring about great improvements in terms of ergonomics, flexibility (Sakamoto [1996]), and sustainability. Ergonomic improvements will mean that the process no longer involves exhausting, dirty, or dangerous work; improvements in terms of flexibility will mean that the system will focus on multi-product, small batch production that generates no waste or stockpiles. At present, even in generation 2.5, waste and stockpile are inevitable because of the contradictions in this system between mass production and multi product small batch production (Inoue [1992] [1998 : 71-80]). The improvements in sustainability that the third generation of steel processing will bring about will result in reduced greenhouse gas emissions, lower pollution, and the use of low-grade materials.

The analysis that will be undertaken in this paper will rely on a deeper investigation of the generation and features of production systems that each company has established. Various reliable and concrete indicators can be used to assess the benefits of various production systems. First, the system can be judged according to whether the integrated iron and steel companies have state of the art equipment and facilities. Second, an effective system will be able to produce the volume and grade of products that

are required for use by the automobile industry, whose requirements regarding quality, cost, and delivery are very strict. Thirdly, a progressive company will have a high level of expenditure for capital equipment and research and development activity, as this ensures that the system is able to evolve over time.

In terms of conducting an economic analysis, it is important to look at both the production system itself and the investment that is made into the system. This paper adopts two approaches that a company's investment activity can be analyzed ; first, the current production system should be considered in the light of past investment and, second, the feature of investment behavior of a company in the international marketplace should be examined as an indicator of competitive strategy.

3. A Comparison of the Production Systems and Investment Behavior of Integrated Steel Companies in East Asia

3.1 Status of Integrated Steel Companies in East Asia

In this section, the production systems that are in place in integrated steel companies in East Asia are investigated. Before the specific case studies are presented, an overview of the large-scale integrated steel companies in East Asia is given¹⁾. In 2010, 59% of the crude steel in the world was produced in East Asia (Table 1). In East Asia, there were 50 large integrated steel companies, and, together, they produced 76.6% of the crude steel in this area. The regional concentration ratio was not high ; however, the national concentration ratios varied in different economies. For instance, the national concentration was high in South Korea and Taiwan, and it was low in China.

For the development of the iron and steel industry, the domestic market is very important. Although steel goods are tradable, the transportation cost is high. A large-scale domestic market is necessary for the existence of large integrated steel companies. In particular, the demand for high-grade steel stimulates the evolution of an integrated production system.

Considering those restraints, we can understand one of the reasons why there are large integrated steel companies in China, Japan, South Korea, and Taiwan. In these economies, the annual demand for crude steel is over 20 million tons (Table 2). Moreover, there is huge demand for high-grade steel products, such as cold rolled sheets and galvanized sheets, in China, Japan, and South Korea. In contrast, the demand for these kinds of products in Taiwan is small and even smaller than Thailand and Malaysia. This disparity reflects a difference in the scale of automobile production.

3.2 Japanese Integrated Companies : Front-runners of System Evolution

There were five big integrated producers in Japan in 2010 ; of these, Nippon Steel Corporation and JFE Steel were the leading companies. NSC and Sumitomo Metal Industries signed a merger agreement in 2012 to institute Nippon Steel & Sumitomo Metal Corporation.

As we explored previously, the Japanese integrated companies developed their generation 2.5 pro-

1) In this paper, the term large-scale refers to a crude steel production capacity of 3 million tons or more per annum.

Table 1 Large integrated steel companies in East Asia, 2010

Economies and companies	Crude steel production (mil. tons)	Production share in East Asia
Subtotal of the Japanese large integrated	90.8	10.9%
Nippon Steel	35.0	4.2%
JFE Steel	31.1	3.7%
Sumitomo Metal Industries	13.3	1.6%
Kobe Steel	7.6	0.9%
Nissin Steel	3.8	0.5%
Subtotal of the South Korean large integrated	48.3	5.8%
POSCO	35.4	4.2%
Hyundai Steel	12.9	1.5%
Subtotal of the Chinese large integrated	486.7	58.4%
Hebei Iron and Steel Group	52.9	6.3%
Baosteel Group	44.5	5.3%
Wuhan Iron and Steel (Group)	36.5	4.4%
Shougang Group	31.2	3.7%
Jiangsu Shagang Group	30.1	3.6%
Shandong Iron and Steel Group	23.2	2.8%
Anshan Iron and Steel Group	21.8	2.6%
Hebei New Wuan Iron and Steel Group	18.6	2.2%
Magang (Group)	15.4	1.8%
Hunan Valing Iron and Steel Group	15.1	1.8%
Baotou Iron and Steel (Group)	10.1	1.2%
Benxi Steel Group	10.1	1.2%
Anyang Iron and Steel Group	10.0	1.2%
Subtotal of other Chinese large integrated (29)	167.2	20.0%
China Steel Corporation Group in Taiwan	12.7	1.5%
Total East Asian Large Integrated Steel Companies (50)	638.5	76.6%
Total in East Asia	834.1	100.0%
Total in the world	1,417.3	—

Note : East Asia includes Japan, South Korea, North Korea, China, Mongolia, Taiwan, Indonesia, Malaysia, Thailand, Philippines, Vietnam, and Myanmar.

Source : Compiled from CISA [2011], WSA [2011a] [2011b].

duction systems in the 1980s. They maintained long-term relationships with major customers, such as automobile assemblers and shipbuilders (Baba and Takai [1997], Kipping [1998]). These Japanese firms conducted joint product development programs with their customers (Nakaoka and Usuda [2002 : 214-223], Kawabata [1995 : 125-132]) and developed multi-product small-batch production process in their steelworks (Kawabata [1998], Inoue [1998 : 71-80]).

The superiority of Japanese integrated companies is demonstrated by the fact that they are the main steel suppliers to Japanese automobile assemblers, such as Toyota, Honda, and Nissan. Indeed, Japanese automobile assemblers need access to the high quality steel goods such as high-tensile cold rolled

Table 2 Market size of crude steel and high-grade steel in East Asian economies in 2010

	Apparent consumption of crude steel (1,000 tons)	Apparent consumption of galvanized sheet (1,000 tons)	Apparent consumption of cold rolled sheets and strip (1,000 tons)	Number of automobiles produced
China	599,969	27,086	63,070	18,264,667
Japan	68,300	8,095	4,779	9,625,940
South Korea	54,573	5,452	5,055	4,271,941
Taiwan	21,320	593	1,328	303,456
Thailand	16,299	1,751	2,422	1,644,513
Vietnam	13,405	N.A.	1,927	32,920
Indonesia	10,884	532	1,222	704,715
Malaysia	9,607	1,072	1,567	567,715
Philippines	4,419	258	283	63,530
Singapore	3,030	- 22	151	-

Source : Compiled from Nikkan Jidoshu Shimbun Sha and Automobile Business Association Japan eds., [2011], WSA [2011a], CISA [2011], SEAISI [2011].

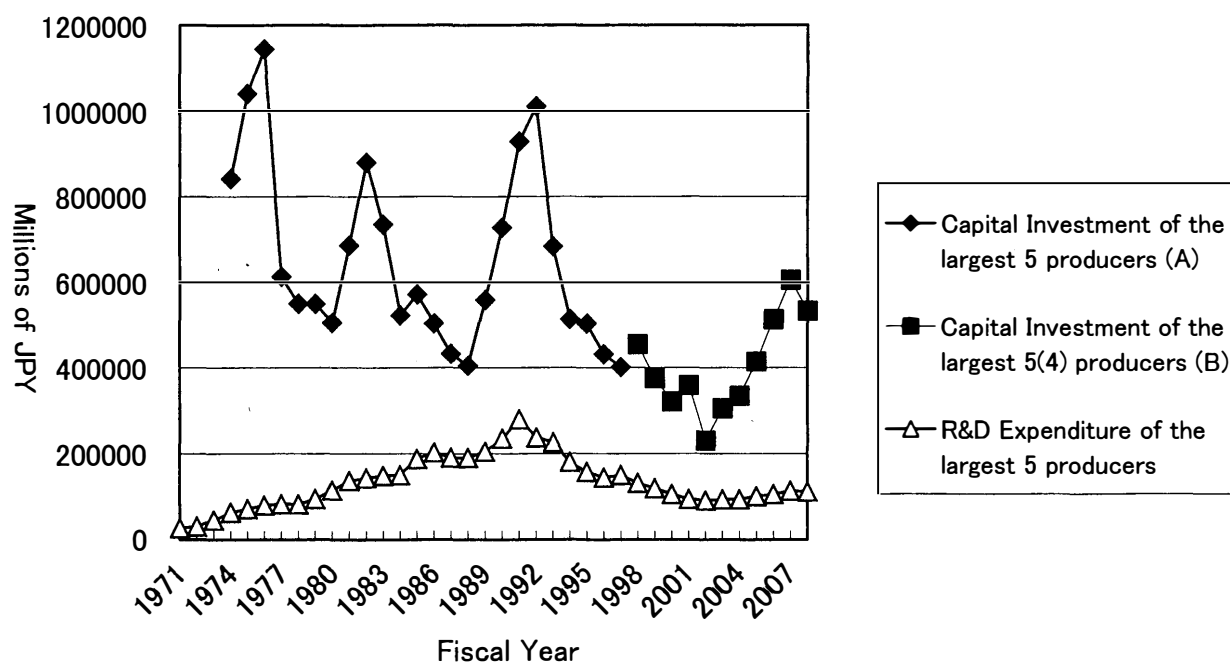
sheets, bearing steel, and various kinds of surface treated sheets that are produced by Japan producers (JRCM-NEDO [1999 : 34]), and the suppliers that meet demands for supplies of high-tensile steel are generally Japanese steel companies (IRC [2004 : 47-75]).

However, the Japanese integrated companies have experienced some problems with one aspect of their investment in systems. After the economy declined rapidly at the beginning of the 1990s, the R&D and capital expenditure of most Japanese integrated companies began to stagnate (Figure 1). Because of this, some of the companies' facilities became obsolete, and the management began to embrace a more conservative approach to innovation. Minor improvements were favored over significant changes to the main facilities. For example, an alternative technology to the blast furnace—the Direct Iron Ore Smelting Reduction Process (DIOS)—was developed with public funding, and a pilot plant was constructed in 1990s. However, no companies had the confidence to put this into practical use. Instead, most Japanese companies adopted the more cautious approach of expanding the internal volume of their existing blast furnaces through incremental thickening.

In the late 1980s and 1990s, most Japanese integrated producers rationalized their production process by job reduction (Kamada [1994], Kawabata [2003 : 10-11]). Then, in 2003, an industrial boom began on the back of the growth of the Chinese economy. At the time, the rapid production recovery meant that the workload for those workers who had been retained was much heavier than it had been before, because there were fewer workers to undertake the work and more work to be done. The result of this was an increase in the number of occupational injuries. In the ten years from 1995 to 2004, the rate of lost work time due to injuries and the severity rate of occupational injuries increased significantly (Kawabata [2006 : 42]).

From 2003 to 2007, most Japanese integrated companies performed well, which led to an upsurge in capital expenditure (Figure 1). Most companies engaged in investment to relieve the bottlenecks

Figure 1 R & D and capital expenditure of the Japanese integrated companies



Note : In terms of capital expenditure, data from four producers are only given from 2003 because the merger between NKK and Kawasaki Steel occurred.

Source : Ministry of General Affairs [various years], JISF [various issues].

encountered when making high-grade products. In particular, they invested in BOF, pickling line, and continuous galvanizing line that were necessary for manufacturing high-grade products.

Moreover, these companies tended to revise their policies toward the expansion of their production scale from passive to active. For instance, NSC and Sumitomo Metal decided business integration and set a steel production goal of a new company as 60-70 million tons in the world, while the target of JFE Steel is 40 million tons in 2017 and 50 million tons eventually²⁾. Further, they became aggressive about foreign direct investment.

The key focus of most foreign investment undertaken by Japanese integrated companies is the diffusion of generation 2.5 systems abroad, so that the same level of technology and management can be implemented in all production units. Until the 1990s, however, Japanese integrated producers did not construct integrated steelworks abroad. Instead, they instituted many joint ventures in rolling and surface-treating processes. Between Japan and the host economies, many cross-border process linkages have been organized (Kawabata [2005 : 151-158]). In these kinds of linkages, the base material was exported from the integrated companies in Japan and then rolled or/and surface-treated by the joint venture companies or alliance partners in the host economies. Technology and production knowledge were transferred from the Japanese companies to these rolling/surface-treating ventures to ensure the consis-

2) Press release of NSC and Sumitomo Metal on April 27, 2012 and JFE Group's Fourth Medium-Term Business Plan released on April 20, 2012.

tent technological level of each process. In addition, the fine-tuning of processes was implemented between the Japanese companies and the ventures in host economies.

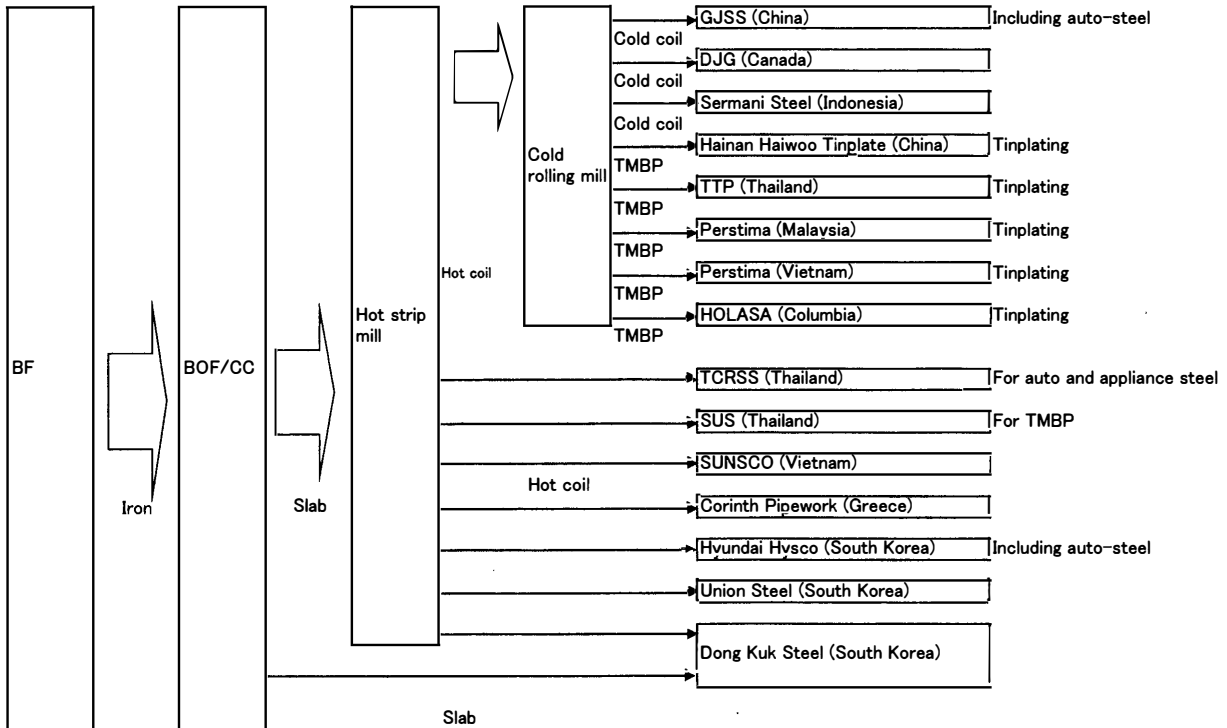
Figure 2 shows the process linkages or inter-firm international divisions of labor that were arranged by JFE Steel. In some cases, slabs were exported to joint ventures or alliance partners abroad ; in other cases, hot coils or cold coils were exported.

After 2003, these kinds of process linkages became more difficult to implement as the supply volume of the base material was constrained by the limited capacity of the upstream processes in Japan. To overcome this limitation, the Japanese integrated steel producer companies developed two kinds of solution.

The first involved participating in the construction of newly integrated steelworks abroad. JFE Steel decided to study feasibility of integrated steelworks in Vietnam with Taiwanese E-United Group. Sumitomo Metal Industries has constructed a new integrated steelworks in Brazil by joint investment with Vallourec, a pipe producer in France. While these joint ventures abroad were one way to overcome the problems with limited Japanese supplies, they were risky as they involved huge capital investment.

The second solution was the procurement of high-grade base materials from reliable partners in host economies. For example, NSC has increased the amount of hot coil that it procured from Baosteel ; this allowed it to expand the capacity of BNA, a cold rolling joint venture in China.

Figure 2 Inter-firm division of labor organized by JFE Steel Corporation



Abbreviation: BF; blast furnace. BOF; basic oxygen furnace. CC; continuous casting machine.

TMBP; tin mill black plate (special cold coil for tinplating).

Source: Author collated the data from various materials.

The challenging aspect of both solutions is that there are only a limited number of reliable partners for these kinds of ventures. Japanese companies have to transfer their technology and knowledge if they are to maintain the production system of generation 2.5.

Figure 3 and Figure 4 show companies' R&D and capital expenditure and their ratios to sales. The two Japanese producers clearly perform highly in terms of R&D. However, it is worth noting that they are not necessarily the two leading companies in East Asia. In terms of capital expenditure, the two big Japanese companies fall below one or two of their Asian rivals.

3.3 POSCO : Technological Independence and Global Expansion

In South Korea, POSCO had been the sole integrated steel producer for many years. In 2010, Hyundai Steel also began integrated production. Because Hyundai's operation is only at the initial stage, their system will not be examined in this paper.

POSCO made huge capital investments in the 1980s and 1990s and installed state of the art facilities in two integrated steelworks (Abe [2008] and Tanaka [2008]). Moreover, POSCO set a goal of 50 million tons of crude steel production per annum. Its strategic target is "become a global leader targeting Big 3, Top 3"³⁾.

In addition, POSCO has been active in R&D. Its R&D efforts came to fruition in the form of new smelting technology, FINEX, which began commercial operations in 2007. Unlike a blast furnace, low quality materials can be used with FINEX, and the amount of SO_x, NO_x, and dust that is emitted is far less than with a blast furnace. The success of FINEX demonstrates that POSCO has moved away from the age of technology imports to the new age of internal development⁴⁾.

In terms of the relationship that the company has with its customers, POSCO is trying to emulate the Japanese strategy, by concentrating on the production of high-grade steel for automobiles, shipbuilding, and electrical and electronic appliances. The production of steel products for automobiles has risen from 1.9 million tons in 2002 to 6.16 million tons in 2008⁵⁾. In addition, in 2005, POSCO has started to supply galvanized sheets for body panels, the highest-grade products, to Japanese automobile assemblers (*Japan Metal News*, March 8, 2005).

In terms of its management, POSCO has promoted business process innovation with the help of information and communication technology⁶⁾. The lead time of hot-coil was shortened from 30 days to 14 days. Additionally, POSCO achieved "just in time" delivery to South Korean automobile assemblers,

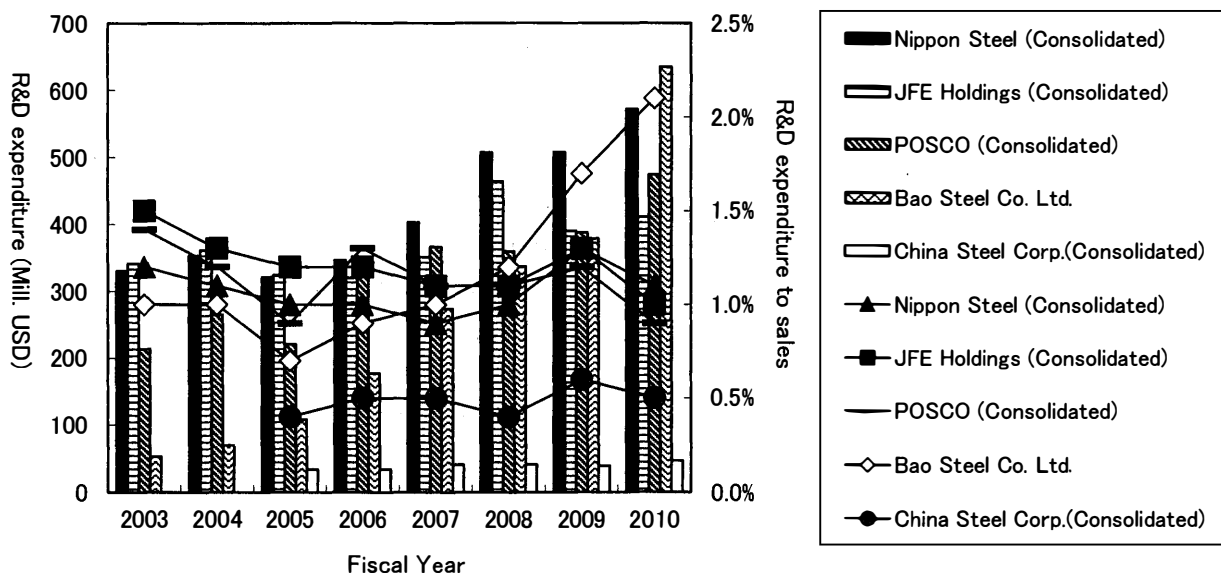
3) POSCO's website (<http://www.posco.com/homepage/docs/eng2/html/invest/faq/s91b8010010l.jsp>).

4) In April 25, 2012, NSC announced it has filed a lawsuit against its former employee and POSCO. NSC insisted that POSCO illicitly acquired and used NSC's trade secrets regarding Grain Oriented Electrical Steel Sheet (GOESS), with involvement of the former employee. POSCO denied the notion of NSC. Technology transfer through former employees is, whether it is formal one or not, one of important issues between the Japanese companies and other Asian companies in some industries. However, this event does not affect the author's judgment on the generation of POSCO's production system. POSCO's achievement in many fields does not disappear in spite of GOESS problem that is under dispute.

5) Presentation at Tokyo Stock Exchange, December 2006 and CEO Forum of POSCO, January 2009.

6) The description of business process innovation in this paragraph is based on Otsuka [2004].

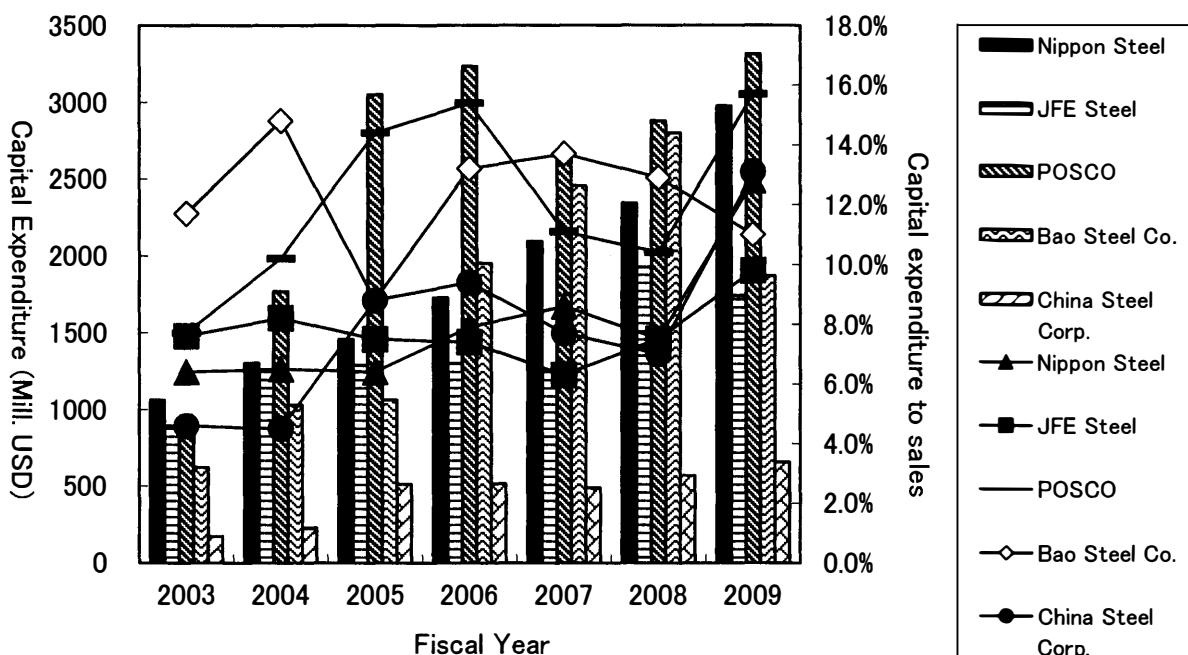
Figure 3 The R & D expenditure of major integrated iron and steel companies in East Asia



Note : The bar chart shows R&D expenditure ; the line chart shows the ratio of R&D expenditure to sales. The Japanese fiscal year begins in April and ends in March, while the fiscal year for non-Japanese companies begins in January and ends in December. The exchange rate that was used to convert between currencies was the rate at December 31 for each year.

Source : Compiled from Nippon Steel [various years], JFE Holdings [various years], POSCO [various years], Bao-steel Co. [various years], and CSC [various years].

Figure 4 Capital Expenditure of major integrated iron and steel companies in East Asia



Note : The bar chart shows capital expenditure ; the line chart shows the ratio of capital expenditure to sales.

Source : Compiled from World Steel Dynamics [2011].

as a result of its implementation of the Six Sigma quality control movement. The information-sharing with automobile assemblers was one of the most important factors behind this achievement, a result of pursuit of long-term cooperation with its customers. POSCO's production systems are now generation 2.5, in line with its Japanese rivals.

About the global strategy, POSCO adopts a different style from the Japanese companies. POSCO's target in foreign market includes not only high-grade segments but also low-grade mass markets, which means they must implement massive investment. According to its plan, 7 million tons of crude steel production capacity will be installed abroad until 2015⁷⁾. For example, POSCO has agreed with Krakatau Steel in Indonesia that they will install new integrated steel facilities there. In 2011, 9% civil works completed. POSCO plans to open it with crude steel capacity of 3 million tons per annum. Moreover, POSCO began to install semi-integrated steelworks in Brazil by a joint venture with Dongkuk Steel Mill from South Korea and Vale, one of the largest mining companies in the world. This steelworks will have a blast furnace and steelmaking factory with the capacity of 3 million tons per annum. There will be no rolling factory and slab will be exported. In 2011, 76% of land preparation completed. According to POSCO, its operation will start in 2015. Besides them, POSCO has constructed some downstream rolling and galvanizing processes abroad, like the Japanese companies.

POSCO's project scale is bigger than the two Japanese leading companies are. In spite of the high risk of investment in the context of the world recession, POSCO remains firmly committed to its investment strategy.

As Figure 3 and 4 make clear, the R&D expenditure of POSCO reached similar level with the two Japanese leaders. Moreover, the volume of capital investment undertaken by POSCO is highest among East Asian major producers in most years.

3.4 Baosteel ; Product Upgrading and Searching for Internal Innovation

The third case that we shall examine is Baosteel Group and Baoshan Iron and Steel in Shanghai, China⁸⁾. China is the largest steelmaking economy in the world. In 2010, there were 42 large integrated steel companies in that economy. However, most of them relied on old, brown field steelworks that had been constructed during the period of the command and control economy. Until very recently, only Baosteel had green field steelworks with state of the art technology.

From the 1970s to the first half of the 1980s, the Chinese government promoted the first stage of Baosteel construction⁹⁾. The technologies for iron making and steel making were transferred from

7) The company's information in this paragraph is from the presentation materials of POSCO, 2012 CEO Forum, February 3 and POSCO News, August 23, 2011.

8) Before the beginning of Reform and Open-door Policy, Baosteel was called Baoshan Steelworks because it was a state-owned production unit rather than independent corporation. After the several steps of reform, Baosteel Group Corporation has become a state owned holding company. Baoshan Iron and Steel Co. Ltd. is a major subsidiary and the largest steel production company under Baosteel Group. In this paper, all of them are cold Baosteel, if there is no inexpediency.

9) The description of the three stages of construction that is given in this paragraph is based on Nakaya [2008 : 94-

NSC, and the piping technology was introduced from former West Germany. The second construction stage was completed in 1991 ; in this stage, Baosteel established an integrated production system for flat products. This effectively amounted to the establishment of a second-generation system. In the third stage of development, in the 1990s, Baosteel installed some facilities that were necessary for the production of high-grade products such as electrical sheets and galvanized sheets. In the 2000s, Baosteel has set the goal of producing 80 million tons of crude steel per annum (*Japan Metal Daily*, November 5, 2007) and planned to construct a new integrated steelworks in Guang Dong Province, China. Moreover, Bao has acquired various domestic steel companies under the industry policy of the Chinese central government. Despite these developments, a big foreign investment project in Brazil came to a standstill as a result of the world financial crisis.

In the 2000s, Baosteel's position in the automobile steel market has improved rapidly. Bao started to supply automobile steel for body panels not only to Chinese automobile assemblers, but also to foreign-affiliated assemblers such as Shanghai General Motors and Shanghai Volkswagen (C-Press [2003 : 181-184] [2008 : 396-397]). Bao's domestic market share of cold rolled sheet for automobiles reached 47% in 2004 (Baosteel [2006 : 19]).

However, the Japan-affiliated assemblers such as Nissan, Honda, and Toyota refused to allow Bao to supply them with steel for car body panel. To solve this problem, Baosteel decided to institute a new joint venture with NSC and Arcelor-Mittal, which was called BNA (the Baosteel-NSC/Arcelor Automotive Steel Sheets Co., Ltd). BNA is only involved in cold rolling and galvanizing processes, but it supplies the highest grade of automotive steel sheets with technologies that were transferred from NSC ; Baosteel is one of the major suppliers of hot coils to BNA¹⁰⁾. In other developing economies such as Thailand, Japan-affiliated cold rolling joint ventures have imported hot coils from Japan to produce the high grade sheets, because there are no reliable local suppliers (Kawabata [2005 : 151-158] [2008 : 276-286]). While Baosteel can supply high-grade hot coils, it is unable to undertake the production of high-grade cold rolled sheets and galvanized sheets by itself for Japan-affiliated automobile assemblers—this highlights both Bao's capabilities and its limitations.

In short, the production systems of Baosteel are now generation 2.5. Baosteel is now able to take advantage of all the available technologies that were imported from industrialized economies. Bao's capital investment volume and their capital investment ratio exceeded the two biggest Japanese steel companies from 2006 to 2008 (Figure 4). Clearly, Bao has established itself as a young third runner in the East Asian steel industry.

Despite this, Bao's R&D capability—in other words, the capability of their system to evolve—has not yet been internalized. Bao still needs technology transfer from Japanese partner in high-grade segment. However, Baosteel has recently started to invest much more in R&D. In 2003, they invested very little in R&D. Since then, this amount has increased significantly and exceeded all major rivals in East Asia in 2010 (Figure 3).

96].

10) The plant visit, interview and telephone interview with an executive of BNA, March 2007, January 2008.

3.5 Chinese Integrated Companies other than Baosteel : Searching for New Development Stage

Aside from Baosteel, there were 41 other large integrated steel companies in China in 2010. For the purposes of this paper, they shall be treated as if they were one homogenous group. In general, the large Chinese steel companies improved their production systems—from first to second generation—in the 1990s, under the reform of China to an open market economy. They balanced the production capacity between iron making, steelmaking, and rolling¹¹⁾. They replaced obsolete open hearth furnaces with basic oxygen furnaces. They shut down ingot casting factories and installed continuous casting machines. They adjusted the product mix so that they now produced more flat products than long products.

However, after this, they encountered difficulties, as high-grade steel products cannot be produced without the knowledge and expertise of engineers, managers, and skilled workers, which the Chinese producers had not yet acquired. This meant that very few Chinese companies were able to enter the high-grade steel market for automobiles and electrical/ electronic appliances.

As a countermeasure to this situation, some Chinese companies instituted joint ventures with foreign companies from Germany, South Korea, and Japan. However, the production lines of most of these ventures were limited to rolling and galvanizing.

To overcome this limitation, some companies have undertaken the construction of new integrated steelworks with state of the art facilities. The largest project of this kind is the Caofeidian steelworks by Shougang Jintang United Iron and Steel Company, whose blast furnaces started operating in 2009. When the construction is completed, the steelworks is expected to have a production capacity of 10 million tons of crude steel per annum. However, state of the art facilities are not the only aspect that is necessary for the production of high-grade steel. For these companies to evolve to the next step, the transfer of knowledge and expertise from foreign companies or Baosteel will be necessary¹²⁾.

Let us examine the case of Maanshan Iron and Steel (Ma Steel) in Anhui Province as another example. Ma Steel was the first state-owned company that was listed on Hong Kong Stock Exchange, which meant that it was one of the leading companies to influence the economic reform policy. Ma Steel improved its product mix in the 1990s and began steel sheet production using the Compact Strip Production system (CSP) that was developed by SMS Demag in Germany. CSP system combines a thin-slab casting machine and compact hot strip mill. It reduced investment cost and minimum efficient scale of hot-coil production. At first, some mini-mills in the United States introduced this system and succeeded (Preston [1991]). In the case of China, some integrated producers adopted it to reduce investment costs ; however, there were technological limitations to the system, as CSP was only able to make low and medium grade sheet products. In 2006, Ma Steel succeeded in shipping sheets for inner body panels to Chery Automobile Co. in China (The Editorial Board of China Steel Yearbook [2007 : 177]). It was the first shipping of sheet for body panel made with CSP in China. On the one hand, it shows the

11) The description of capital investment given in this paragraph is based on Ye [2003].

12) The necessity of technology transfer from Baosteel was suggested by Takashi Sugimoto in personal communication.

superiority of Ma Steel. On the other, it means any producers in China, including Ma Steel, cannot make sheet products for outer body panel with CSP¹³⁾.

To overcome the limitations of CSP, Ma Steel constructed a new integrated steelworks alongside the Chang Jiang River, which included a full-scale strip production system and other state of the art facilities from Japan and other advanced economies. Nonetheless, it is not clear how Ma Steel will acquire the knowledge and technical expertise that will be necessary to make high-grade steel.

In addition to those capital expenditures, large-scale domestic mergers and acquisitions are being carried out under the guidance of central government. For example, Hebei Steel Group, Shang Dong Steel Group, Hebei New Wuan Iron and Steel Group are newly instituted companies as results of mergers. However, those mergers do not necessarily lead the construction of new integrated steelworks.

Indeed, Chinese integrated companies in this category are still relying on second-generation production systems.

3.6 China Steel Corporation in Taiwan : Capacity Expansion and Upgrading in Its Own Way

Gaoxiong steelworks of the China Steel Corporation (CSC) had been the only integrated steelworks in Taiwan from the 1970s to 2009. At that steelworks, a second-generation production system has been developed over a four-stage construction project. After the 1990s, however, CSC failed to expand its crude steel production capacity because of strict environmental regulation. In Taiwan, both CSC and other steel producers have only managed to add rolling mills in the 1990s (Y, Sato [2008 : 93-97]), which has led to a slab shortage. In 2006, CSC imported 1.8 million slabs from a joint venture in Japan¹⁴⁾. Moreover, high-grade steel only makes up a small share of the company's product mix. In mid-2000s, the galvanizing capacity at CSC was only 12% of its hot strip mill capacity. This was significantly smaller than the 28% share that galvanizing has at Japanese integrated producers, 15% at POSCO, and 23% at Baosteel¹⁵⁾. This means that not only was quantitative expansion a challenge for CSC, but so too was qualitative upgrading.

However, this does not necessarily mean that CSC has only a low level of technical potential. Rather, CSC is able to supply galvanized sheets to be used for body panels to foreign-affiliated automobile assemblers, including Japan-affiliated companies in Taiwan¹⁶⁾. The constraining condition of the ability to upgrade its product mix is market size. The number of automobiles that are produced in Taiwan is very small (Table 2). This means there is very little demand for high-grade sheets. Moreover, there are also very few R&D centers of automobile companies in Taiwan. This means that CSC is unlikely to experience joint material development with automobile producers¹⁷⁾.

In the 2000s, CSC instigated two kinds of upgrading program. The first involved expanding its

13) The plant visit and interview with the managers of Ma Steel, March 2007.

14) Presentation on the company given on May 29, 2007. The author downloaded it on November 4, 2008 from the website of CSC.

15) The author calculated the statistics on the basis of data taken from the Japan Iron and Steel Federation.

16) Plant visit and interview conducted by the author with executives and managers of CSC, in August 2008.

17) *Ibid.*

capacity to 20 million tons of crude steel per annum. After a long period of environmental assessment, Dragon Steel, a 100% subsidiary of CSC, undertook the building of a new integrated steelworks, and the first blast furnace started operation in 2010. The second upgrading program involved establishing R&D alliances with nine user industries, including those involved in the production of bolts, nuts, and hand tools¹⁸⁾. Those business partners included not only big businesses but also medium and small companies. This type of upgrading approach is different from those adopted by POSCO and Baosteel.

In terms of a global strategy, there does not seem to be much room for CSC to make massive investments abroad, although it does have some plans to institute rolling/galvanizing joint ventures. In Taiwan, two other companies have plans involving the establishment of integrated steelworks abroad. One is a project by E-United Group and the other is by Formosa Plastics ; both projects are proceeding in Vietnam.

In Figures 3 and 4, CSC's volume of expenditure to R&D and capital equipment seems to be small. About capital expenditure, however, it might be a result of a limitation in statistics. It is possible that CSC's capital expenditure does not include its major subsidiaries, such as Dragon Steel, which means that CSC's investment volume is undervalued.

4. Conclusion

Through the case studies presented in this paper, it is clear that the achievement of major integrated steel companies can be summarized as follows : Japanese companies are the leaders in the field of the evolution of steel production systems. However, POSCO has established a generation 2.5 system ; it is rapidly catching up to its Japanese rivals. Baosteel also has a generation 2.5 system with imported technology ; it has also begun to develop its own R&D activity so that it will then have the capability to evolve. All of the Chinese integrated companies (other than Bao), and the Taiwanese company CSC are trying to improve their production systems from the second generation. CSC has adopted a unique approach to upgrading by alliances with non-automobile industries. Table 3 presents an overview of the result of this analysis.

The major finding of this research is very simple—investment for construction and upgrading of production systems is a driving force that improves the competitiveness of integrated companies in East Asia.

Additionally, we can draw some suggestions about the challenges that integrated companies in East Asia face.

From the perspective of international competition, there are some issues that may well cause upheaval in terms of the status of integrated companies in East Asia.

The first issue is the maturity and catch-up among the East Asian companies. Front runners in the field may well be overtaken by other companies. This is a particular threat for Japanese integrated companies, in the face of huge capital investment and R&D expenditure by Asian rivals. The Japanese com-

18) *Ibid.* See also Y. Sato [2008 : 100-107].

Table 3 Abstract of comparative analysis

	Japanese Integrated Steel Companies	POSCO	Baosteel	Chinese Integrated Companies (with the exception of Baosteel)	China Steel Corporation
Integrated Steel Production System	Generation 2.5	Generation 2.5	Generation 2.5	Generation 2	Generation 2
Target of crude steel production	Nippon Steel & Sumitomo Metal : 60-70 million tons. JFE Group : 40-50 million tons	50 million tons	80 million tons	Company by company	20 million tons
Capital Expenditure in home economy	Large-scale domestic mergers. Debottlenecking and expansion for high-grade steel	Debottlenecking and expansion for high-grade steel	Large-scale domestic mergers. Construction of new integrated steelworks	Large-scale domestic mergers. Some are building new integrated steelworks	New integrated steelworks started operation
Research and Development	High level	High level	Previously weak, but increasing rapidly	Not Available	Low level, but making alliances with various industries
Status as supplier of steel sheet for automobiles	Major suppliers and joint development partners of the Japanese automobile assemblers. Monopolistic supplier of some important materials	Expansion of customers, including Japanese assemblers. Reinforcing the joint development with assemblers	Supplier to local and US/European affiliated automobile assemblers. Supply to Japanese affiliated assemblers through joint venture with NSC	Technology transfer through joint venture is needed to supply auto steel sheet	Supplier to local and foreign-affiliated assemblers. Because of small domestic demand, production volume is small. Scope of joint development is limited
Foreign direct investment in steel production	Diffusion of generation 2.5 system abroad. Investment in downstream processes and institution of process-linkage. Some plans of new integrated steelworks	Investment in both high-grade and commercial grade steel production. Construction of downstream processes and integrated steelworks abroad	Concentration to investment within home economy	Concentration to investment within home economy	Investment in downstream processes

Source : Author compiled.

panies are struggling to keep their aging facilities up to date. However, it is difficult for the Japanese companies to keep pace with rivals in emerging economies. Strategic choice in investment field for keeping their competitiveness is an important challenge for the Japanese companies.

The second issue is cross-border mergers and acquisitions (M&A) for corporate growth. Many of the integrated companies in East Asia have been built up on the basis of capital expenditure. Japanese companies tend to focus on internal growth or domestic mergers because they are keen to maintain the

level of technology and management for high-grade steel in all of their steelworks. In China, not only a wave of construction of new integrated steelworks, but mergers and acquisitions have been observed in recent years, while the latter is domestic movement under political pressure of the central government. In the face of the emergence of Arcelor-Mittal and Tata Steel, it is clear that companies can expand faster when cross-border mergers and acquisitions are the main tactic than when internal growth and domestic merger are stressed. The attitude toward cross-border M&A will be a critical strategic issue for integrated companies in East Asia.

From the perspective of system evolution, one major challenge in the long-term is the evolution of a company's system to third generation. Even those companies that have 2.5 generation systems in place already should not become complacent; there is fierce international competition and public pressure to develop technologies and revise practices to prevent global warming. Energy saving and the reduction of CO₂ emission are important focus areas for the iron and steel industry. Intensive R&D should be conducted into establishing new technologies including CO₂ collection and reposition, and hydrogen reduction. Unless these kinds of technological advances take place, companies will have to adjust their main technological focus from an integrated system to a mini-mill system, as the CO₂ emissions of the mini-mill system are currently far smaller than the integrated system. This will be a great challenge for all integrated steel companies, not only in East Asia, but also throughout the world.

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