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Prospect of Industry-academia Cooperation in the Future Ironmaking Field Centering on the National Project Aiming at Consideration of High Phosphorus Iron Ore

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Abstract

The economic growth of China, the rapid expansion of steel production, and the increase in crude steel production depended on the production of pig iron in blast furnaces from iron ore resources, and the situation of raw materials for iron making changed significantly. Reflecting the tightness of supply and demand, conventional stable prices have risen and then become volatile. For this dramatic environmental change beyond the conventional expectation, there is an urgent need for an approach that includes innovative process development that differs from efforts such as conventional extension. In particular, with regard to the expected rise of P in iron ore in the future, a more precise and bold industry-academia collaboration is essential, and new efforts by creating national projects are urgently required.

1. Introduction

The ironmaking field in Japan has been promoting various process development and other projects by continuing industry-academia cooperation in a wide range of sectors for an extended period of time through work by study groups under The Iron and Steel Institute of Japan, work of the 54 and 148 Committees under the Japan Society for the Promotion of Science, and multiple national projects. Subsequently, such projects have produced a large number of results. Specifically, many new processes have been established and they are used even now, producing excellent outcomes. Such a representative example is the Super Coke Oven for Productivity and Environmental enhancement toward the 21st century (SCOPE21) that was promoted as the next-generation coke project.[1] In addition, CO_2 Ultimate Reduction in the Steelmaking process by Innovative technology for the cool Earth 50 (COURSE50) project—a prolonged environmental harmonic steelmaking process[2]—that has been continued for over 10 years involving many industry-academia cooperation projects is still underway.

The supply environment of iron ore and coal resources started to significantly change in 2000, which has been affecting ironmaking significantly. The economic growth of China, the rapid expansion of its steel production, and the increase in crude steel production depend on the production of pig iron in blast furnaces from iron ore resources. As a result, the situation of raw materials for ironmaking has changed significantly. Reflecting the tightness of supply and demand, conventional stable prices have risen and then become volatile (**Fig. 1**).[3, 4] This report first describes important points when the

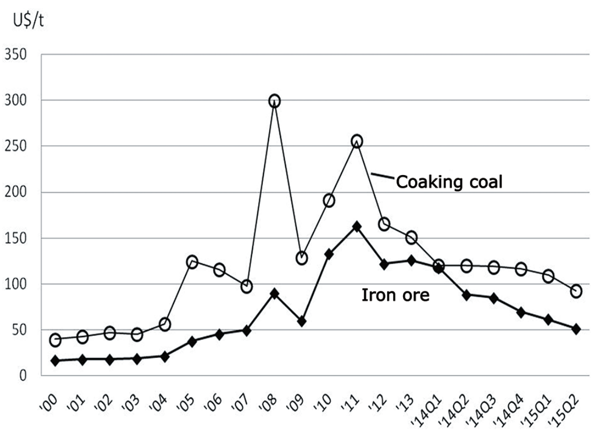

Fig. 1 Price change of iron ore and coal for coke

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relationship between resources and raw materials is considered and then presents the situations and future of resources—iron ores, in particular. This report also discusses future trends in new process development in the steel industry in Japan conducted in line with such changes, including how industry-academia cooperation should be promoted.

2. Background

The upstream processes in the steel production have not changed. However, as explained previously, the environment surrounding the steel industry in Japan has significantly changed for some years. It is reiterated here that such changes can be broadly divided into two causes: significant changes in the input conditions in the steel production processes with deterioration of raw fuel as its core as a result of vigorous demand for raw fuel mainly in East Asia, and significant changes in the output conditions from the steel production processes due to the manifestation of energy and environmental problems. This section describes how the steel production processes have coped with changes in the resources and mines[5, 6] and how the processes should cope with such changes in the future regarding each of the two types of resources (coal and iron ore resources). This section also describes results from industry-academia cooperation along with the framework for industry-academia cooperation in the future and how it should be promoted. Especially, this section discusses future trends in new process development in the steel industry that is promoted in line with changes in raw materials for iron ores and how industry-academia cooperation in such development should be promoted.

2.1 Processes expansion focusing on increasing the utilization of non-coking coal

Regarding the decrease in the expansibility of coking coal when it is heated, many researchers have reported that increasing the coal packing density (bulk density) in coke ovens significantly contributes to maintaining the coke strength.[7–14] The packing density is increased mainly by reducing the moisture in coal and by coal agglomeration.

Regarding the reduction of coal moisture, although charging moist coal (moisture of 9 to 12%) was formerly the main operation, the ratio of furnaces using moisture-controlled coal (moisture of 6 to 7%) also is currently large. A process for further reducing the coal moisture is DAPS (moisture of 2 to 4%), the utilization of which began in 1992 at Oita Works of Nippon Steel Corporation (NSC). The less moisture there is, the more fine powder is released. In DAPS, fine powder is separated from coarse grain using a fluidized-bed dryer in advance and the fine powder is agglomerated in order to suppress powder emission.[15]

Regarding coal agglomeration, one approach is that approximately 30% at maximum of coking coal is turned to briquette, it is mixed with fine coal, and the mixture is charged into coke ovens. As coal blending in briquette, in the developed method, part of the blended coal was briquetted without further treatment, first.[16] After that, the Sumi Coal System[17] was developed in which coal is intensively blended into high-density briquette to compensate for the insufficient expansion of non-coking coal and asphalt pitch (ASP) (binder) is added. **Figure 2** summarizes the various pretreatment processes focusing on increasing the utilization of non-coking coal including grinding in addition to bulk density increase.

The SCOPE21 process (moisture of 0%) is a composite process for which packing density increase by moisture reduction was combined with the fine-powder briquetting technology and to which a coking property improvement effect by rapid temperature rise of coal was added. The operation of the SCOPE21 process began at Unit 1 at Oita Works in 2008. Industry-academia cooperation played a major role in establishing this process. The process starting from searching seed technologies in a special fundamental research group under The Iron and Steel Institute of Japan was developed and first applied to Unit 1 at Oita Works. In fact, the project took approximately 20 years from the fundamental research to the incorporation into commercial equipment. The non-coking coal ratio is only 20% in conventional operation using moist coal. In the SCOPE21 process, it is over 50% and the operation has been continuously stable. Unit 2 installed at Nagoya Works in 2013 (**Fig. 3**) has been operating stably as well.[18]

To promote industry-academia cooperation effectively, the following items may be important: (1) common needs for effective promotion of projects, (2) academic support from various sectors and strong leadership, and (3) clear division of roles between participants. Especially, the industry needs to participate to the extent of contacting academia after clarifying objectives and academia needs to do so to the extent of understanding industry needs and producing tangible results (create a product or system). The first step in industry-academia cooperation is to create a foundation starting with something small that will lead to the immersion of participants in frank discussion. This may have led to the success of SCOPE21.

2.2 Future work for coal resources with further inferior quality

The aforementioned advancement of the pretreatment processes increased the utilization of non-coking coal. The preconditions of

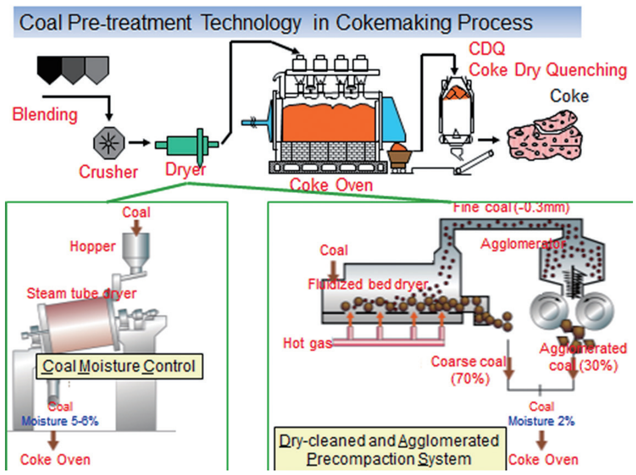

Fig. 2 Various pretreatment processes focusing on utilization of non-coking coal

Fig. 3 Second SCOPE21 process introduced in Nagoya Works

these processes are that non-coking coal has coking property to some extent and the chamber oven process is used. When considering using bony coal, which has not been used as a resource, by expanding resources from conventional non-coking coal, the technologies as listed below may require examination.

First, such technologies required are chemical upgrade and compensation of coking property. Unlike coal with coking property, bony coal contains more functional oxygen groups. Therefore, they form cross-links (higher molecules) when heated as a result of the deoxidization reaction, so they do not show thermal activation (coking property). Ashida et al. have shown that such bony coal may be converted into an alternative raw material equivalent to non-coking coal by reforming it while suppressing cross-linking through solvent treatment (1-methylnaphthalene solvent at 350°C) under relatively mild conditions.[19] In addition, adding a material for compensating for coking property to coal without such property is also effective. Some researchers have reported that coke with crushing strength at the same level as that of coke produced from coking coal was produced by adding hyper coal obtained through solvent extraction of sub-bituminous coal to the sub-bituminous coal itself.[20]

Subjecting bony coal that was subject to the aforementioned chemical modification to physical modification (hot pressure briquetting) is more effective. As mentioned previously, the briquetting technology is used in current processes. To obtain stronger coal, it is effective to use the plasticity of the coal by briquetting it under hot conditions. Hayashi et al.[21] produced coke with higher cold strength than common coke for blast furnaces from bony coal by binder-less briquetting under hot conditions.

Combining the aforementioned chemical modification with the physical modification may clear the way for the use of bony coal in coke production. For coke production processes focusing on the utilization of coal resources with inferior quality, processes that substantially exceed the restrictions of the conventional chamber oven process may be assumed. The New coking process elementary technology study group (type II study group under The Iron and Steel Institute of Japan) studied a process assuming actual processes with chemical and physical modification technologies as its core through the collaboration of industry, academia, and government. **Figure 4** shows the new process that the group proposed. Future advancement is expected.[22] Thus, the course of industry-academia cooperation developed in SCOPE21 has been continuously followed in the coal and coke sectors.

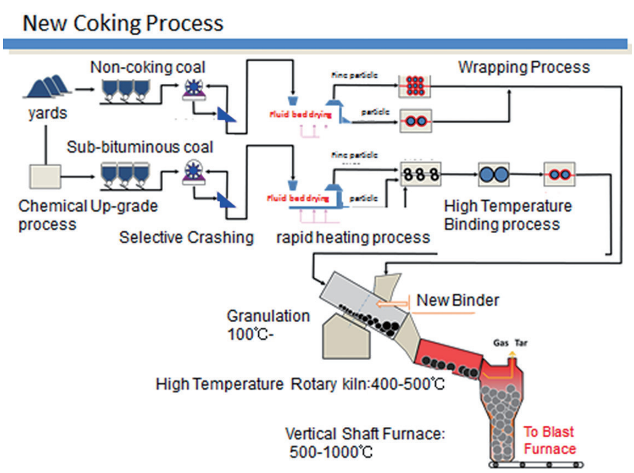

Fig. 4 Example of the future coke production process flow

2.3 Trend in processes toward finer iron ores

Natural resources are often dressed to remove impurities that were mixed in when they are mined.[23, 24] Liberation that is a step prior to dressing is important. Regarding the production of iron ores from banded iron formation (BIF) with Fe of around 40%, the production of pellet feed with Fe of 67% has been increasing by ore grinding to 45 μm or smaller and dressing. This extended the possibility of using iron ore fines in the sintering processes and various types of processes have been developed. As representative examples, in order to prevent the productivity in sintering from decreasing, which is a problem when iron ore fines are pretreated and used, hybrid pelletized sinter (HPS) in which pan pelletizers are fully used[25] or return fine-mosaic embedding iron ore sintering (RF-MEBIOS)[26] using some of the pan pelletizers are available.

This section describes RF-MEBIOS (**Fig. 5**). The RF-MEBIOS process can improve the permeability in the sintering raw material layer, with the aim of improved productivity in sintering. In this process, dry returns that have not been pelletized are added to pelletized moist raw materials. This technology is partly a seed technology produced in the sintering study group under The Iron and Steel Institute of Japan. The two factors contributing to the high permeability are the low ratio of quasi-particle size (−0.25 mm) and low packing density. The former can increase the moisture during pelletizing when the moisture in the raw materials when charged is at a certain level since pelletizing is performed without dry returns. This technology has been applied to five sintering machines as of now and it has improved the productivity of all of them. As a result, the usage ratio of iron ore fines has been increased. However, this approach has a limit and thereby there is a demand for new pretreatment and pelletizing technologies based on new concepts so that iron ore fines can be further used in sintering in the future.

2.4 Measures to cope with future increase in P in iron ores

Presently, Japan imports iron ore resources of approximately 1.6 trillion yen annually and 90% of these are from Australia and Brazil. It is predicted that the quality of iron ores from those countries will be inferior (the Fe content will decrease).[27] This will increase the slag volume in blast furnaces by approximately 10% in 2030 from the current level, which may increase the reduction agent ratio (usage ratio of coke and coal) in blast furnaces (worsening of 6 to 13 kg per one ton of molten metal) and may reduce the productivity,

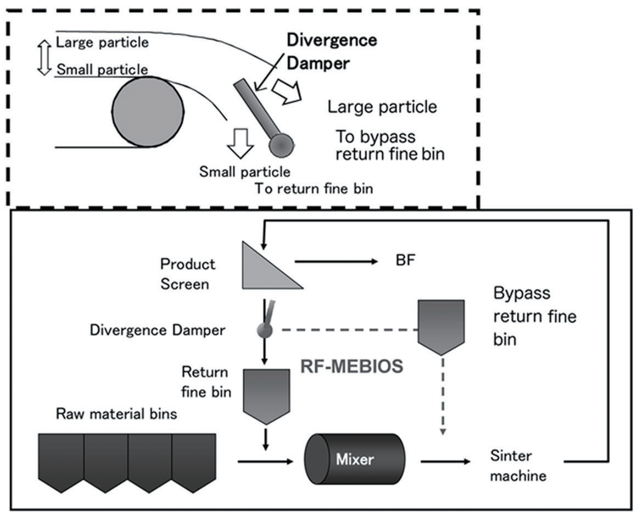

Fig. 5 Process flow of RF-MEBIOS

which may in turn weaken the global competitiveness of the steel industry in Japan significantly.[28] It is also predicted that the concentration of impurity P that deteriorates the characteristics of steel will increase (increase by 0.051%, increase rate of 42%) in Australian iron ores. Therefore, increase in loads to the steelmaking process (dephosphorization process) and steelmaking slag and decrease in the competitive edges for high-quality steel are of concern (**Fig. 6**).

Australia still has high-Fe and high-P iron ores as undeveloped resources.[29] Therefore, Nippon Steel should contribute to continuous expansion of the steel industry in Japan by establishing new iron ore dephosphorization processes to use such iron ores effectively and to prevent our global competitiveness from decreasing due to the aforementioned quality deterioration of resources. Our urgent tasks required to achieve such objectives are: (1) assessing the amount of P present in iron ores, (2) dephosphorizing iron ores, (3) agglomerating dephosphorized iron ore ultra fines, (4) using dephosphorized slag as a resource, and (5) evaluating the entire processes. Recently in particular, mainly universities have been proposing new seed technologies, such as micro area X-ray and high-temperature scanning electron microscopy and reduction-vaporization dephosphorization technologies, which are essential for such studies. These technologies should be actively used (**Fig. 7**).

For these tasks, optimization study is required to establish final process flow (**Fig. 8**) because they involve multiple elements such as mines and their treatment, testing, analysis, ironmaking, and steelmaking. To that end, new approaches beyond conventional industry-academia cooperation are required. Conventionally, it was considered that academia (universities) was in charge of seed studies and industries (companies) fostered such seeds. However, it is important for new approaches in which both academia and industry work together from the first step. In the currently-promoted feasibility study "NEDO Feasibility Study Program/Advanced Research Program for Energy and Environmental Technologies/Innovative and integrated high-grade steel making processes coping with inevitable degradation of iron ore"[30] under New Energy and Industrial Technology Development Organization (NEDO) in Japan, academia and industry discuss needs and seeds together to manage the project. Such studies are related to wide-ranging fields and thereby industry-academia cooperation with researchers other than those in the steel field is also important. Therefore, it is indispensable to establish industry-academia cooperation that involves a very large number of fields.

In these large tasks, while each elemental technology is further advanced and its characteristics are improved, all processes from the large-scale testing process verification to integrated assessment need to be conducted on a full-scale basis, and energy-saving and economic efficiency thanks to their combinations need to be assessed. In addition to these, toward practical implementation, technologies for analyzing iron ores, dephosphorization, using a sintering process, and collecting Fe and P to turn them into resources need to be individually established; and such technologies should be combined in an optimum way to realize innovative technologies that can use inferior-quality resources and reduce CO_2 emissions as the final goal. In recent years, nonferrous metals manufacturers in Japan have been developing resource technologies to cope with inferior-quality resources and resource exhaustion actively. Therefore, it is also important to enhance cooperation with fields other than the steel field while making the most use of this trend.

To solve the aforementioned problems, developing and applying new processing technologies based on characteristic analysis of iron ores may prevent cost increase due to inferior-quality resources and decline in the global competitiveness of the steel industry in Japan due to quality deterioration; and supplying the world's best steel materials may continuously contribute to Japan's continuous growth. For example, the estimated energy increase due to the quality deterioration of iron ores and increase in the quantity of P is 1.1 to 1.5 million kl (crude oil equivalent) per year and the estimated CO_2 emissions increase is approximately 4.2 to 6.0 million tons per

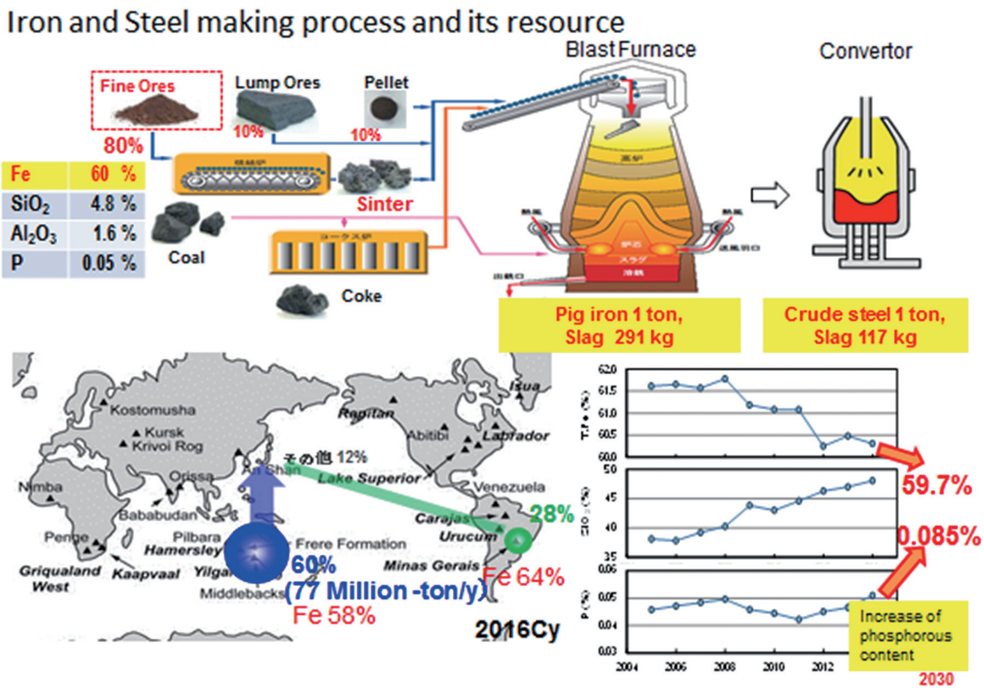

Fig. 6 Problem of phosphorus rise in iron ore and its background

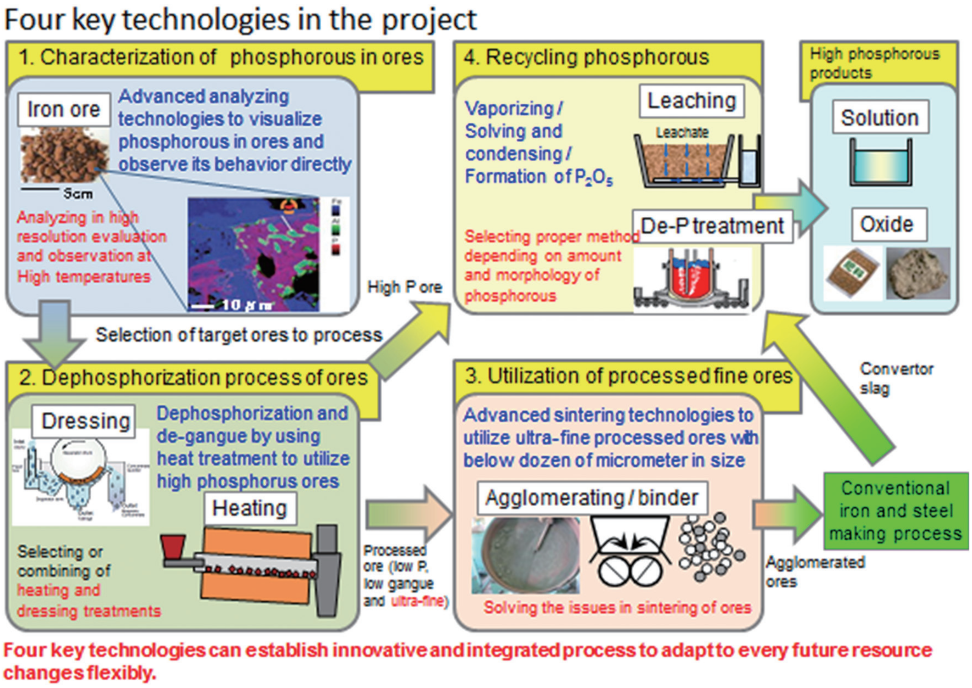

Fig. 7 Structural analysis of phosphorus in iron ore and concept of de-phosphorus treatment

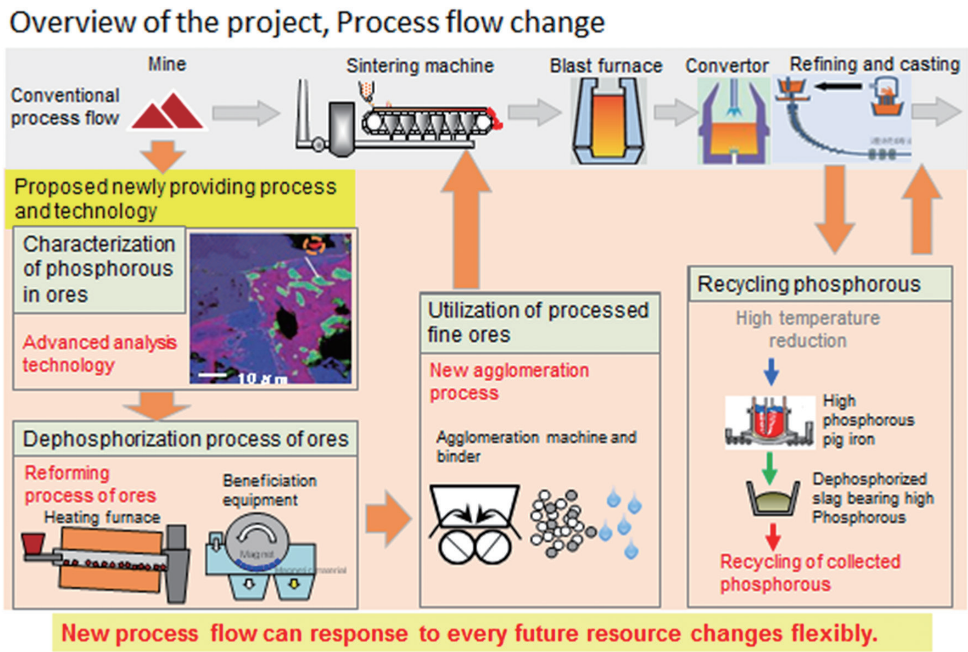

Fig. 8 Overall feeling of this research subject and its effects

year. New processing technologies could reduce such increase.[31)]

3. Conclusion

The last decade saw significant changes in steel raw materials and it is difficult to foresee the future although China's attitude is a conclusive factor. Recent important subjects are the violent fluctuations of resource prices and quality deterioration of resources. When viewing resources in the future from a long-term perspective, the projected quality deterioration is startling as described previously. To cope with such drastic environmental changes exceeding conventional prospects, approaches including innovative process development are required rather than approaches that are a mere extension of conventional work, that is to say, processes per se need to be urgently developed in an innovative manner.

We have to start working to develop innovative processes now to radically solve the aforementioned problems arising from the changes in the environment surrounding the steel industry in Japan. Developing practical equipment naturally takes time. Therefore, our most pressing need is formulating projects considering the final images of processes. To that end, opportunities for discussing innovative steelmaking process development need to be provided through the cooperation and collaboration between industry and academia. The formulation of a project for measures against the increase in the quantity of P in iron ores may be a good theme to establish new industry-academia cooperation in the ironmaking sector.

For creative and efficient industry-academia cooperation, the ability of researchers in the steel industry to provide explanation (to other sectors, in particular) and creative development is somewhat lacking. Improvement of this ability is a task in future human resource development. Example new tasks in industry-academia cooperation are: (1) producing synergistic effects through personnel exchange in industry-academia cooperation, (2) extending the students' internship period, and (3) industry's actively participating in human resource development programs of universities.

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