1. Introduction

The steel manufacturing process requires enormous quantities of resources, including iron ore, coal, and water, and large amounts of energy in the form of electric power and fuels. It also uses a variety of chemical substances. To reduce the resulting environmental loads, JFE Steel carried out a diverse range of technical development and implemented environmental countermeasures from an early date.

On the other hand, today's affluent society is faced with new problems, such as the effect of chemical substances on the ecosystem and global warming, which demand maximum use of the technologies and potential possessed by JFE Steel, including timely technical development and equipment/operational measures suited to changing times. In particular, this will mean promoting measures to prevent global warming, which will become an increasingly important problem in the future.

In these circumstances, JFE Steel supplies environment-friendly iron and steel products which make a large contribution to reducing the environmental loads in industrial society, and is continuing its efforts, including

Counter-
measures
—Facility

boasts the world's highest levels of energy efficiency and resource recycling ratios.

Energy saving measures such as waste heat recovery equipment and power generating equipment in each steel manufacturing process, and the main technologies applied as environmental protection measures, including desulfurization/denitrification, dust collecting equipment, and various kinds of water treatment equipment, are shown in **Table 1**.

To systematically promote these environmental conservation efforts, in 1991, the company created an internal Environmental Committee and constructed a company-wide environmental management system under the president. The company also actively promoted acquisition of certification under ISO14001, which is the international standards for Environmental Management Systems (EMS) issued in September 1996, and completed acquisition of the certification for all its iron and steel works in July 1999. At present, activities aimed at continuous improvement, based on EMS, are being developed. One particular objective is to create urban-type steel works which exist in harmony with the environment through voluntary efforts and disclosure of information in order to obtain the full understanding and trust of local communities. Environmental information includes publication of the company's environmental policy, the status of environmental loads, PRTR data, and environmental accounting through Environmental

Reports.

3. Efforts to Prevent Global Warming

3.1 History of Energy Saving Activities

As energy saving activities in JFE Steel, the company began its 1st energy saving plan in 1973 and has promoted energy saving activities continuously up the 5th energy saving plan, which is now in effect. An outline of the activities under each plan is presented below.

1st Plan (1973–1978)

Energy saving was promoted mainly through operational improvements, including reduction of the reducing agent ratio at blast furnaces and reduction of fuel consumption at reheating furnaces, etc.

2nd Plan (1979–1985)

Energy saving was implemented by positive introduction of large-scale waste heat recovery equipment, including power generation by the blast furnace top-pressure recovery turbine (TRT), sintering cooler waste heat recovery, and coke dry quenching (CDQ) equipment.

3rd Plan (1986–1994)

Energy saving operation was promoted by process continuation/elimination, as exemplified by the continuous casting machine and continuous annealing line, introduction of pulverized coal injection (PCI) for the blast furnace, and coal moisture control (CMC) equipment, and efficient operation of various energy-related facilities.

4th Plan (1995–2002)

Against the background of the increasing serious global warming problems, the objective of energy saving activities changed from cost reduction to reduction of CO_2 emissions by reducing energy consumption, and the company made efforts to identify new technologies and develop seed technologies from a wider perspective, for example, including environment-friendly technologies (regenerative burner) and waste recycling technologies (blast furnace feed of waste plastic).

5th Plan (2003–)

To implement complete globally warming prevention measures, JFE Steel is developing new energy saving activities through further technical innovation, and is expanding the scope of its efforts to include the development of recovery/use technologies for unused energy and study of comprehensive energy saving through cooperation with regional society and other industries.

Among the results of these activities, as equipment for recovery of energy from steel manufacturing processes, JFE Steel has installed CDQ (15 units), heat recovery equipment for BOFs (10 units), sintering main waste heat recovery equipment (3 units), sintering cooler waste heat recovery equipment (6 units), and TRT (9 units, which is the total number of operating blast furnaces). As a result, it is now possible to cover 16% of steel works power consumption and 75% of works steam consumption with recovered energy. The results of these energy saving activities can be seen in reduced unit energy consumption (energy consumption per ton of crude steel), as shown in **Fig. 1**. Unit energy consumption was reduced by approximately 33% between the beginning of the 1970s and fiscal year 2003.

3.2 Specific Examples of Energy Saving Measures

This section introduces specific examples of measures in the 1st to 3rd energy saving plans, as mentioned in the previous section.

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Examples of the latter frequently require large-scale facilities such as the TRT, CDQ, sintering cooler waste heat recovery, basic oxygen furnace (BOF) gas sensible heat recovery equipment, waste heat recovery boiler, etc. By installing these equipments, it was possible to obtain approximately 260 MW of recovered electric power and approximately 790 t/h of recovered steam.

3.2.2 Examples of process continuation and elimination

In iron and steel manufacturing processes, products must be repeatedly heated and cooled a number of times. However, energy savings can be realized by minimizing the temperature drop in this process.

Process continuation and elimination have long been used as means of minimizing temperature drop. To mention several representative examples, these include PCI, in which pulverized coal is injected directly into the blast furnace without passing through the cokemaking process, the continuous casting (CC) machine, which produces slabs directly from molten steel from the BOF, direct rolling (DR), in which slabs produced by the CC are rolled directly, the continuous annealing line (CAL), and continuous pickling/cold rolling lines. Another notable example is the endless rolling process at No. 3 hot strip mill at East Japan Works (Chiba), which is the world's first practical continuous hot rolling process[1]. This process eliminates the unsteady parts at the head and tail ends of strips in the finishing mill, and thus dramatically improves the stability of the rolling operation. At the same time, it also substantially improves the quality of hot rolled strip by reducing deviations in the strip thickness and finishing temperature, and also enables a maximum energy saving of 20% during endless rolling.

3.2.3 Examples of high efficiency in energy equipment

High efficiency in energy-consuming equipment has been achieved by the development/introduction of highly efficient equipment as such, and by realizing advanced control systems.

Important examples of high efficiency technologies for the coke oven are the end flue heating burner and CMC[2]. Installation of the end flue heating burner makes it possible to realize a uniform furnace temperature extending to the two ends of the coke oven, where the temperature had been low in conventional ovens, and thus makes it possible to realize an energy saving by reducing the average furnace temperature. It also has the additional benefit of preventing dust generation during coke pushing. Introduction of CMC reduces coke oven fuel consumption for pre-drying coal, and at the same time, also increases coke strength and improves productivity by enabling increased coal charging, which is possible due to the higher bulk density of the coal.

In the field of energy conversion, facilities which consume large amounts of energy are power plants and air separation plants. As an example of high efficiency in a power plant, in 1987, East Japan Works (Chiba) started up Japan's first large-scale byproduct gas-fueled gas turbine combined cycle power plant[3]. In comparison with the conventional boiler-turbine type, generating efficiency is improved by approximately 5%. In its air separation plants, JFE Steel has also made every possible effort to improve separation efficiency and reduce oxygen diffusion by installing variable absorption devices.

Examples of high efficiency achieved by adopting advanced control systems include introduction of a carbonization control system for the coke oven, application of fuzzy logic to hot stoves, and building physical proptechnologies have been applied to 21 facilities in the company, achieving important results which include an average energy saving ratio of 17%, energy savings of 2 PJ, and a CO_2 reduction of 230 000 t/y. In particular, with reheating furnaces and heat treatment furnaces in the rolling process, in addition to achieving large energy savings, improved product quality has also been achieved as a result of uniform heating of steel products.

(2) Receiving of Waste Plastic and Other Wastes

JFE Steel has realized a reduction in consumption of coke and other reducing agents by receiving, pretreating and feeding waste plastic into blast furnaces.

The company also receives waste from regional society, which it treats using gasification and melting furnaces that generate virtually no dioxins. The gas generated in this process supplies part of the fuel used in the company's steel works.

(3) Supply of Energy to Outside Users

Taking advantage of the capacity of power plants in its steel works, JFE Steel supplies surplus power to PPS (power producer and supplier: power producers of a designated scale). With the approval of the Minister of Economy, Trade and Industry in January 2005, the company began supplying approximately 10 000 kW of power to an adjoining redevelopment area as Japan's fifth PPS. In addition to this, the company also supplies byproduct gas and steam to outside users.

(4) Supply of Oxygen, Nitrogen, and Argon

Utilizing the steel works' oxygen, nitrogen, and argon manufacturing capacity, the company supplies surplus production of these products to outside users. To ensure a stable supply to outside users, JFE Steel has constructed oxygen and nitrogen liquefaction plants to absorb fluctuations in on-site consumption. These are high efficiency gasification/liquefaction facilities which utilize the cryogenic temperature difference between liquefied oxygen and nitrogen.

(5) Optimization of Energy Equipment for Construction of Optimum Production System

Accompanying the adoption of a one blast furnace

widely recognized by the general public as matters which directly affect people themselves. For example, while a diverse range of substances are used in society, as in the case of chemical substances, there are still some substances whose risk in the environment has not been clarified. Therefore, in 2002, the PRTR system was introduced, requiring that businesses identify and report the quantities of releases and transfers of these chemical substance to the national government, and there has been heightened public concern about chemical substances.

JFE Steel was quick to respond to these social changes, and has made voluntary efforts to actively reduce environmental risk by taking measures that anticipate problems from the viewpoint of preventing harm before it occurs. The basic policy for these voluntary measures is to implement reduction measures on a priority basis, beginning with the substances with higher toxicity and larger release amounts among the various chemical substances which the company handles. For example, JFE Steel is steadily reducing dioxins and benzene by the following measures.

For dioxins released from the sintering process, the company reduced dioxin emissions by installing a wet-type electrostatic precipitator (EP) at West Japan Works (Kurashiki) in 2002 as a sintering flue gas treatment process, and is now expanding the wet-type EP to further reduce dioxin emissions. Fukuyama District of the same works introduced activated coke equipment (**Fig. 6**) in 2002 in order to reduce both dioxin emissions and SOx emissions. As a result of these measures, releases of dioxins by JFE Steel have been reduced by more than half, from 26 g-TEQ in fiscal year 2001 to 12 g-TEQ in FY2003.

As benzene countermeasures, fully-sealed systems have been introduced at coke ovens and chemical treatment plants, which are the main sources of emissions, while measures to remove benzene emissions by suction/combustion of gas leaks have been adopted in hard-to-seal places. An example of a benzene removal system using a catalytic combustion process at East Japan Works (Chiba) is shown in **Fig. 7**. As a result, JFE Steel's benzene emissions were reduced by more than 50%, from 127 t in FY2001 to 57 t in FY2003.

In recent years, with rapid urbanization of areas surrounding steel works, environmental protection for coexistence with the local community has also become increasingly important. JFE Steel is devoting great effort to environmental measures suitable for urban-type steel works by strengthening dust countermeasures, for example, by expanding and improving its dust collectors and introducing a laser dust monitoring system (**Fig. 8**)[10]

5. Efforts to Create a Recycling-oriented Society

5.1 Zero Emissions Activities in Steel Works (Activities and Results to Date)

The resource recycling flow in JFE Steel in FY2003 is shown in **Fig. 9**. JFE Steel generates 15.6 million tons of byproducts annually. More than 99% of these byproducts are recycled by recycling in the works or by use in society. In the breakdown of byproducts, slag accounts for an overwhelming percentage of 77%. As recycling technologies for slag have been reported elsewhere[11], this chapter will describe Zero Emissions efforts for dust and sludge, which account for the next largest percentage (total: 22%) following slag.

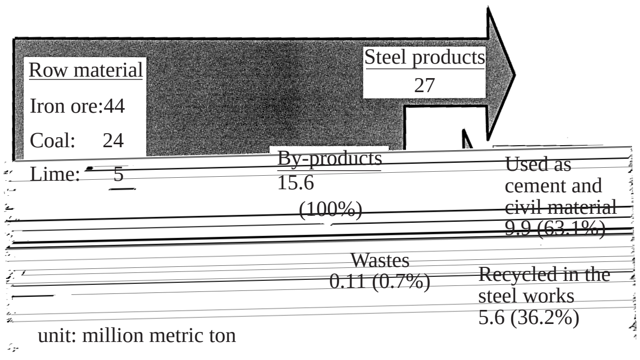
JFE Steel promotes recycling under three basic policies: (1) reduction of amounts generated, (2) maximum possible recycling in the works, and (3) use as resources through cooperation with other industries outside the works.

5.1.1 Reduction and promotion of recycling in steel works

(1) Dust Recycling

Dust recycling includes the long-used method of recycling the iron component to the sintering process. JFE Steel also developed the STAR reactor (coke packed bed-type smelting reduction process)[12] as a recycling technology for stainless steel dust, which contains Cr and Ni, making it possible to separate dust into its individual components for recycling.

Figure 10 shows the hot cyclone system, which reduces steelmaking dust generated by the BOF in the stainless steelmaking process. Among the generated dust, that with a comparatively coarse size is captured near the top of the BOF and returned to the BOF while still at high temperature. This not only reduces dust generation by more than 25%, but also makes it possible to eliminate the conventional dust treatment process. Because dust oxidation is avoided, it also contributes to energy saving.



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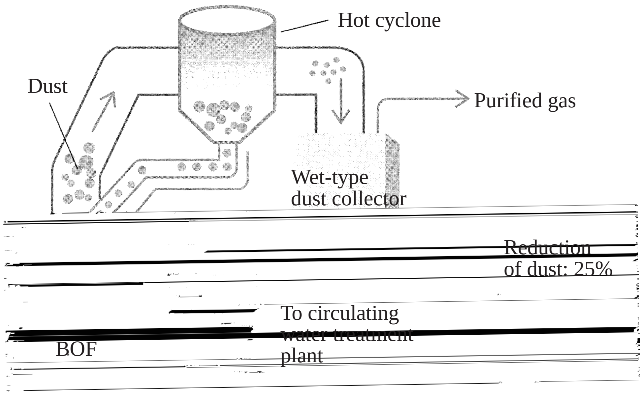

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For recycling of other types of Fe-bearing dust, JFE Steel has developed a technology for using oxidized dust in hot metal pretreatment (use in desiliconizing iron oxides) and a technology for using dust containing metallic iron in the steelmaking process (efficient use of metal). Thus, JFE Steel has established recycling technologies matched to the properties of the dust concerned.

(2) Sludge Recycling

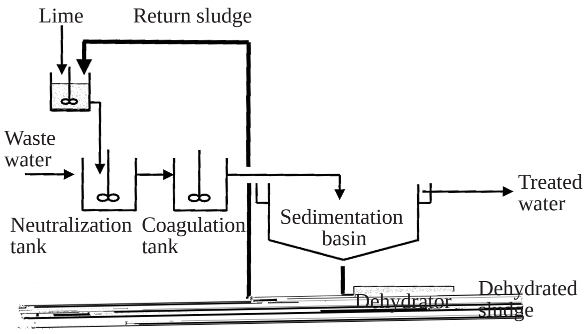
(a) Reduction of coating wastewater sludge

JFE Steel developed technology for reducing the generation of sludge and materialized this technology in equipment. In the treatment of plating wastewater, JFE Steel uses a precipitation/separation process in which the wastewater is neutralized and dissolved metals are precipitated out as solid hydroxides (sludge). Because this sludge is highly hydrophilic, with the conventional technology, the water content could only be reduced to approximately 75%, even when pressed under strong pressure. This resulted in the generation of sludge with 4 times the dry weight of the solid content. In contrast, with the new method shown in **Fig. 11**, sludge properties are improved, making it possible to reduce the water content after dehydration to about 50%, thereby reducing sludge generation to 1/2 that with the conventional method.

(b) Use of sludge as hot metal pretreatment material

JFE Steel developed a recycling method for sludge which was difficult to use as a raw material. Because the sludge generated in the stainless steel sheet rolling process contains Cr, use as a material in the blast furnace is subject to restrictions, as it would affect the composition of ordinary carbon steel products. On the other hand, because the material is extremely fine, use in the BOF is also difficult, as it scatters easily. JFE Steel solved this problem by developing a technology

	Dehydrating speed (kg/m^2h)	Solid contents in dehydrated sludge (%)	Amount of sludge (relative)
Conventional	3	22	1
New methodrom thiN34172 TD35Tj0.T45[St8 626.921method)]TJa7(y-)]TJT*0 Tw.375 TD4337 -626.921m e5D8e5C(n:ensi978Tw[1hod)9 an5978Tw[1hl(n:ensi9766)242ho			



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for using stainless sludge as a material in the hot metal pretreatment process, which is an intermediate process between the blast furnace and BOF, and installed the equipment shown in **Fig. 12** (sludge drying equipment capacity: 16 000 t/y). With the hot metal pretreatment equipment, there are no composition-related restrictions because the sludge is used in hot metal for stainless steel products, and scattering is not a problem because the powder is injected into the hot metal. Moreover, the components of the sludge also act effectively as a treatment agent.

5.1.2 Recycling in cooperation with local society and other industries

Because the steel manufacturing process has great potential for recycling, it is important to promote recycling through mutual cooperation between the steel works and local society and other industries while demonstrating that potential.

JFE Steel's recycling technologies are contributing to recycling various substances generated by society, beginning with waste plastics. JFE Steel's recycling technologies and businesses, and the Eco Town Project which the company is promoting with local communities, are described in detail in a report mentioned in the references[13]. Here, therefore, **Fig. 13** shows the results of a life cycle assessment (LCA) of a example of cascade use of mixed waste acid generated by a semiconductor maker in the stainless steel pickling line at JFE Steel's works, together with the effects achieved[14].

5.2 Future Efforts

As described above, JFE Steel has implemented zero emissions activities and is achieving steady results. Nevertheless, many problems still arise in recycling as resources as the recycling ratio increases. Depending on the constituent contained, recycling in the steel works may be difficult (e.g., Cl, Zn, etc. which hinder blast furnace operation). Moreover, there are cases where the cost of recycling far exceeds the value as raw material, and also cases where recycling increases environmental loads such as energy consumption. Accordingly, future efforts to create a recycling-oriented society will demand changes in the manufacturing process itself and technical development which contributes to both recycling and energy saving.

From this viewpoint, JFE Steel is conducting technical development including (1) research and development for recovery of acid from the waste acid discharged by stainless steel pickling lines and recycling use as a pickling agent, (2) applied research on the Hi-QIP type rotating bed furnace, which is under development as a new steel manufacturing process for dust and sludge containing Zn, which had been subject to quantitative restrictions on recycling due to its harmful effect on blast furnace operation.

In the future, JFE Steel will continue to play a key role in the creation of a recycling-oriented society through the development of technologies for recycling in the steel works and cooperation with local society and other industries.

6. Conclusion

As many environmental problems, such as global warming, have grown from single regions to the global scale, the role of the steel works can no longer be limited to supplying environment-friendly steel products which contribute to reducing environmental loads in society, but also must include serving as the base for a regional industrial complex which utilizes the environmental/ energy technologies and potential of the steel manufacturing process.

Further, in the future, JFE Steel will continue to play a responsible role as a good citizen in society as a whole, the industrial complexes where it operates, and the local community. As such, JFE Steel will promote energy saving which contributes to the prevention of global warming, tackle continuously, flexibly, and tenaciously reduction/improvement of environmental loads, and contribute to realizing a society which is capable of sustained development.

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