Countermeasures of Carbon Dioxide Emission in Steel Industry

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ABSTRACT

To mitigate the global warming problem, control of CO_2 emission would be very important in near future. Steel industry consumes much coal as reductant and energy resources and emits a considerable amount of CO_2. Potential reduction of CO_2 emission, cost and technical problems were examined for various technology options; ①Pulverized coal injection, oxygen blast furnace, smelting reduction, utilization of scrap, coal gasification by ironmaking process and its combination with power generation. ②Injection of natural gas into blast furnace, injection of charcoal into blast furnace as a renewable biomass energy, utilization of electricity from renewable resources. ③Fixation of CO_2 from ironmaking process. ④International transfer of energy conservation technology.

INTRODUCTION

World crude steel production totalled 730 million t-s (tons of steel) in 1990. On the assumption that 0.5 t-c (tons of carbon)/t-s are emitted, it is found that 365 million t-c are emitted by the steel industry in that year. This works out to about 5.9 % of the total global carbon emissions of 6,170 million t-c/y. The amount of carbon emitted by the Japanese steel industry totalled 45 million t-c in 1990, or 14.2 % of the total Japanese carbon emissions of 314 million t-c in that year.

In this paper, the current status of energy flow and carbon emissions in steelworks in Japan is introduced. Energy conservation, alternative energy and carbon fixation technologies that could be implemented in Japan to suppress carbon emissions are examined.

ENERGY FLOW and CARBON EMISSONS in STEELWORKS

Energy Flow Characteristics in Integrated Steelworks

Integrated steelmakers account for approximately 70 % of crude steel production in Japan and consume about 5.7 million kcal/t-s of energy. The large majority of this energy -- 91.8 % of the total -- is provided by coal[1].

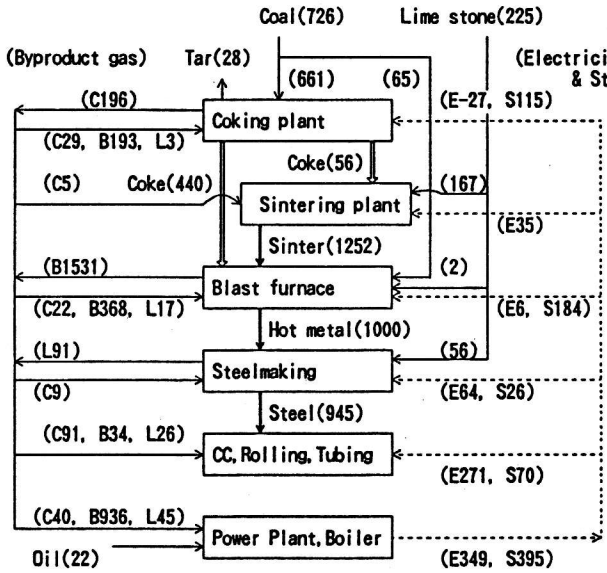
Because product mixes and quantities vary among steelworks, there can be quite a difference in the amount of energy consumed for a particular process in different steelworks. In this study, a hypothetical "typical steelworks" was created and the material and energy flow (Figure 1) was estimated on the basis of several data sources[1, 2, 3]. Here, it is assumed that electricity and lime are produced in-house and that any energy deficiencies are made up by heavy oil in the power sector.

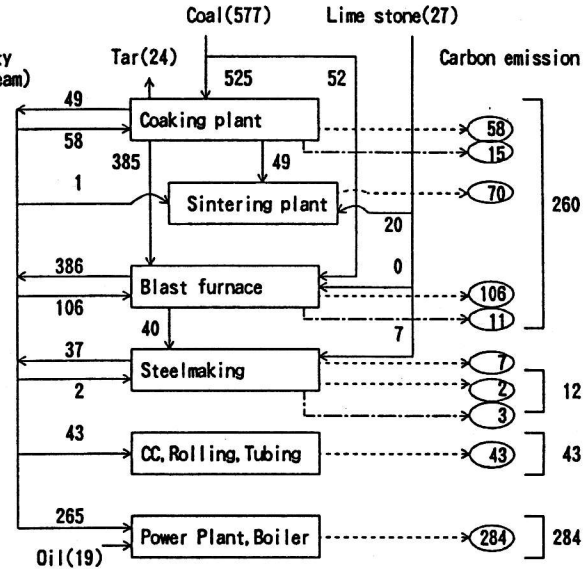
The upstream ironmaking process (coking of coal, sintering of iron ore and

blast furnace) and steelmaking process consume much energy and, in the form of by-product gas, produce much energy as well. The net energy supply to the down-stream processes (Continuous casting(CC), Rolling and Tubing) works out to about 1 Gcal/t-p (per ton of pig iron).

Carbon Emissions in Integrated Steelworks

The amount of carbon contained in coal, coke, by-product gas and others was taken from Table I . The carbon contents of by-product gas were calculated based on typical compositions[4]. Figure 2 shows the flow of carbon and the amount of carbon emissions as calculated from the material and energy flow of Figure 1.





C, B, L: Coke oven gas, Blast furnace gas, LD gas (Nm³/t-p)

E, S : Electricity (kwh/t-p), Steam (Mcal/t-p)

Input carbon 599 = 577+27+19-24=Total emission 599 (kg-c/t-p)

-------> Waste gas, —·—·—> Material loss

Fig. 1 Material and energy flow in a typical integrated steel works

Fig. 2 Carbon flow and emission in a typical integrated steel works

Table I Calorific value and carbon content

Material	Calorific value (HHV)	Carbon content
Coal	7,480 Kcal/kg	0.795 kg-c/kg
Coke	7,170 Kcal/kg	0.875 kg-c/kg
Tar	8,810 Kcal/kg	0.850 kg-c/kg
Heavy Oil	10,400 Kcal/kg	0.850 kg-c/kg
Natural Gas	13,100 Kcal/kg	0.766 kg-c/kg
COG	4,800 Kcal/Nm³	0.264 kg-c/Nm³
BFG	800 Kcal/Nm³	0.252 kg-c/Nm³
LDG	2,000 Kcal/Nm³	0.412 kg-c/Nm³
Lime stone	——	0.12 kg-c/kg

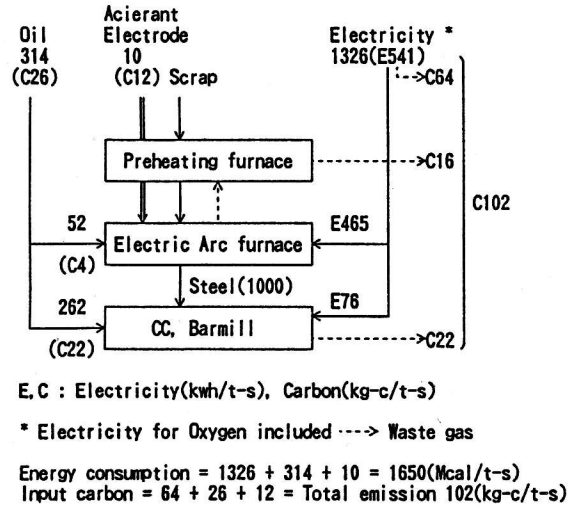


Fig. 3 Energy and carbon flow in an electric arc furnace shops

It is noted that, in each process, much carbon is produced by the combustion of by-product gas. Also, while the greatest amount of carbon is given off by the power sector, which burns much BF gas (a fuel with a low calorific value), the next greatest amount is given off by the ironmaking sector. The total amount of carbon given off by each process is 599 kg/t-p. This can be converted to 634 kg/t-s.

This total emission is different from the statistical figure averaged for all integrated steelworks in Japan. Because a large amount of by-product gas (110 kg-c/t-p) is sold to electric utilities and a part of electricity (171 kwh/t-p × 0.119 kg-c/kwh = 20 kg-c/t-p) is supplied from the utilities grid, the total emission is 509 kg-c/t-p or 539 kg-c/t-s. However, in terms of coal based steelworks, that 634 kg-c/t-s should be charged.

Energy and Carbon Flow in Electric Arc Furnace Shops

Electric arc furnace steel mills are producing about 30% of steel mainly from scrap. Figure 3 shows energy and carbon flow in an electric arc furnace shops with bar mill. Principal energy consumed is electricity and oil. Energy consumption of 1650 Mcal/t-s and carbon emission of 102 kg-c/t-s are very low in comparison with integrated steelworks. If electricity is supplied from coal based power plant and steel product has the same quality as in integrated steelworks, energy consumption and carbon emission might increase respectively to 2524 Mcal/t-s and 267 kg-c/t-s, which are yet 60% lower than in integrated steelworks.

TECHNOLOGIES for REDUCING CARBON EMISSIONS and THEIR ASSESSMENT

Table II presents a summary of the technologies to reduce carbon emissions covered in this report, divided into four categories: energy conservation, alternative energy, carbon fixation and technology transfer. In this table, assessment for each technology in terms of its potential for lowering carbon emissions, costs, time frame and technical issues is shown.

The cost performance depends on energy supply/demand structures and costs in the particular country where the technologies are to be applied. Unit costs used for application in Japan are as follows: coking coal, 8.4 yen/kg; non-coking coal, 7.2 yen/kg; natural gas, 2.8 yen/Mcal; heavy oil, 2.8 yen/Mcal; electricity, 10 yen/kwh; iron ore, 5.3 yen/kg; scrap, 12 yen/kg; by-product gas, 2.8 yen/Mcal.

Pulverized Coal Injection, Oxygen Blast Furnace and Smelting Reduction

Figure 4 shows the amount of energy produced by the conventional blast furnace, the oxygen blast furnace[5] and the smelting reduction process[6].

Current ironmaking processes that utilize coal already have a fairly high thermal efficiency, so there is little room for improvement here. Assuming a constant downstream energy requirement of 1.0 Gcal/t-p, one could expect a drop in carbon emissions of only 4 % . Yet, by lowering the energy requirements of downstream processes to 0.75 Gcal/t-p, carbon emissions could be reduced by 10 %. This shows that energy conservation is also an important issue for downstream processes.

Utilization of Scrap

If scrap charges in the steelmaking of integrated steelworks are increased by 100 kg/t-s with no new carbon additions, a reduction could be expected to be 8 to 13 % in corresponding to the energy requirements of 1.0 to 0.7 Gcal/t-p. If the 12 yen/kg were to double, then the hot metal cost would increase by about 1,000 yen/t-p -- clearly, it is important to have some system of stable pricing.

In electric arc furnace shops, it is important to develop a technology for efficient scrap preheating using sensible heat from off-gases.

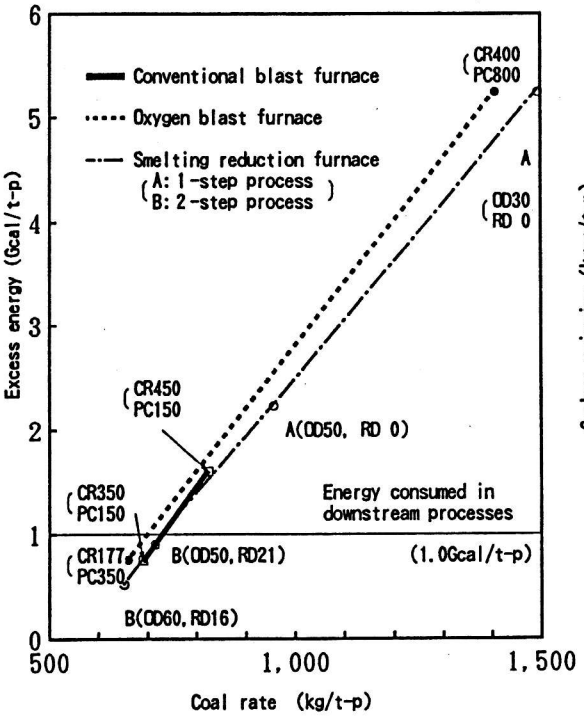


Fig. 4 Coal rate vs. Excess energy

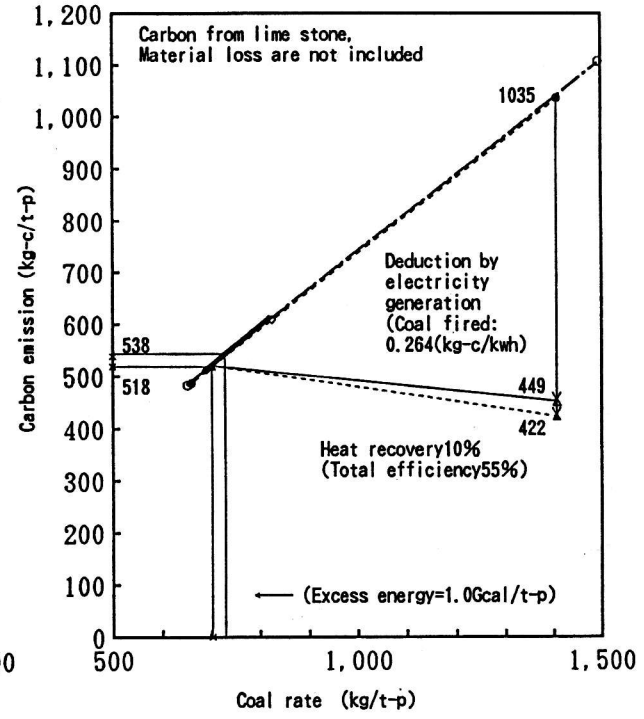


Fig. 5 Coal rate vs. Carbon emission

Table II Carbon emission reduction technology of ironmaking process

Technology	Reduction potetial	Partial reduction cost: Reduction amount of carbon (kg/t-p)	Partial reduction cost: Incremental cost of hot metal (yen/t-p)	Carbon emission reduction cost (yen/t-c)	Time (2000 – 2020)	Technical issue
(Energy Conservation) Pulverized coal injection	~3%	18	-180	-10000	○	Coal/Oxygen mixing
Oxygen blast furnace	4~10%	26	-261	-10000	○	Demonstration
Smelting reduction	4~10%	20	-270	-13500	○	Process efficiency
Utilization of scrap	8~13% (+100kg/t-s)	41	(12yen/kg) -153 (24yen/kg) 1011	-3700 24700	○	Refractocy Tramp element Efficient preheating
Coproduction of electricity	17% (2218kwh/t-p)	89	-3146	-35400	○	Demonstration
(Alternative Energy) Methane injection into blast furnace and methanol synthesis	16% (100Nm³/t-p)	41	1186 *	32800*	○	Catalyst
Utilization of solar electricity	95%	100	(10yen/kwh) 2700 (5yen/kwh) 1000	27000 10000	○	Sticking in H_2 reduction Efficient melting Energy transport
Forestation and charcoal injection into blast furnace	25% (100kg/t-p)	100	1900	19000	○	Lumbering, Carbonizing
(Fixation of CO_2) Biological fixation in sea	100%	100	300~10000	3000~10000	○	Ocean mixing rate
CO_2 separation, liquefaction and storage in sea	100%	100	2700~4000	27000~40000	○	Stable storage, Environmental effect
Transfer of energy conservation technology	20%	100	(5.6yen/Mcal) -1200 (2.8yen/Mcal) 130	-12000 1300	○	

* Methnol synthesis not included

Because the proportion of bad-quality scrap is expected to increase steadily, ways must be found to efficiently remove impurities from such scrap in order to produce high-quality steel. In this regards, much is anticipated from technical development projects currently underway[7].

There are also supply limitations. Even including bad-quality scrap, the amount of scrap distributed for use as a material is expected to increase by about 10 % by the year 2020[7].

Coproduction of Electricity

As can be seen in Figure 4, the oxygen blast furnace and the smelting reduction process have much potential to generate energy for external use while continuing to supply a constant 1.0 Gcal/t-p to downstream processes. For example, a blast furnace production of 10,000 t-p/d with an excess energy of 5 Gcal/t-p would be equivalent of coal gasification at a rate of 10,000 t-coal/d. This performance is significant compared to that of existing gasification process. Another advantage is that most of the sulfur is caught up in the slag.

If this excess by-product gas is utilized to generate electricity for supply to external users, then the public utility can reduce its own coal fired power generation by the same amount. As shown in Figure 5 ,taking unit carbon emissions for coal-fired electricity generation (efficiency 35%) as 0.264 kg-c/kwh , relative to a conventional blast furnace emitting 538 kg-c/t-p, carbon emissions of an oxygen blast furnace with combined cycle power generation (efficiency 45%) would decrease by 17 percent to 449 kg-c/t-p at a coal rate of 1,408 kg/t-p and electricity generation of 2,218 kwh/t-p. This approach is also quite promising in terms of cost.

Methane Injection into Blast Furnace and Methanol Synthesis

Injecting methane into a blast furnace does produce a considerable drop in carbon emissions, but, because natural gas (2.8 yen/Mcal) is more expensive than coal (1.1 yen/Mcal), overall costs rise.

On the other hand, methane can be effectively used as a source of hydrogen. For example, a system in which methanol is synthesized from a hydrogen-rich blast furnace top gas created by blowing methane through the tuyeres is studied[8]. Compared to a system in which ironmaking exists as a process independent of coal gasification and methanol synthesis, this combined system offers a higher overall efficiency with lower carbon emissions.

Utilization of Renewable Energy Resources and Carbon Fixation in Ocean

The diffusion of solar photovoltaic systems has not progressed very far because of low durability and efficiency, and high costs. Transportation of solar energy is also to be studied, because the area abundant in solar energy are located mostly far from the industrial regions. The electrolytic generation of hydrogen with high efficiency is being studied. As for the reduction and melting processes, it is believed that existing technology is sufficient.

Forestation and charcoal utilization in blast furnace is partially realized in Brazil [9]. Issues remaining to be addressed include the development of technologies for the large-scale felling and handling of trees and for carbonization and by-product recovery.

The plant plankton in the sea needs iron for their proliferation, in addition to nutrient salt[10]. By dispersing iron in ocean regions having a low iron concentration -- for example, the Antarctic, Equatorial Pacific and North Subtropic Pacific -- it would be possible to increase the production of plant plankton. This is called biological fixation.

Another conceivable method would be to separate carbon dioxide from steelworks' off-gas, liquify it and pump it through a pipeline to a point 3,000

meters underwater for storage.

It is thought that, with societal support and technological advances, solar energy, biomass energy and carbon fixation could become practical means for limiting carbon emissions. If it is determined that a "carbon tax" of 20,000 yen/t-c should be levied on emissions, then these technologies will most likely come into active use.

Transfer of Energy Conservation Technology to Developing Countries

From 1979 through 1988, the Japanese steel industry invested a total of 1,365 billion yen in energy conservation equipment[11]. During this time, unit energy consumption dropped by 10 % (480 Mcal/t) and unit carbon emissions decreased by 12 % (55 kg/t). From this we can calculate the cost of reducing carbon emissions in taking account of the merit of energy conversation. The cost of reducing carbon emission is 1,300 yen/t-c and -12,000 yen/t-c respectively for the energy price of 2.8 yen/Mcal and 5.6 yen/Mcal.

CONCLUSION

Global warming is, of course, a global issue. Considering economic trends in the developing countries, it is clear that energy consumption and steel demand will greatly increase in the 21st century. Even with future technological developments, carbon emissions within Japan can only be reduced by ten percent at best. Instead, it is necessary to create an international framework and work together to determine how energy can be efficiently utilized in satisfying the world's demand for steel.

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REFERENCES

1. JISF, ed., Unutilized energy in integrated steelworks, (1992), 11
2. JISF, ed., Iron and Steel Statistics Summary, (1992), 118
3. T. Yamamoto and R. Nakagawa, The 80th-81st Nishiyama Memorial Seminar, ISIJ, Tokyo, (1982), 11
4. R. Nakagawa, Journal of the Fuel Society, 67 (1988), 942
5. Y. Ohno, M. Matsuura, H. Mitsufuji and T. Furukawa, ISIJ International, 32 (1992), 838
6. T. Kanamori, Journal of the Japan Mechanical Engineering Society, 95 (1992), 210
7. T. Yugawa, Steel Industry, (1991), 3, 14
8. T. Akiyama, H. Sato, A. Muramatsu and J. Yagi, ISIJ International, 33 (1993), 1136
9. F.Ackerman et al.,Enegy Policy,September,(1990),661
10. J.H. Martin et al., Nature 331 and 334, (1988)
11. JISF, ed., Iron and Steel Statistics Summary, (1984 and 1990)
12. ISIJ, Control of Carbon dioxide gas and future of ironmaking process, (1993)
13. Y.Ohno and H.Komiyama, Proc. 1st International Congress of Science and Technology of Ironmaking, (1994),Sendai,ISIJ,684