A Study on Carbon Dioxide Emission Reduction Potential in the Iron and Steel Industry in Korea

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Abstract[1]

The reduction potential of carbon dioxide emission in iron and steel industry in Korea is studied in the carbon tax scenarios with technology options. The MARKAL model is used for the technology assessment with five scenarios such as the base case, technology options only, carbon taxes of 30 USD, 60 USD and 90 USD per carbon ton with technology options. And 62 kinds of existing technologies and 48 future technologies are considered as technology option. The reduction potential of CO_2 emission in iron and steel industry in Korea is estimated about 5.1% with technology option scenario without carbon emission tax and about 36% under 90 USD/TC carbon tax scenario with technology options in 2030.

1. Introduction

Korean economy has grown rapidly since 1970s and was somewhat slowing down due to the 1997-1998 economic crises in Asia, but it was recovered in 1999-2000. The GDP growth in 1999 was more than 10% and is expected to grow about 4% in 2003. There is a huge plant industry in the background of Korea's rapid growth such as iron and steel, refinery, petrochemical, and so on, but energy consumption level of Korea is very high in the world because of energy intensive industrial structure.

In 2000, Korea was ranked 10th in terms of total energy consumption with total energy consumption of 8,075 PJ on the basis of primary energy, and 6th in terms of petroleum consumption in the world. However, Korea depends on the energy imports up to 97% as the destitute country of energy source, and Korea is the world's 4th petroleum importer and 2nd LNG importer in 2000.

Korea's iron and steel industry was ranked 6th in the world on the basis of the production of crude steel, and the amounts of production was 43.1 million tons in 2000. In addition, Korea has the world's 1st ranked company POSCO on the basis of the production of crude steel. The production of crude steel in Korea was increased by 17.2% in 2000 comparing with 36.8 million tons in 1995 and was increased by 1.3% comparing with 42.6 million tons in 1997. The low increasing rate between 1997 and 2000 was caused by decreased demand due to the economic crises of Asia in this period.

The main facility of Korea's iron and steel industry is considered as the iron producing facility, which has the total 11 blast furnaces with the capacity of 26,010 thousand tons/year. The steel-making facilities are 12 basic oxygen furnaces with the capacity of 26,180 thousand tons/year and electric arc furnaces with the capacity of 23,475 thousand tons/year. The proportion of electric arc furnace to the total steel making was 47.3% in 2000 and is continuously tending upwards. Besides the continuous caster with the capacity of 47,760 thousand tons per year are equipped. Almost all of the facilities of iron and steel industry in Korea are evaluated as most excellent one in the world in terms of energy efficiency. The products of iron and steel industry are various from plate, hot rolled coil to stainless steel products, and the various production lines are ready to produce many kinds of product. Fig. 1 shows the production route of main products of iron and steel industry and it is the Reference Iron & Steel System that is designed by searching and analyzing whole process of the main company in Korea for model operation.

The energy consumption of iron and steel industry sector in Korea was about 696.3 PJ, which was about 11% of the total final energy consumption, the portion of coal was 530 PJ in 2000. The carbon dioxide emission of iron and steel sector in Korea was estimated 14.3 million t-c and it is about 12% of the nationwide carbon dioxide emission and 34% of the industrial sector emission in 2000 [1].

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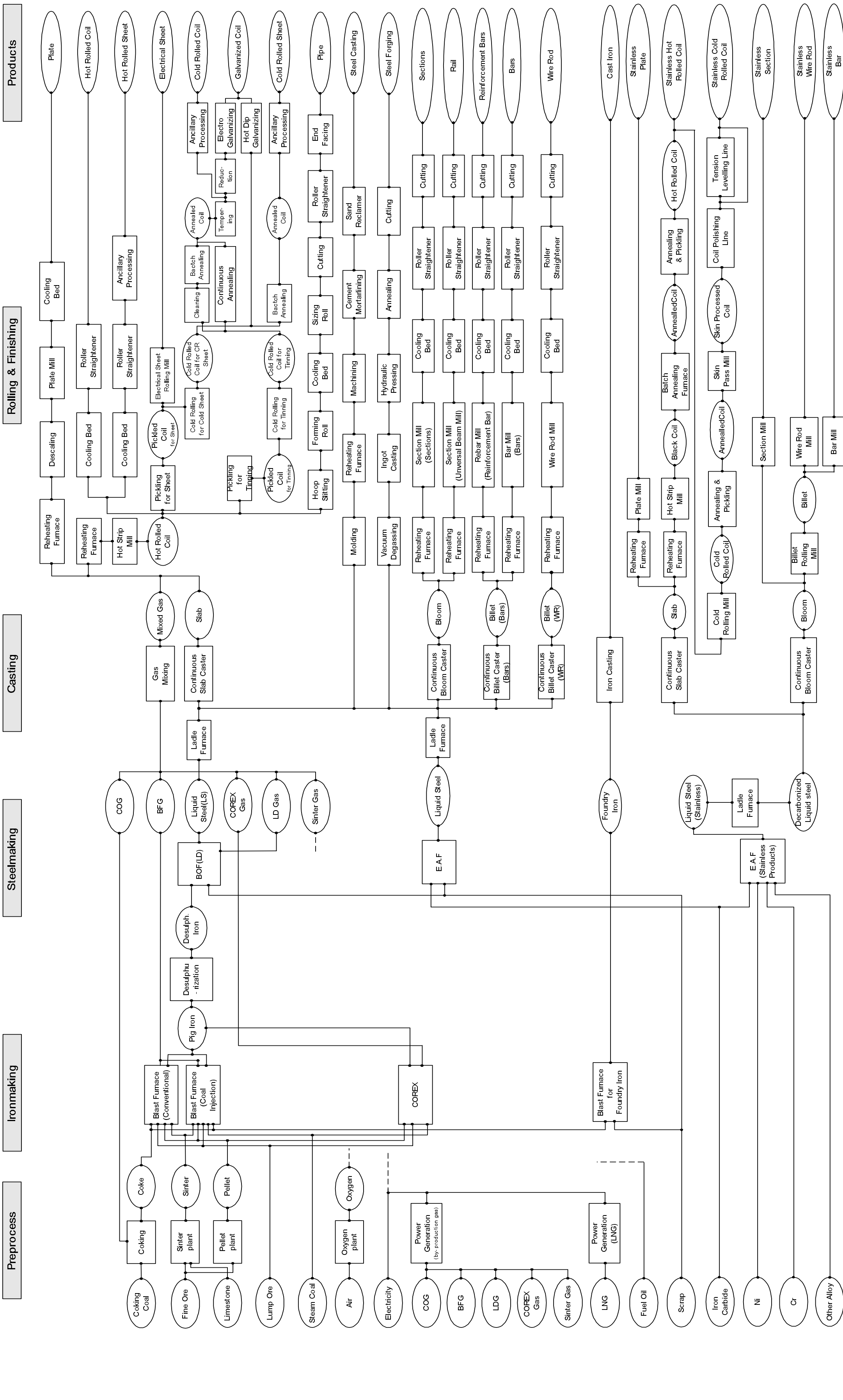

Fig. 1. Iron and Steel Production Route in Korea

Iron and steel industry is important comparing with the other industry in Korea for the GHG emission control because of the huge amount of energy consumption that is the primary source of carbon dioxide emission. Therefore, new technologies are important factor in this field, which are to preserve energy continuously and to minimize the environmental effect. This study is to evaluate the reduction potential of carbon dioxide emission in iron and steel industry in Korea with new technology options and applying carbon tax to fuel for mid and long-term based on the study of technology assessment [2]. This study emphasis on;

- Analyzing the state of technology in Korea's iron and steel industry
- Evaluating the competitiveness of new technology options in iron and steel industry in Korea
- Finding the cost-effective technology options considering the environmental cost arising from carbon dioxide emission

2. Assessment of CO_2 emission reduction potential

2.1 Methodological approach

The iron and steel industry has been lasting a rapid growth but it is recently showing stable state. The whole economics of Korea, however, is still growing, and the nationwide GHG emission in industry is expected to increase for short- and mid-term prospect. And iron and steel industry plays an important role in nationwide GHG emission. However, iron and steel industry is already on the high level in technology and environment concern, therefore it is not easy to find the additional reduction options of GHG emission in iron and steel industry in Korea.

This study applies the MARKAL (MARKet Allocation) model for evaluation of the technical options in iron and steel industry in Korea. The MARKAL model is an optimization model with detailed energy system engineering data. The MARKAL model was developed in 1979 by IEA/ETSAP (International Energy Agency/Energy Technology System Analysis Programme), and more than 77 institutions in 37 countries use this model in the world [3]. This study selected the MARKAL-MATTER model with special regard to the characteristics of iron and steel industry that is able to do the Material Flow Analysis (MFA) among the various types of MARKAL models [4]. The MARKAL-MATTER is able to evaluate various technologies including the flows of products and materials through their all life cycles, so-called 'from the cradle to the grave'. It is, therefore, very suited to evaluate the cost competitiveness of technology with the consideration of materials availability and GHG reduction possibility under various circumstances. The constraints considered are the limitation of possible resources such as the demands of iron and steel products, the time of introducing new technology options, the energy and materials availability, and political considerations on price and so forth.

For technology database, 62 kinds of existing technologies were selected on the base of the production line layout of iron and steel industry in Korea as shown in Fig. 1. In addition, 48 kinds of new technologies were introduced as new technology options and they were mainly selected through the literatures. As a result, the 110 kinds of technologies were evaluated in total. The technology data are defined in terms of the amount of energy and materials input and output, cost, and characteristics of carbon dioxide emission. A statistical data related to iron and steel industry was used for the estimation of installation year and capacity of facilities. [5], [6]. The properties of the energy and materials, cost, and carbon dioxide emission of the other existing technologies are partially introduced by the materials of actual company, but almost all of them are introduced from other country's literatures owing to the shortage of statistical data in Korea. The technology characteristic data of the new technology options is also introduced from the overseas materials such as IISI [7], [8]. And the carbon dioxide removal technologies are included to the technology option in addition to the traditional and new technology. One study [9] suggested that the costs for CO_2 capture would be about 35 USD/t CO_2 in iron and steel industry. This cost is about twice as high as the estimate of IGCC for power plants. However, the carbon dioxide removal technologies for the iron and steel sector are analyzed in various viewpoints in this study, and the Selexol (dimethylether of polyethylene glycol) based CO2 removal is also included as an applicable technology option. Table 1 presents the cost characteristics of the CO_2 removal technologies used in this study [10], [11], [12], [13].

Table 1 CO_2 capture, transportation and storage costs, using the Selexol

	Conventional blast furnace	Oxygen blown blast furnace	COREX	CCF	DRI
Electricity consumption [GJe/t CO_2]	0.38	0.7	0.7	0.7	0.21
Investment [US$/t CO_2.yr]	25	20	25	25	1
O&M costs [US$/t CO_2]	1.25	2	1.25	1.25	0.05
Storage costs [US$/t CO_2]	10	10	10	10	10
CO2 emission Ele. Production [t CO2/t CO_2]	0.038	0.07	0.07	0.07	0.021
Total costs [US$/t CO_2]	21.0	27.0	26.9	26.9	14.5

Assumptions: electricity cost - 15 USD/GJ, 12% of depreciation rate, 25 years of life span for the CO_2 capture installation, total costs range from 15 USD for DRI to 24 USD for Corex and CCF.

The year 1995 is selected as the base year because of the convenience of available data, and the time span of model is divided into nine time periods that has an equal length of 5 years, therefore, the total time span of the model is 1995~2035 (45 years). In the characteristics of MARKAL model, the year 1995 means the mid-period year of the start period.

The demands for iron and steel products as the basis for evaluation are classified by 22 products. The demands for the year 1995 and 2000 are used the actual production results, 38,367 and 44,776 thousand tons each [14]. The total demand of iron and steel products at the year 2035 is estimated up to 50,000 thousand tons according to the domestic production trend, and the distribution ratio for each product is defined maintaining the same ratio of the year 2000. The prices of energy and materials are assumed maintaining the same price of the year 2000 without a particular price scenario after that period [15].

The reduction potential of carbon dioxide emission is evaluated on the basis of the carbon dioxide emission coefficient of IPCC for each energy and material. In this study, a discount rate of 12% has been applied. This high discount rate is introduced because of the uncertainty of Korean economy for the future as a developing country.

2.2 Assessment Scenarios

The various and detailed alternative scenarios are prepared in the step of preliminary evaluation, and five scenarios are selected through preliminary evaluation as follows.

- BASE(Base case): This scenario is assumed that the trend of the basic year 1995 and 2000 will continue for the whole period of evaluation. However, the efficiency of technology improvement and changing the ratio of material supply are considered by means of reflecting Autonomous Energy Efficiency Improvement (AEEI), and the major AEEI reflecting ideas are as follows.
  - pulverized coal injection (PCI) of a blast furnace would be continuously extended up to 150 kg/t irons until the year 2035.
  - improvement of the self-generation efficiency using by-product gas would be up to 30% for the year 2000, and 35% for the year 2035.
  - the material losses of the rolling process would be low down up to 5% until the year 2035.
- TECH(Technology Option Scenario) : All technology options are applied.
- CTAX-30 (carbon tax 30 USD/TC) : carbon tax 30 US dollar will be applied per ton of carbon dioxide emission.
- CTAX-60 (carbon tax 60 USD/TC) : carbon tax 60 US dollar will be applied per ton of carbon dioxide emission.
- CTAX-90(carbon tax 30 USD/TC) : carbon tax 90 US dollar will be applied per ton of carbon dioxide emission.

3. Results

In this section, the output of the model running will be discussed emphasyzing on three major points.

- Energy consumption in Korea's iron and steel industry from 1995 to 2035.
- Carbon Dioxide emission.
- Carbon dioxide emission reduction potential with major technology options.

3.1 Energy consumption of iron and steel industry

Table 2 shows the results of energy consumption for 5 scenarios, at the year 1995, 2000, 2010, 2020, and 2035 respectively. The energy consumption of BASE has been increased from 615 PJ(1995) to 718 PJ(2035). In terms of the weight of each energy resource, the consumption of steam coal is increased while cocking coal is decreased, and these changes are from the increase of steam coal injection to the blast furnace.

Table 2
Energy consumption in iron and steel industry for 5 scenarios, 1995-2035

Scenario	Energy	Unit	1995	2000	2010	2020	2035
BASE	Total Consumption	(PJ/year)	615	682	694	699	718
	SEC	(GJ/ton)	16.03	15.22	15.00	14.64	14.36
TECH	Total Consumption	(PJ/year)	615	682	662	657	684
	SEC	(GJ/ton)	16.03	15.22	14.31	13.76	13.68
CTAX-30	Total Consumption	(PJ/year)	615	682	662	657	684
	SEC	(GJ/ton)	16.03	15.22	14.31	13.76	13.68
CTAX-60	Total Consumption	(PJ/year)	615	682	662	638	655
	SEC	(GJ/ton)	16.03	15.22	14.31	13.36	13.10
CTAX-90	Total Consumption	(PJ/year)	615	682	656	637	656
	SEC	(GJ/ton)	16.03	15.22	14.18	13.35	13.12

The energy consumption of TECH has shown 1.30% decrease in 2005, 4.62% in 2010, and 6.14% in 2030 comparing to BASE. This reduction could come from the effects of extended direct input of steam coal and the effects of various technology adaptation. Also, much more decreasing caking coal consumption and increasing steam coal use was noted comparing to BASE.

In case of the CTAX that considers the cost of carbon dioxide emission in the model, there was not any notable change on the energy consumption especially in the case of 30 USD/TC comparing to the TECH. This is seamed that the present technologies, which belong to the technology options, do not affect to energy consumption in spite of the additional cost of 30 USD/TC. In the CTAX -60, it is decreased by 9.75% in 2030 and in CTAX-90 case, it is decreased by 9.62% in 2030 comparing with BASE scenario.

In TECH scenario, it shows a significant decrease of energy consumption comparing with the year 1995, and energy consumption per unit production can be improved up to 13.68 GJ/t in 2035 using new technologies. In case of the CTAX, the energy consumption has significantly decreased comparing with the BASE but does not have much difference from the TECH. This indicates that even though the cost of carbon dioxide emission is imposed, the total energy consumption has not been much effected by the cost. Thus more innovative technologies are required.

3.2 CO_2 emission

According to the evaluation results, in case of the BASE, the carbon dioxide emission is increased from 14.9 million TC in 1995 to 16.8 million TC for the year 2035. Fig.2 illustrates the comparisons of total emission for each scenario.

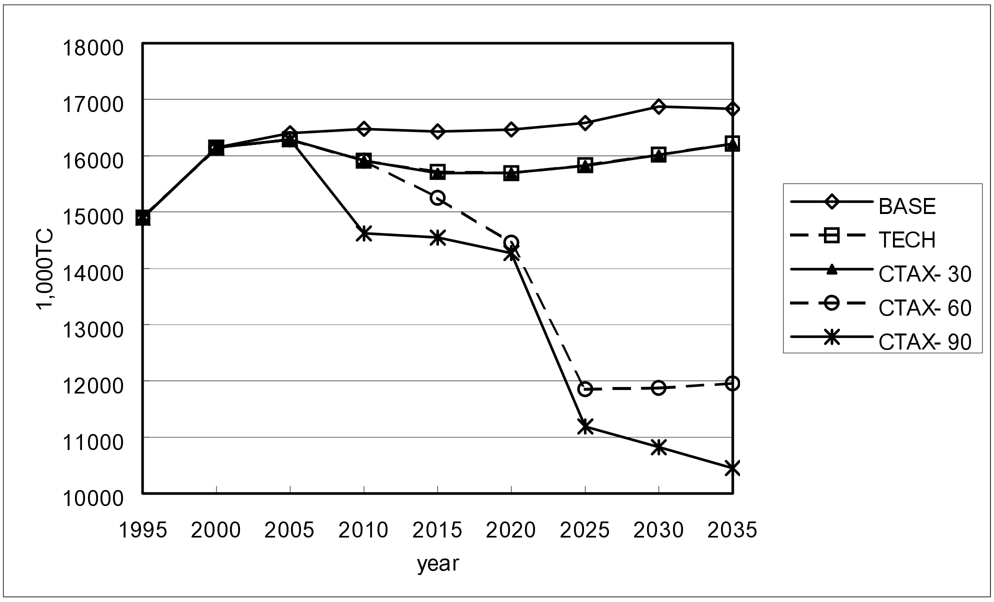

Fig. 2. CO2 emission trends by scenarios

In case of the TECH, the reduction of emission ranges from 0.67% in 2005 to 5.15% in 2030. And in the CTAX case, the cost of 30 USD is not affected comparing with the TECH, and this means that the cost of 30 USD is not a significant level for carbon dioxide emission since the iron and steel industry, is capital-intensive industry. In case of high tax application, it shows a very sensitive response for carbon dioxide emission. The carbon dioxide emission will be decreased by 3.4% in 2010 and 29.0% in 2035 in case of the CTAX-60, and by 11.4% in 2010 and 37.9% in 2035 comparing with BASE.

3.3 Analysis on CO2 emission reduction potential by major technology options

It is difficult to present the reduction potential of carbon dioxide for each technology by a quantitative way, because of various conditions such as the possibility of market enters, costs, usable resources, and so forth. Besides, various uncertainties could be involved due to the lack of reliability of the input data used. Most of evaluators sometimes do not pay attention to the uncertainties of evaluation result. They, however, tend to be very sensitive to a slight difference of numerical values. This leads to limit the selection of technology options. Therefore, the degree of the carbon dioxide emission reduction potential is divided into several levels based on the contribution of reduction for each scenario. The reduction potential of introducing technology is computed on the base of competitiveness under the given scenarios and conditions.

The degrees of reduction potential are divided into 3 levels, such as low, medium, and high for each scenario. The level is given according to the production weight of each technology among technologies which produce the same products. The level of each technology is defined according to the usage of this technology such as low if the usage rage is 0~10%, medium if the range is 10~30%, and high if the range is beyond 30%.

• Low: weight 0～10%
○ Medium: weight 10～30%
● High: weight beyond 30%

The result is analyzed on the base of the year 2020 since the result was most significant to figure out in term of the introducing new technology options. The technology that belongs to the new technology options are marked by * onto the name of technology in the tables below.

Table 3
CO_2 emission reduction potential – preprocess technologies

Name of Technology	BASE	TECH	CTAX-30	CTAX-60	CTAX-90
Sintering	○	●	●	•	•
Sintering - Ecotech*		○	○	○	●
Cocking	●	●	●	●	●
Cocking - Plastic Waste*		•	•	•	•
Coking - Wood Waste*		•	•	•	•
Pelletizing	•	•	•	•	•
Oxygen Production	○	○	○	○	○

Table 4
CO_2 emission reduction potential – iron-making technologies

Name of Technology	BASE	TECH	CTAX-30	CTAX-60	CTAX-90
Blast Furnace - Conventional	•	•	•	•	•
Blast Furnace - Coal Injection (150kg)	●	•	•	•	•
Blast Furnace -Maximum Coal Injection (200kg)*		●	●	●	●
Blast Furnace - Gas Injection*		•	•	•	•
Blast Furnace - Plastic Waste Injection*		•	•	○	○
Blast Furnace for Foundry Iron	○	○	○	○	○
COREX	•	•	•	•	•
Direct Reduction - Gas Based*		•	•	•	•
Direct Reduction - Coal Based*		•	•	•	•
Oxygen Enrichment*		•	•	○	○
Cyclone Converter Furnace*		•	•	•	•
COREX + DRI*		•	•	•	•

Table 5
CO_2 emission reduction potential – steel-making technologies

Name of Technology	BASE	TECH	CTAX-30	CTAX-60	CTAX-90
Basic Oxygen Furnace	●	●	●	●	●
Basic Oxygen Furnace - Ecotech*		•	•	•	•
EAF/DRI - Double Electrode DC Furnace*		•	•	•	•
Electric Arc Furnace (Scrap)– Conventional	●	•	•	•	•
Double Electrode DC Furnace-Continuous Charge*		●	●	●	●
EAF-Preheating (Contiarc Process)*		•	•	•	•
EAF -Scrap Based for Stainless Steel	○	○	○	○	○

Table 6
CO_2 emission reduction potential – CO_2 removal technologies

Name of Technology	BASE	TECH	CTAX-30	CTAX-60	CTAX-90
CO2 Removal from BF*		•	•	○	○
CO2 Removal from COREX*		•	•	•	•
CO2 Removal from CCF*		•	•	•	•
CO2 Removal from DRI*		•	•	○	○

The main reason of the high reduction potential in the CTAX-60 and CTAX-90 is closely related to the selection of the carbon dioxide removal technology. It means that the carbon dioxide removal technology became very competitive starting from the CTAX-60. The carbon dioxide removal technologies are accounted with the consideration of technology cost, properties, and the cost of carbon dioxide emission of each technology. The carbon dioxide removal in the blast furnace and DRI turns out to be applicable when carbon dioxide cost is imposed, but it has a low potential in the cases of the COREX and CCF.

From the results, the carbon dioxide removal technology will be competitive with new production technology if the emission tax imposed more than 60 USD/TC. The possibility of application is not fully supported by the actual data of domestic industry but it is very important to try the new evaluation method for the carbon dioxide removal technology in various aspects.

4. Conclusion and future study

According to the results using the designed technology system and technical properties, the reduction potential by the technology options will be at most 7~8% between 2020 and 2035 in case of excepting the removal technology. But the reduction potential including the carbon dioxide removal technology will be at most 38% in 2035 for the CTAX-90. Table 7 shows the reduction potential of each scenario. And table 8 represents the reduction effects of removal technologies in each scenario.

Table 7
CO_2 emission reduction potential iron and steel sector (Units: %)

	1995	2000	2005	2010	2015	2020	2025	2030	2035
TECH	0	0	-0.7	-3.4	-4.4	-4.7	-4.6	-5.1	-3.7
CTAX-30	0	0	-0.7	-3.4	-4.5	-4.7	-4.6	-5.1	-3.7
CTAX-60	0	0	-0.7	-3.4	-7.2	-12.2	-28.5	-29.7	-29.0
CTAX-90	0	0	-0.7	-11.3	-11.5	-13.3	-32.5	-35.9	-37.9

Table 8
CO_2 emission reduction by removal technologies (Units: 1,000TC)

	1995	2000	2005	2010	2015	2020	2025	2030	2035
CTAX-60	0	0	0	0	96	747	3,429	3,470	3,499
CTAX-90	0	0	0	749	749	902	4,050	4,532	5,019

Considering carbon dioxide emission for the iron and steel products of one ton, it is decreased up to 0.32 TC/T-S in 2035 in case of TECH. In case of the CTAX-90, it has the maximum decrease up to 0.21 TC/T-S in 2035. Fig.3 shows the state of carbon dioxide emission for the iron and steel products of one ton for each scenario.

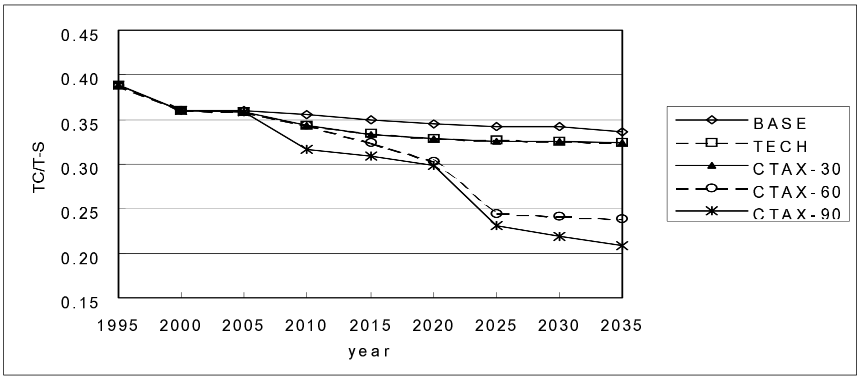

Fig. 3. CO_2 emission trends by T-S(ton of steel)

The limitation of this study is the lack of detailed information of technology propagation and the technical properties data for the iron and steel industry. These are the common problems in the fields of Korea's energy industry, and they are considered as big obstacles for the more accurate decision making related to energy technology. In order to get more information of technology data, the project of ETD (Energy Technology Database) had launched by the government of Korea in 2001 and is expected to complete by 2005. The Korea-MARKAL model will be improved along with the ETD project and it will contribute to national energy policy development related to technology.

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