CO_2 Reduction Potential by Energy Efficient Technology in Energy Intensive Industry*

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1. Introduction

There should be a variety of approaches to improve problems existing Kyoto protocol and make the future framework widely acceptable to most of countries. However, various national circumstances, such as economy, political/social structure, capacity of industry/technology, resources and geographical features, cause confliction of interests so that the realization of equitable decision and discussion of future framework are expected to be difficult. Therefore it is necessary that various information is grasped more precisely while considering circumstances between each countries. For example, information of energy technology such as energy efficiency or cost is uneven in a value by various difference (for example, available technology/fuel, a nature and ability of a market, regulation, a difference of a demand side) and evaluation objects (facilities, a factory, a complex) by an area or difference in way of boundary setting. Accordingly, we focus at a framework based on technology, which ensures more equitable scheme, attempt to establish evaluation criteria for them, and provide useful information to domestic/international discussion on this issue. In this research, through doing quantification of CO_2 reduction potential with technology in industry, problems and requirements for the indexization were identified.

2. Concept of Calculation of Reduction Potential

2.1 Outline of calculation

The outline of calculation, including targeted sector and basic assumption of baseline, was shown as follows.

- Estimation of the amount of possible <u>CO_2 emissions reductions in 2030</u>
- <u>Iron and steel, cement, and pulp and paper industry</u>
- Under the premise that the <u>best available technology(BAT) today would have been adopted</u>.
- <u>Future production</u> assumed to be proportion to energy consumption in industry described in <u>IPCC-SRES-A1 and B2</u> marker scenarios.
- The introduction of high-efficiency and energy-conserving technologies at the manufacturing stage (including the utilization of unused heat) was in large part envisaged.

2.2 Difference in the evaluation depending on sectors/type of industries

Due to the variation in data available, different methodologies were used for each type of industry. (see **BOX 1** relating to this issue.)

・Iron and steel industry: energy savings from several of the energy-saving technologies were

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combined.

・Pulp/paper industry and the cement industry: macro indicators were used.

BOX 1 Importance of considering "boundary"

Energy consumption and CO_2 emissions are subject to how assessment boundaries are set and how materials and energy coming in and out over the boundary are counted, namely the utilization of waste heat from each process, giving and receiving of by-products and electricity and/or heat with other industries, recycling levels, etc. In the case of transfer of such materials/energy over any boundaries, what kind of conversion factors is used is also critical issue.

Therefore, the given results of international comparisons of unit energy consumption, etc. can serve as reference but require cautious observation.

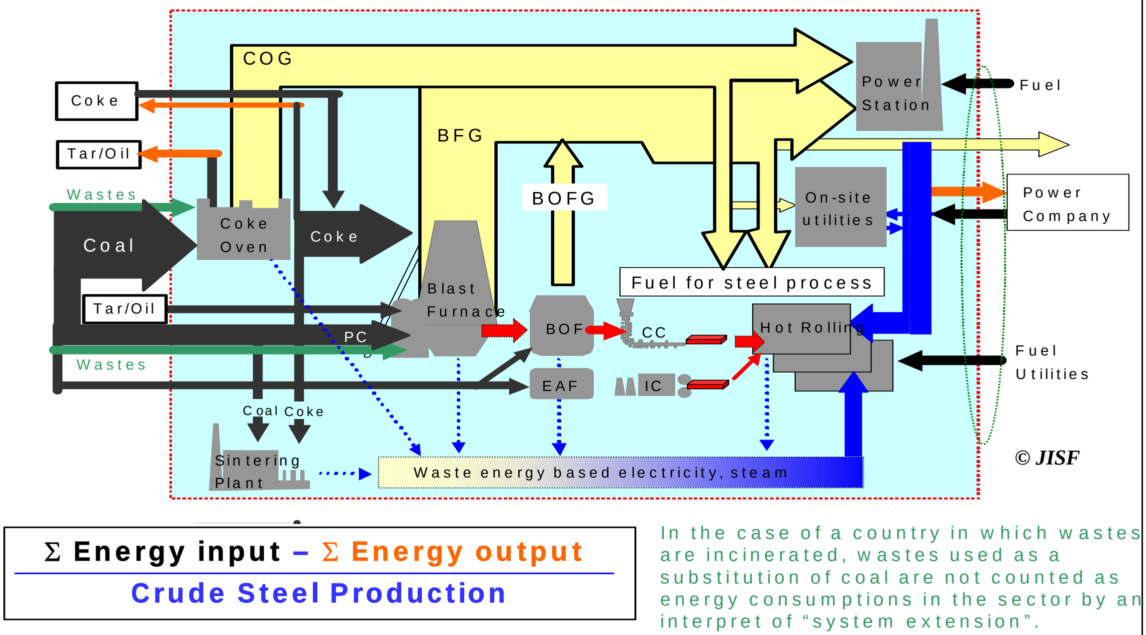


Figure 1 Energy flow at typical integrated steel making plant in Japan

As an example of problems caused when different boundary conditions are considered, energy consumption at coke oven process in iron and steel industry are estimated using different definitions due to different boundary setting here. When only looking at input energy to a process (e.g. definition 1 of Figure 3), energy consumption amount may be overestimated in such a case that energy, which was abandoned, from one process is utilized in another process as recovered heat/energy.

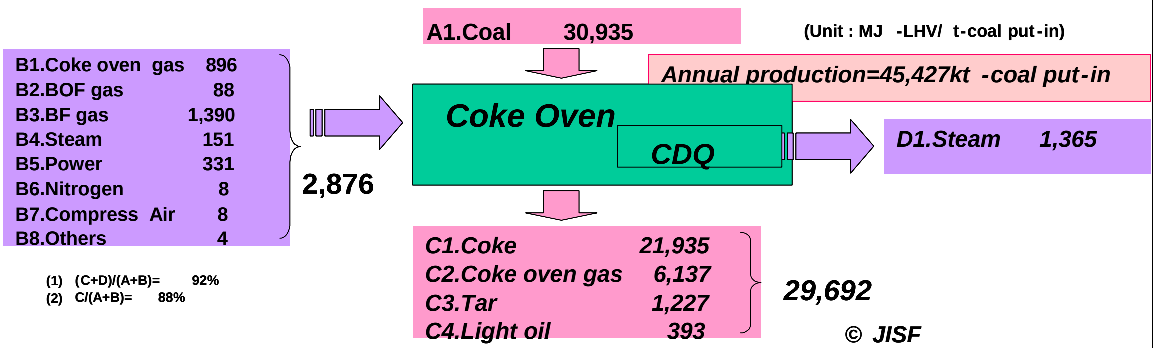


Figure 2 Specific Energy Consumption of Coke Oven of Japan's Steel (National average of the fiscal year 2002)

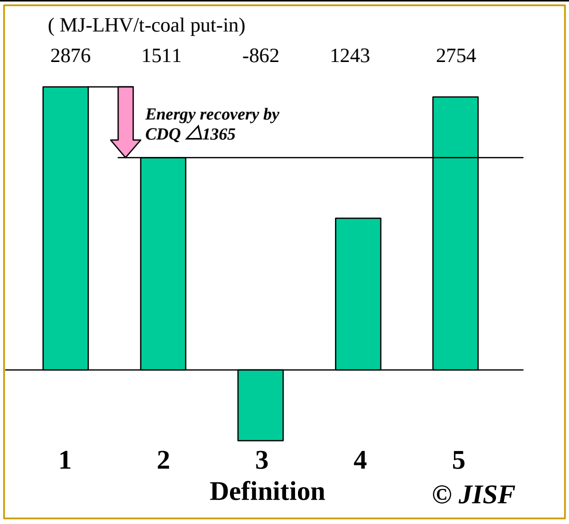


Figure 3 Energy Consumption of Coke Oven per 1 ton-coal in Japan based on various definitions.

"Specific energy consumption (SEC) of coke oven can have many definitions"

-Definition 1: energy used for coking, SEC= ΣB_i

-Definition 2: recovered energy by CDQ(=D1) considered, SEC= $\Sigma B_i - D1$

-Definition 3: by-product gas (B1,B2,B3) neglected as they are internal use of energy, SEC= $\Sigma B_i - D1 - B1 - B2 - B3$.

-Definition 4: focusing on material loss through coke oven, SEC= $A1 - \Sigma C_i$

-Definition 5: focusing on whole energy/materials balance, SEC= $A1 + \Sigma B_i - \Sigma C_i - D1$

Other than national average, each works has own boundaries because of separate company for coke oven operation etc.

2.3 Definition of Potential

Potential estimated here was defined as follows.

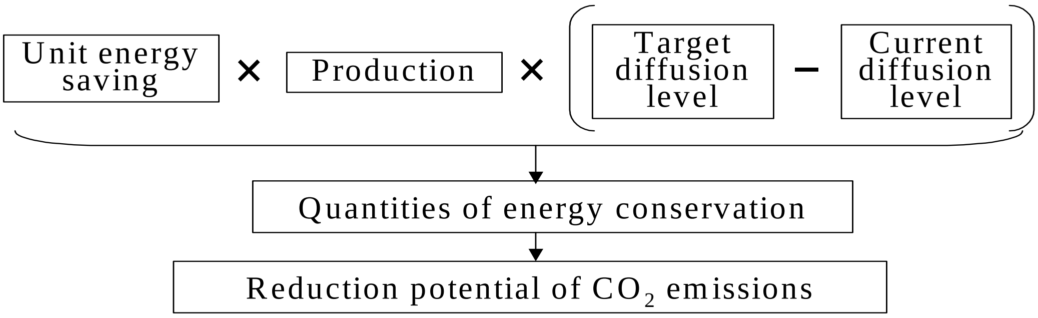
- Technical potential was estimated.
- Social and economic barriers were not taken into account.
  E.g., social factors (regulations, economic situation, public acceptance, etc.), differences in the availability of energy (energy sources, energy prices), equipment-specific constraints (weather conditions, geographic conditions), differences in product demand (the manufacturing process may be affected in the industrial sector), and cultural differences between countries, etc.

3. Estimation of Reduction Potential

3.1 Iron and Steel

3.1.1 Calculation methodology

Calculation scheme was shown in Figure 4 and methodology was summarized.



CO_2 emission reduction quantity in 2030
= Σ [Unit energy-saving of the technology × Production quantity in 2030 × (Targeted diffusion level of the technology – Current diffusion level of the technology) × CO_2 emission quantity per energy consumption quantity]

Figure 4 Calculation scheme (iron and steel industry)

- Energy saving technology adopted:
  CDQ(Coke Dry Quenching), **TRT**(Top-pressure Recovery Turbine),
  CC(Continuous Casting), **BOFG**(Basic Oxygen Furnace Gas) **recovery**,
  BOFG WH (waste heat) **recovery**, **HS**(Hot stove) **WH Recovery**,
  SC (Sinter cooler) **WH Recovery**,
  SP ME (Sinter plant Main Exhaust)**WH Recovery,**
  which are considered to be particularly effective and of which introduction is regarded as technologically feasible. (The information required to assess them is also readily available or can be reasonably assumed.)
- Current diffusion level was decided based on data from the IISI (2004) and experts' judgment from iron and steel industry (Japan Iron and Steel Federation (JISF)).
- Targeted diffusion level: 100 %
- Energy saving amount per unit production quantity was based on the existing survey (NEDO, 2001).
- Type of fuel for the offset energy: CDQ and TRT→ Electricity, CC and BOFG recovery → Oil
- CO_2 emission coefficients for fuels and for electricity were based on IEA data (OECD/IEA, 2004(a)).
- Production quantity: TRT, BOFG recovery, and CC→ based on the crude steel production quantity (IISI, 2005). CDQ→ based on the coke production quantity (IISI, 2005), estimated from the quantity of pig iron using the ratio between the pig iron quantity and coke quantity in 2002 in Japan (0.4)(JISF, 2003).

3.1.2 Results

- 0.26, 0.21 billion ton of CO_2 emissions per year an be reduced globally, at A1 and B2 scenarios respectively, through eight technologies.
- High potential in Central Planned Asia including China in light of future increase in production volume and the current low diffusion rates.
- CDQ and BOFG recovery reduce the largest amount of CO_2, because of current low diffusion rates and unit energy saving amount. CC, which has highest unit energy saving amount, has comparatively small potential because of current very high diffusion rate. TRT is also expected to demonstrate high energy-saving effects.
- Even though the rest four technologies don't have high unit energy saving amount, some reductions can be expected because of low diffusion rates.

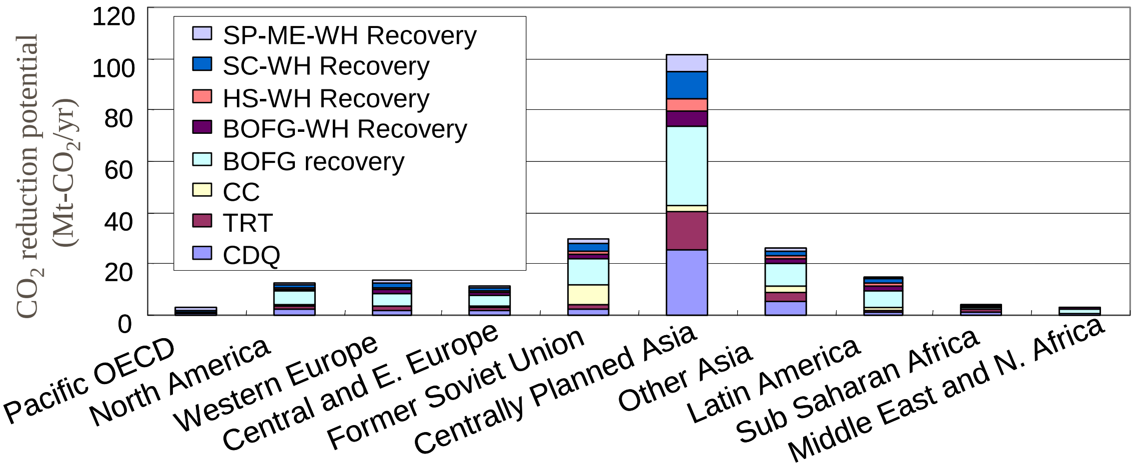


Figure 5 CO_2 reduction potential of eight technologies (iron and steel, 2030, B2 scenario)

3.2 Cement

3.2.1 Calculation methodology

Calculation scheme was shown in Figure 4 and methodology was summarized.

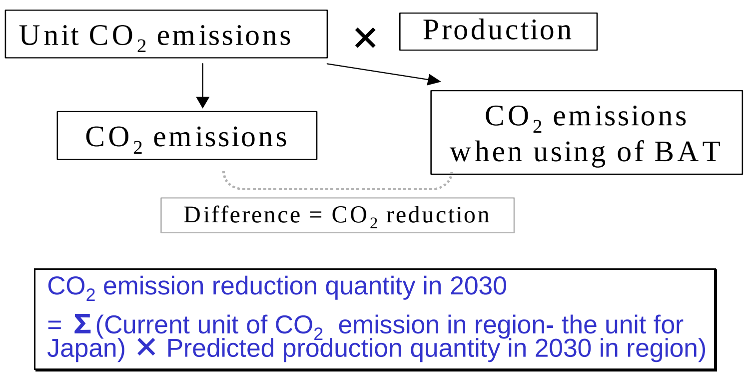


Figure 6 Calculation scheme (cement industry)

- CO_2 emissions per unit of production was assumed to be reduced to Japanese level. Data was referenced from the existing literature (Battelle, 2002)
- Cement production quantity: data of 2004 for each country (International Cement Review, 2005).

3.2.2 Results

- 0.76, 0.62 billion ton of CO_2 emissions per year can be reduced globally, at A1 and B2 scenarios.
- High potential in Central Planned Asia including China of more than 0.3 billions ton –CO_2 because of future increase in production volume.

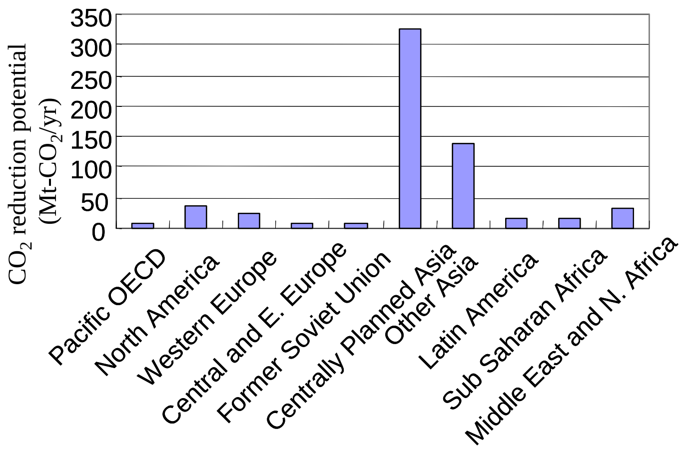
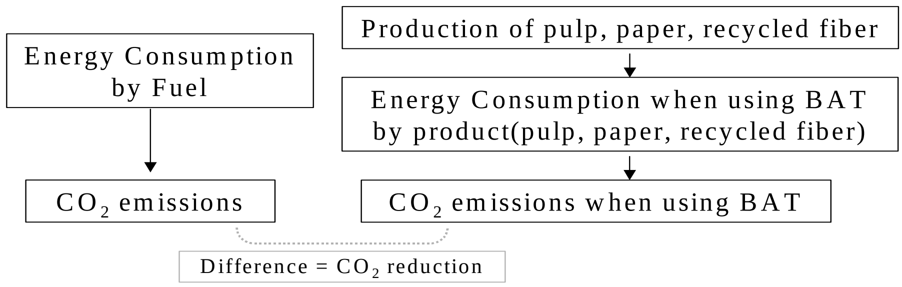


Figure 7 CO_2 reduction potential (cement, 2030, B2 scenario)

3.3 Pulp and Paper

3.3.1 Calculation methodology

Calculation scheme was shown in Figure 4 and methodology was summarized.



CO_2 emission reduction quantity in 2030
= Σ [CO_2 emission quantity in 2030 × (1 - Unit energy consumption in Japan by product/Unit energy consumption in the region by product)]
Unit energy consumption by product
= Σ (energy consumption quantity by fuel) by product /Current production quantity by product

Figure 8 Calculation scheme (pulp and paper industry)

- Items: paper, paper and paperboard, and recovered paper
- Production quantity: the FAO data (FAO, 2005)
- Total energy consumption quantity: estimated from the fuel input quantity according to the types of fuels (OECD/IEA, 2005)
- BAT energy consumption: pulpà literature data (JAPAN TAPPI, 2001), recycled fiber à literature data (Farla et al, 1997) , paper à derived from the differences of energy consumption between total value and the summation of pulp and recycled fiber in Japan.
- Energy consumption in 2030 using BAT in each region/country was estimated from these energy consumptions per production by product and each future production quantity. (The energy consumptions per production of several countries were estimated to be lower than that in Japan. In this case, the potential was not calculated.)
- CO_2 emission quantity of the fossil fuel used :by multiplying the energy consumption quantity and the unit CO_2 emission for each energy source (OECD/IEA, 2004).

- CO_2 emission derived from biomass and waste use systems: assumed to be zero.
- Fuel composition and products ratio was assumed to be unchanged

3.3.2 Results

- 0.17, 0.15 billion ton of CO_2 emissions per year can be reduced in several countries, at A1 and B2 scenarios.
- Approximate 0.1 billions ton –CO_2 emission reductions is available in North America.

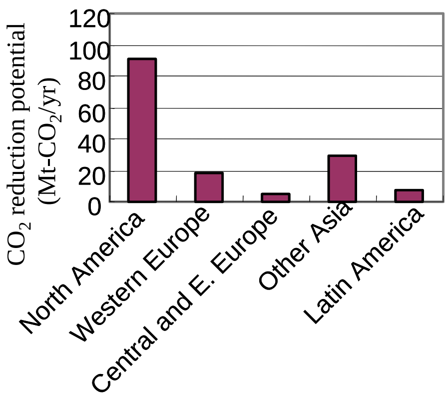


Figure 9 CO_2 reduction potential (pulp and paper, 2030, B2 scenario)

4. Economic assessment

4.1 Assumptions for the assessment

Cost per 1 t-carbon reduction was calculated based on the following assumptions.

- Discount rate: 10%
- Annual maintenance cost: 5% of initial investment cost.
- Investment cost, energy reduction using technology: literature data (NEDO, 2001)
- Energy price: values of 2004 in Japan. (IEA, 2005)

4.2 Results

Table 1 shows the results of the economic assessment. Only technologies listed in yellow cells in the tables are linked to the CO_2 reduction potential assessment in the section 3.

- Among eight technologies for iron and steel industry in this research, TRT, CDQ, HS-WH recovery, and SP-ME-WH recovery, which have negative cost, are most cost-effective. Secondly, BOFG recovery of less than 100 US$/t-C.
- Most of technology adopted here in pulp and paper has negative cost.
- For cement industry, SP kiln is most cost-effective.

For iron and steel industry, both potential and economic assessments were done for same technologies (listed in the yellow part of table 1) so that those results can be interlinked. Figure 10 shows the relations between cost and CO_2 reduction potential, where only negative cost options are shown. There are less reduction potential left at highly beneficial options but still much potential exists at negative cost options in many regions, especially Asia and FSU.

Table 1 Results of economic assessment for iron and steel, cement and pulp and paper industries

Iron and steel		Cement	
CDQ	+++	Suspension preheater (SP) kiln	+++
TRT	+++	New suspension preheater kiln	++
CC	-	Vertical roller mil for grinding	-
BOFG recovery	+	Efficient clinker cooler	+++
BOFG WH Recovery	-	**Pulp and Paper**	
HS WH Recovery	+++	Rod size press	+++
SP Cooler WH Recovery	-	Heat recovery of thirmo-mechanical pulp	+++
SPMain Exhaust WH Recovery	+++	Shoe press	+++
Pulverized coal injection	+++	Repowering system, gas turbin and boiler using wasted heat	+++
Direct hot rolling	++		
Regenerative Burner on heating	+++		
Scrap preheating in EAF	+		

"+++": benefit > cost, "++": US$0 – $100/tC, "+":US$100 – $300/tC, "–": >US$300/tC

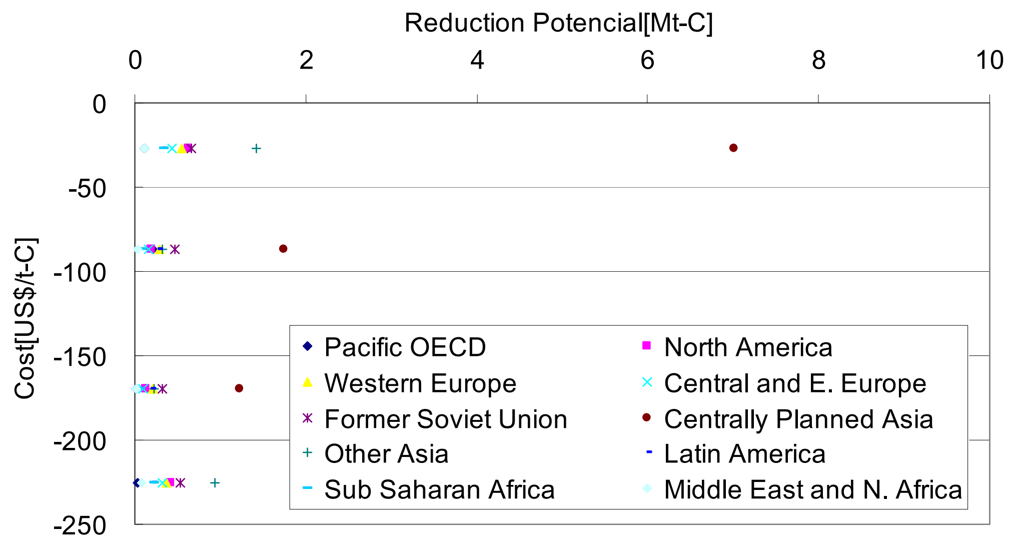


Figure 10 Cost and potential of CO_2 reduction by technology at iron and steel industry (2030, B2 scenario)

5. Discussion -- comparison of macro assessment using statistical data (top-down type) and bottom-up assessment based on technologies

5.1 Top down type macro assessment

In this study, top down type macro assessment means the way using unit energy consumption/CO_2 emissions from statistical data, which was applied to pulp and paper, and partly to cement industries. The character, merit and demerit were summarized as follows.

- Easy to provide the indicator, such as unit energy CO_2 emissions as a benchmark, which is used in assessment.
- Difference in evaluation boundaries by regions – namely, the difference in the size of the

countries/regions/business institutions, the difference in contents of facilities/processes and structural differences by countries cannot be dealt with properly.

- How to categorize the evaluation boundary and subdivide the factors affecting the indicator are critical. (By regions, by fuel types or by ages of facilities.)
- In case of looking at technical potential (not social/economic one), potential is likely to be overestimated.
- In some case, low reliability and credibility of statistical data.

5.2 Technology based bottom-up assessment

In this study, technology based bottom-up assessment is the way focusing on the energy-saving effect of each technology, which was applied to iron and steel. The character, merit and demerit were summarized as follows.

- Helps clarify and quantify the reduction effect of the technology, and has the additional advantage of making the economic cost easier to be grasped.
- Provides a quantitative indicator of action-based cooperation between countries, such as transfer of measures.
- Has the advantage that it is not so affected by the difference in boundaries.
- Effective in case that there are difficulties in setting common evaluation boundary, even if manufacturing process is similar among countries.
- Requires the data of diffusion rate and unit energy saving / CO_2 emissions reduction amount of targeted technologies.
- Limitation of kinds of targeted technology limits the range of CO_2 emission reduction potential.
- Methodology of developing database should be considered: Cooperation with industry circles is important. Combination with nationally introduced mechanism, e.g., Top-Runner scheme in Japan, Dutch Benchmark Covenant, Labelling scheme in US or Singapore.

6. Conclusion

- 1.0-1.2 billion tons of CO_2 emissions can be reduced by use of energy efficient technologies in iron and steel, cement and pulp and paper industry, at global scale. (However, not all applicable technologies and countries were considered because of data limitation.)
- It is suggested that the importance of development of framework which draws CO_2 reduction potentials through utilization of efficient technology as much as possible, as an effective mitigation measure for climate change and new international technology based cooperation.
- Merit and demerit of top-down and bottom-up type methodologies were clarified.
- More detailed analysis of specific aspects in each industry is required to seek better ways to assess its CO_2 emissions and its reduction potential.
- To obtain more accurate and consistent database, more systematic data preparation methodology should be discussed.
- More detailed economic assessment, quantitative assessment of social barrier, and “dynamic” assessment considering timeframe are worth taking into account.

Table 2 summarised all results estimated in this study.

Table 2 Summary of CO_2 reduction potential in 2030

$Mt\text{-}CO_2$	Iron and steel		Cement		Paper and pulp	
	A1	B2	A1	B2	A1	B2
Pacific OECD	2	2	13	9		
North America	15	12	45	36	100	91
Western Europe	18	12	36	25	22	18
Central and E. Europe	14	10	9	7	5	4
Former Soviet Union	38	28	12	9		
Centrally Planned Asia	110	95	380	330		
Other Asia	31	25	170	140	32	29
Latin America	21	14	22	14	9	7
Sub Saharan Africa	3	4	13	16		
Middle East and N. Africa	5	3	63	32		
	260	210	760	620	170	150

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Appendix

As an extension[1] of the paper, we identified uncertainty ranges in reduction potentials of GHG by several technologies. For this purpose, Monte-Carlo simulations were adopted based on the following assumptions.

(1) Energy-saving potentials in energy intensive industries are expressed in the following equations, in which all factors include uncertainties.

Energy saving potentials =

Unit-energy-saving ① × Production ② × (Target-diffusion-level ③ – Current-diffusion-level ④)

(2) In the above equation, actual data were available for factors ①, ③ and ④, although some of them are insufficient to statistically estimate uncertainty.

(3) Regarding ①, we evaluated uncertainty ranges based on actual operation data of the specific technologies.

(4) Regarding ②, we did not include uncertainty this time, since we follow scenario A1b or B2 of SRES, which project future production without uncertainty ranges.

(5) Regarding ③, we evaluated uncertainty ranges based on actual diffusion data of continuous casting. Since continuous casting is cost-effective enough and well established, its diffusion was also assumed to express the target level of the other technologies.

(6) Regarding ④, we assessed present diffusion data of each technology. Then standard deviation in each data was assumed to be half of the present diffusion level.

Monte-Carlo simulations were performed on coke dry quenching (CDQ), blast furnace top pressure recovery turbine (TRT), and basic oxygen furnace gas recovery (BOFG recovery) in iron and steel industry. We will also deal with the other technologies in our future work, although actual operation data were not presently available on them.

Identified uncertainty ranges on CDQ, TRT, and BOFG recovery are shown in the tables 1, 2 and 3,

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[1] This additional assessment on uncertainties was done by authors after the main body of text was published at IEEJ WEB in March 2006, and updated in June 2006. It is noted that this part was, therefore, not reviewed at the Industry Expert Review Meeting to the Fourth Assessment of Working Group 3 IPCC, Cape Town, 17-19 January 2006, but peer-reviewed by some experts Japan including Iron and Steel Federation.

respectively.

Table 1. Ranges of uncertainty in GHG reduction potentials by introducing CDQ.

	CDQ	
	A1	B2
	Range of reduction potentials (90%)	range of reduction potentials (90%)
	1000t-CO_2	1000t-CO_2
PacificOECD	300〜410	310〜420
North America	2660〜3120	2110〜2460
Western Europe	2260〜3510	1540〜2410
Central and E.Europe	1700〜2350	1270〜1800
Former Soviet Union	1880〜4700	1330〜3370
Centrally Planned Asia	24400〜33400	21200〜28800
Other Asia	5600〜6740	4570〜5460
Latin America	1550〜1820	1040〜1210
Sub Saharan Africa	950〜1110	1110〜1300
Middle East & N.Africa	320〜370	180〜210

Table 2. Ranges of uncertainty in GHG reduction potentials by introducing TRT.

	TRT	
	A1	B2
	range of reduction potentials (90%)	range of reduction potentials (90%)
	1000t-CO_2	1000t-CO_2
pacificOECD	20〜60	20〜60
North America	1190〜1370	960〜1100
Western Europe	1040〜1590	700〜1070
Central and E.Europe	930〜1110	720〜850
Former Soviet Union	1430〜2230	1020〜1600
Centrally Planned Asia	10400〜13200	9100〜11500
Other Asia	2580〜3030	2110〜2480
Latin America	720〜830	480〜550
Sub Saharan Africa	440〜510	520〜590
Middle East & N.Africa	150〜170	80〜100

Table 3. Ranges of uncertainty in GHG reduction potentials by introducing BOFG recovery.

	BOFG recovery	
	A1	B2
	range of reduction potentials (90%)	range of reduction potentials (90%)
	1000t-CO_2	1000t-CO_2
pacificOECD	0	0
North America	2440〜3650	1860〜2820
Western Europe	220〜3770	150〜2540
Central and E.Europe	1750〜2890	1300〜2170
Former Soviet Union	4760〜6720	3340〜4750
Centrally Planned Asia	31100〜44800	27400〜38700
Other Asia	5040〜7950	4070〜6400
Latin America	860〜1910	600〜1310
Sub Saharan Africa	0〜960	0〜1120
Middle East & N.Africa	30〜370	20〜220

Although histogram could be depicted for each of the above uncertainty ranges, we show only three histograms due to page limits.

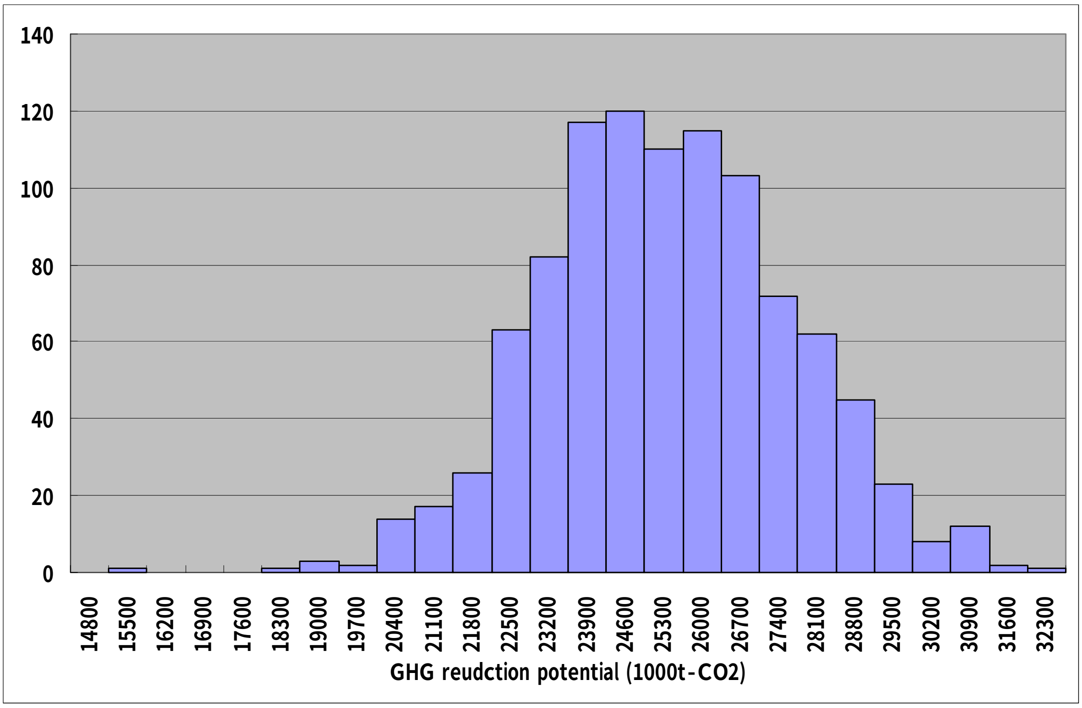

Figure1. Histogram in GHG reduction potentials by introducing CDQ in Centrally Planned Asia.(SRES B2)

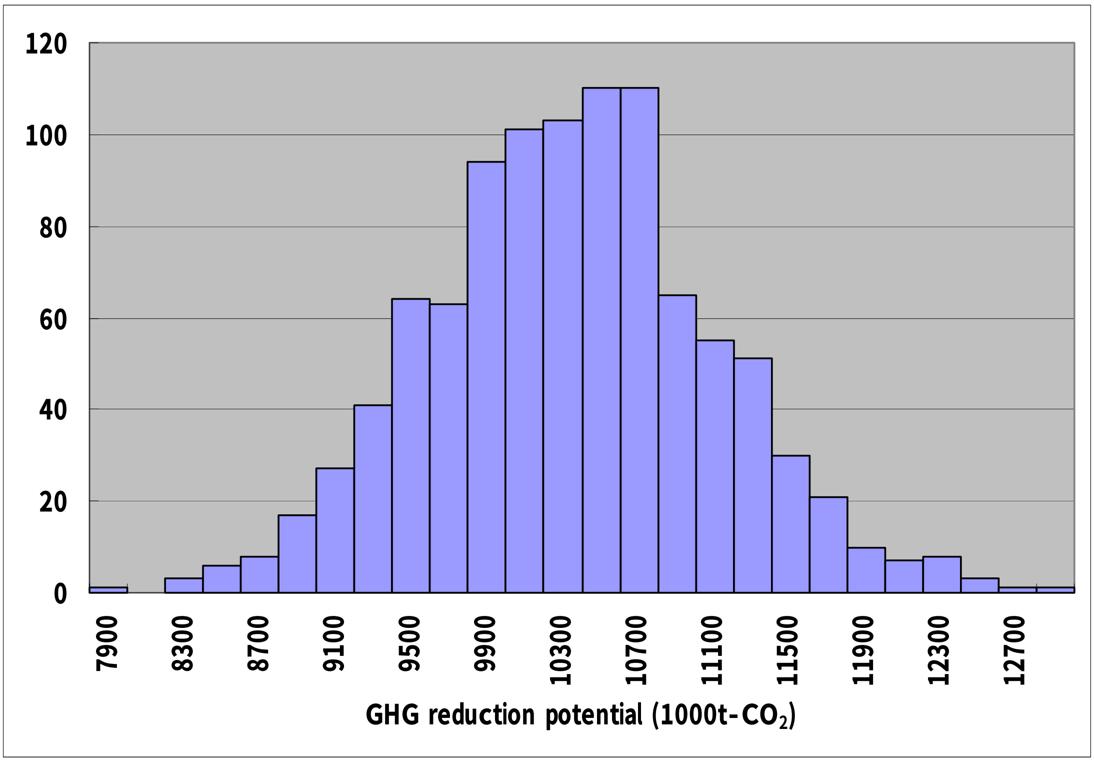

Figure2. Histogram in GHG reduction potentials by introducing TRT in Centrally Planned Asia.(SRES B2)

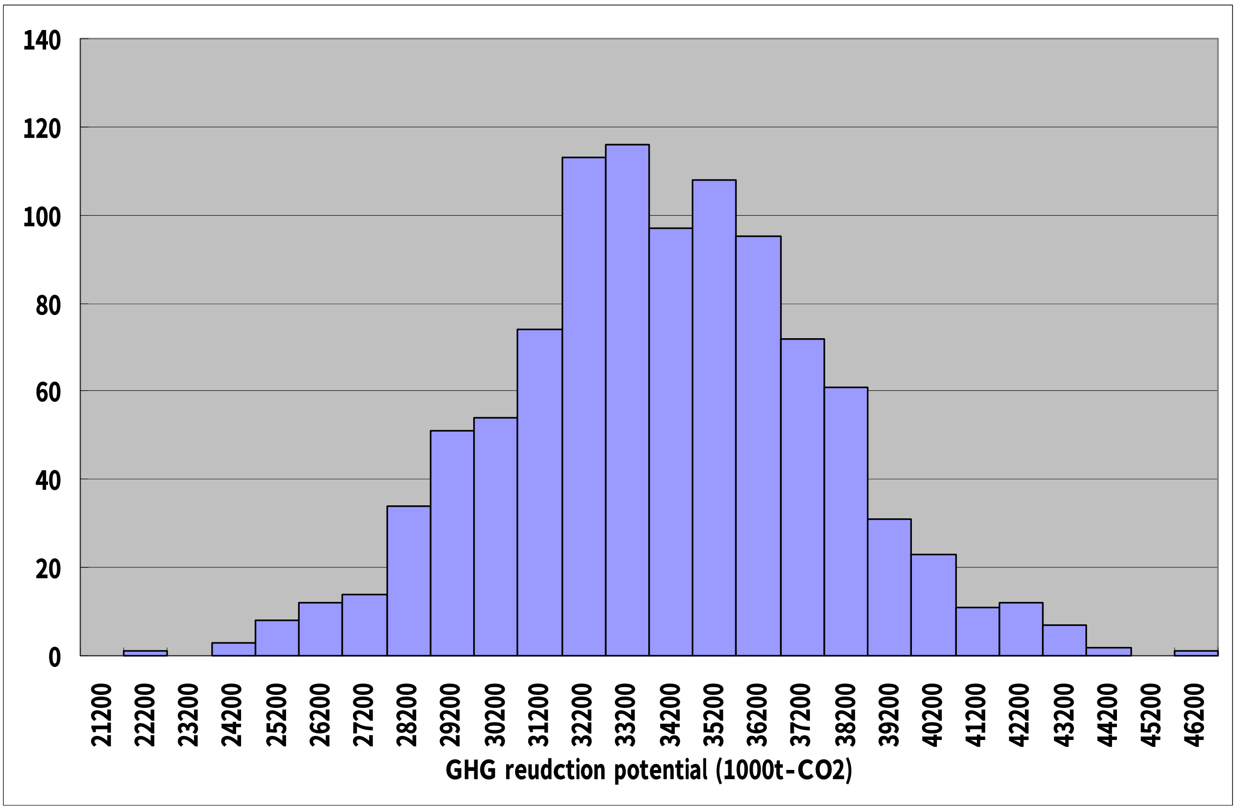

Figure3. Histogram in GHG reduction potentials by introducing BOFG recovery in Centrally Planned Asia. (SRES B2)