2005 Energy Intensity
(Basic oxygen furnace Steel; Iron and Steel Sector)

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An international comparison study of energy efficiencies in the iron and steel sector in 2000 has already been published on our website under the title "International Comparisons of Energy Efficiency; Sectors of Electricity generation, Iron and Steel and Cement." (For electricity generation, the 2005 comparison is available.)

As for the 2005 comparison of iron and steel sector's energy intensity, preliminary results were obtained using the same model as in the 2000 analysis (http://www.rite.or.jp/Japanese/labo/sysken /about-global-warming/download-data/Comparison_EnergyEfficiency2005temp.pdf)

The present report aims at analyzing and summarizing energy intensity in the iron and steel sector for 2005, based on most recently released data. It provides estimates of energy intensity in each country: these estimates reflect the technological levels as accurately as possible, and can be regarded as highly valuable in displaying basic data for both equipment approach and sector approach, as well as for proposing concrete emission reduction measures.

1. Overview of Estimate

As indicated in IEA [1], the two main technologies in the iron and steel sector are blast furnace to basic oxygen furnace (BF-BOF) and scrap based electric arc furnace (scrap-EAF). They have different characteristics: on the one hand, scrap-EAFs consume less energy; on the other hand, from a global perspective, scrap iron availability is limited. Thanks to technological improvement, EAFs are now able to produce high-class iron that used to be produced only by BF-BOFs. Yet, most of high-class iron is still produced by BF-BOFs. Therefore, for CO_2 emissions assessment purposes, separate estimates of the energy intensity of BF-BOFs and scrap-EAFs are required.

Moreover, the iron and steel sector has a lot of energy inputs and outputs (e.g. coke import/export). It would hence be wrong to focus only on the energy consumption in the "Iron and Steel" sector as in the IEA Energy Balance [2]. (For more details, refer to page

2.) Appropriate boundary adjustment is thus required.

In view of the above-mentioned considerations, cross-national energy intensity is assessed through cross-comparisons of energy intensity based on the following bottom-up approach and top-down approach.

Referred statistical reports for top-down approach

- IEA statistics (Energy Balances of OECD/Non-OECD Countries, 2008) [2]
- Aggregated crude steel production by World Steel Association ([3],[4])

Referred data and source materials for bottom-up approach

- Energy intensity and/or CO_2 intensity by company and country
- Investigation of individual plants (NEDO research reports)
- Estimate based on the diffusion rate of equipments
- Estimated energy intensity at 2005, based on the 2000 estimate
- Reducing agents rate by region
- IEA estimates of CO_2 reduction potentials at 2005 by region

Primary assumptions for this estimate are:

- Electricity and steam are counted as primary energy base. (The electricity is converted at the rate of 1MWh=10.8GJ in all regions and the heat is counted using regional energy intensity.)
- Net energy consumptions (by-product gases, electricity) are counted.

2. Top-down Approach

(1) Adjustments of energy input and boundaries based on IEA[2]

One may find in IEA[2] the energy inputs for steel production: they include not only the energy input in the “Iron and Steel” sector which is described as one of the energy demand sectors, but also the ones in “Coke Ovens” and “Blast Furnaces”, as shown in table 1. Since some coke, by-product gases and electricity produced in “Iron and Steel” sector are used in other sectors or regions, boundary adjustments are required.

Table 1. Abstract from energy balance related to steel and iron in IEA[1], world 2005

(PJ/yr)	Coal	Coke Oven Coke	Coke Oven Gas	Blast Furnace Gas	Oxygen Steel Furnace Gas	Elec	Total
Coke Ovens	-17,020	12,739	1,908			16	-2,391
Blast Furnaces	-841	-8,731	-49	3,400	132	1	-5,732
Iron and Steel	2,135	2,084	1,176	2,419	45	3,280	15,091

Note 1) “Coke Ovens”, “Blast Furnaces” and “Iron and Steel” in this table refer to terms in IEA energy balance [2]. Accordingly “Iron and Steel” in this table is completely different from the defined boundary of iron and steel sector in this paper.

Fig.1 shows the conceptual diagram of boundary.

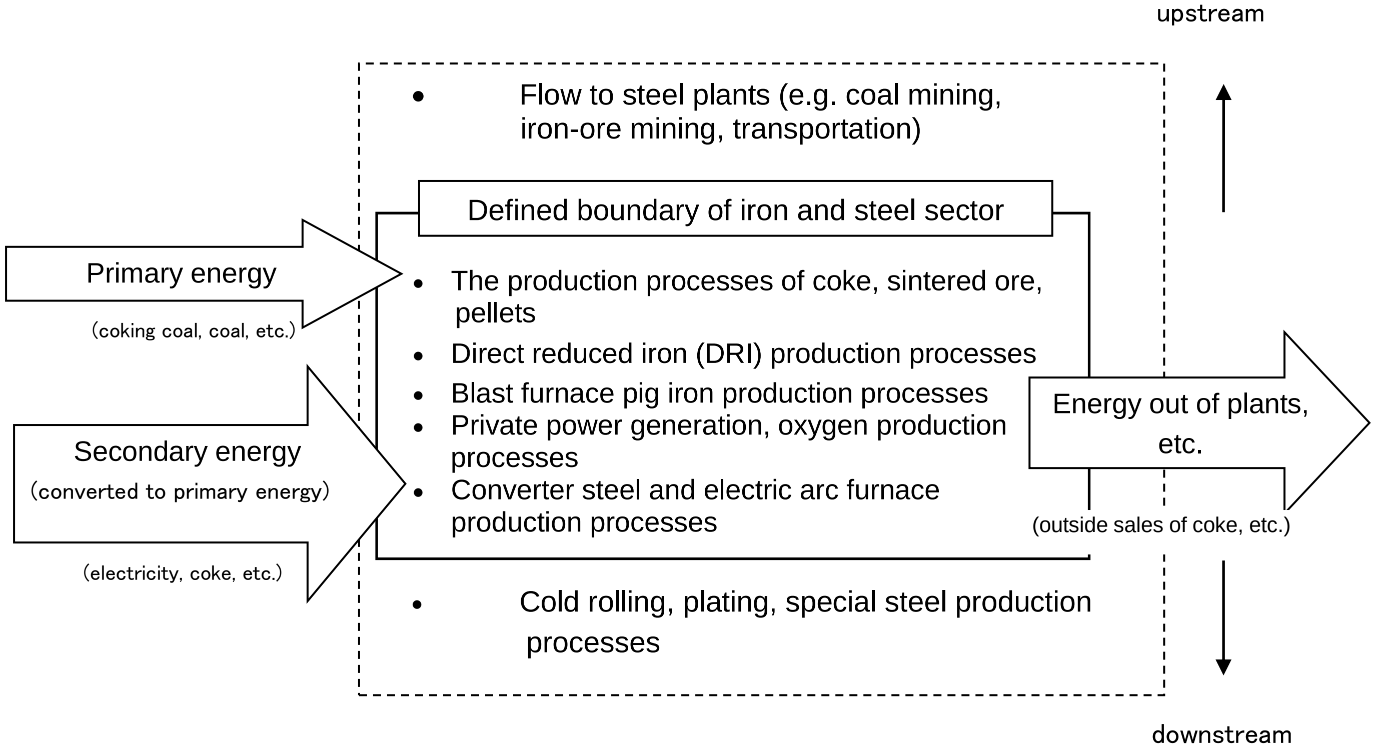

Fig.1 Boundary diagram

Note 1) The diagram shows the simple process without the energy loop configuration. Actually, it has complicated loop configurations of by-product gases, steam and electricity and in this analysis the net consumption of the energy is counted.

In Fig.1, upstream operations of steel production are shown on top of the diagram, while downstream operations are going down to the bottom. Above all, the following boundaries are set for each process of steel production:

- The consumed energy is counted from the upstream operations of coke, sintered ore and pellets production.
- The consumed energy is counted to the downstream operations of hot rolling, except for the energy consumed for cold rolling, plating and special steel production.

Fig.1 also shows the energy flow from the left to right. The primary energy on the left includes coking coal and coal for blast furnace brought into the steel plants. The secondary energy (converted to primary energy) on the left includes purchased electricity, coke and steam. The energy out of plants on the right includes coke, by-product gases, steam and electricity sold outside.

Given the complicated energy balance in steel production, we chose to include energy consumption of imported products as energy consumption within the importer country, in order to enable international comparisons of energy intensity which reflects technological levels.

Table 2 shows the net energy input for steel production. We used a calculation spreadsheet based on Fig.1 and available IEA[2] data.

Table 2. Energy input for steel production (RITE estimate, based on IEA[2]) [2005]

(PJ/yr)	Non-electricity	Electricity	Total
US	1,064	869	1,933
Canada	204	116	319
UK	241	54	296
France	277	169	446
Germany	583	303	887
EU (15)	2,070	1,229	3,299
EU (27)	2,446	1,492	3,938
Japan	1,587	748	2,335
Korea	668	467	1,135
China	7,676	2,748	10,424
India	1,152	0	1,152
Russia	1,978	1,612	3,591
World	20,322	9,876	30,198

Note 1) Non-electricity = energy excluded net electricity input. Coal accounts for most energy in fact (already converted to the primary energy base)
Note 2) electricity = net electricity input (already converted to the primary energy base; 1[kWh] = 3.6(1/3)[MJ] = 10.8[MJ])

Note 3) MJ = 10^6J, PJ = 10^{15}J
Note 4) Energy is described as 10^3[ktoe] in IEA[2]. In this report, it is described in joule [J] (1[ktoe] = 0.041868[PJ])
Note 5) Only major regions are in the table.

It should be noted that the energy required for BF-BOFs and for EAFs is not separated at this stage.

(2) Adjustment of crude steel production by production system

Table 3 shows the data on material resources such as crude steel production, based on [3] and [4] by World Steel Association. BOF steel is defined as steel made from pig iron etc which is produced in BF-BOF, Scrap-EAF steel as steel made from scrap iron, and DRI-EAF as steel made from direct reduction iron in this report. Since most of the energy consumption for crude steel production is required for DRI production, the amount of crude steel is calculated assuming that it is produced in the same region where DRI steel is produced.

Table 3. Crude steel production by production system

(Mt/yr)	BF-BOF	Scrap-EAF	DRI-EAF
US	41.7	52.0	0.2
Canada	9.0	5.8	0.6
UK	10.6	2.7	0.0
France	12.2	7.3	0.0
Germany	30.9	13.2	0.5
EU (15)	97.9	66.8	0.5
EU (27)	120.5	74.5	0.6
Japan	83.6	28.8	0.0
Korea	26.7	21.1	0.0
China	314.0	41.5	0.3
India	21.0	12.4	12.4
Russia	55.3	7.4	3.4
World	781.6	305.7	59.5

Note 1) BOF steel includes crude steel produced by open hearth furnace (OHF).
Note 2) Calculating method assumes that DRI-EAF is produced in the same region where DRI is produced
Note 3) Only major regions are in the table.

(3) Summary of top-down approach

Table 4 shows the energy intensity of BF-BOFs. It is estimated from the energy consumption (Table 2) and crude steel production (Table 3), based on IEA[2]. In some regions such as Russia, no rational explanations can be found to explain such energy intensity and defective statistics in IEA[2] seem the major factoring cause, as IEA admitted themselves [5].

Table 4 Energy intensity of BF-BOFs based on top-down approach, 2005

(GJ/tcs)	Estimated energy intensity of BF-BOFs based on non-electricity	Estimated energy intensity of BF-BOFs based on total energy
US	30.9	35.5
Canada	27.5	30.0
UK	29.3	26.9
France	26.4	30.6
Germany	24.0	26.4
EU(15)	26.1	28.9
EU(27)	25.5	28.8
Japan	23.5	25.7
Korea	28.9	34.2
China	28.6	30.5
India	40.9	30.0
Russia	47.8	65.0
World	29.8	32.7

Note 1) The unit is energy consumption per ton of BF-BOF [GJ/t crude steel]
Note 2) Only major regions are in the table.

Assuming that there are no statistical deficiencies, in the regions which have low diffusion rates of EAFs, the intensity estimates of BF-BOFs based on both non-electricity (the left column in Table 4) and total energy (the right column in Table 4) seem to serve as a useful reference.

In the regions which have high diffusion rates of EAFs, the left column based on non-electricity seem to serve as more useful reference than the right column based on total energy, since electricity consumption is depending on the intensity of EAFs.

As well, the rates in the right column are higher than the left in Table 4. This is due to the influence of energy consumption when steel is processed for end items in the downstream.

3. Bottom-up Approach

The top-down approach statistically covers all the regions in detail, but it has difficulties in sorting out the regional differences of energy intensity and defective statistics.

Therefore, estimates based on bottom-up approach should be combined and organized, not relying on IEA statistics [2]. We use the following 5 bottom-up approaches for the estimates.

(1) Energy intensity by company and region, CO2 intensity and its revision (OECD membership countries)

In this approach, we aim at revising energy intensity figures published by companies and countries' steel associations and at assessing energy intensity by region. It should be noted that since they come from different sources, these energy intensity and CO_2 intensity values were not necessarily assessed under the same set of assumptions, and that these assumptions were also not always specified.

Among the data provided by companies, the most reliable ones are the reports of ThyssenKrupp, Corus, POSCO and five Japanese blast furnace companies. Energy intensity of BOF steel figures released by the American Iron and Steel Institute constitutes the best reference among other regional Iron and Steel Institutes' publications.

To make data cross-comparisons relevant on an international level, especially regarding the fact that electricity can be counted as primary energy base or not, several figures are required: the ratio of BOF steel to hot metal (or pig iron), the boundary adjustment of purchase/outside sale of row materials in the upstream, energy consumption in the downstream, and so on.

(2) Bottom-up estimate in China

Since BOF steel production in China accounts for 40% of the world total in 2005, China deserves particular attention. For bottom-up estimates, energy intensity of BOF steel of major plants and small-scale plants is assessed separately, since there are differences in volume of information: major plants indeed have important volume of information, while small-scale plants have little information.

Table 5 shows pig iron, BOF steel, and crude steel production of major and small-scale plants, based on [11]. In the table, since 2001 BOF steel production of small-scale plants has been increasing rapidly. Within 4 years, small-scale plants' share of BOF steel production increased dramatically from less than 7% to nearly 20%.

Moreover, the table implies that small-scale plants had a high rate of pig iron selling outside to electric arc furnace in 2001, but that the pig iron rate as materials for BOF steel was higher in 2005.

Table 5. Iron and steel production of major and small-scale plants in China

		2000	2001	2002	2003	2004	2005	2006	2007
Pig iron production (Mtpi/yr)	Total	131	147	171	214	257	345	408	471
	Major plants		119	139	155	208	260		
	Small-scale plants		28	32	59	48	85		
Converter steel production (Mtcs/yr)	Total	106	126	152	181	239	314	379	450
	Major plants		117	139	157	200	256		
	Small-scale plants		8	12	24	39	58		
Crude steel production (Mtcs/yr)	Total	127	151	182	220	280	356	423	495
	Major plants		137	164	186	234	289		
	Small-scale plants		14	18	34	47	66		

Source: Iron and steel industry in China, Shipuresu 2008 [11]

Note 1) Mtpi=million ton pig iron, Mtcs=million ton crude steel

Since we are focusing in this report on energy intensity of BOF steel, only the pig iron used for BOF steel is included in the iron and steel sector. It should be noted that in both this estimate and the 2000 estimate, energy consumption to produce pig iron for EAF iron source, mostly by small-scale plants, is not considered. In a nutshell, we do not include the whole pig iron production in the iron and steel sector, as Alliance for American Manufacturing (AAM)[12] does.

Table 6 shows estimated energy intensity based on the data and materials of [13][14][15][16]. The energy intensity in Table 6 is converted to comparable value with parameter adjustment such as different rates of pig steel. Table 6 also shows bottomed up energy intensity by BF capacity of major plants (Table 7).

Table 6. Aggregated energy intensity

(GJ/tcs)		Coking	Sintering	BF	BOF	Rolling	Total
Average	2004	4.6	2.1	14.2	1.0	3.6	25.2
	2005	4.5	2.1	13.8	1.0	3.7	24.7
Major plants	2004	4.2	1.9	13.7	0.8	2.7	23.3
	2005	4.1	1.8	13.2	0.8	2.7	22.6
Small-scale plants	2004	6.5	3.1	16.9	2.2	8.4	35.0
	2005	6.3	3.0	16.4	2.1	8.1	33.9

Note 1) source: [13][14][15][16]

Table 7 Energy intensity of pig iron production by BF capacity in major plants

Major plants 2005	Pig iron production (Mt-pi/yr)	BF (GJ/t-pi)
>3,000m^3	26	11.5
2,000-2,999m^3	61	12.4
1,000-1,999m^3	52	12.8
300-999m^3	132	13.9
<299m^3	18	14.1
total	289	13.2

Note 1) source: [13][14][15][16]

According to Table 6, the energy intensity of China's BF steel in 2005 is about 25GJ/tcs. However, the computation method applied to the Chinese case is different from the method defined in this analysis. If the computation method used for China was to be applied to Japanese data, energy intensity would be 21.2GJ/tcs. On the other hand, based on the method defined in this analysis, Japan's energy intensity should be 23.1GJ/tcs and China's energy intensity 27.2GJ/tcs.

(3) Bottom-up estimate in India

BF steel production remains small-scale in India for now, but if social infrastructures develop simultaneously with economic take-off, steel market can be expected to expand largely. After the case of China, estimates for India are displayed here.

Energy intensity by plant and the situation of specific plants can be found in [17].

Table 8 below shows energy intensity by plant.

Table 8 Energy intensity by Indian plant

	BF steel production	Basic unit	Notes
Steal Authority Of India Limited (SAIL)	10.9Mtcs [2000] [4] 13.4Mtcs [2005] [4] 13.5Mtcs [2006] [4]	33.5GJ/tcs [2000] 30.1GJ/tcs [2005] 29.9GJ/tcs [2006] ([17], P95)	• Basic units in the left column are the data from India • The basic unit [2006] of SAIL Rourkela Steel Plant calculated in India is 33.4GJ/tcs, while recalculated in Japan, it is 36.1GJ/tcs based on the data from India. • *By the same Japanese calculation technique, Japan's average basic unit is 21.67GJ/tcs.*
Rashtriya Ispat Nigam Visag	10.9Mtcs [2000] [4] 10.9Mtcs [2000] [4] 10.9Mtcs [2000] [4]	31.4GJ/tcs [2000] 27.7GJ/tcs [2000] 25.5GJ/tcs [2000] ([17], P95)	• The data [1990] in the left column is based on the source [18]
Tata Steel	n.a [2000] 4.73Mtcs [2005] [4]	31.0GJ/tcs [2000] [19] 29.1GJ/tcs [2000] [20]	• The data in the left columns can be referred to ([17], P46)

Based on Table 8, Indian energy intensity of BF steel in 2005 is estimated 33.3GJ/tcs with weighted means of energy intensity by BF steel production and individual corrections (e.g. pig iron rate, difference in calculation [relative differences between Japanese and Indian energy intensity])

(4) Methods based on the estimated 2000 data

Since we have already estimated the 2000 energy intensity based on 2000 data, 2005 energy intensity could technically be obtained by subtracting from the 2000 estimate the energy saved thanks to the additional energy-saving equipments and improved collection rate of by-product gases that appeared between 2000 and 2005. This method would be effective at the following respects.

- The BF capacity and facility vintage are explicitly considered in the 2000 estimate.
- The diffusion rates of individual energy-saving equipments are explicitly considered in the 2000 estimate.
- Time-series net efforts made by technology diffusion could be prospective.

In some regions, the change in the diffusion rates of energy-saving technologies and the improvement rates of energy intensity can be explicitly obtained, but such data are intermittent by region. For some regions where the explicit improvement rates can not be obtained, the estimate of the improvement rates are based on the same top-down approach as Table 4 to calculate energy intensity.

(5) The other methods

Even applying the methods mentioned above, there are still some regions in which enough information can be obtained, e.g., developing countries except China and India. We therefore referred to the following estimated data.

- Estimate from reducing agents rate in [21], [22]
- Estimate based on potentials of CO2 emission reduction by region in IEA[1]

4. Summary

Figure 2 shows the estimate of BOF energy intensity by region based on relative consistency and reliability, with the energy intensity calculated by the individual estimates in this cross-compared report. Figure 3 shows the 2005 estimate (identical to Fig.2) combined with the 2000 estimate.

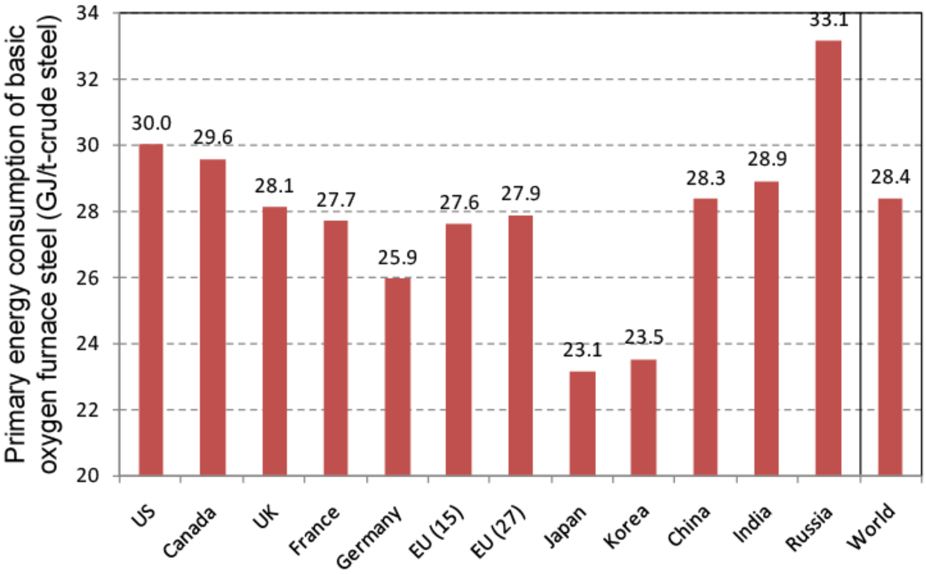

Fig.2 2005 BOF energy intensity

Note 1) To show the precise differences of regional energy intensity, the vertical axis starts at 20GJ/tcs.

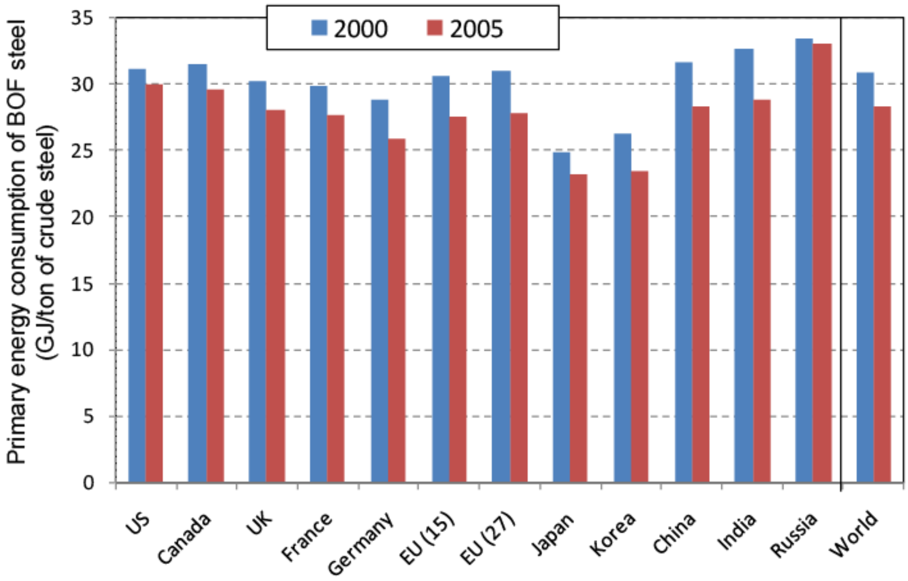

Fig.3 2000/2005 BOF energy intensity

Fig. 2 and Fig. 3 indicate the following.

- The highest energy intensity is found in regions such as Japan and Korea.
- This can be explained by differences in diffusion rates of individual energy-saving equipments, recovery rates of by-product gases, etc.
- Energy intensity seems to have improved in a number of countries between 2000 and 2005.
- China and India have known relatively quicker progress in energy intensity than the other regions.
- In particular in China, despite the mushrooming of small-scale plants with low intensity performance, the effort made to substantially increase newly-built large-scale equipments and enhance energy-saving equipments of existing facilities has improved the national average of energy intensity.
- On the other hand, these figures show slow progress in energy intensity for Russia.

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