2010 Energy intensity
(Converter Steel; Iron and Steel Sector)

September 25, 2012

Systems Analysis Group, RITE

Analyses of international comparison of energy intensity of converter steel in iron and steel sector were published on our website on October 5, 2009. Please refer to "2005 Energy Efficiency (Converter Steel; Iron and Steel Sector)". The analyses have been also published as a peer-reviewed paper in the international journal. [1]

In this report, based on the available historical data which were newly released, the energy intensity of converter steel in the iron and steel sector in 2010 is analyzed and summarized. The following estimates of the energy intensity in each country which reflect the technological levels as accurately as possible could be considered to be highly crucial.

1. Overview of Estimates

The iron and steel sector has two different characteristics such as blast furnace to converter iron making process based on ore iron and scrap based electric arc furnace (scrap-EAF). Scrap-EAFs have an advantage of less energy consumption but the comprehensive global availability of scrap iron is limited. Technological improvement has enabled EAFs to produce some of high-class iron which used to be essentially produced only by BF-BOFs. Yet, BF-BOFs remain technologically integral to the production of most of high-class iron. Also from the viewpoint of CO2 emission curb, separate estimates of the energy intensity of BF-BOFs and scrap-EAFs are required. However, as the energy consumptions are not recorded separately in the IEA Energy Balance table [3], [4], it is necessary to devise the estimate of the each furnace consumption. The iron and steel sector has a lot of incomings and outgoings of various kinds of energy (e.g. coke import/export, direct sale of by-product gas). After appropriate boundary adjustment, the estimate of the energy intensity is required to take into account of these factors.

In this paper, based on the above, energy intensity for BF-BOF steel product in 2010 were estimated by region, intercomparing the following several approaches.

Approach based on the world statistics

- Approach based on IEA Energy Balances ([3],[4]) and aggregated crude steel production by World Steel Association ([5],[6])

Approach based on bottom-up data

- Approach based on corporate environmental reports and national iron and steel association reports of each country
- Approach referred to the diffusion rate of technologies
- Approach referred to energy saving potentials by region estimated by IEA
- Approach based on recycling rates by region

Primary assumptions of this estimate are followings;

- Primary energy input per ton of crude steel (GJ/t crude steel) is presented based on the lower heating value (LHV).
- The electricity is converted at the IEA primary energy statistic rate of 1MWh=3.6GJ÷0.333=10.8GJ in all regions
- The heat ("Heat" in IEA statistics) is converted to primary energy with regional efficiency.
- Net energy consumptions including cokes, by-product gases and electricity are counted.
- Pig iron production per unit of converter steel production is referred to "pig iron steel ratio" here and this pig iron steel ratio is corrected to 1.025 that is the world average value in 2005.

Coefficient iron steel ratio was corrected to 20.46GJ/t (a ton of pig iron steel/a ton of converter steel) on the basis of 'Energy saving and environmental measures in iron and steel industries ([8]). For example, when pig iron production per 1 ton of converter steel increases 100kg, apparently 2.064 (GJ/t crude steel) energy intensity has deteriorated, and the 2.064 (GJ/t crude steel) is subtracted for correction. By correcting pig steel ratio, the influence of pig iron, which is externally sold to EAF companies or casting furnaces companies, can be evaluated properly and enables international comparison reasonable.[1] The followings are concrete 'approach based on the world statistics' and 'bottom-up approach.'

---

[1] In some cases companies improve technical development for the blast furnace hot metal ratio in integrated steelworks to reduce the ratio. The energy intensity per a ton of converter steel is greatly improved due to the hot metal ratio reduction [9]. As shown in J. Oda *et al.,* 2012 [1], how apparent the energy intensity could change depends on the corrected pig iron steel ratio or not corrected.

2. Approach based on the world statistics

(1) Adjustments of energy input and boundaries based on IEA Energy Balance 2011and 2012 [(3], [4])

The tables in IEA Energy Balance 2011 and 2012 ([3], [4]) contain the not only energy input for production of “Iron and Steel” but energy output from “Coke Ovens” and “Blast Furnaces” in energy conversion 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.

In this paper as in ‘2005 Energy Efficiency’, Fig.1 shows the boundary. In Fig.1, upstream operations of steel production are in the top of the diagram, and downstream operations are going down to the bottom. In this paper, the following boundaries are set for each process of steel production;

- From the upstream operations, the consumed energy for coke, sintered ore and pellets production is counted.
- To the downstream operations the consumed energy for heating machine and hot rolling is included but cold rolling, the additional energy consumed for cold rolling, plating and special steel production is excluded.

Table 1. Abstract from IEA Energy Balance [4] related to steel and iron [Japan, 2010]

(PJ/yr)	Coal	Coke Oven Coke	Coke Oven Gas	Blast Furnace Gas	Oxygen Steel Furnace Gas	Electricity	Total
Coke Ovens	-1,600	1,241	286	-62	-4	-6	-109
Blast Furnaces	-319	-917		449	73		-714
Iron and Steel	79	116	150	152	31	229	911

Note 1) “Coke Ovens”, “Blast Furnaces” and “Iron and Steel” in this table refer to terms in IEA Energy Balance [4]. Please note that “Iron and Steel” in this table is completely different from the defined boundary of iron and steel sector in this paper.
Note 2) PJ represents 10^{15}J

Fig.1 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 on the left includes purchased electricity and coke. The energy out of plants on the right includes coke, by-product gases and electricity for external sales.

For the complicated energy balance in iron and steel production, setting up such a common boundary for all the regions in the world would enable international comparisons of energy intensity which reflects technological levels.

Numbers listed in the IEA Energy Balance table ([3], [4]) is converted to the net energy input for iron and steel production, based on the boundary in Fig.1. Table 2 shows the results. It should be noted that Table 2 is at the stage that energy required for BF-BOFs and for EAFs is not separated.

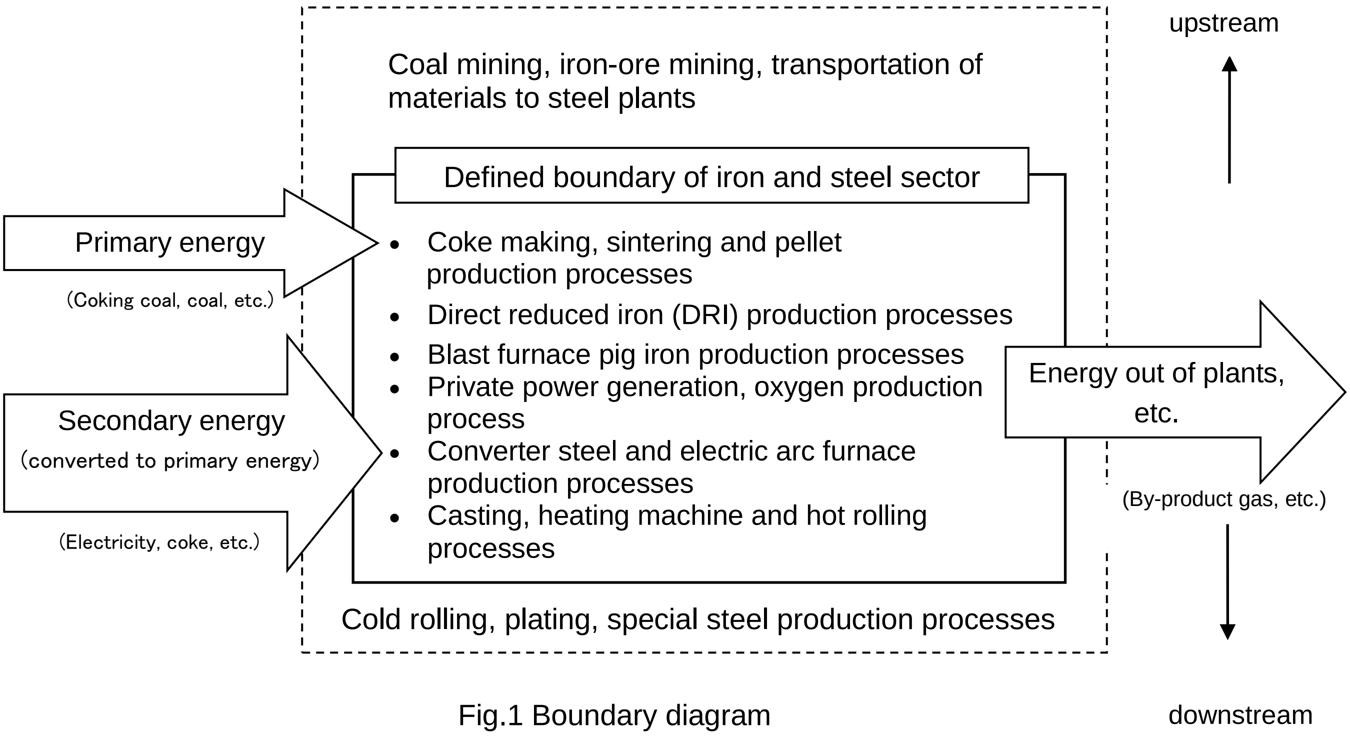

Fig.1 Boundary diagram

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

Table 2. Energy input for iron and steel production (RITE estimate, based on IEA [4]) [2010]

(PJ/yr)	Non-electricity	Electricity	Total
US	911	828	1,739
UK	184	37	221
France	554	110	335
Germany	537	296	833
Japan	1,370	703	2,073
Korea	693	532	1,226
China	11,720	4,981	16,701
India	1,305	0	1,305
Russia	2,351	601	2,953
World	**24,059**	**10,985**	**35,044**

Note 1) Non-electricity = energy excluded net electricity input. (Coal accounts for most energy in fact)
Note 2) electricity = net electricity input (already converted to the primary energy base; 1[kWh] = 3.6÷0.333[MJ] = 10.8[MJ])
Note 3) PJ means 10^{15}J
Note 4) Only major regions are in the table (and so forth).

(2) Adjustment of crude steel production by production system

Table 3 shows the material data such as crude steel production, based on [5] and [6] by World Steel Association. BOF steel is defined as steel made from pig iron which is produced in BF-BOF or OHF. The most scrap-EAF steel is made from scrap iron, but in some regions direct reduction iron and pig iron are applied extensively. 100% scrap-EAF steel is sorted out from EAF steel from 100% direct reduction iron or house waste.

Table 3. Crude steel production by production system [2010]

(Mt/yr)	BF-BOF	Scrap-EAF	DRI-EAF	Total
US	31	49	0	80
UK	7	2	0	10
France	10	6	0	15
Germany	31	13	0	44
Japan	86	24	0	110
Korea	34	24	0	58
China	565	61	0	627
India	27	14	27	68
Russia	49	13	5	67
World	1007	339	72	1,417

Note 1) BOF steel includes crude steel produced by open hearth furnace (OHF).
Note 2) estimated that DRI-EAF is produced in the same region where DRI is produced

(3) Introduction of the standard energy intensity by production system

As shown in the table 3, the ratio of production systems depends a lot on region. For example, in the US and India, the ratio of EAF is high, 61% and 60%, respectively, while in UK, Germany, Japan and China, it is low, 25%, 30%, 22%, 10%, respectively.

As shown in the table 4, the standard energy intensity by production system is introduced so that we could assess the difference appropriately.

Table 4. The standard energy intensity by production system

(GJ/ton of crude steel)	non-electricity	electricity	total
BF-BOF steel	22.3	4.8	27.1
Scrap-EAF steel	2.5	6.3	8.8
DRI-EAF steel	15.9	7.6	23.5

Note 1) the world average energy intensity 2010 estimated by RITE

(4) Summary of approach based on the world statistics

The table 5 shows the BFBOF energy intensity estimated from table 2., 3. and 4. The energy intensity of some regions is difficult to be rationally explained. Since the energy consumption in India are not ever recorded to the IEA[4], there is a large gap in the number of left and right lines. Russia shows the quite big numbers. IEA itself admits that such regions have improper statistics [2].

Table 5. BF-BOF energy intensity based on the world statistics [2010]

(GJ/ton of crude steel)	Energy intensity referred to 'non-electricity' consumption	Energy intensity referred to 'total' consumption
US	34.7	40.2
UK	30.5	28.1
France	25.9	28.6
Germany	22.0	25.2
Japan	20.0	23.2
Korea	22.8	29.1
China	21.5	28.1
India	27.5	20.7
Russia	55.4	53.1
World	26.8	29.8

Assuming that statistics are not improper, in the regions where the diffusion rates of EAFs are low, the estimates of BF-BOF energy intensity based on both non-electricity consumption (the left column in Table 5) and total energy consumption (the right column in Table 5) serve as a useful reference.

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

As well, the rates in the right column are higher than the left in Table 5 in most regions. This is due to the influence of energy consumption in the downstream process outside the boundary (Fig.1).

We have seen about the absolute value of the energy intensity while it is also possible to obtain information of time-series changes from the IEA energy Balance table ([3], [4]). Fig.2 shows the time-series transition in major regions. In 2008 and 2009 when steel demand changed rapidly, large numbers of energy intensity are observed and this is considered to be due to the impact of reduced operating rates of steel plants.

Table 6 shows the energy intensity of the five-year change rate up to 2010 which is applied to RITE 2005 estimates [1]. Since in IEA Energy Balance table ([3], [4]), the inherent trends by country are observed and it is not easy to evaluate whether such trends reflect the actual situation or poor statistics, focusing on the time series rate of change shown in Table 6 as well as the absolute value is also one of the most effective means.

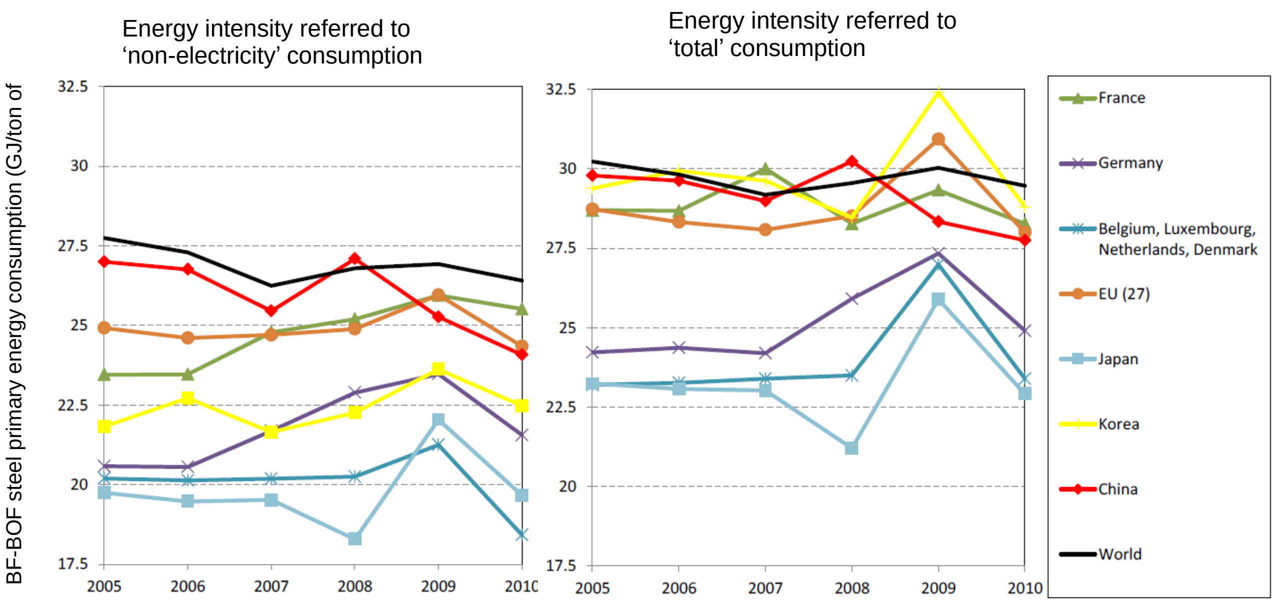

Fig.2 Transition of BF-BOF steel energy intensity based on the world statistics

Table 6. BF-BOF steel energy intensity [2010] based on the five year rate of change in IEA Energy Balance table ([3], [4])

(GJ/ton of crude steel)	Energy intensity referred to IEA Energy Balance
US	30.8
UK	28.8
France	28.4
Germany	26.6
Japan	22.9
Korea	23.8
China	26.2
India	26.1
Russia	34.0
World	27.0

3. Bottom-up Approach

The approach based on a statistics has advantages to cover all the regions in detail and obtain information about time-series transition. On the other hand, since the approach has a challenge to show the total value of energy consumed in BF-BOF and EAF process which should be sorted out and this makes difficult to identify whether the regional energy intensity reflects the actual situation or poor statistics,.

Therefore, estimates based on bottom-up approach should be organized and referenced along with top-down approach, not relying on IEA statistics ([3], [4]). In this report, the estimates are referred to a number of the following wide range of approaches.

(1) Approaches based on corporate and institute environmental reports

With this approach, the energy intensity released by companies and steel institutions of individual countries are referenced. Data by company such as five Japanese blast furnace companies, POSCO, Korea and major Indian companies serve as reference. Data released by iron and steel institutions of individual countries such as American Iron and Steel Institute, German Iron and Steel Institute and China Iron and Steel Association (CISA) serve as reference.

However, since the given energy intensity and CO2 emissions per unit are calculated based on the boundaries and methods on their own ways of companies and countries, calculating the mutually comparable energy intensity would require to be corrected. For example in case electricity is counted as secondary energy base, it is necessary for the electricity to be converted to the primary energy. It is also necessary to correct pig iron production per unit of converter steel production (described as pig iron ratio in this paper). For the boundary, it is necessary to adjust the purchase and external sales (coke, by-product gas, steam, e.g.) of the intermediate product.

Though data were obtained over a wide range, from a regional perspective the referred main data are followings.

[I] Japan

Fig. 3 shows energy intensity to the weighted average of the energy intensity in environmental reports of five Japanese blast furnace companies and crude iron produced by five blast furnace companies.

. The weighted average improved slightly from the fiscal year of 2005 to 2010.

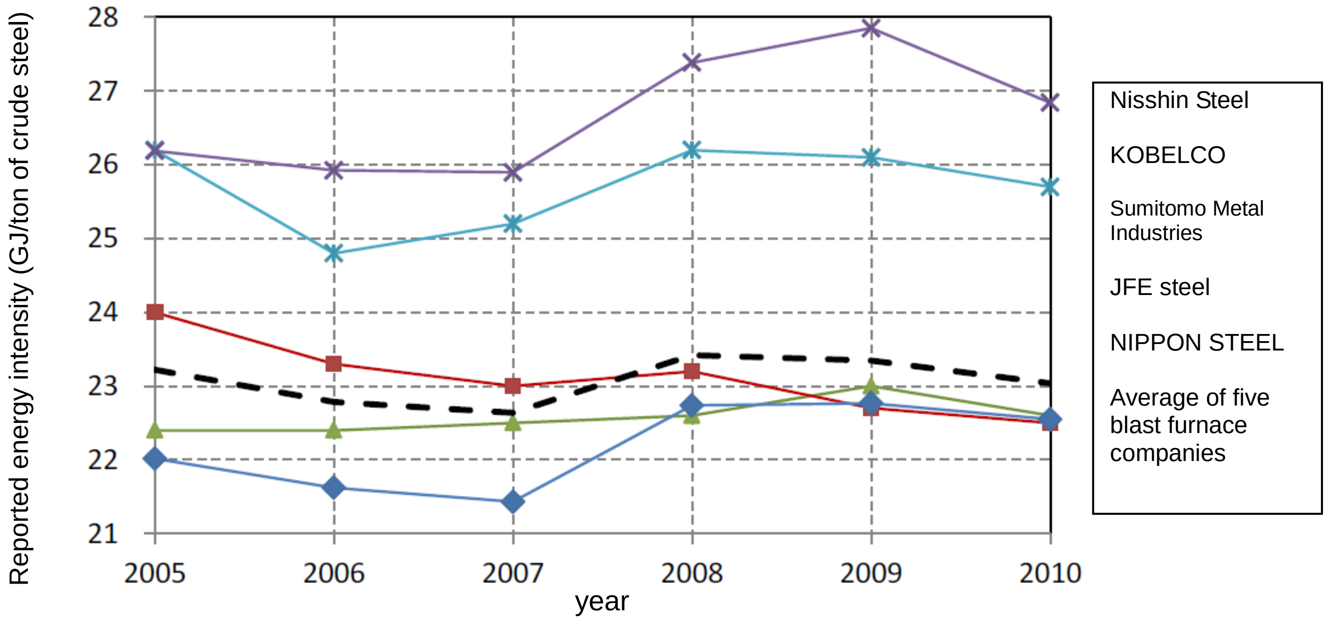

Fig.3 Reported energy intensity and weighted average of five Japanese blast furnace companies

Note 1) Energy consumption per one ton of crude iron of five blast furnace companies [GJ/ton of crude steel]

Note 2) Simple comparisons of companies are impossible, since some companies also include the related electric furnace production, in addition to product differences of each company.

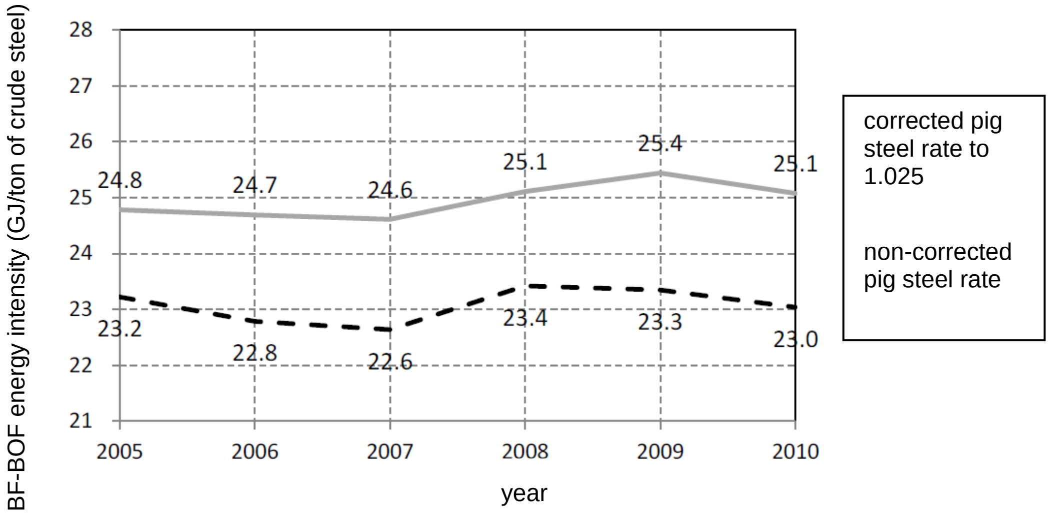

Fig.4 Reported energy intensity and weighted average of five Japanese blast furnace companies

On the other hand, "crude steel production for pig iron production" of these five companies tends to decline slightly over the last five years. Figure 4 also shows the energy intensity in the case the steel ratio is corrected. We have got the data which show steel ratio correction makes the energy intensity 1.2% worse over five years. Though energy-saving equipment diffusion and further intensification of blast furnace have progressed over five years, figure 4 suggests the result that capacity utilization cut has more prominent potential.

[II] Korea

POSCO published 'Sustainability Report' (10) until 2008, and since 2009 it has published 'Carbon Report' (11) every year. For 5 years up to 2010 the basic unit slipped down 3.4% from 2.06tCO2/ton of crude steel to 2.13tCO2/ton of crude steel in the reports. Subtracted 0.6% equivalent ratio correction of pig iron steel and 0.4 percent equivalent deterioration influence of CO2 basic units of system electricity from this value, we have got the data of 2.4% deterioration.

Hyundai Steel fired up the first blast furnace in January and the second blast furnace in October in 2010. But because it was unable to obtain sufficient information about the energy intensity of Hyundai Steel this time[2], the above 2.4% deterioration was applied as a rate of entire South Korea.

[2] Based on the information that it has avoided the CDQ introduction, blast furnace in integrated steel plant of Hyundai Steel lead to a potential for the poorer basic unit of energy than POSCO, but further information is not available. Therefore, the basic unit has not yet explicitly been reflected the data

[III] India

In India, private companies such as TATA and JSW as well as government-run SAIL and RINL have conventionally documented the energy intensity. Fig. 5 shows the data organized by year and company. [Gcal/ton of crude steel] has been conventionally used as a unit in India, so in fig. 5, the same unit, [Gcal/ton of crude steel] is used to facilitate the comparison with the original document. (1Gcal=4.1868GJ)

40% of India's crude steel is made from direct reduced iron (see Table 3) and some companies in Fig. 5 reflect energy intensity in production of direct reduced iron. The energy intensity of 4 steel plants (SAIL, RINL, TATA, JSW) mainly operating integrated blast furnace are weighted averaged with crude steel production, 6.5% improvement over a five-year period up to 2010 comes out form the data.

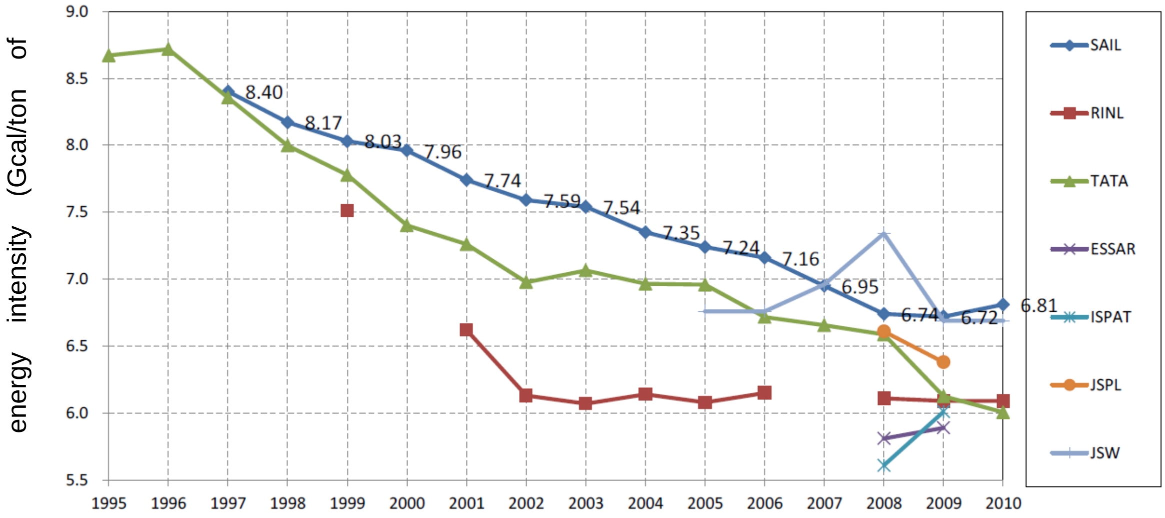

Fig. 5 Reported energy intensity of five major Indian Steel Companies

Note1) The only values of SAIL are referred.

[IV] The United Stated

American Iron and Steel Institute shows energy intensity of all the crude steel production (included EAF). ([17],[18]) Efficiency improved 2.8% in the five years until 2010 when simply calculated as the basic unit is shown. However, this is a numerical value that does not take into account the reduction of pig iron production per all crude steel. 1.6% deterioration comes out due to iron steel ratio correction.

[V] Germany

German Steel Association has showed energy intensity and basic units of CO2 emissions [19]. Efficiency deteriorated 3.0% in the five years up to 2010 when simply calculated as the energy intensity is shown. But the ratio of pig iron production being high, 1.7% deterioration comes out due to iron steel ratio correction.

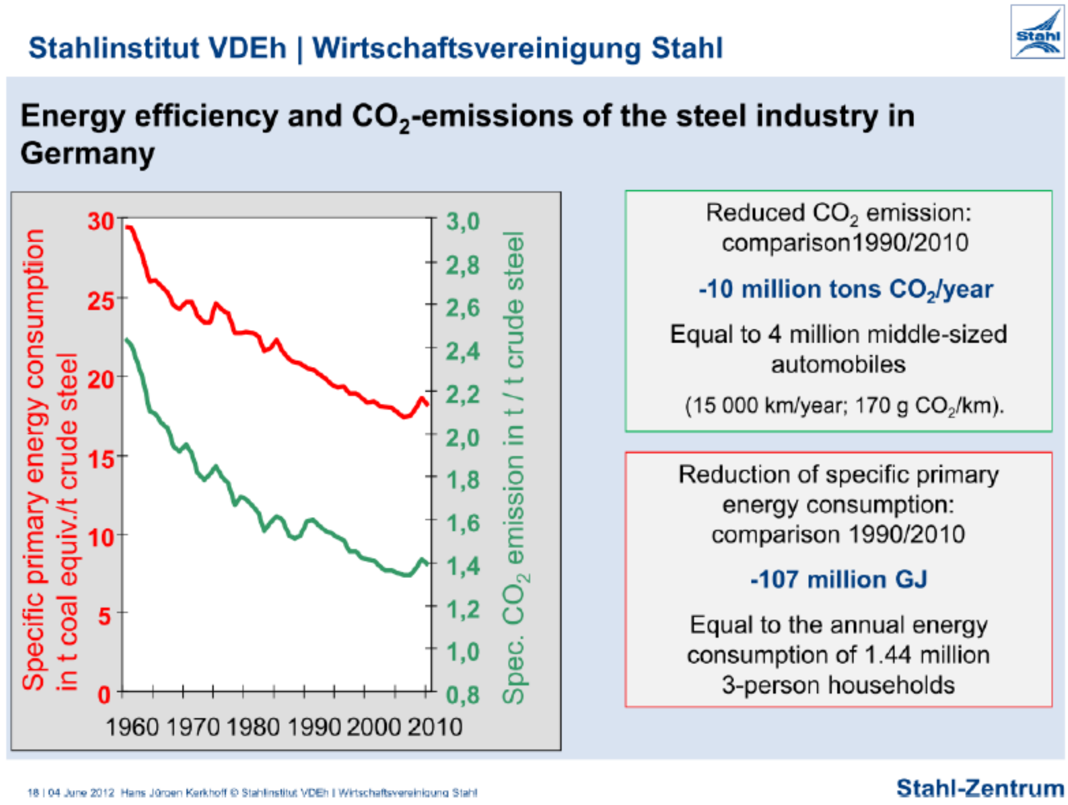

Fig.6 German Steel Association Report [19]

[VI] China

Chinese iron and steel industry has a background that has sorted into two, key Companies and the others. The most of the key companies are members of the China Iron and Steel Association (CISA) and they have reported the energy consumption data to CISA.

The energy intensity of key companies are in CISA statistics [(20),(21)]. However, the method of calculating the energy intensity was changed in 2005, so 2006 data and 2005 data are not continuous. Information of the others are very limited, but estimates for 2005 could be obtained from Oda et al.[1] and for 2010 CISA presented figures

Figure 7 shows the organized comparable energy consumption per unit of key companies and the others in 2005 and 2010, on the basis of the above. (before correcting the pig steel rate) China improved average 12.6% over a five-year period in Figure 7. During this period, pig iron steel ratio was low in China, so that with the pig iron steel ratio corrected, it turns out to be estimated 8.9% improvement.

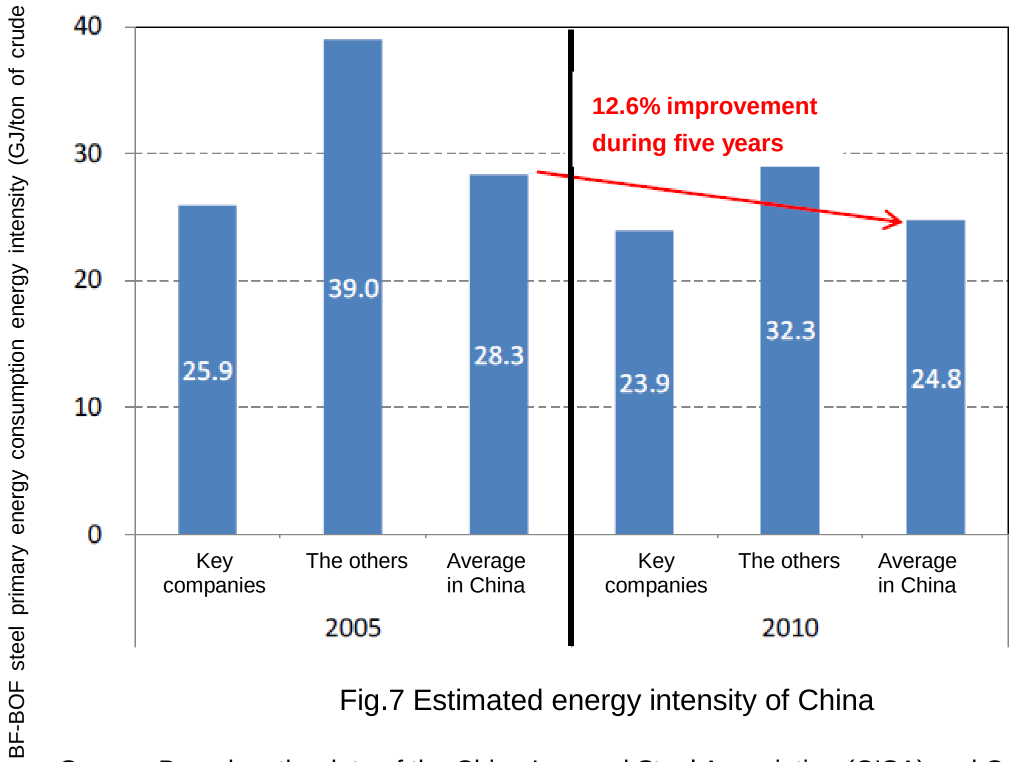

Fig.7 Estimated energy intensity of China

Source: Based on the data of the China Iron and Steel Association (CISA) and Oda et al., the energy intensity is organized by RITE

(2) Methods referring to technology diffusion

Reference to technology diffusion makes it possible to explain essential reasons why energy intensity is different by region. Focused on the technological characteristics, bottomed-up estimates were carried out each by category divided into three.

- Recovery rate of effective utilization of by-product gas
- Diffusion of energy-saving technologies (five majors)
- Utilization of old technologies (open-hearth, ingot and blooming)

[I] Recovery rate of effective utilization of by-product gas

The generation amount of by-product gas (COG (coke oven gas), BFG (blast furnace gas), LDG (converter gas)) is large and the energy intensity of converter steel depends on how much it is recovered and how effective the recovered gas is utilized.

COG is normally generated 7.45GJ per a ton of coke, BFG, 5.45GJ per a ton of pig iron and LDG, 0.85GJ per a ton of converter steel. If 398kg pig iron is input per a ton of coke (2010 RITE estimate of global average) and 1.025t of pig iron is produced per a ton of converter steel (standard value of this analysis), the total amount of COG 3.0GJ, BFG 5.6GJ and LDG 0.9GJ is 9.5GJ per a ton of converter steel.

In addition to reference to IEA energy balance table ([3], [4]) as the main data of by-product gases utilization, in this analysis, the energy saving potential of by-product gases recovery by IEA [7] is confirmed to be assessed. Fig. 8 shows the energy saving potential of by-product gases recovery. China Steel and Iron Production are also referred for recovery rates and effective utilization rates [20].

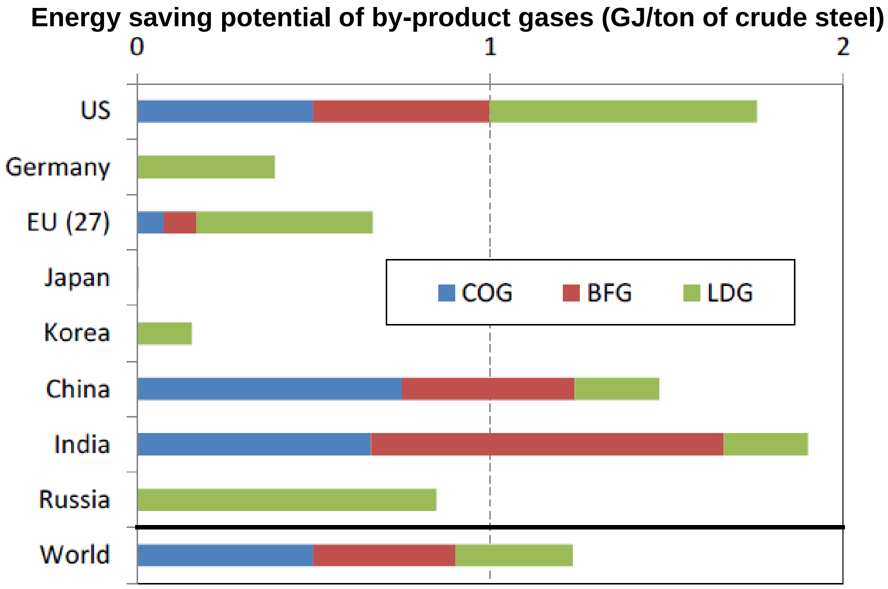

Fig. 8 Energy saving potential by effective utilization of by-product gases

[II] Diffusion rates of energy saving technologies (major five types)

In this paper, five technologies which are constantly effective and the data of diffusion rates are relatively available of as CDQ, TRT, sintering waste heat recovery, hot air furnace waste heat recovery and pulverized coal rate injection are referenced.

As of technological diffusion rates, the rates of China are referred to Chinese statistics ([24], [25]), India's rates are referred to the NEDO report by JISF (the Japan Iron and Steel Federation) [26], and Korea's rates are referred to the NEDO report by JISF and POSCO reports ([8], [10], [11]). As for the pulverized coal rate injection, assuming it is possible to drive off one-to-one from the view point of coke based on calorie and to reduce the energy loss in the coke production stage [2] as long as injection amount is small, energy-saving potential of the pulverized coal rate injection is assessed[3].

[3]When pulverized coal rate injection comes to the levels of more than 180kg/thm (kg of pulverized coal rate injection weight per ton of hot metal), additional cokes effect driven off is not observed [2]. to conduct a simplified here the effect is not observed eviction coke additional, to Korea data 174kg/thm to effect eviction coke blowing pulverized coal I have been calculated by the premise and is maintained at a heat-based one-to-one

[III] Utilization rates of old technologies (Open-hearth, ingot and blooming)

In Russia, Ukraine and India, open-hearth furnace and ingot and blooming technologies are widely utilized at the time point of 2010. Though these have been converted to converters and continuous casting since 2005, some of them are still utilized at the time point of 2010 [5]. Figure 10 shows the energy-saving potential by reducing these old technologies.

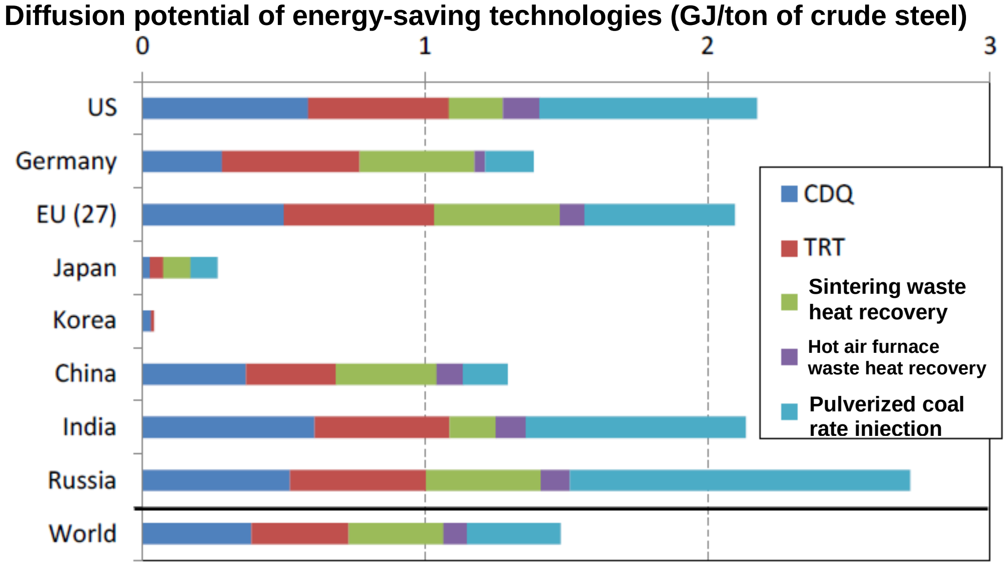

Fig.9 Energy-saving potential by diffusion of energy-saving technologies (five majors)

Note1) Assumed that diffusion of advanced coke wet quenching conspire to reduce the agent ratio though CDQ diffusion is very little in Germany, the figure shows diffusion potential deducted the energy-saving effect.

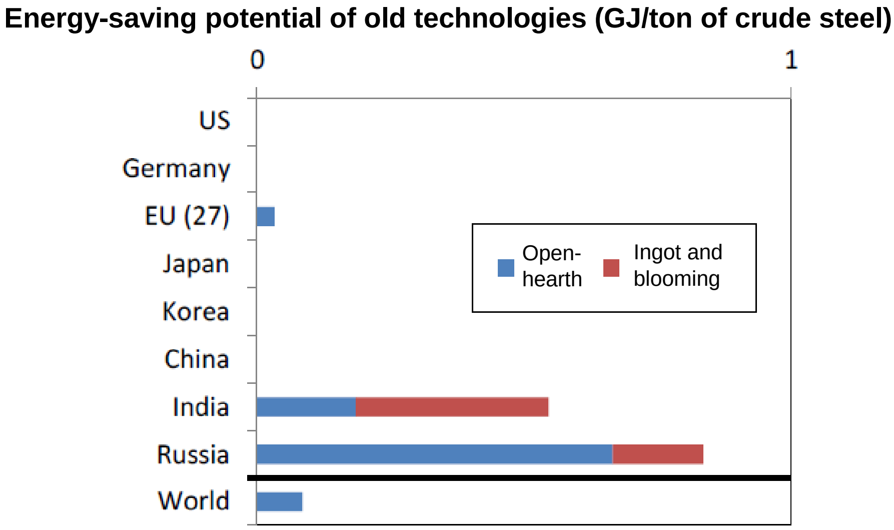

Fig.10 Energy-saving potential by diffusion of old technologies

(3) Methods referring to the regional energy-saving potential estimated by IEA [7]

Figure 11 shows energy-saving potential with BAT technology diffusion of blast furnace converter process estimated by IEA [7]. This energy-saving potential is one of the important information and is referred to in this analysis, though it is necessary to note that the denominator is all crude steel, including electrical steel and that Europe shows regionally aggregated energy-saving potential.

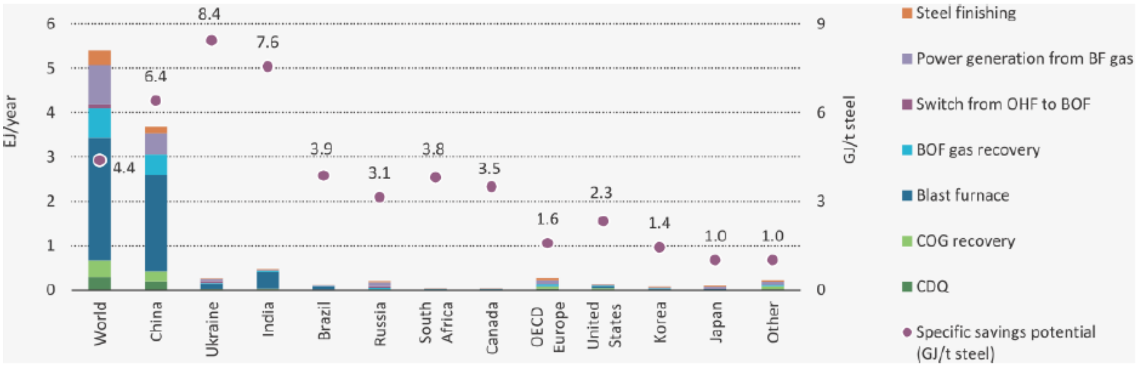

Fig.11. Energy-saving potential with BAT technology diffusion of blast furnace converter process estimated by IEA [7].

(4) Method calculating based on regional reducing agent ratio

For the data of reduction agent ratio (cokes per a ton of pig iron, pulverized coal rate injection, natural gas), data estimated by German Iron Steel Institute [27] are basically referenced. However, ‘China Steel and Iron Production’ [20] is referred for China and ‘2011 AIST Industry Roundups, North American Blast Furnace Roundup’ [28] is referred for the United States.

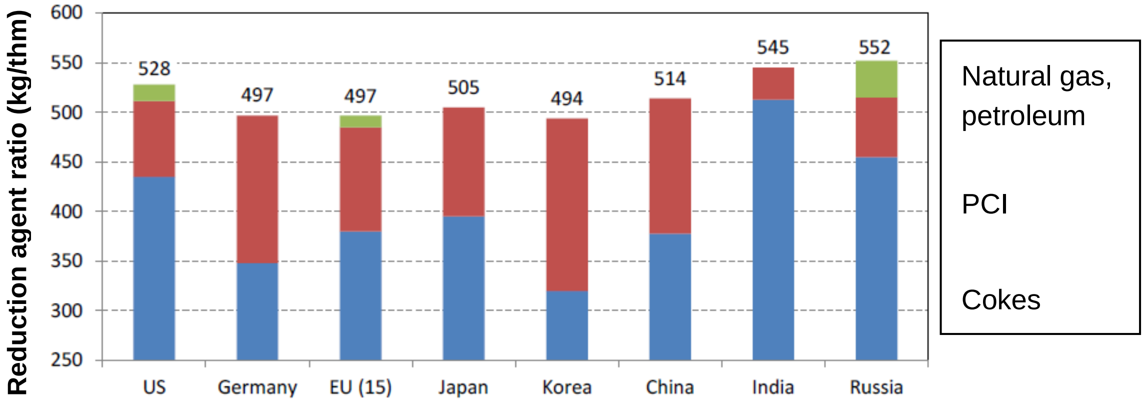

Fig.12 Estimates of reduction agent ratio

Note 1) Units are reduction agent input (kg) per ton of molten pig iron

4. Summary

Intercomparing energy intensity estimated by each method above, energy intensity of the converter steel are estimated by region, based on the integrity and relative reliability. Fig. 13 shows the results. Fig. 14 shows the estimates of 2000, 2005, 2010. (The values of 2010 are reprinted.)

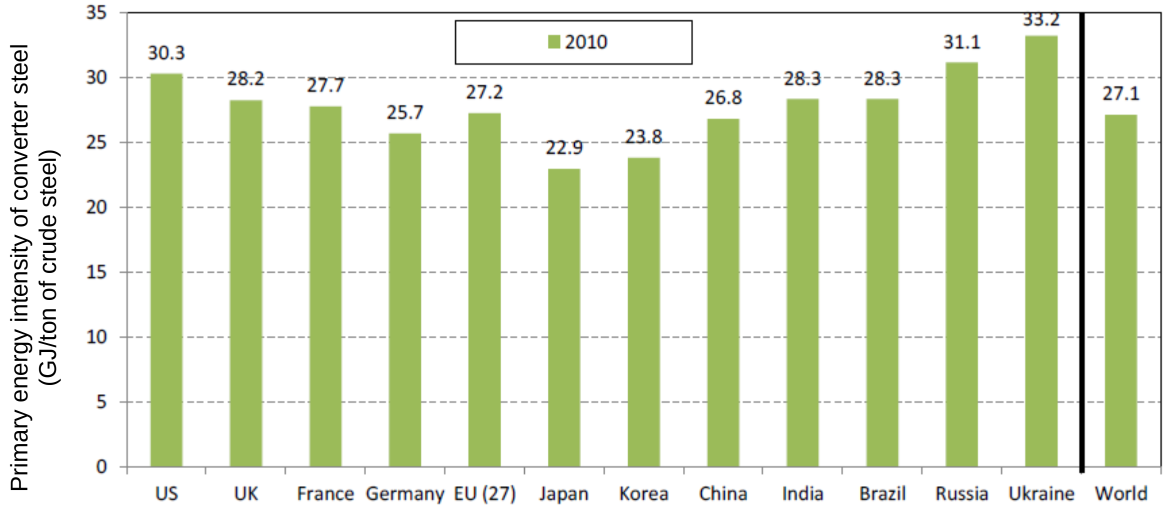

Fig. 13 Estimates of energy intensity for converter steel (2010)

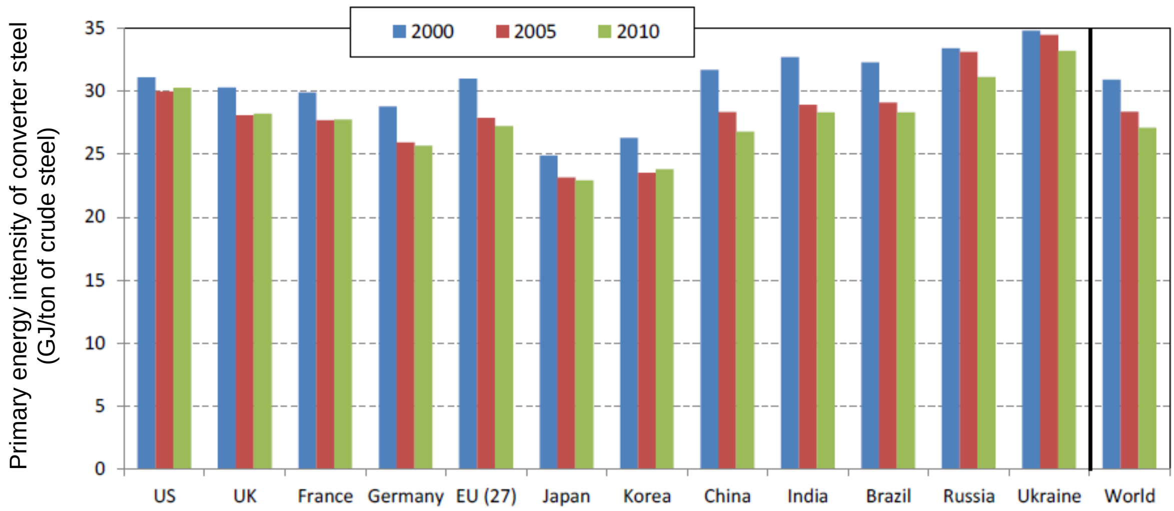

Fig. 14 Estimates of energy intensity for converter steel (2000, 2005, 2010)

From Figs 13 and 14 (or consideration based on all the analyses above), the followings are suggested for the energy intensity of converter steel.

- Energy intensity has improved gradually from the view point of the world average
- Japan and South Korea especially show the excellent energy intensity.
- This is due to effective recovery utilization rates of by-product gas and different diffusion rates of various types of energy-saving equipment
- Some regions have been forced to decrease utilization rates between 2008 and 2009, which can be considered as one of temporary factors to aggravate energy intensity. (Also some regions where energy intensity of 2010 is observed to have dropped off compared to the ones of 2005 are assumed that lower utilization rates impacted on such basic units.)
- Non-OECD countries such as China have improved energy intensity by introducing new equipment and diffusing energy-saving technologies.
- Russia and Ukraine seemingly had not improved energy intensity during the 2000 to 2005, but since 2005, a significant improvement in energy consumption can be seen. (This is because the effects of reduced old technologies since 2005 are considered to be profound.)

Reference

[1] Junichiro Oda, Keigo Akimoto, Toshimasa Tomoda, Miyuki Nagashima, Kenichi Wada, Fuminori Sano, International comparisons of energy efficiency in power, steel, and cement industries, Energy Policy, 44, pp.118-129, 2012.

[2] IEA, Tracking Industrial Energy Efficiency and CO2 Emissions, 2007.

[3] IEA, Energy Balances of OECD/Non-OECD Countries 2011, CD-ROM, 2011.

[4] IEA, Energy Balances of OECD/Non-OECD Countries 2012, CD-ROM, 2012.

[5] worldsteel, Steel Statistical Yearbook, 2006-2011.

[6] worldsteel, Steel Statistical Yearbook, 2002-2012.

[7] IEA, Energy Technology Perspectives 2012, 2012.

[8] Alliance for American Manufacturing (AAM), An Assessment of Environmental Regulation of

[9] Alliance for American Manufacturing (AAM), An Assessment of Environmental Regulation of the Steel Industry in China, 2009.

[10] POSCO, Sustainability Report 2005-2008 (2005-2008).

[11] POSCO, Carbon Report 2009-2012 (2009-2012).

[12] Supreme Audit Institution of India, Report no-27 of 2010-11 for the period ended March 2010. Annexures. http://saiindia.gov.in/english/home/Our_Products/Audit_Report/Gover cnment_Wise/union_audit/recent_reports/union_performance/2010_2011/Commercial/Repor t_ no_27/Report_no_27.html

[13] SAIL, Environmental Performance Report 2010-2011, 2011.

[14] TATA. http://www.tatasteelindia.com/sustainability/2011/

[15] TATA. http://ecocitizen.tatasteelindia.com/eco-management/energy.asp

[16] JSW. http://www.jsw.in/companies/JSWSteel_Sustainibility_Report0911.pdf

[17] American Iron and Steel Institute. http://www.steel.org/Sustainability/Energy%20Reduction.aspx

[18] American Iron and Steel Institute. http://www.steel.org/Sustainability/Energy%20Reduction.aspx

[19] Steel Institute VDEh, http://www.icrf2012.com/files/0900_hans_juergen_kerkhoff.pdf

[20] China Steel & Iron Association Yearbook Editorial, China Steel and Iron Production, China Steel & Iron Association, 2005-2011

[21] China Steel Industry Association Statistics Editorial, China Steel Industry Statistics, China Steel & Iron Association, 2005-2011

[22] Huang Dao, Energy Efficiency in China Iron and Steel Industry, International Workshop on International Workshop on industrial Energy Efficiency, China Iron & Steel Association, New Delhi, January. 27-28, 2010. http://www.iea.org/work/2010/india_bee/dao.pdf, http://www.iea.org/work/2010/india_bee/dao.pdfhttp://www.iea.org/work/2010/india_bee/dao.pdf

[23] Junichiro Oda, Keigo Akimoto, Fuminori Sano, Toshimasa Tomoda, Diffusion of energy efficient technologies and CO2 emission reductions in iron and steel sector, Energy Economics, Volume 29, Issue 4, pp.868–888, 2007.

[24] 王維興,「 2010 年重点鉄鋼企業能耗述評」，世界金属導報, March 8, 2011.

[25] 王維興, 「鉄鋼工業能耗現状和節能潜力分析」，中国鉄鋼業, April, 2011.

[26] Nippon Steel Corporation, JFE Steel Corporation, Sumitomo Metal Industries, Ltd., Kobe Steel, Ltd., The Japan Iron and Steel Federation, Fundamental Survey Project Concerning Energy Conservation and Environmental Protection Measures in the Indian Iron and Steel Industry, entrusted by NEDO, adm. No. 20090000000887, March 2009.

[27] Steel Institute VDEh, http://www.stahl-online.de/english/documents/Increased_Efficiency_eng.pdf

[28] Association for Iron & Steel, 2011 AIST Industry Roundups, North American Blast Furnace Roundup, 2011