2010 Energy intensity
(Scrap-EAF; Iron and Steel Sector)

December 18, 2012

Systems Analysis Group, RITE

"2010 Energy intensity (Converter Steel; Iron and Steel Sector)" was posted on the web on September 25, 2012[1].
(http://www.rite.or.jp/Japanese/labo/sysken/about-global-warming/download-data/Comparison_EnergyEfficiency2010steel.pdf)

In this report, based on the available historical data which were newly released, the energy intensity in the iron and steel sector in 2010 is analyzed and summarized. It should be noted that the comprehensive global production scale of EAF is limited by the availability of iron scrap. However, segregated industrial structures are observed between the electric arc furnace with imported iron scrap more than several million tons in some regions (Turkey, Spain and Southeast Asian nations) and integrated blast furnace steel plants (blast furnace) in other regions.

In addition to the detailed paper on energy intensity of integrated blast furnace steel plants (converter steel) [1], reference to this paper on estimates of EAF energy intensity makes it possible to discuss the iron and steel sector extensively.

1. Estimate Overview of EAF Energy Intensity

EAF steel consists of a wide range of product portfolio such as ordinary steel and special steel. Compared with integrated blast furnace steel plants (converter steel), EAFs are relatively characterized by 1) a number of furnaces and companies, 2) high energy input ratio of down process, though depending on products. These characteristics make estimates of energy intensity not easy.

Acknowledging the difficulties, in this report the energy intensity is estimated, combined some extended approach of "2005 Energy Efficiency (Scrap Steel, Iron and Steel Sector)" ([2], [7]) with the following approach.

Approach referring to the absolute values of energy intensity (method A)

- The data of individual EAFs published by US Association for Iron and Steel Technology (AIST) [3] are aggregated and organized. (method A1)
- Energy intensity calculated from the distinctive regional energy statistics is referred. (method A2)
- The absolute value of energy intensity is calculated, based on IEA, Energy

Balances [4]. (method A3)

<u>Approach referring to the change rates compared with energy intensity in 2005 (method B)</u>

- Calculated energy intensity based on IEA, Energy Balances [4] (method A3) is referred to the change rates compared with energy intensity in 2005 (method B1).
- Energy intensity calculated from the distinctive regional energy statistics is referred to the change rates compared with energy intensity in 2005. (method B2).
- The ratio of newly-built EAFs is referred to (method B3).

As for the methods Bs above, energy intensity in 2005 is referred to our estimates ([2], [7]). Primary assumptions of this estimate are followings, which is consistent with '2005 Energy Efficiency (Scrap Steel, Iron and Steel Sector)' [2] and '2010 Energy Intensity (Converter Steel, Iron and Steel Sector)'. [1]

- 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
    - ➢ Oxygen is converted to primary energy at the rate of 6.48MJ/Nm3-O2.
- The boundary to be evaluated is energy input required for EAFs from upstream scrap preheating processed to downstream hot rolling processes. (Additional energy for special steel production is excluded from the boundary) (Fig.1)

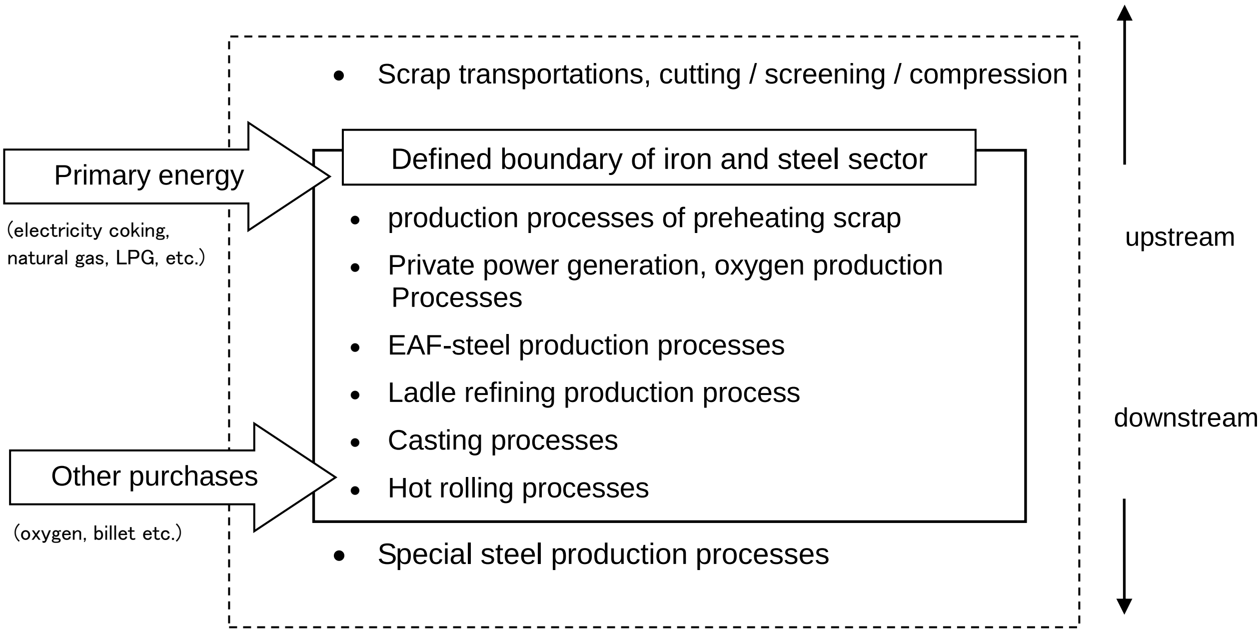

Fig. 1. Boundary diagram of EAF

Though a main source of EAFs is iron scrap, the iron source ratio of direct reduced iron (DRI) or pig iron other than iron scrap is high in some regions in the world. In this report, steel production systems are aggregated and organized into three routes; 1) integrated BF-BOF, 2) scrap-EAF, 3) DRI-EAF (see Figure 2). "2) scrap-EAF" is defined as an EAF whose iron source is 100% iron scrap.

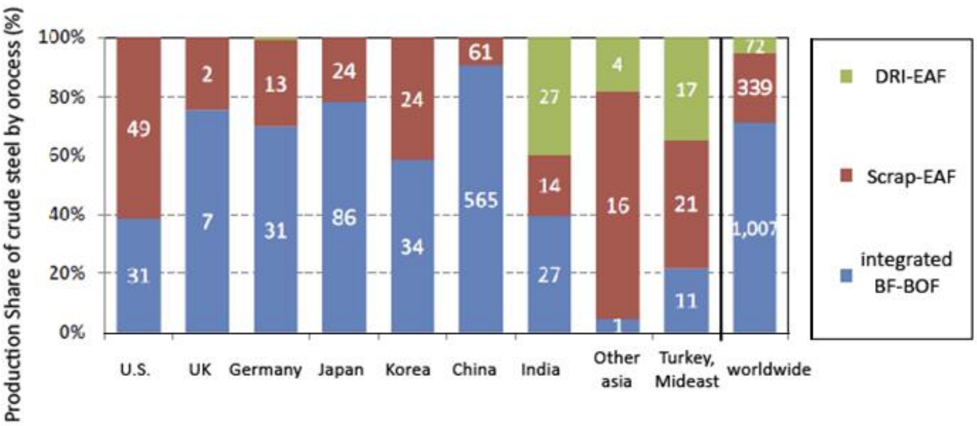

Fig. 2. The share of crude steel production by production route (2010)

Note) The numbers in the figure is amount of crude steel by route (Mt of crude steel/yr).

Source) RITE organized, based on worldsteel statistics

On the organization in Fig.2, I assessed "primary energy input per electrical steel scrap

(GJ/t crude steel)" in this report. The followings are details of method A1 through method B3 mentioned above.

2. Overview of each Method

(1) Reference to The data of individual EAFs published by AIST [3] (method A1)

2011 EAF Roundup [3] published by US Association for Iron and Steel Technology is referred. AIST data [3] contain individual EAF data of 10 countries with a focus on North America. 1) capacity of individual EAF, 2) power consumption, 3) natural gas consumption, 4) oxygen consumption, and 5) the ratio of iron source are specifically described. EAF coverage of each 10 country is relatively high, but for example, power consumption of some electric furnaces is described as "N/A". Table 1 shows the ratio of N/As in four items, 2) power consumption through 5) the ratio of iron source.

Table 1. Countries and “N/A” ratios described in AIST data

	EAF steel production capacity coverage	The ratios of N/A items
Canada	100%	4%
The United Sates	100%	17%
Mexico	81%	36%
Trinidad and Tobago	65%	0%
Brazil	46%	27%
Peru	64%	0%
Chile	100%	0%
Argentina	100%	21%
Uruguay	100%	0%
Australia	100%	31%

Note 1) EAF steel production capacity coverage is estimated by RITE based on worldsteel statistics [5].
Note 2) The ratios of N/A items are calculated by the weighted average of installed capacity of each EAF.

Since AIST document [3] contains individual EAF data, it is very useful. On the other hand, Table 1 shows some N/A items. For example, EAFs with N/A items in electric consumption is performed a simple multiple regression and interpolated, based on the energy consumption of EAF data (Figure 3). Formula 1 shows the results of multiple regression. Formula 1 works out the empirically reasonable and statistically significant results that "the more installed capacity increases, the more power consumption decreases," and "the higher scrap ratio (the low DRI ratio) is, the smaller power consumption is".

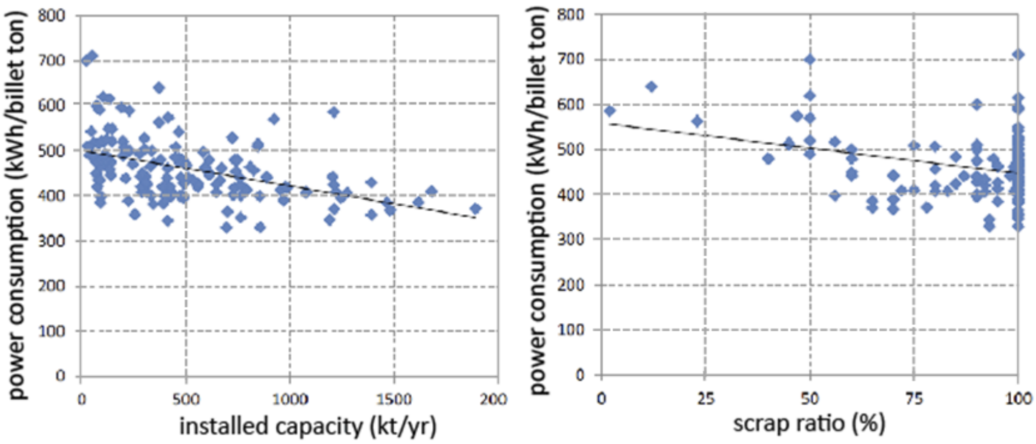

Fig. 3 The relation between installed capacity and scrap ratio, and power consumption

Note) Lines in figures show simple linear regression

Power consumption (kWh/billet ton)

= -0.088 x installed capacity (kt/yr) – 1.36 x scrap ratio (%) + 626 (Formula 1)

(-7.7) (-5.8)

* Values in parentheses are t. As an index, if the absolute value of t is more than 2, it is statistically significant.

In this analysis, iron source is assumed 100% scrap. As for EAFs which DRI is input, power consumption is discounted in Formula 1 above for correction.

This work finally leads to calculating the energy intensity by region from AIST data [3], as shown in Figure 4. In Fig.4, the length of vertical lines varies in accordance with the N/A items but to be conservative estimates upper ends of the lines are to be referred.

Not like the boundary shown in this report (Fig. 1), the energy required for the operation of ladle furnaces, continuous casting equipments, heating furnaces and hot rolling device is not included. Based on 1) energy intensity of North America published by American Iron and Steel Institute [6], 2) 2005 energy intensity estimated by RITE (3.2GJ/t crude iron) [7], 3) common energy intensity of EAFs indicated by IEA [8], 4) estimates by the methods other than A1 in this paper, energy intensity, 2.77GJ/t crude iron is added. That work leads to comparable energy intensity to the estimates by methods other than A1 in this paper.

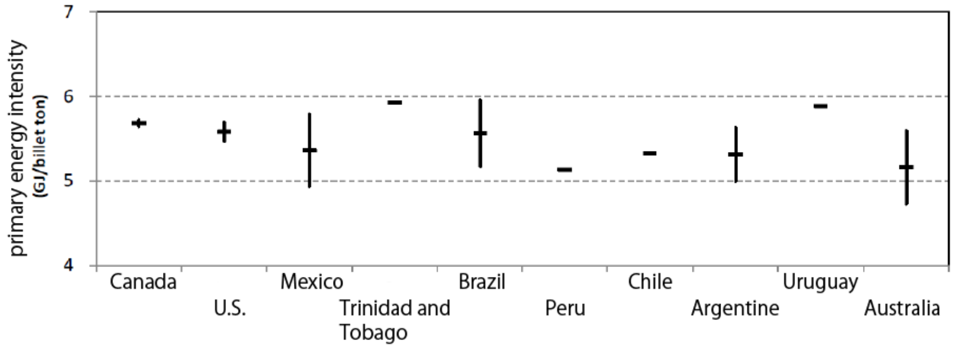

Fig. 4 Organized primary energy intensity referred to AIST data

Note 1) This figure includes only the primary energy input for EAFs and is not consistent with boundary (1).

Note 2) This figure is based on Formula 1, converted iron source into 100% scrap.

(2) Energy intensity calculated from the distinctive regional energy statistics is referred. (method A2 and B2)

European Environmental Agency [9] shows the final energy consumption of iron and steel sector by member state, based on ODYSSEE database. (Fig. 5)

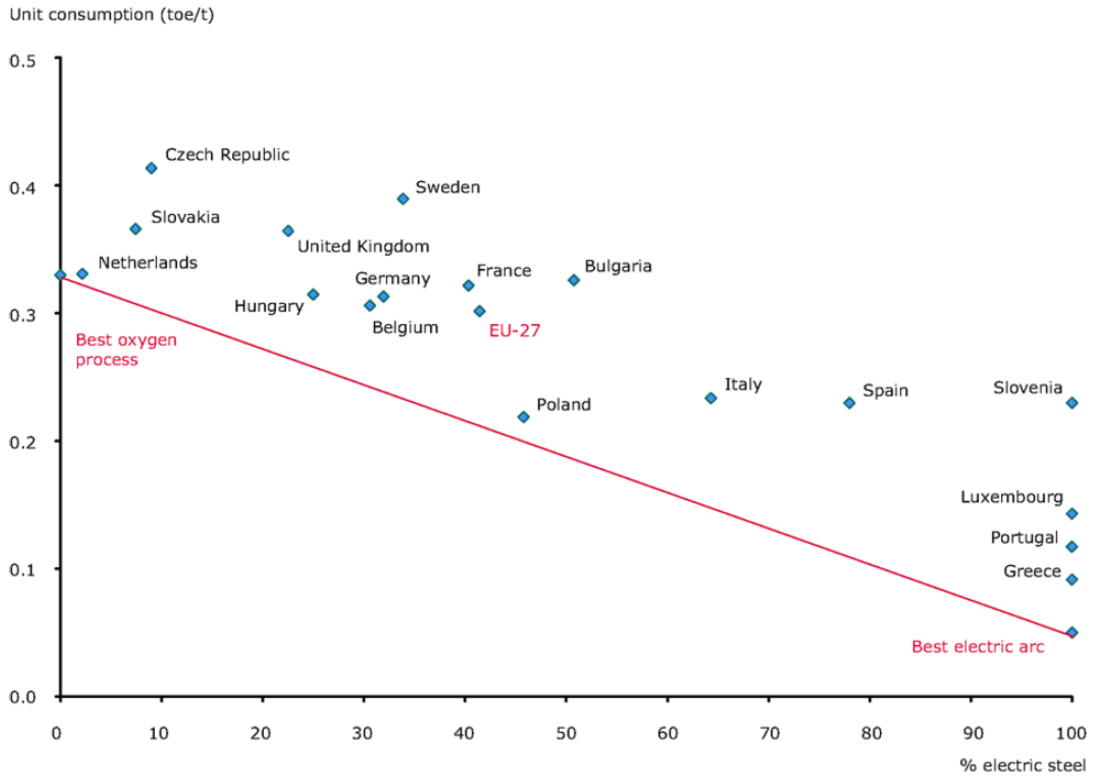

Fig. 5 Final energy consumption of iron and steel sector by EU member state

Note 1) The vertical axis is equivalent to oil tons per ton of crude steel per ton [toe/t] (1toe = 41.868GJ)

Note 2) No correction of pig iron ratios (It should be noted that unit consumption in some countries such as the Netherlands makes shift upward, when the pig iron ratio is adjusted to the reference value of 1.025 set by RITE.)

Source) European Environment Agency [9]

Fig.5 basically shows the values at the time point of 2010. The source [9] contains annual data by region since 2000 and is very useful. However, it also contains such issues as 1) energy consumption of EAFs and converter furnaces not counted separately and 2) energy consumption based on the final energy not on primary energy which this report refers to. So, in this report, primary energy intensity of scrap EAFs of each EU member state is estimated, based on Table 2 and the pig iron ratios of each state. More specifically, energy intensity in Italy was estimated 9.2GJ/t crude steel in 2005, and 8.9GJ/t crude steel in 2010. The estimated absolute values of energy intensity are referred as 'Method A' and the improved ratio compared to the values in 2005 is referred as 'Method B2'.

Table 2 Standard energy intensity (RITE estimate)

Primary energy consumption			(GJ/t crude steel)	Final energy consumption		
non electricity	electricity	total		non electricity	electricity	total
22.3 (note 2	4.8	27.1	BF-BOF(note 1	20.1 (note 2	1.6	21.7
2.5	6.3	8.8	Scrap-EAF	2.5	2.1	4.6
15.9	7.6	23.5	DRI-EAF	15.9	2.5	18.4

Note 1) The pig iron ratio is 1.025
Note 2) To produce a unit of coke (final energy), 1.17 units of primary energy is input on the world average. This is why there is about 10% difference between the non-electricity primary and final energy of BF-BOF.

Japan

Agency for Natural Resources and Energy has compiled energy statistics of Japan over the past long-term. Fairly detailed energy balance tables have been published in General Energy Statistics as main tables since FY1990 [10]. The Statistics divided iron and steel sector into "sinter", "blast furnace iron making", "converter", "electric furnace", and "rolling and steel pipe" as the final demand sector, as well as "coke manufacturing" as the energy conversion sector and contains energy consumption for each process.

The calculated 2010 primary energy intensity of EAF is 5.8GJ/t crude steel on the basis of the energy balance table. Adding 2.77GJ/t crude steel to 5.8GJ/t crude steel like AIST analysis leads to 8.6 GJ/t crude steel (referred to method A2). The energy intensity in FY 2010 was estimated to be worsening 3.1% compared with FY2005 (referred to method B2). This is considered as the result that rapid changes in demand for steel have forced utilization rates to decrease since FY 2008, though energy-saving technology diffusion, such as regenerative burners, has been developing steadily these five years.

On the other hand, The Japan Iron and Steel Federation has reported "acceptable steel production per unit of electricity (kWh/t)" since FY 2008 every year [11]. It is otherwise confirmed that trends of EAF energy intensity each year since 2008 are consistent with the data calculated every year from the General Energy Statistics.

(3) Reference to IEA energy balance tables (method A3 and B1)

IEA energy balance tables [4] are useful because they are regionally comprehensive and time series transition provides reference. However, the problem is that energy consumption is not divided into two, converter and EAF steel. Based on the method of energy intensity estimates of converter steel (Table 2 and method of estimates based on the pig iron ratio by country), energy intensity of EAFs is also estimated. This absolute value of energy intensity is referred as “method A3” and the improvement rate compared 2005 is referred as "method B1".

Through such work, for example, the estimated values of Turkey, 8.8GJ/t crude steel with method A3, 9.0GJ/t crude steel with method B1. The reference is in [1], [7] about specified methods referred to IEA energy balance tables.

(4) Reference to newly-built EAFs (method 3)

Even with the estimating methods above, some regions still do not have sufficient data and EAFs newly-built in regions such as China, India, and Turkey after 2005 stand out. Therefore, on the basis of production changes in EAFs [5], the new EAF capacity between 2005 and 2010 is estimated, assumed that the duration period is 40 years. The 2010 estimated ratios of newly-built EAFs in China, India, and Turkey compared with EAF capacity of each country are 40%, 48%, and 38%, respectively.

Energy intensity of newly-built EAFs in OECD countries based on the data ([3], [8], [12]), in Non-OECD countries based on NEDO research report [13] and India with high share of small induction furnaces [14] is set 8.0 GJ/t crude steel, 8.5 GJ/t crude steel, and 9.5GJ/t crude steel, respectively.

With the method 3, energy intensity in China, India and Turkey was estimated to be 8.6 GJ/t crude steel, 9.6 GJ/t crude steel, and 8.6 GJ/t crude steel in 2010, respectively.

3. Results and summary

Mutually comparing the estimated energy intensity with method A1 through method A3 above, energy intensity by region is estimated, based on consistency and relative reliability. Figure 6 shows the final estimation results of the major regions. North America and some regions of EU, as well as Japan and Korea , have maintained a relatively good energy intensity. In Japan, the existing facilities have been continually inspected and repaired and in the United States and South Korea, new large EAFs have added and replaced, which is considered to lead to good energy intensity. On the other hand, energy intensity of Russia and India is relatively poor.

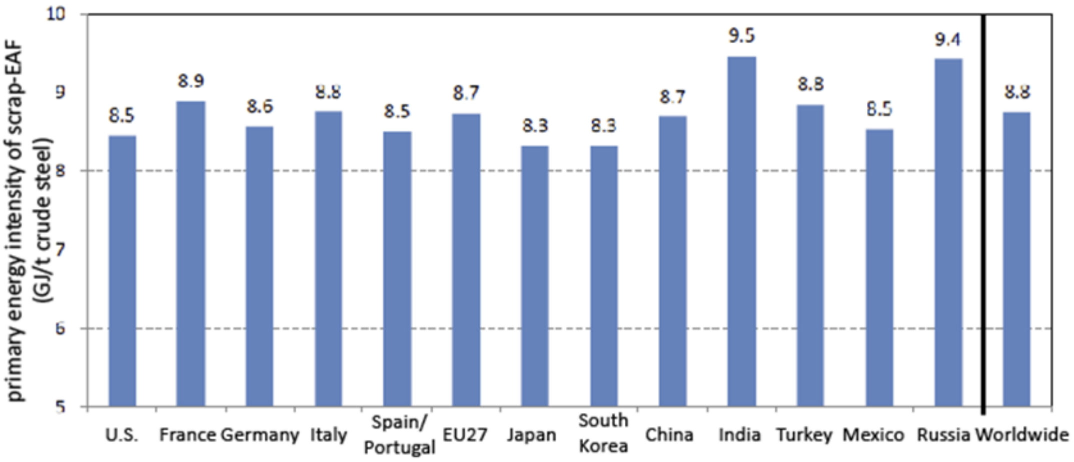

Fig.6 The 2010 primary energy intensity of scrap-EAF

The published data on the EAFs are widely collected and organized as much as possible in this report, but the worldwide energy intensity failed to be estimated more directly. Statistical data that specialize in EAFs such as 2011 EAF Roundup of individual furnace by AIST [3], General Energy Statistics of Japan [10] and The Steel Industry of Japan 2008-2012 by JISF [11] are very useful. These statistical data are required to expand continuously in more regions of the world.

Reference

[1] 2010 Energy Intensity (Converter Steel; Iron and Steel Sector), September 25, 2012, RITE, in Japanese. http://www.rite.or.jp/Japanese/labo/sysken/about-global-warming/download-data/Comparison_EnergyEfficiency2010steel.pdf

[2] 2005 Energy Efficiency (Scrap Steel, Iron and Steel Sector), November 16, 2010, RITE, in Japanese. http://www.rite.or.jp/Japanese/labo/sysken/about-global-warming/download-data/Comparison_EnergyEfficiency2005steelEAF.pdf

[3] Association for Iron and Steel (AIST), 2011 EAF Roundups, 2011 AIST Industry Roundups, 2011

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

[5] worldsteel, Steel Statistical Yearbook, 2011.

[6] American Iron and Steel Institute. North American Steel Industry Reduces Energy Intensity. http://www.steel.org/en/Sustainability/Energy%20Reduction.aspx

[7] 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.

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

[9] European Environment Agency, 2012. http://www.eea.europa.eu/data-and-maps/figures/benchmarking-in-the-steel-industry

[10] Energy Balance Table 2005-2010, General Energy Statistics, Agency for Natural Resources and Energy. http://www.enecho.meti.go.jp/info/statistics/jukyu/index.htm

[11] The Steel Industry of Japan 2008-2012, The Japan Iron and Steel Federation

[12] Yuri N. Toulouevski, Ilyaz Y. Zinurov, Innovation in Electric Arc Furnace: Scientific Basis for Selection, Springer, PA, USA, 2010

[13] Survey of energy conservation technology in major industries in ASEAN countries, Energy Conservation Center, NEDO Research Report, 2003

[14] Current Status and Recent Trends in Investment in Asia’s Iron and Steel Industry 2002, in Japanese, JFE Techno-Research Corporation