2005 Energy Efficiency
(Scrap Steel, Iron and Steel Sector)

November 15, 2010

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1. Introduction

As for international comparison of energy efficiency, converter steel in the iron and steel sector at 2005 was assessed. The further assessment of scrap steel at 2005 has not caught up with converter steel. In this report, energy efficiency of scrap steel at 2005 is assessed, referring to the available historical data which were newly released.

Estimating energy efficiency of scrap steel allows us to estimate CO2 emission potentials as a whole iron and steel sector. In this report, the estimate of energy efficiency which reflects the technological level as accurately as possible can be useful as basic data for the approach to energy basic unit by equipment or sector, as well as for the acceleration of specific and effective emission reductions.

2. Methodology overview

Many steel companies own a large number of electric arc furnaces (EAF) with diverse product configuration and the bottom process in EAF requires a high consumption rate, which makes it difficult to estimate energy efficiency.

Acknowledging the difficulties, in this paper three kinds of estimates such as bottom-up approach to data by furnace in AIST(2010) [2] (referred to as method A), macro statistics in IEA statistics [3] and RITE existing estimate of EAF energy efficiency (referred to as method B1 and B2, respectively) are combined and calculated using weighted average, along with the research of updated technology trends [1]. These estimates are under the following conditions.

<u>Energy conversion</u>

- Primary energy is counted at low heating value (LHV). (Electricity is converted at 1MWh=3.6/0.333GJ. Cokes is converted at the rate increased 17%, counting the world average loss in production [3].)
- Oxygen is converted to primary energy at the rate of 6.48MJ/Nm3-O2 globally, referring to power consumption in oxygen production[1] [4][5].

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[1]Under the assumption of actual energy efficiency in PSA; Pressure Swing Adsorption

Boundary

- From the upstream operations of scrap preheating, oxygen and coke production, the consumed energy is counted.
- To the downstream operations of hot rolling, the consumed energy is counted, excluding the energy consumed for special steel production. (Fig.1)

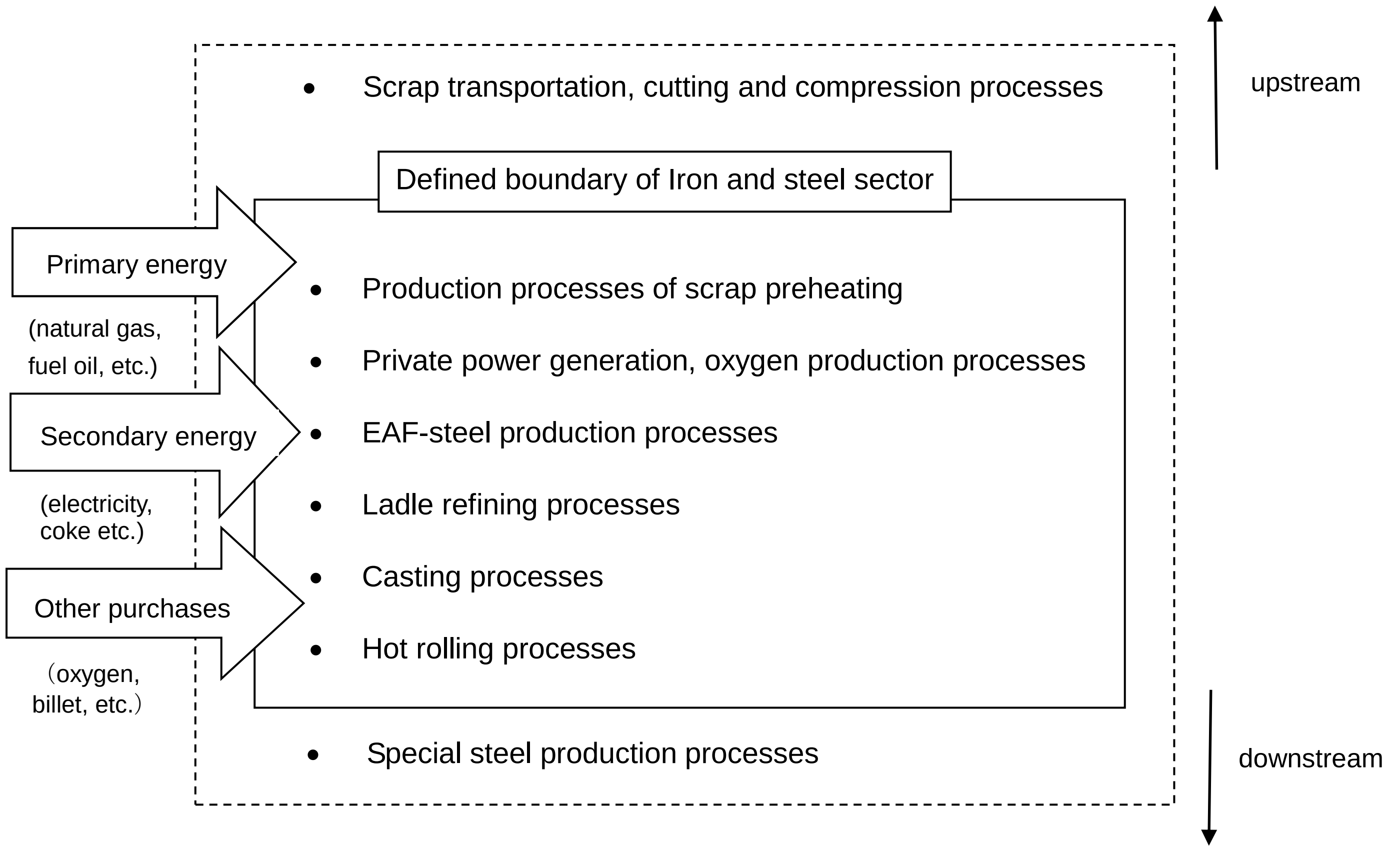


Fig.1 Boundary diagram

Production

- Referring to the World Steel statistics ([6][7]), the scrap-EAF production was organized. (The energy efficiency presented in this paper is organized and adjusted to 100% scrap iron source).
- In AIST(2010) [2] EAF data include some DRI (direct reduction iron) as iron source and the data are adjusted to 100% scrap iron source.
- Estimates are shown as the primary energy input (GJ) per 1 metric ton crude steel.

3. (A) Estimates based on AIST(2010) [2]

(1) Overview of AIST(2010) [2]

The US Association for Iron & Steel (AIST) published the data by each furnace in EAF Roundup 2010. The following seven countries which have AIST branch offices are surveyed. The coverage rates are relatively high. (Table 1)

(2) Organizing AIST(2010) [2]

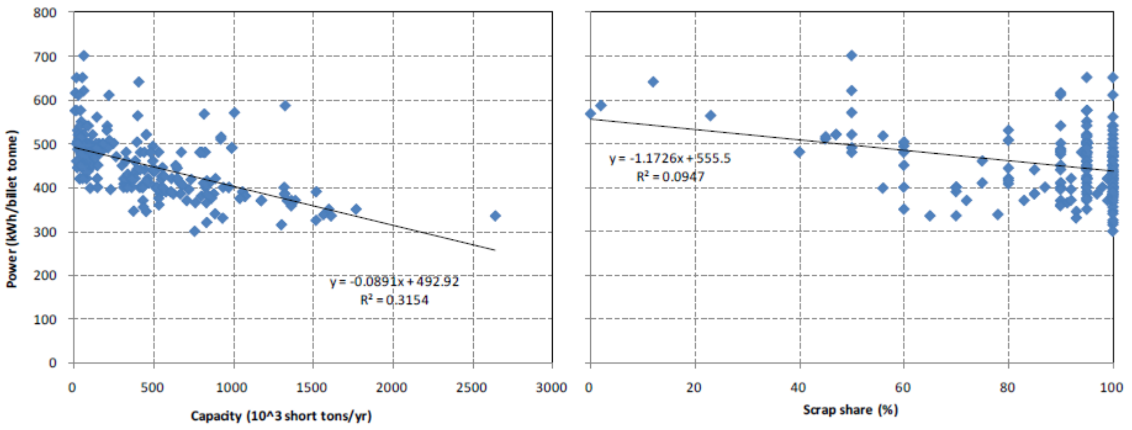
AIST(2010) [2] provides useful and rigid data by furnace, but also some N/A sections can be found. The followings are complemented.

1. Power consumption of furnaces with no available data is estimated, using production capacity and scrap rates as explanatory variables. (Fig.2, Formula 1)
2. For the furnaces with no available data of oxygen and gas consumption, the total primary energy input is estimated, using production capacity and scrap rates as explanatory variables. (Fig.3, Formula 2)

Table 1 Countries listed in AIST(2010) [2] and the coverage rate of production capacity

	Coverage rate of EAF production capacity
Canada	100%
US	100%
Mexico	76%
Trinidad &Tobago	17%
Brazil	30%
Argentina	100%
Australia	97%

Note) The coverage rates are calculated by RITE, based on World Steel statistics



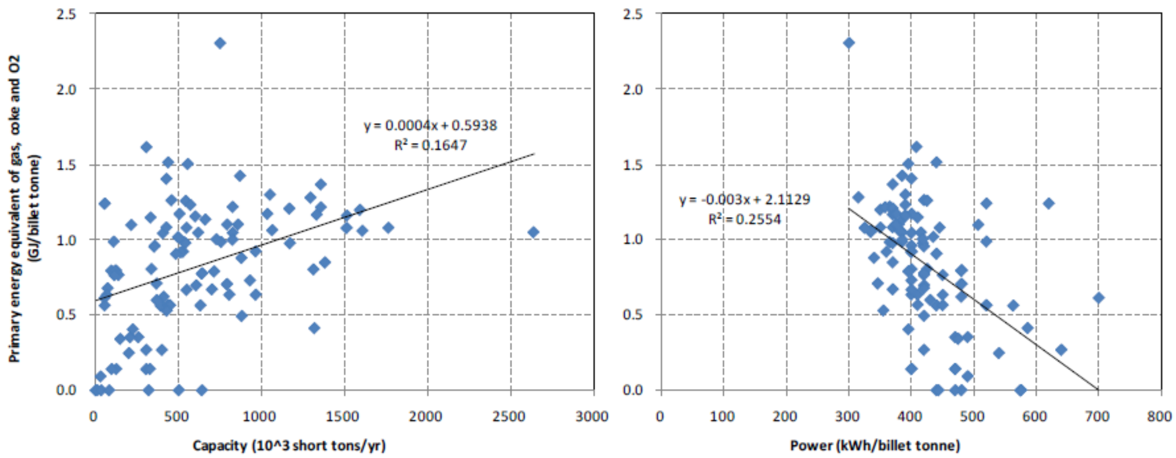
(a) horizontal axis: capacity (10^3short tons/yr) (b) horizontal axis: scrap share (%)

Fig.2 Power consumption (kWh/billet metric ton) [2]

Note) Lines in figures show simple linear regression

Power consumption (kWh/billet metric ton)
=-0.0986 x capacity (10^3short tons/yr)-1.76 x scrap share (%) + 647.7 (Formula 1)
(-10.7) (-8.3)

*Values in parentheses are T



(a) horizontal axis: capacity (10^3short tons/yr) (b) horizontal axis: power consumption (kWh/billet metric ton)

Fig. 3 Non-electric energy input (GJ/billet metric ton)[2]

Note) Lines in figures show simple linear regression

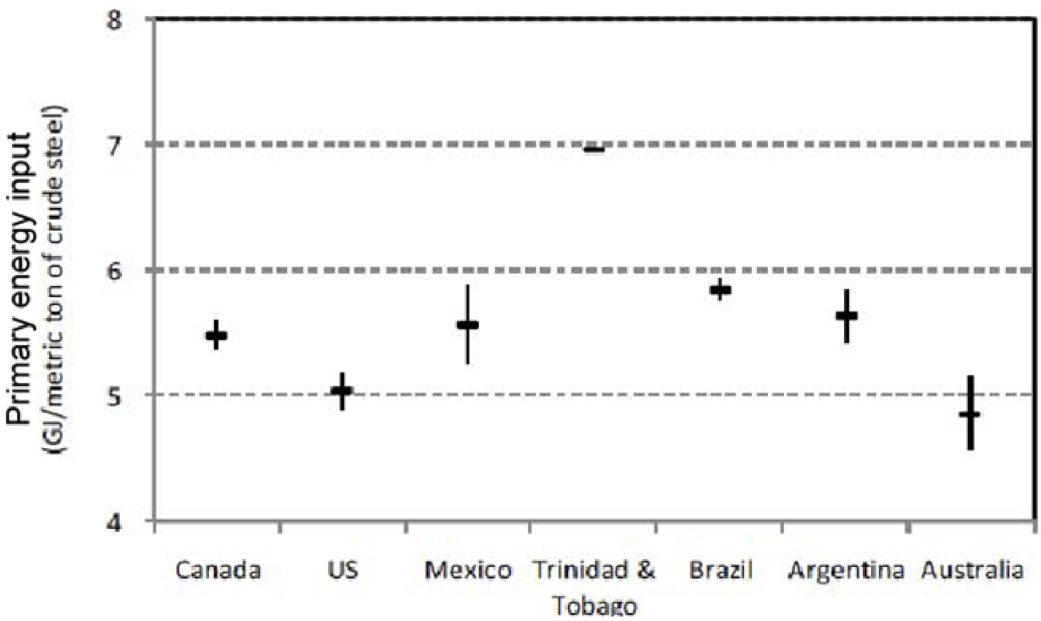
No-electric input (kWh/billet metric ton)
=0.00018 x capacity (10^3short tons/yr) - 0.189 x electric consumption(GJ/billet metric ton)+ 1.40 (Formula 2)
(3.0) (--5.1)

*Values in parentheses are T

(3) Energy efficiency by country based on AIST(2010) [2]

Using the weighted average of primary energy multiplied by capacity by furnace, energy efficiency by country based on AIST(2010) [2] is calculated. Figure 4 shows the results and horizontal lines represent directly the results of regression analysis.

The regression analysis (Formula 1 and 2) with ranges results in some ranges by country and more N/As tend to grow the ranges wider.



AIST coverage rate	100%	100%	76%	17%	30%	100%	97%

Fig. 4 Organized energy efficiency referred to AIST(2010)[2] (A)

Note 1) Only the primary energy input required for electric furnaces is counted and is not consistent with the boundary in this analysis

Note 2) Iron source is converted as scrap 100%

(4) Summary of estimate (A) based on AIST(2010)[2]

The energy efficiency of EAF is estimated based on AIST(2010)[2] (Fig.4) However, Fig.4 is different from the used boundary (Fig.1), as the energy required for continuous casting, furnace heating and hot rolling as well as ladle refining is not counted in Fig.4.

Therefore, in this report, based on the data ([8],[9]), to be consistent with the boundary (Fig.1), 3.23GJ/tcs is added to the energy efficiency referred to the top value of Fig.4 to be conservative estimates.

4. (B) Estimates based on IEA statistics and 2000 RITE estimates

(1) (B1) Methods based on the change rate in IEA Energy Balances[3]

By this method like the one used for converter steel energy, efficiency is estimated through the following steps

1. To the extent allowed to decipher IEA Energy Balances, the boundary is adjusted

and energy consumption for steel and iron production is converted to primary energy

2. Each production by BF-BOF, scrap-EAF and DRI-EAF is organized from World Steel statistics ([6], [7]).
3. The ratio of energy consumption in IEA Energy Balances[3] and typical efficiency which was rated for each production system is assessed by region

Table 2 Assumed typical energy efficiency

(GJ/tcs)	Non-Ele	Ele	Total
BF-BOG	26.2	6.7	32.9
scrap-EAF	2.9	7.3	10.2
DRI-EAF	18.1	8.6	26.7

Table 3 shows energy efficiency of scrap-EAF assessed by the methods above. However, energy efficiency estimate itself is difficult to account for logical data in some regions, as scrap-EAF rate is low and the influence of the downstream processes can not be ignored (or due to statistical deficiencies).

So in this report, "Reliability indicators" are calculated as well as energy efficiency estimates. "Reliability indicators" are calculated based on the following idea.

[Reliability indicators]= [Energy consumption share of scrap-EAF accounted for steel and iron sector] x [The indicators based on the differences with the typical energy efficiency, reflecting statistical deficiencies and so on (Fig.5)]

(Formula 3)

The first term of Formula 3 is equal to 1 if scrap steel accounts for 100%. Even if converter and scrap steel share crude steel half and half, the latter shares less than 50%, 39% due to the low contribution ratio of energy consumption.

The second term of Formula 3 is a function shown in Fig.5 (similar to a lognormal distribution). If the ratios of energy efficiency to typical energy efficiency are less than 0.5 or more than 2, the second term of Formula 3 is a function to be less than 0.2.

The above calculation in Table 3 by region shows, for example, that "Turkey" has a rather high reliability indicator, 0.49. Since logical explanation is difficult for absolute values of energy efficiency and reliability indicators are low, energy efficiency at 2005 is estimated by multiplying by five-year improvement ratio shown in Table 5 (set that even if energy efficiency worsens, the improvement ratio remains the same without any exceptions) to energy efficiency estimate at 2000 (RITE estimate). (Table 4)

Table 3 Estimates of scrap-EAF energy efficiency based on IEA Energy Balance [3] (absolute value)

	Absolute values in IEA Energy Balance 2000	2005	Five-year improvement ratio (%)	Reliability indicator
United States	11.5	12.5	-8%	0.32
Canada	9.3	10.5	-12%	0.25
United Kingdom	8.1	7.0	13%	0.10
France	11.7	11.7	0%	0.25
Germany	8.3	9.6	-16%	0.19
Italy	11.4	10.5	8%	0.45
Spain, Portugal	12.1	14.2	-18%	0.45
Japan	9.8	9.4	4%	0.19
Australia, New Zealand	11.2	12.6	-12%	0.06
Korea	12.1	12.8	-6%	0.26
China	13.1	11.1	15%	0.09
India	9.9	9.3	6%	0.03
Turkey	9.4	8.6	9%	0.49
Mexico	10.1	7.7	24%	0.18
Brazil	11.4	11.3	1%	0.13
Russia	16.3	20.9	-28%	0.02
Ukraine	13.6	12.9	5%	0.03
EU (15)	10.2	10.3	-2%	
EU (27)	10.4	10.6	-1%	
World Average	11.4	11.8	-3%	

Note 1) In five-year improvement ratio (%), negative values mean energy increase (worsening energy efficiency) and positive values means improved energy efficiency.
Note 2) The closer to 1 [reliability indicators] is, the more credible the estimate of energy efficiency is. Contrariwise, The closer to 0, the less credible. Average of 2000 and 2005.

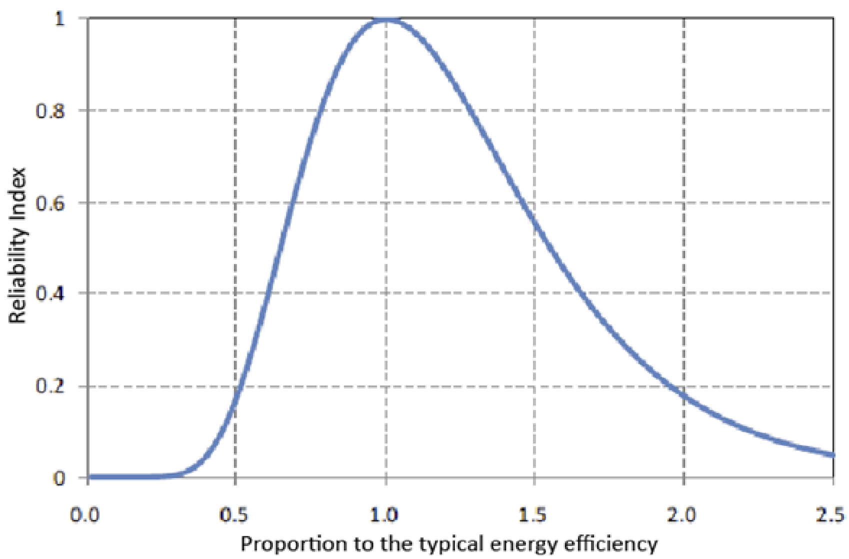


Fig. 5 Indicators to reflect statistical deficiencies (the second term of Formula 3)

Table 4 Energy efficiency referred to change rates in IEA Energy Balances[3] (B1)

	RITE existing estimates 2000	B1 on the adoption of improvement 2005	Five-year improvement ratio (%)	Reliability indicator
United States	8.6	8.6	0%	0.32
Canada	9.2	9.2	0%	0.25
United Kingdom	9.4	8.2	13%	0.10
France	9.1	9.1	0%	0.25
Germany	8.8	8.8	0%	0.19
Italy	9.3	8.6	8%	0.45
Spain, Portugal	9.0	9.0	0%	0.45
Japan	8.4	8.1	4%	0.19
Australia, New Zealand	9.0	9.0	0%	0.06
Korea	8.4	8.4	0%	0.26
China	9.1	7.7	15%	0.09
India	10.0	9.4	6%	0.03
Turkey	9.9	9.0	9%	0.49
Mexico	9.9	7.5	24%	0.18
Brazil	9.1	9.0	1%	0.13
Russia	10.2	10.2	0%	0.02
Ukraine	10.2	9.7	5%	0.03
EU (15)	9.1	8.7	4%	
EU (27)	9.2	8.8	4%	
World Average	9.0	8.6	5%	

(2) (B2) Methods based on the new capital ratio of scrap-EAF and RITE existing estimates (2000)

Even with the estimating methods mentioned above, some regions do not have sufficient data and also in China and India the new capital ratio of scrap-EAF is high after 2000.

So, based on transition production of scrap-EAFs, the new equipment capacity estimated from 2000 to 2005 is combined with RITE existing estimates, as shown in Table 5.

The followings are the main settings for this method, B2.

- The new equipment ratio is calculated based on Formula 4 below (setting the equipment life period 40 years)[2]

  new equipment ratio = (2005 production – 2000 production) x (5years/40 years)/2005 production

Formula 4

[2]Acknowledging that idle equipment can not be ignored in Russia and Ukraine, the new equipment ratio is calculated, referred to 1992 production (10.4Mt/yr and 3.2Mt/yr, respectively)

- Energy efficiency of new equipment for OECD countries is set 8.0GJ/tcs, based on the data ([1] [2] [8])
- Energy efficiency of new equipment for Non-OECD countries is set 8.5GJ/tcs, based on 'Energy saving in key industries in ASEAN countries' , NEDO ([10])
- Energy efficiency for India is set 9.5GJ/tcs, due to high share of small induction furnaces.

Table 5 Energy efficiency referred to the new capital ratio of scrap-EAF (B2)

	Scrap-EAFs			Energy efficiency	
	Production			RITE existing estimates	B2 on the adoption of improvement
	2000 (Mt/y)	2005 (Mt/yr)	New capital ratio (%)	2000(GJ/tcs)	2005(GJ/tcs)
United States	46.2	52.0	22%	8.6	8.4
Canada	5.8	5.8	12%	9.2	9.1
United Kingdom	3.6	2.7	0%	9.4	9.4
France	8.4	7.3	0%	9.1	9.1
Germany	12.9	13.2	15%	8.8	8.7
Italy	16.1	17.7	20%	9.3	9.0
Spain, Portugal	12.3	14.9	27%	9.0	8.7
Japan	30.7	28.8	7%	8.4	8.4
Australia, New Zealand	0.8	1.4	41%	9.0	8.6
Korea	18.4	21.1	23%	8.4	8.3
China	20.9	41.5	56%	9.1	8.8
India	4.0	12.4	70%	100	9.6
Turkey	9.1	14.8	46%	9.9	9.0
Mexico	4.6	5.4	23%	9.9	9.5
Brazil	5.3	6.5	29%	9.1	8.9
Russia	6.6	7.4	5%	10.2	10.1
Ukraine	1.0	3.8	43%	10.2	9.5
EU (15)	64.5	66.8		9.1	8.9
EU (27)	71.2	74.5		9.2	9.0
World Average	244.1	309.1		9.0	8.8

5. Summary

To estimate efficiency, three methods, A, B1 and B2, were attempted. However, finally, these values need to be integrated in some way. As shown in Table 6, weight coefficients are set, based on the followings.

- The estimate, (A) referred to AIST(2010)[20] is likely to reflect actual data by furnace. Coverage ratios in appropriate regions are adopted as priority weight coefficients.

- The estimate, (B1) referred to IEA Energy Balance[3] seems to counteract regional influences of bottom process and statistical deficiencies to some extent. So, priority weight coefficients are allocated to Method B1, following Method A, which are no higher than reliability indicators.
- For the regions where even the weight coefficients above are explainable adequately, Method B2 is referred.

Figure 6 shows energy efficiency in major regions. This estimate suggests the following.

- The regions which have high ratios of new capital or Asia-Pacific Ocean regions, such as The United States, Australia, Japan and Korea have relatively high energy efficiency.
- On the other hand, India and former Soviet Union have relatively poor energy efficiency.

Table 6 Estimates of energy efficiency (A+B1+B2)

	Energy efficiency (GJ/tcs) Estimates by method 2005			Weight coefficients			Energy efficiency (GJ/tcs) 2005 estimates
	A	B1	B2	A	B1	B2	
United States	8.41	8.56	8.44	100%	0%	0%	8.41
Canada	8.82	9.23	9.08	100%	0%	0%	8.82
United Kingdom		8.19	9.39		10%	90%	9.27
France		9.12	9.12		25%	75%	9.12
Germany		8.77	8.66		19%	81%	8.68
Italy		8.58	9.03		45%	55%	8.83
Spain, Portugal		8.98	8.71		45%	55%	8.83
Japan		8.12	8.41		19%	81%	8.36
Australia, New Zealand	8.38	8.96	8.56	91%	6%	3%	8.42
Korea		8.43	8.33		26%	74%	8.36
China		7.68	8.75		9%	91%	8.66
India		9.37	9.64		3%	97%	9.64
Turkey		9.03	9.01		49%	51%	9.02
Mexico	9.11	7.54	9.47	76%	18%	6%	8.85
Brazil	9.16	9.00	8.91	30%	13%	57%	9.00
Russia		10.21	10.13		2%	98%	10.14
Ukraine		9.70	9.47		3%	97%	9.48
EU (15)		8.73	8.90		32%	68%	8.85
EU (27)		8.84	8.97		30%	70%	8.93
World Average	8.51	8.56	8.83	21%	18%	61%	8.78

Note 1) Listed for reference to the second largest minority. The estimates are under the condition of limited data available so the second largest minority is insignificant.

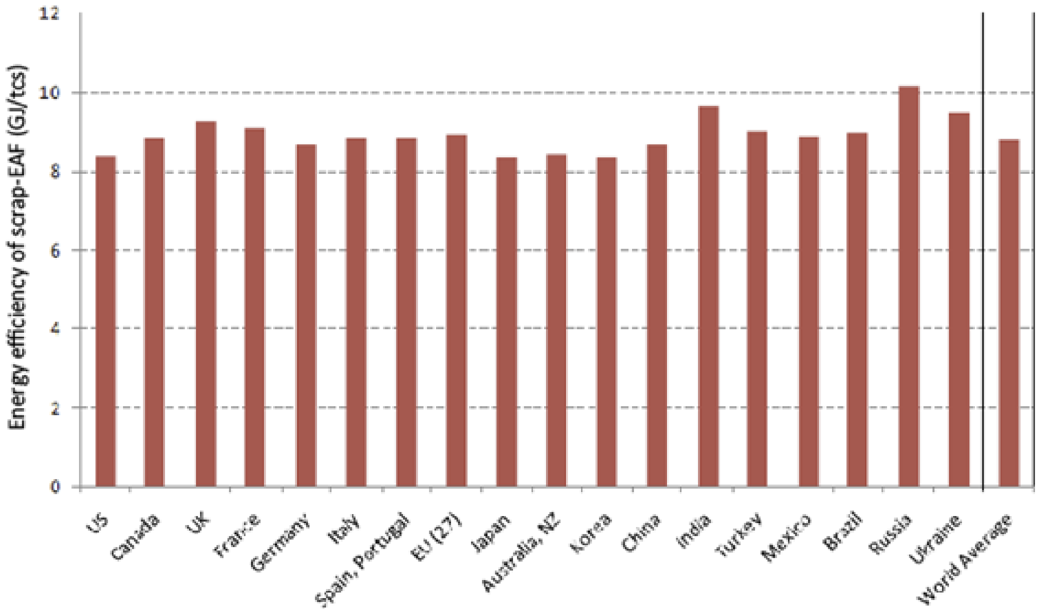


Fig. 6 Estimates of energy efficiency

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