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Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 2, No.1. Pages 19-40, 2014

Efficiency Benchmarking of the Iron and Steel Industry via the Benchmark Curve: A Review

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Abstract – *Evidence on rising global temperature, melting of ice caps, and withdrawal of glaciers brings attentions to the enhancement of energy efficiency in energy intensive industries. Having a realistic comparison between one plant and the best practice technology (BPT) in operation in the field helps significantly to distinguish and diagnose the potentials where measures towards energy efficiency improvement would be applicable. In this regard, for manufacturing industries, one of the most widely used energy benchmarking tools is the Energy Benchmark Curve. An energy benchmark curve plots the efficiency of plants as a function of the total production volume from all similar plants or as a function of the total number of plants that operate at that level of efficiency or worse. This paper reviews the methodology through which the benchmark curve is obtained for a specific industry followed by a comparison of energy intensity for the iron and steel industry among China and the US. According to the international energy benchmark curve for the iron and steel industry, the savings potentials per ton of crude steel for the US. and China have been respectively 4.1 and 7.1 gigajoule comparing with the BPT in the field. Finally, an overview over certain measures to enhance efficiency of such plants is presented.*

Keywords: Iron and Steel Industry, Energy Benchmark Curve, Energy Efficiency, U.S. Iron and Steel Production, China Iron and Steel Production, Energy Flows Sankey Diagrams, Best Practice Technology (BPT)

1.0 INTRODUCTION

The continued depletion of fossil energy sources and the related ongoing emissions have caused major environmental concerns. Evidence on rising global temperature, melting of ice caps, and withdrawal of glaciers brings attentions to enhancement of energy efficiency in energy intensive industries. Worldwide, manufacturing industry accounted for a total final energy use of 127 exajoules (EJ) in 2007. This is equivalent to one-third of the total final energy consumption of the global economy [1]. Developing countries and the economies in transition account for 60% of industry's total final energy consumption but industry's total energy use continues to grow as a result of continuing and large increases in the volume of production. Production is expected to continue to expand very substantially in the coming decades, particularly in developing countries. As a result, modest energy efficiency improvement rates will not be sufficient to stabilize or decrease the sector's energy demand in absolute terms. In order to make significant reductions, ambitious energy savings measures need to be implemented.

Benchmarking has been recognized as an effective analysis methodology and management tool that helps to improve efficiency and performance in many areas for different objectives.

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 | Vol. 2, No.1. Pages 19-40, 2014

Industrial energy benchmarking is a process of evaluating energy performance of an individual industrial plant or sector against a reference plant or sector. Energy benchmarking based on the performance of industry leaders or best practices is particularly useful for identifying energy inefficiencies in the production processes and estimating the potential for energy savings. Furthermore, the adoption of wider Best Practice Technologies (BPT) would enable significant reductions in energy use.

Iron and steel have both played an important role in the development of human civilization over several millennia. The manufacture of iron and steel has a complex industrial structure. Yet, it only has a small number of processes that are employed worldwide and they use almost similar raw materials and energy forms. What matters from energy efficiency and carbon dioxide (CO_2) emissions perspective are the quality of the resources used and the costs of energy, which determines the cost-effectiveness of energy recovery technologies. According to the IEA (International Energy Agency) statistics, the total final energy use by the iron and steel industry, including coke and blast furnaces, was 21.4 EJ in 2004. Global steel production was 1,057 million tons (Mt) in 2004. Globally, the iron and steel industry accounts for the highest share of CO_2 emissions from the manufacturing sector at about 27%. This is due to the energy intensity of steel production, its reliance on coal as the main energy source, and the large volume of steel produced.

In this paper, we first provide an overview on the methodology for obtaining the energy benchmark curve for an energy sector, and then the BPT energy use of the iron and steel industry is determined based on the benchmark curve prepared at global-level. Finally, further discussion is carried out to compare China and the US in this industry by detail.

2.0 METHODOLOGY TO OBTAIN THE ENERGY BENCHMARK CURVE

The most widely used benchmarking tool in manufacturing industries is the Energy Benchmark Curve [2]. An energy benchmark curve plots the efficiency of plants as a function of the total production volume from all similar plants or as a function of the total number of plants that operate at that level of efficiency or worse (Fig. 1).

The most efficient plants are represented to the left and lower part of the curve, and the least efficient plants are represented to the right and higher part of the curve. The shape of benchmark curves would vary for different sectors and regions. However, typically a few plants are very efficient and a few plants are very inefficient. This is generally represented by the steep slopes of the benchmark curve before the 1st decile and after the last decile respectively. Between these two deciles, benchmark curves tend to display a broadly linear relationship between energy efficiency and the share of cumulative production. This relationship can be used to support a rough assessment of the energy efficiency potential for an industrial process, which is defined as 50% of the difference between the efficiencies observed at the first and last deciles. The most efficient plants in the benchmark curve are used to define the best practice technology (BPT).

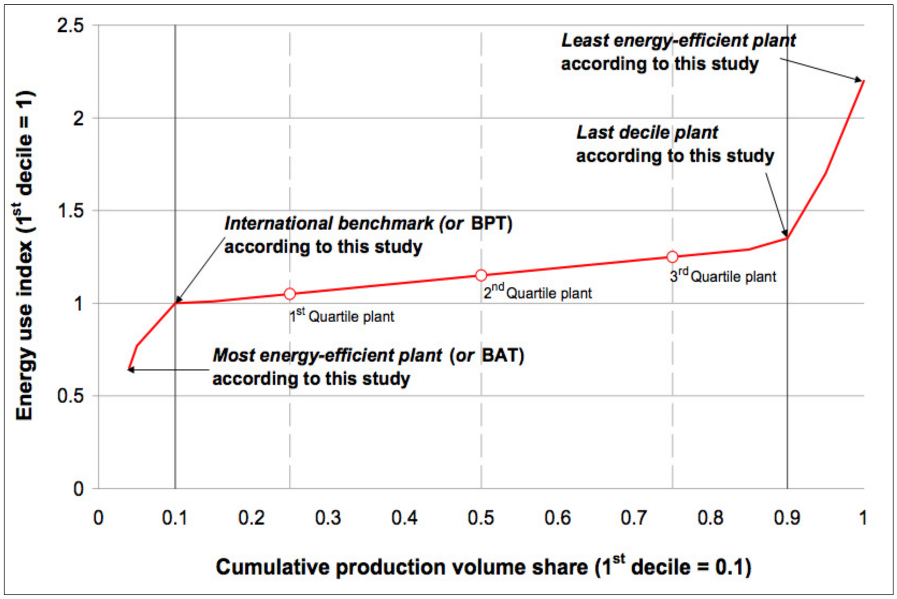

Figure 1: Illustrative energy benchmark curve for the manufacturing industry. Energy use index of BPT is normalized to 1 for the 1st decile production share [2]

Normally, where possible, physical production levels are used to define the deciles. Where the lack of data makes such an approach inappropriate or unreliable, deciles are based on the number of plants. Global benchmark curves are already available for the following sectors: steam crackers [3], clinker production [4], petroleum refineries [5] and ammonia production [6]. Benchmark curves are also available for the cement industry, as compiled by the Cement Sustainability Initiative [6], and for the aluminium industry, as compiled by the International Aluminium Institute [7]. The accuracy of these curves often suffers from incomplete data particularly for fast-growing developing countries (DCs) such as China. Plant benchmark data can be complemented by two further types of analysis based on either (i) the average current specific energy consumption (SEC) by world region or country, or (ii) the Energy Efficiency Index (EEI). The SEC analysis uses the average current SEC at country or regional level depending on data availability. If SEC data are not available, energy statistics provide the only basis for assessing energy efficiency. Energy statistics provides information on energy use at sectorial level, thereby including all production processes within that sector.

The EEI approach estimates the EEI of country j for sector x with i production processes as follows:

$$EEI_{j,x} = \frac{TFEU_{j,x}}{\sum_{i=1}^{n}\left(P_{i,j} \times BPT_{i,x}\right)} \tag{1}$$

where TFEU is the actual energy use of sector x as reported in Energy Balances prepared by the International Energy Agency (in petajoules (PJ) per year), P is the production volume of product i in country j (in megatonnes (Mt) per year), BPT is the best practice technology energy used for the production of product i (in GJ per ton of output), and n is the number of products

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to be aggregated. On this basis, a country is the most efficient worldwide when all its processes for a given sector have adopted BPT. In that case, the country or region has an EEI of 1.

On the basis of these approaches, the energy efficiency improvement potentials in sector x and in country or region j are determined as:

$$IP = 1 - \frac{Int.Benchmark(BPTorSEC_{lowest,x})}{SEC_{j,x}} = 1 - \frac{EEI_{lowest,x}}{EEI_{j,x}} \quad (2)$$

Where data availability constraints are required, "nameplate" energy efficiency plant data are used. These do not necessarily capture the variations in efficiency that result from daily operational practices, the frequency and quality of maintenance activities or the application of measures for debottlenecking and continuous improvement (including retrofitting) that are likely to change energy efficiency. If these aspects are accounted for, the SEC of the most energy efficient plants would probably be lower than as shown on the benchmark curves (i.e. these plants would be more efficient); and the SEC of the least energy efficient plants would probably be higher than shown (i.e. these plants would be less efficient). The slopes of the benchmark curves would therefore probably be steeper at the beginning and at the end.

For some developing countries, it is not possible to apply either SEC or EEI methodologies to some sectors, primarily due to limitations in the availability of data on physical production, SEC or sector-specific total final energy use as given by international energy statistics. For these sectors, a comparison of the current average SEC needs to be provided in developed countries and in developing countries. The international benchmark for estimating energy efficiency potentials is then set by the lowest achievable SEC that is identical with the BPT energy use.

This report analyses the energy use of iron and steel sector based on the data issued by World Steel Association (WAS) in 2009 [1]. An indicator, i.e. EEI is used to obtain an international benchmark and to estimate improvement potentials. The data is insufficient to support a deeper differentiation between types of raw material, feedstock or plant size, therefore the analysis focuses only on energy use and also the products analysed (denoted as i in Equation 1) are chosen according to data availability, and the most important processes operated in the sector are combined into a single EEI.

3.0 BENCHMARKING THE IRON AND STEEL INDUSTRY

Iron and steel are key products for the global economy. Since 2000, global steel production has grown by 75%, reaching 1.49 billion tons of steel in 2011. The sector is the largest industrial emitter of CO_2 (with direct emissions of 2.16 Gt in 2006) and the second largest industrial user of energy (consuming 24 EJ in 2006). Although considerable improvements have been made in recent years, the iron and steel sector still has the technical potential to further reduce energy consumption and CO_2 emissions by approximately 20%, saving 4.7 EJ of energy and 350 Mt of CO_2 [8].

Normally, an iron and steel plant produces a variety of products such as slabs, ingots to thin sheets. Fig. 2 presents a simplified scheme of the production routes. The primary output of the iron and steel sector is crude steel. Across the world, four major routes are applied for the production of crude steel which include:

- Blast furnace (BF)/Basic oxygen furnace (BOF)
- Smelt reduction/Basic oxygen furnace (BOF)
- Direct reduced iron (DRI)/Electric arc furnace (EAF)
- Scrap/Electric arc furnace (EAF)

Table 1 provides the best practice energy consumption data for different and commonly used process routes for iron and steel production. It should be noted that the totals for different process routes depend highly on feedstock and material flows and can show significant variations between different plants. Therefore, comparing individual plants to the totals listed here may be misleading.

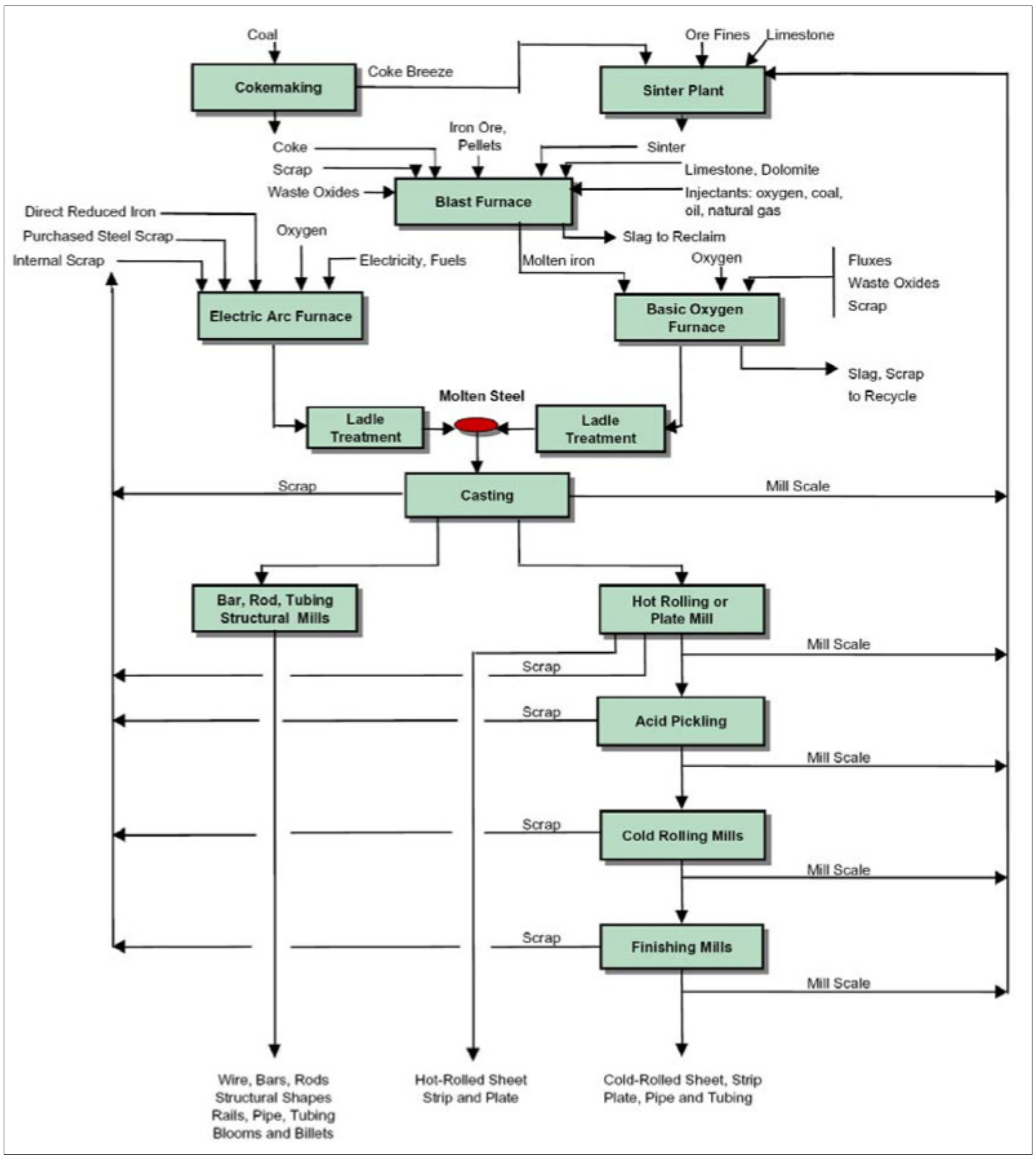

Figure 2: Simplified scheme of iron and steel production routes [9]

Journal of Advanced Review on Scientific Research
ISSN (online): 2289-7887 I Vol. 2, No.1. Pages 19-40, 2014

The process shares of crude steel production differ between countries. The most commonly used processes are BOF and EAF. BOF accounts for approximately two-thirds of worldwide production, and EAF for slightly less than one-third. Around 3% of the worldwide capacity is based on open-hearth furnaces, and these are being phased out.

For each country, an EEI value is estimated, which reflects the process mix and includes the production processes of the most important end products into which crude steel is further processed. These are:

- Hot-rolled flat products,
- Hot-rolled bars and concrete reinforcing bars, and
- Wire rod.

Table 1: World best practice of final and primary energy intensity values for iron and steel process (values in GJ/metric ton of steel) [10]

Production Step	Process	Blast furnace-basic oxygen furnace		Smelt reduction-basic oxygen furnace		Direct reduced iron-electric arc furnace		Scrap-electric arc furnace	
		Final	Primary	Final	Primary	Final	Primary	Final	Primary
Material Preparation	Sintering	1.9	2.2			1.9	2.2		
	Pelletizing			0.6	0.8	0.6	0.8		
	Coking	0.8	1.1						
Iron Making	Blast furnace	12.2	12.4						
	Smelt reduction			17.3	17.9				
	Direct reduced iron					11.7	9.2		
Steelmaking	Basic oxygen furnace	-0.4	-0.3	-0.4	-0.3				
	Electric arc furnace					2.5	5.9	2.4	5.5
	Refining	0.1	0.4	0.1	0.4				
Casting & rolling	Continuous casting	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Hot rolling	1.8	2.4	1.8	2.4	1.8	2.4	1.8	2.4
Sub-total		**16.5**	**18.2**	**19.5**	**21.2**	**18.6**	**20.6**	**4.3**	**8.0**
Cold rolling & finishing	Cold rolling	0.4	0.9	0.4	0.9				
	Finishing	1.1	1.4	1.1	1.4				
Total		**18.0**	**20.6**	**21.0**	**23.6**	**18.6**	**20.6**	**4.3**	**8.0**
Alternative: Casting & rolling		0.2	0.5	0.2	0.5	0.2	0.5	0.2	0.5
Alternative total		**14.8**	**16.3**	**17.8**	**19.2**	**16.9**	**18.6**	**2.6**	**6.0**

Plants in Asia/Pacific operate with the lowest energy use (EEI=1), followed by the plants in Europe (1.15), China (1.2) and North America (1.21). Iron and steel plants in India (1.35), Africa (1.42), Developing Asia (1.65) and CIS (Commonwealth of Independent States) (1.7) have relatively high levels of energy use. EEI values can also be expressed in terms of potential energy savings (in GJ) per ton of crude steel production compared to BPT. Regional averages on this basis are shown in Fig. 3 as purple dots with respect to the secondary y-axis.

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Journal of Advanced Review on Scientific Research
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The savings potentials per ton of crude steel do not necessarily follow the same ranking as the EEI. This reflects structural differences in the activities of the sector between countries. In countries with a high EEI and a high share of secondary steel production, the specific improvement potentials tend to be lower than in those countries that have an equally high EEI but produce more primary steel. This can be seen, for example, in the figures for North America and Europe. The Asia Pacific Partnership (APP) is increasingly active in collecting comparable and consistent data on the energy performance of BOFs and EAFs operating in Australia, Canada, China, India, Japan, Korea and the United States. Together, this account for around 60% of the total global iron and steel production. The APP's latest industry survey shows that the most efficient BOF in the region has an energy use of 18.2 GJ per ton of steel and the least efficient blast furnace uses 40.9 GJ per ton of steel. The best EAF has a specific energy use of 6.2 GJ per ton of steel and the least efficient EAF uses 30.1 GJ per ton of steel [11]. The coverage of the study is complete for Australia, Canada and Korea and partly for Japan with limited coverage of EAFs. The data for all other countries have major gaps. Given this patchy coverage, the APP results are not used in the present analysis.

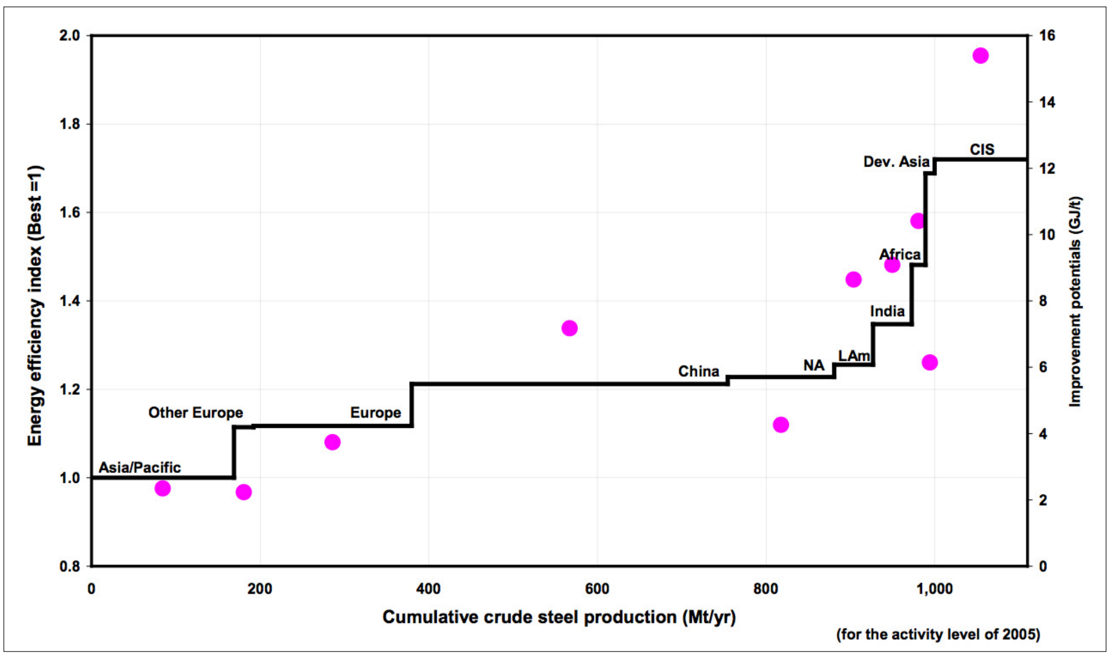

Figure 3: Estimated benchmark curve for the iron and steel industry. The benchmark curve is based on the left-hand y-axis. The dots show the specific improvement potentials in each region relative to BPT based on the right-hand y-axis [1]

4.0 INDUSTRY COMPARISON BETWEEN CHINA AND THE US

In this study, “energy intensity” has been chosen as the index for comparison of the Chinese and the US iron and steel industries. It presents within the prescribed boundary (as illustrated in Fig. 4), the energy consumption per ton of crude steel during production.

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$$Energy.Intensity = \frac{Energy.consumption.of.the.iron.and.stell.industry}{Crude.steel.production.within.the.prescribed.boundary} \quad (3)$$

The energy intensity of steel production is influenced by industry structure, technology, fuel choice, and materials, e.g. availability of scrap steel.

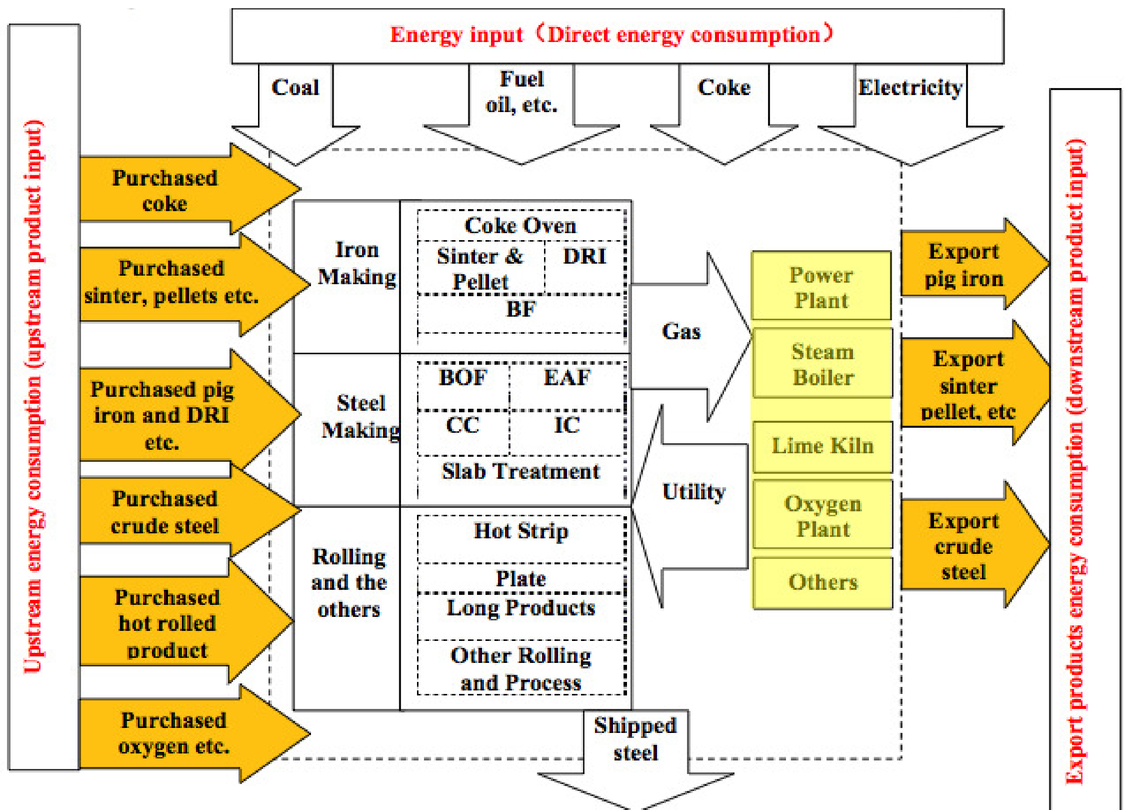

Figure 4: Flowchart of iron and steel sector boundaries used in the study [12]

4.1 Energy intensity of the iron and steel production in the US

Final energy intensity (energy use per ton of crude steel) for the US iron and steel industry in 2006 is provided in Table 5. This value is calculated using the production data from Table 2, as well as the electricity and fuel consumption data from Table 3.

Table 2. Production and trade data for pig iron, DRI, crude steel, ingot, blooms, billets, slabs, and steel products in the US in 2006 (Mt) [13]

Product	Production	Exports	Imports	Net imports	Used in industry
Pig Iron	37.9	0.813	6.73	5.92	43.8
DRI	0.24	-	2.61	2.61	2.85
Crude Steel	98.2	-	-	-	-
Ingots, Blooms, Billets, Slabs	-	0.20	8.46	8.26	-
Steel Products	99.3	8.83	41.1	32.3	-

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Table 3: Total electricity and fuel consumption for iron and steel production in the US based on the study boundary. [12]

Components	Electricity Use (GWh)	Fuel Use (TJ)	Final (TJ)	Primary (TJ) *
Energy use reported for the iron and steel industry in EIA (excluding the energy use for production of intermediary products given below)	51,198	912,623	1,096,936	1,481,942
Energy used for the production of net imported oxygen	4,750	0	17,101	52,824
Energy used for the production of net imported pig iron	2,603	107,784	117,175	136,735
Energy used for the production of net imported direct reduced iron	809	33,473	36,383	42,463
Energy used for the rolling and finishing of net imported ingots, blooms, billets, and slabs	4,396	43,257	59,083	92,141
Embodied energy of net imported ingots, blooms, billets, and slabs	7,509	109,109	136,141	192,608
Energy used for the production of net imported coke	351	10,237	11,502	14,145
Energy used for the production of net imported lime	334	6,816	8,019	10,532
Energy used for the production of net imported pellets	0	103,530	103,530	103,530
Total energy consumption of steel industry with embodied energy of net imported/exported auxiliary/intermediary products included	**71,951**	**1,326,830**	**1,585,853**	**2,126,919**

* In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with T&D losses, electricity use at the end-use is converted to the primary energy sources by taking into account the power generation efficiency (average net heat rate of power plants) and transmission and distribution losses.

Crude steel production in the US in 2006 was 98.2 Mt. In addition, there were 8.261 Mt of net imported ingots, blooms, billets, and slabs in 2006. Thus, the total crude steel production used for the calculation of energy intensities in 2006 in this analysis was 106.461 Mt. Energy use for the production of net imported ingots, blooms, billets, and slabs is calculated using international average conversion factors provided by the World Steel Association (worldsteel) since imported products can be from different countries and will thus vary in their energy consumption during production due to differences in production technology and energy structure [14,15].

The total electricity and fuel consumption in the iron and steel industry in the US in 2006 based on the defined boundary of this study were 71,951 million kWh and 1,326,830 TJ respectively. If these energy uses are divided by the production of crude steel given above, the electricity and fuel intensity can be calculated separately. The sum of the electricity and fuel intensity is given as the total final energy intensity.

Primary energy intensity is calculated by converting the final electricity to primary energy intensity using the average power generation efficiency of fossil fuel power plants in the US, as well as transmission and distribution losses. By multiplying the final electricity intensity by the conversion factor given in Table 4 for the US, the primary electricity intensity can be calculated. Finally, the fuel intensity (for which final and primary energy value is the same in this analysis) is then added to the primary electricity intensity to calculate the total primary energy intensity. Presenting the energy intensity in primary energy has the advantage of showing the relative efficiency of the power generation in both countries. Table 5 presents the various energy intensities explained above.

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Table 4: Fuel conversion factors for China and the US [12]

Fuel	IEA-Typical		Country-Specific				Unit
	IEA-Typical	Source	China	Source	U.S.	Source	
Other bituminous coal (used as fuel)	24.05[a]	IEA 2005	20.91	NBS 2007	25.65	EIA 2009	MJ/kg
Coking coal	28.20[b]	IEA 2005	26.34	NBS 2007	30.56	EIA 2009	MJ/kg
Coke oven coke	27.45	IEA 2005	28.44	NBS 2007	28.85	EIA 2009	MJ/kg
Natural gas	35.04[c]	IEA 2008c	38.93	NBS 2007	38.33	EIA 2009	MJ/kg
Residual fuel oil	42.18[d]	IEA 2005	-		44.18	EIA 2009	MJ/kg
Distillate fuel oil	40.19	IEA 2008c	41.82	NBS 2007	40.94	EIA 2009	MJ/kg
LPG	46.15[e]	IEA 2005	50.18	NBS 2007	45.81	EIA 2009	MJ/kg
Other washed coal	-	-	10.47[g]	NBS 2007	-	-	MJ/kg
Crude oil	42.85[f]	IEA 2008c	41.82	NBS 2007	-	-	MJ/kg
Gasoline	47.10	IEA 2005	43.07	NBS 2007	-	-	MJ/kg
Kerosene	46.22	IEA 2005	43.07	NBS 2007	-	-	MJ/kg
Diesel	45.66	IEA 2005	42.65	NBS 2007	-	-	MJ/kg
Other petroleum products	-	-	35.17	NBS 2007	-	-	MJ/kg
Tar	-	-	33.45	NBS 2007	-	-	MJ/kg
Benzene	-	-	41.82	NBS 2007	-	-	MJ/kg

[a] IEA provides a range for typical NCVs of other bituminous coal of 22.6 to 25.5 MJ/kg. The average value of 24.05 MJ/kg (0.821 kgce/kg) is used in the table above.
[b] IEA provides a range for typical NCVs of coking coal of 26.6 to 29.8Mj/kg. The average value of 28.2 MJ/kg (0.962 kgce/kg) is used in the table above.
[c] Natural gas as supplied contains gases in addition to methane (usually ethane and propane). As the heavier gases raise the calorific value per cubic meter, the gross calorific values can vary quite widely. Therefore, the average NCV of natural gas of the top ten largest producers in 2008 is used in the table above.
[d] This is for low sulfur fuel oil.
[e] IEA value for LPG is a typical value and is the same for both countries.
[f] The average NCV of crude oil of the top ten largest producers in 2008 is used in the table above.
[g] Average value of 8.37 and 12.56 MJ/kg.

Table 5: Energy intensity of the US iron and steel industry in 2006 [12]

Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity[1]		Primary Energy Intensity with T&D[2]		Primary Energy Intensity without T&D	
	kWh/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel
U.S.	675.84	83.44	12.46	425.25	14.90	508.69	19.98	681.68	19.47	665.71

[1] Total final energy intensity of the US iron and steel industry using the US country-specific energy conversion factors for the purchased coke and auxiliary/intermediary products instead of worldsteel conversion factor would be 14.5 GJ/tone crude steel, that is around 2.7% less than the intensity calculated using worldsteel conversion factors.
[2] In the final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution losses (T&D), electricity use at the end-use is converted to the primary energy sources by taking into account the power generation efficiency (average net heat rate of power plants) and transmission and distribution losses.
Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

4.2 Energy intensity of the iron and steel production in China

Table 8 shows the energy intensity (energy consumption per ton crude steel) calculated based on the 2006 revised energy data for China. Final energy intensity for the Chinese iron and steel industry in 2006 is provided in Table 8. This value is calculated using the Chinese production data from Table 6 and the electricity and fuel consumption data from Table 7. Crude steel production in China in 2006 was 421.02 Mt. In addition, there were 8.57 Mt of net exported

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ingots, blooms, billets, and slabs in 2006. Thus, the total crude steel production used for the calculation of energy intensities in 2006 in this analysis was 412.45 Mt. The total electricity and fuel consumption of steel industry in China with embodied energy of net imported/exported auxiliary/intermediary products included were 178,039 GWh and 8,882,760 TJ respectively. By dividing these energy consumption values with the production values, the energy intensities presented in Table 8 are obtained.

Table 6: Production, Imports and Exports of Pig Iron, DRI, Crude Steel, Ingots, Billets, and Steel Products in China, 2006 (Mt) [16]

Product	Production	Exports	Imports	Net Trade	Used in industry
Pig Iron	413.64	0.87	0.17	-0.70	412.94
DRI	0.21	0.01	0.31	0.30	0.51
Crude Steel	421.02	-	-	-	-
Steel Ingots	-	0.04	0.14	0.10	-
Steel Billets	-	9.04	0.37	-8.67	-
Steel Products	399.97[a]	43.01	18.51	-24.50	375.47

* In order to avoid double-counting of steel products, this number was calculated as 95% of crude steel.

Table 7: Total energy consumption of China's steel industry production in 2006 [12]

Components	Electricity Use (GWh)	Fuel Use (TJ)	Final (TJ)	Primary (TJ) *
Reported energy consumption (excluding the energy use for production of intermediary products given below)	174,293	8,593,558	9,221,013	10,515,967
Energy used for the production of purchased coke	5,883	488,395	509,574	553,283
Energy used for the production of net exports of pig iron	-114	-13,412	-13,822	-14,669
Energy used for the production of net imports of coal-based DRI	42	4,934	5,085	5,397
Energy used for the production of net imports of steel ingots	17	1,589	1,650	1,776
Energy used for the production of net exports of steel billets/slabs	-2,082	-192,304	-199,799	-215,268
Total energy consumption of steel industry with embodied energy of net imported/exported auxiliary/intermediary products included	**178,039**	**8,882,760**	**9,523,701**	**10,846,487**

* In the final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with T&D losses, electricity use at the end-use is converted to the primary energy sources by taking into account the power generation efficiency (average net heat rate of power plants) and transmission and distribution losses.
Note 1: The negative values indicate the energy use by export products was subtracted.
Note 2: The reason that there is no energy use data given separately for lime and pellets is that the energy use for the production of these products is included in the reported energy consumption of the steel industry in China (first row of this table) and there is no import or export of these two products.

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Table 8: Energy intensity of the China's iron and steel industry in 2006. [12]

Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D[1]		Primary Energy Intensity without T&D[2]	
	kWh/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel	GJ/t crude steel	kgce/t crude steel
China	431.66	53.02	21.54	734.96	23.11	788.53	26.30	897.38	25.97	886.12

[1] In the final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution losses (T&D), electricity use at the end-use is converted to the primary energy sources by taking into account the power generation efficiency (average net heat rate of power plants) and transmission and distribution losses.

[2] In primary energy without transmission and distribution losses (T&D), electricity use at the end-use is converted to the primary energy sources by taking into account only the power generation efficiency (average net heat rate of power plants). This is presented here because it is the common method in Chinese statistics. Thus, for consistency, both primary energy calculated using the international standard (with T&D losses) and using the Chinese standard (without T&D losses) are presented.

5.0 EXPLANATORY VARIABLES

In industries, consultants compile plant performance data, which are presented in confidential multi-client studies. Results are disclosed in publicly available literature, either at a high level of aggregation or sometimes in more detail once the benchmark study is slightly outdated and newer data is collected, and one reason is the influence of the data on value of the shares and other monetary matters. On the other hand, industry partnerships tend to publicize energy and production data to an increasing extent, however, without individual plant data. Therefore, usually when it comes to energy benchmarking, the study would suffer from lack of sufficient/updated data.

The purpose of the analysis presented in the previous section is quantifying and comparing the energy intensity of steel production in China and the US with defined boundaries and conversion factors, but it is not exceptional of uncertainties due to certain assumptions made and inaccuracy of the base data. This section provides a discussion of some possible reasons that the energy intensity values differ in the two countries. Three explanatory variables are discussed: 1) the age of steel manufacturing facilities in each country, 2) structure of the steel manufacturing sector, and 3) fuel shares.

5.1 Age of steel manufacturing facilities

As is evident from Fig. 5, most of China's steel production capacity has been constructed since 2000, when annual production jumped from 129 Mt to 627 Mt in 2010. During the same time, production in the US dropped from 102 Mt to 80 Mt. While there are no data available on the exact age of each steel enterprise in China, we can infer from the production data that in 2011, about 500 Mt of production (or about 80%) are from plants that are 10 years old or younger. In contrast, the average age of BOF vessels in the US is 31.5 years [17], and the average age of EAF furnaces in the US is 30.9 years [18]. Even though the vessels have been relined and other upgrades have been made to the US facilities, they are overall older than most of the steel production facilities in China. However, it should also be noted that not all of the new Chinese plants have necessarily installed the most energy-efficient technologies.

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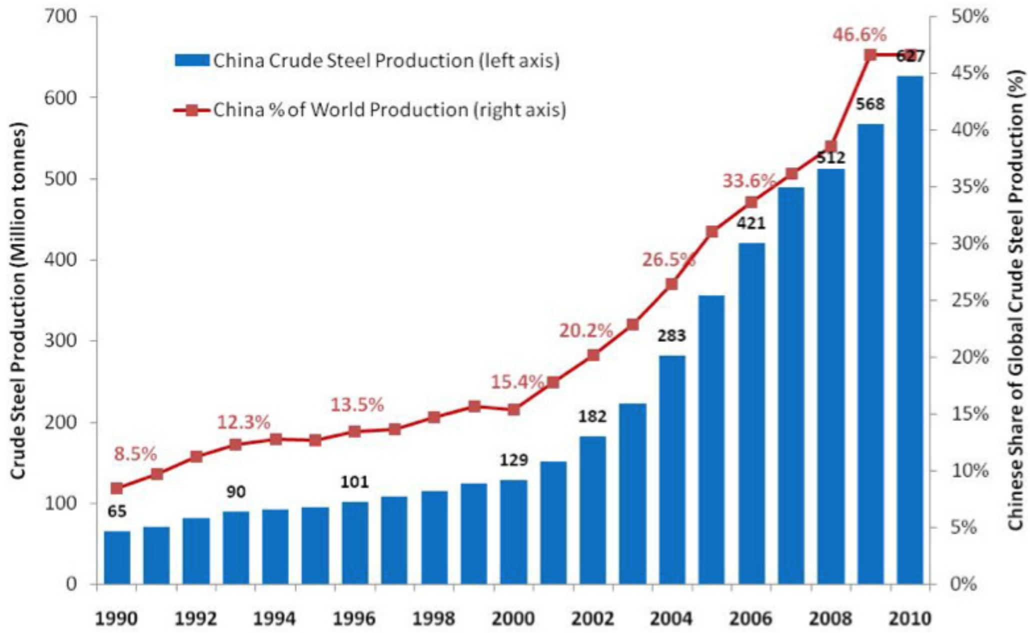

Figure 5: China's crude steel production and share of global production (1990-2010) [19]

5.2 Structure of steel manufacturing sector

The structure of the steel manufacturing sector is one of the key variables that explains the difference in energy intensity values in China and the US since EAF steel production uses significantly less energy for the production of one ton of steel. In 2006, the share of EAF steel production in the total steel production was 10.5% in China and 56.9% in the US. The world average EAF production in 2006 was 31.6% (Fig. 6).

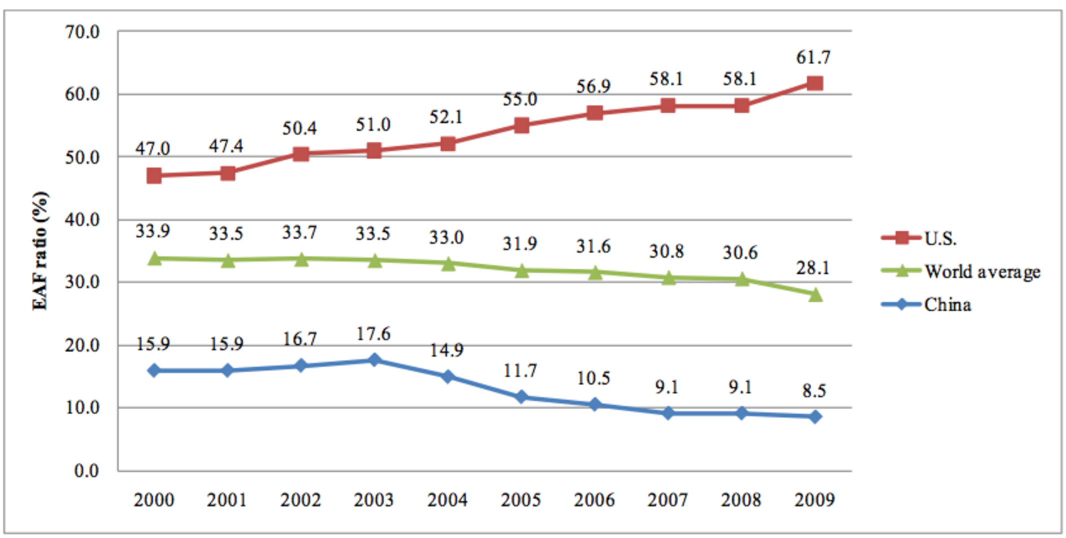

Figure 6: Share of EAF in total steel production in China and the US and world average values [14]

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5.3 Fuel shares

The share of different fuels used in the iron and steel industry in both countries is also another an important variable that should be considered. The fuel shares will influence the energy intensity of the iron and steel industry, as well as the related carbon dioxide emissions. Fig. 7 and Fig. 8 show the shares of different fuels used (both as fuel and nonfuel) in the US and Chinese iron and steel industries. As can be seen, there are significant differences in the types of fuel used in this industry in the two countries. For example, the US natural gas accounts for 34.5% of the final energy use whereas it only accounts for 0.45% in China.

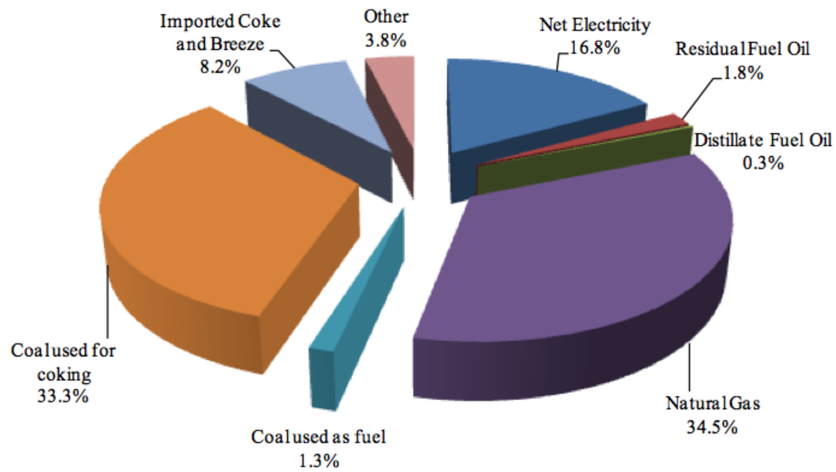

Figure 7: Total energy use (fuel and nonfuel) in the US iron and steel industry in 2006 [20]

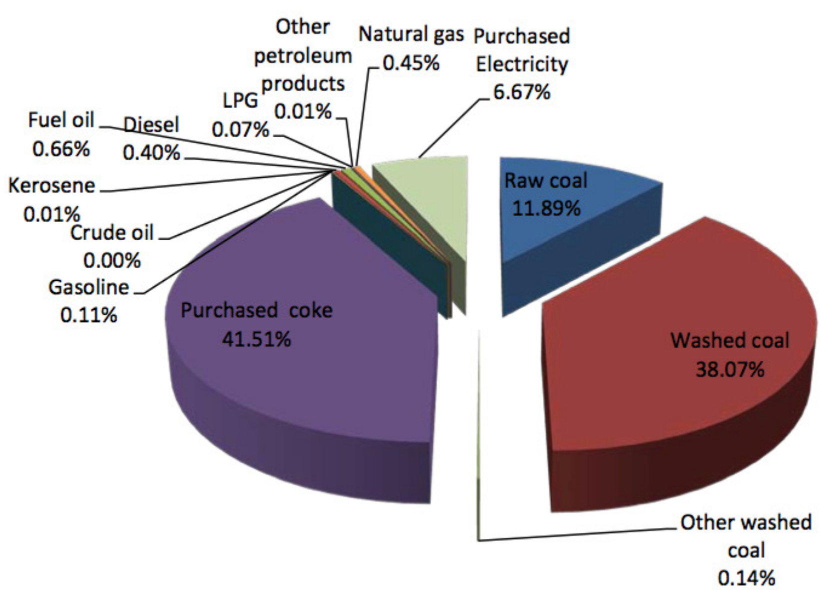

Figure 8: China primary energy use (fuel and non-fuel) of iron and steel industry in 2006 [21]

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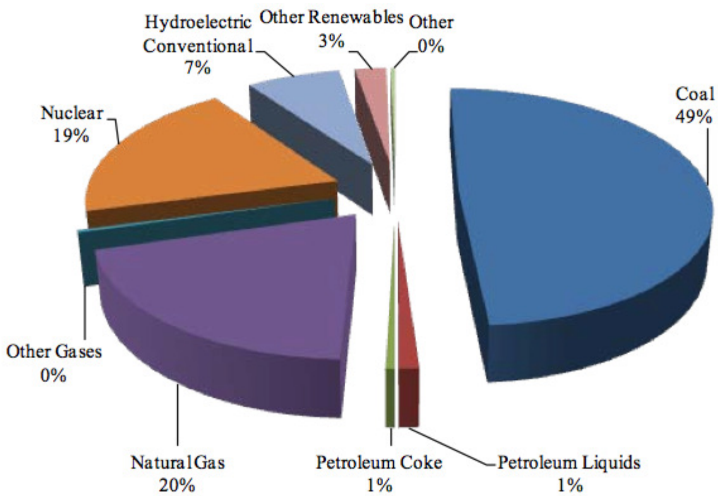

Figure 9: Electricity generation fuel shares in the US in 2006. [20]

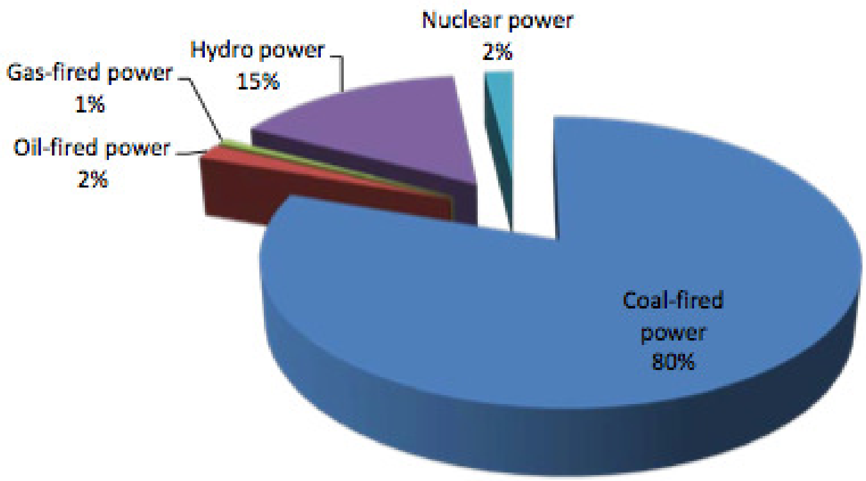

Figure 10: Electricity generation fuel shares in China in 2006. [21]

In addition to the share of fuels used directly in the iron and steel industry, the share of fuels used for power generation in each country is also an important factor, especially if the CO_2 emission of the industry in two countries are compared. This becomes even more important because of the significant difference in the share of EAF steel production in China and the US. Since the share of EAF steel production in the US. is higher, the share of electricity use in total energy use is also higher compared to that of the Chinese iron and steel industry. In this case, the fuel share for the power generation in the country and as the result the emission factor of the grid (kg CO_2/kWh) plays an important role when comparing the CO_2 emissions of the iron and steel industry in the two countries. However, it should be noted that the comparison of the CO_2 emissions is beyond the scope of this report.

Fig. 9 shows the fuel shares for electricity generation in the US. in 2006 and Fig. 10 for China. Coal is the major source for power generation, accounting for about 49%, with around 20% of

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the electricity in the US. was generated from natural gas, 19% from nuclear energy, and around 10% from hydroelectric and other sources of renewable energy. In contrast, 80% of electricity in China was generated by coal in 2006. The comparison of fuel shares in the US and China shows that the share of fossil-fuel has a higher percentage in both countries, i.e., 83% in China (the sum of coal, oil and gas), and 71% in the U.S. (the sum of coal, natural gas, petroleum coking and oil).

6.0 CERTAIN MEASURES IN ENHANCING PLANT EFFICIENCY

Steel production involves numerous process steps that can be laid out in various combinations depending on product mix, available raw materials, energy supply and investment capital. The key characteristics of the three main processing routes are as follows:

- In Blast Furnace (BF)/Basic Oxygen Furnace (BOF) route, pig iron is produced using primarily iron ore (70% to 100%) and coke in a blast furnace, and then turned into steel in a basic oxygen furnace. Due to the inclusion of coke making and sintering operations, this route is highly energy intensive.
- Scrap/Electric Arc Furnace (EAF) route is primarily based on scrap for the iron input and has significantly lower energy intensity compared to the BF/BOF route due to the omission of coke making and iron making processes.
- Direct Reduced Iron (DRI)/EAF route is based on the iron ore and often scrap for the iron input. Energy intensity of DRI production can be lower than BF route, depending on the size, fuel and ore characteristics.

In recent years, there is also increasing attention being paid to smelting reduction, which is emerging as a contender to blast furnace process. Fig. 11 illustrates the general iron and steel production schematic along with certain available measures/technologies to increase efficiency of each step in the production process.

7.0 MAJOR IRON AND STEEL GLOBAL ORGANIZATIONS

Certain major global organizations which are directly or indirectly in charge of the iron and steel industry are mentioned, followed by a brief description on their contribution.

International Energy Agency (IEA): The International Energy Agency (IEA) is an autonomous organization that works to ensure reliable, affordable and clean energy for its 28 member countries and beyond. IEA has been a key partner in various studies on energy efficiency, energy technologies, and energy policies. It also offers a wealth of information on energy and CO_2 emission statistics.

United Nations Framework Convention on Climate Change (UNFCCC): The United Nations Framework Convention on Climate Change (UNFCCC or FCCC) is an international environmental treaty produced at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro from June 3 to 14, 1992. The objective of the treaty is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

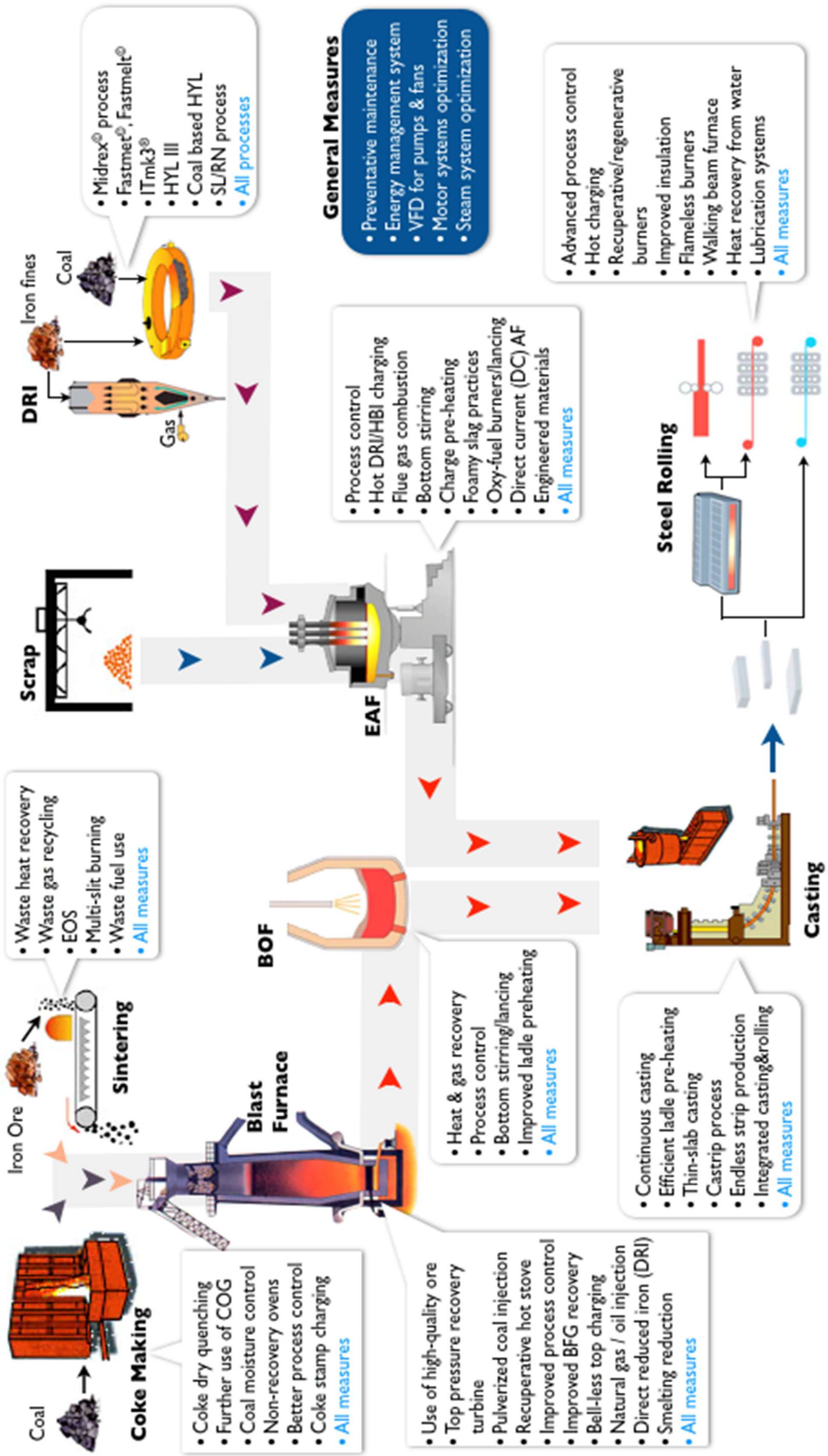

Figure 11: Iron and steel production schematic [22]

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United Nations Industrial Development Organization (UNIDO): The United Nations Industrial Development Organization (UNIDO) is a specialized agency of the United Nations. One of the aims of UNIDO is to promote and accelerate sustainable industrial development in developing countries and economies in transition. One of the areas the UNIDO focuses is related to fostering environmental sustainability. UNIDO has organized several workshops on energy efficiency and CO_2 emissions reduction in the industry. UNIDO also plays a key role in the development of the ISO management system standard for energy, ISO 50001.

World Steel Association (WSA): World Steel Association represents approximately 170 steel producers, national and regional steel industry associations, and steel research institutes. World steel members represent around 85% of world steel production. The organization is a focal point for the steel industry, providing global leadership on all major strategic issues affecting the industry, particularly focusing on economic, environmental and social sustainability.

8.0 ILLUSTRATIVE ENERGY FLOWS BY SANKEY DIAGRAMS

When it comes to energy management issues, one simple and attractive way to show energy flows/consumptions for different sectors whether at the nationwide or global scale is to take advantage of Sankey diagram. In Sankey diagram, according to the relative magnitude scale of each flow comparing to other sources, a user would be able to simply interpret the origins, destinations and amounts of various type of energy flows in one diagram. The Sankey diagrams of World's Iron and Steel Final Energy Consumption 2011 and the Projection of World's Iron and Steel Final Energy Consumption 2050 published by the International Energy Agency are amended respectively in Fig. 12 and Fig. 13 [23].

9.0 CONCLUSION

Improved energy efficiency is among the key measures for CO_2 emission abatement in the industry. Energy benchmark curves provide data measured at individual plants and they offer a basis to estimate the sectorial energy efficiency improvement potentials (IP) compared to a best practice technology (BPT) currently in operation worldwide. However, it is also important to note that during the analysis, problems were discovered related to the availability and reliability of the data provided for the Chinese and the US iron and steel industries. Hence, both countries should make efforts to improve data collection and management.

According to the international energy benchmark curve for the iron and steel industry, it was shown that the savings potentials per ton of crude steel for the US and China were respectively 4.1 and 7.1 GJ as compared with the best practice technology (BPT) in the field. The industries shall achieve such improvements by adopting efficient technologies that are involved upon the production process.The findings presented above indicate the impact of different variables on the calculated energy intensity value for the steel industry in China and the US, which can help to explain the observed differences in energy intensity. The results indicate that overall, the Chinese steel industry is more energy intensive than the US steel industry. This is primarily, but not only, due to the difference in the structural composition of the two industries, with the US producing a significantly greater share of the less energy-intensive EAF steel.

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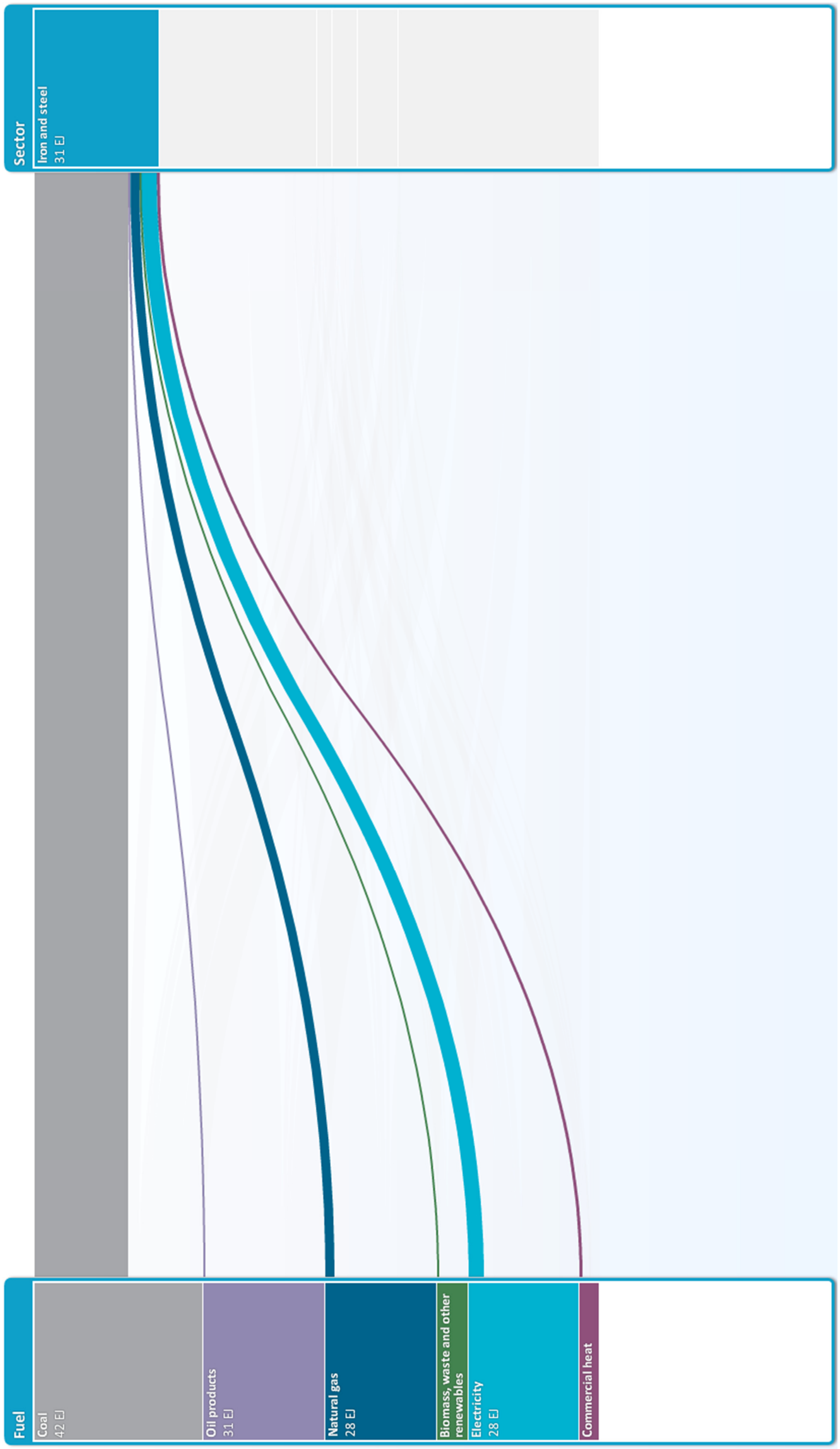

Figure 12: World's iron and steel final energy consumption (2011) [23]

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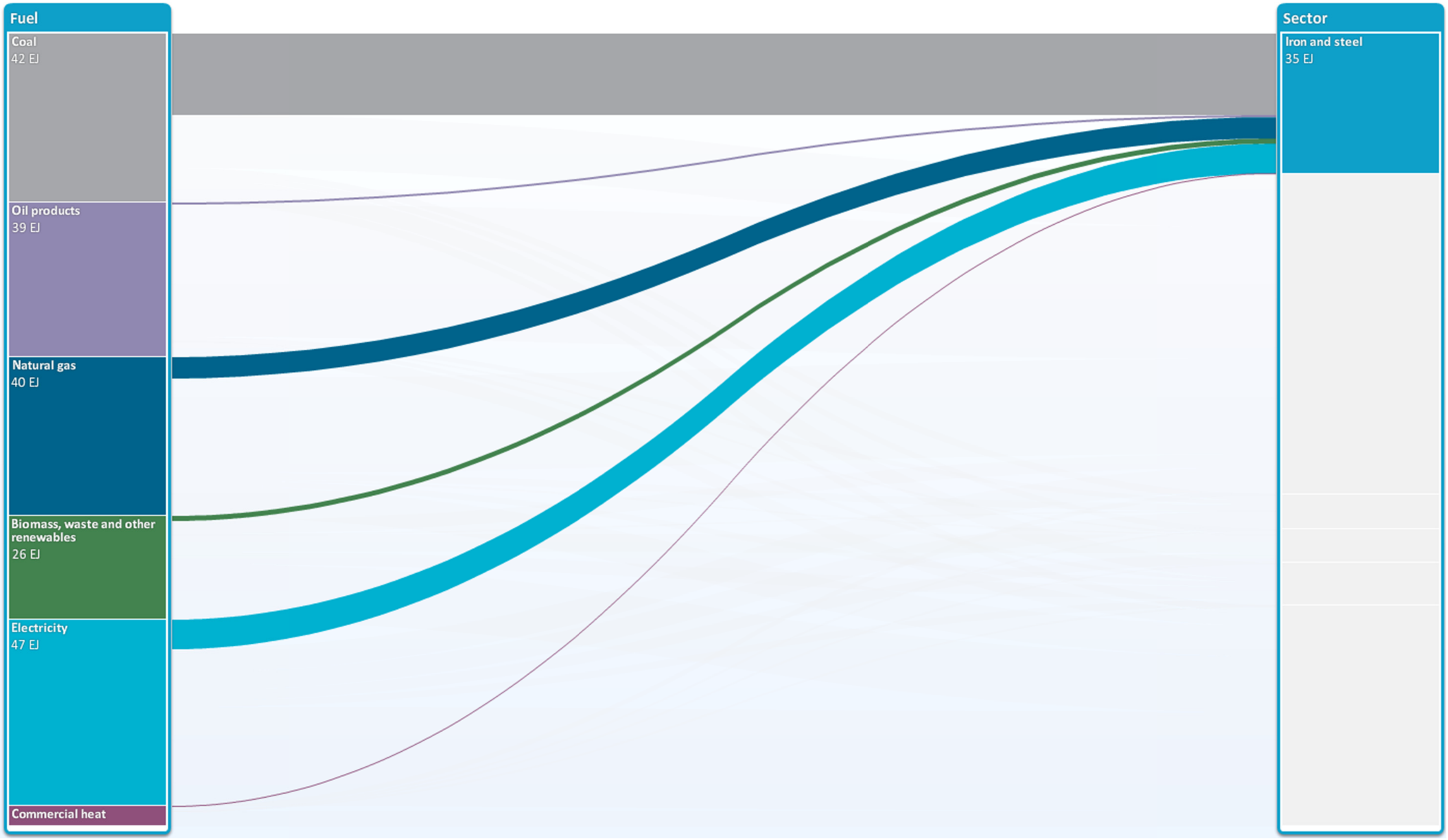

Figure 13: Projection of world's iron and steel final energy consumption (2050) [23]

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ISSN (online): 2289-7887 I Vol. 2, No.1. Pages 19-40, 2014

It is important to remember that China is at a different development stage than the US, which contributes to differences in the efficiency of energy consumption. In the early stages of industrialization, the economic growth in China has primarily depended on the development of energy-intensive industries.

The comparisons of energy consumption for different country's iron and steel industries need to take into account the impact of parameters such as fuel conversion coefficients, electricity conversion factors, and the EAF steel ratio. In addition, there are significant differences within China's iron and steel industry, with a number of inefficient "laggards" co-existing with top performers that represent the advanced level in the world i.e. Baosteel Co., Ltd [12]. If this analysis only focuses on China's key steel enterprises, which account for more than 80% of crude steel production in China, the energy intensity values would most likely be lower than those for the entire country's steel industry (the energy intensity per ton steel of China's overall iron and steel industry is around 2.92 GJ/ton crude steel more than that of the key steel enterprises).

On the other hand, many of China's steel production facilities have been constructed in recent years while most of the US steel production capacity are much older. As China phases out both smaller and older steel production capacity, the energy intensity of steel production in these two countries will converge slightly, but the more significant convergence happens when the share of EAF steel production in both countries converges as well. This may take a while until more scrap is available in China.

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