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A Comparison of Iron and Steel Production Energy Use and Energy Intensity in China and the U.S.

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Abstract
Production of iron and steel is an energy-intensive manufacturing process. In 2006, the iron and steel industry accounted for 13.6% and 1.4% of primary energy consumption in China and the U.S., respectively (U.S. DOE/EIA, 2010a; Zhang et al., 2010). The energy efficiency of steel production has a direct impact on overall energy consumption and related carbon dioxide (CO_2) emissions. The goal of this study is to develop a methodology for making an accurate comparison of the energy intensity (energy use per unit of steel produced) of steel production. The methodology is applied to the steel industry in China and the U.S. The methodology addresses issues related to boundary definitions, conversion factors, and indicators in order to develop a common framework for comparing steel industry energy use.

This study uses a bottom-up, physical-based method to compare the energy intensity of China and U.S. crude steel production in 2006. This year was chosen in order to maximize the availability of comparable steel-sector data. However, data published in China and the U.S. are not always consistent in terms of analytical scope, conversion factors, and information on adoption of energy-saving technologies. This study is primarily based on published annual data from the China Iron & Steel Association and National Bureau of Statistics in China and the Energy Information Agency in the U.S.

This report found that the energy intensity of steel production is lower in the United States than China primarily due to structural differences in the steel industry in these two countries. In order to understand the differences in energy intensity of steel production in both countries, this report identified key determinants of sector energy use in both countries. Five determinants analyzed in this report include: share of electric arc furnaces in total steel production, sector penetration of energy-efficiency technologies, scale of production equipment, fuel shares in the iron and steel industry, and final steel product mix in both countries. The share of lower energy intensity electric arc furnace production in each country was a key determinant of total steel sector energy efficiency. Overall steel sector structure, in terms of average plant vintage and production capacity, is also an important variable though data were not available to quantify this in a scenario. The methodology developed in this report, along with the accompanying quantitative and qualitative analyses, provides a foundation for comparative international assessment of steel sector energy intensity.

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1. Introduction

Production of iron and steel is an energy-intensive manufacturing process. In 2006, the iron and steel industry accounted for 13.6% and 1.4% of primary energy consumption in China and the U.S., respectively (U.S. DOE/EIA, 2010a; Zhang et al., 2010).[1] The energy efficiency of steel production has a direct impact on overall energy consumption and related carbon dioxide (CO_2) emissions. The goal of this study is to develop a methodology for making an accurate comparison of the energy intensity of steel production in China and the U.S. Energy intensity is defined as energy use per unit of steel produced. Energy efficiency is defined as the ratio of useful output of service/product from a piece of industrial equipment or an industrial process to the energy used by that equipment/process. The methodology addresses issues related to boundary definitions and conversion factors in order to develop a common framework for comparing steel industry energy use in these two countries.

The areas covered in this study are: (1) a literature review of existing research on energy efficiency and intensity of steel production in China and the U.S. and comparisons of energy intensity levels between the two countries, (2) a review of the available data on technology, production, and energy use for the Chinese and U.S. steel industries, (3) development of a methodology with consistent boundaries and conversion factors for comparing energy intensity of steel production in China and the U.S., (4) comparison of the energy intensity of steel production in China and the United States, and (5) development of explanatory variables to explain the differences in energy intensity.

This report begins with an overview of the iron and steel industry in China and the U.S. in Section 2. Section 3 describes the methodology used for this study, including an assessment of the data available in both countries, definition of boundaries of the iron and steel industry used in this study, and issues related to the calculation of the energy content of fuels as well as conversion factors to convert electricity from final to primary energy[2] for use in this study. Section 4 outlines the base year production and energy use data for both countries. Section 5 presents the quantitative comparison of energy intensity of iron and steel production in China and the U.S. This comparison provides a base case and six alternative scenarios that present the results using different assumptions than those used in the base case. Explanatory variables such as the share of electric arc furnace (EAF) steel production, product mix, fuel shares, etc. are also qualitatively discussed in Section 5. Section 6 summarizes study findings, while Section 7 provides a discussion, policy implications and recommendations for future research.

[1] Note that the 2009 China Energy Statistical Yearbook lists total primary energy use for Smelting and Pressing of Ferrous Metals as 447 million tons of coal equivalent (Mtce) in 2006, thereby comprising 17% of total primary energy use for that year (NBS, 2010a). This also includes the energy use by facilities that belong to steel enterprises but are not part of the steel production process such as residential houses of the enterprises. The results of this report, which is focused solely on the energy used for iron and steel production and is thus less comprehensive than the Yearbook category of Smelting and Pressing of Ferrous Metals, is that this industry accounted for 13.6% of total primary energy use in China in 2006.

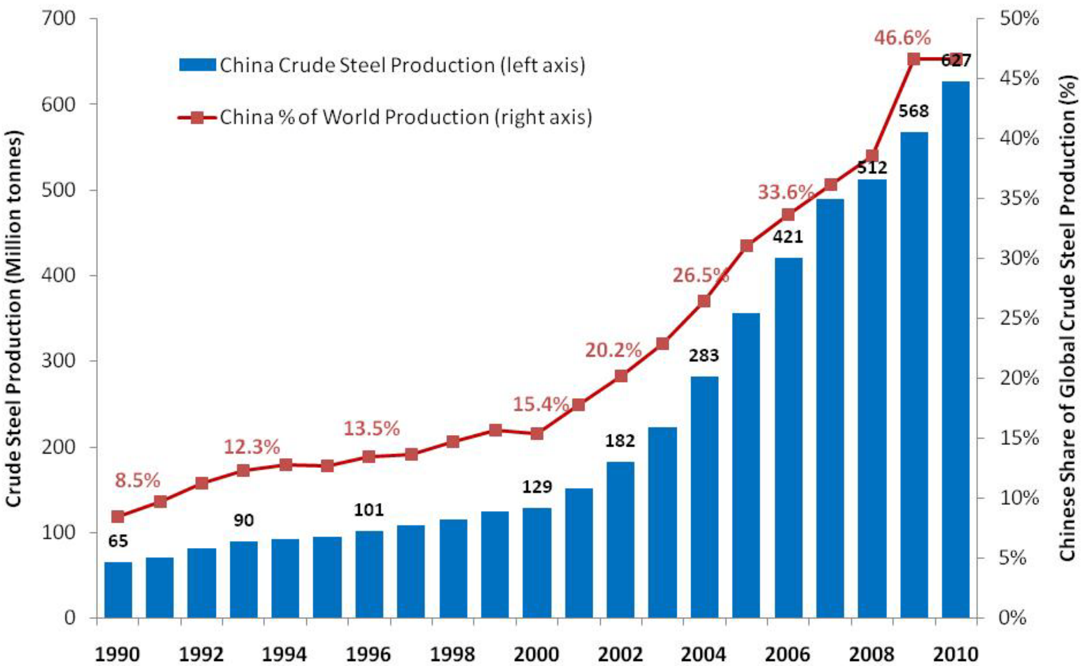
[2] Final (or site) electricity is the electricity consumed at the production facility. This value, however, does not include the primary energy used to generate, transmit, and distribute electricity to the site. To convert final electricity to primary energy, the average efficiency of power generation and transmission and distribution losses must be taken into account.

2. Overview of the Iron and Steel Industry in China and the U.S.

2.1. The Iron and Steel Industry in China

China is a developing country and is currently in the process of industrialization. The iron and steel industry, as a pillar industry for Chinese economic development, has grown rapidly along with the national economy. Starting in the 1990s, the industry development accelerated, with crude steel production in 1996 exceeding more than 100 million metric tonnes (Mt). Since then, steel production in China has continued to increase rapidly, and China has been the world's largest crude steel producer for 14 continuous years. The average annual growth rate of crude steel production was 18.5% between 2000 and 2009. Steel production in 2010 was 627 Mt (worldsteel, 2011), representing 46.6% of the world production that year (see Figure 1).

Figure 1: China's Crude Steel Production and Share of Global Production (1990-2010)



Source: China Iron and Steel Industry Yearbook, various years; World Steel Association 2011

The Chinese iron and steel industry has made much progress in reducing energy use, starting from energy saving on individual equipment and process energy conservation in 1980s to systematic energy conservation via process optimization in 1990. China's energy consumption per tonne of steel has declined significantly, especially since the 1990s, largely due to process restructuring and optimization (see Table 1). Energy intensity in China is measured in units of kilograms of coal equivalent per metric tonne (kgce/tonne).[3]

[3] To convert kgce to GJ, multiply by 0.02931 and to convert kgce to Million Btu, multiply by 0.02778.

Table 1: Energy Savings and Components of China's Steel Industry (1990-1999)

Component Type	Energy savings (Mtce)	Energy savings (%)
Optimization of steel production process [a]	18.7	40.7%
Use of energy-saving technologies and equipment	8.71	18.9%
Steel production auxiliary materials improvements and others	7.07	15.4%
Energy management	11.5	25.0%
Total	46.0	100%

Source: Yin RY, et al., 2003.

[a] This category refers to upgrading the steel making process to be more efficient and more environmentally-friendly (e.g., by using more alternative fuels and wastes). Specific measures may include: upgrading technologies and equipment, upgrading the steel product structure (by producing more value-added steel products), and increasing the quality of steel products. The goal is to increase the energy efficiency of steel making and to utilize more wastes (scrap, plastics, municipal wastes, tires, sewage sludge, etc.).

During the ten years between 1990 and 2000, China's steel production almost doubled, but total energy consumption only increased 31%. From 2000 to 2005, steel production increased 174.2%, but energy consumption only increased 120% (Editorial Board of China Iron and Steel Industry Yearbook, various years). Specific energy consumption per tonne of steel in key medium and large - sized steel enterprises[4] dropped from 920 kgce/t steel in 2000 to 741 kgce/t steel in 2005 (Editorial Board of China Iron and Steel Industry Yearbook, various years).[5] Specific energy consumption per tonne of steel was reduced 19.5% from 2000 to 2005. Table 2 provides more detailed information on the reduction of energy intensity in the main processes of key steel enterprises.

Since 2000, energy conservation and emission reduction in China's steel industry has improved significantly (see Table 2 for key medium and large - sized steel enterprises). Academic advisors recommended that the steel industry explore the functions of steel product manufacturing, energy conversion, and utilization and treatment of waste resources (Yin, 2009). This focus leads to energy conservation and emission reduction in the steel industry. Meanwhile, China's national government is actively promoting the concept of a circular (or recycling) economy in the steel industry, encouraging widespread energy saving, emission reduction, increased steel scrap recycling rate, and resource conservation as necessary foundations of the circular economy. In addition, energy conservation is also seen as an effective way of reducing greenhouse gas emissions.

Under the guidance of the concept of "expanding the functions of steel manufacturing processes," promotion and application of energy-saving technologies has already become an important step for increasing energy efficiency and reducing energy consumption of steel enterprises. During this time, energy-conservation technologies adopted in China include: Coke Dry Quenching

[4] These enterprises are members of the China Iron and Steel Association. A list of these companies can be found at here: http://www.chinaisa.org.cn/index.php?id=298

[5] The key steel enterprises do not represent the total Chinese iron and steel industry; thus the energy intensity of the whole iron and steel industry in China would be different from what is presented above for the key steel enterprises. Throughout this report all the data presented are for the whole Chinese iron and steel industry unless it is mentioned otherwise.

(CDQ), Top-pressure Recovery Turbine (TRT), recycling converter gas, recycling waste heat from converter steam, continuous casting, slab hot charging and hot delivery, Coal Moisture Control (CMC), and recycling waste heat from sintering. The penetration level of energy-conservation technologies in the steel industry has improved greatly in China, increasing energy conservation and emission reductions.

Table 2: Changes in Energy Intensity of Key Medium and Large-sized Chinese Steel Enterprises and in the Main Steel-Making Processes (2000-2008)

Year	Comprehensive Energy Consumption per tonne of steel (kgce/t)	Energy Intensity of Main Processes (kgce/t)				
		Coking	Sintering	Iron-making	Basic Oxygen Furnace (BOF)	Electric Arc Furnace (EAF)
2000	920	160.20	68.90	466.07	28.88	265.59
2001	876	153.98	68.60	452.01	28.03	230.09
2002	815	150.32	67.07	455.13	24.01	228.94
2003	770	148.51	66.42	464.68	23.56	213.73
2004	761	142.21	66.38	466.20	26.57	209.89
2005	741	142.21	64.83	456.79	36.34	201.02
2006	645	123.11	55.61	433.08	9.09	/
2007	628	121.72	55.21	426.84	6.03	/
2008	630	119.97	55.49	427.72	5.74	/

Source: Editorial Board of China Iron and Steel Industry Yearbook, various years.

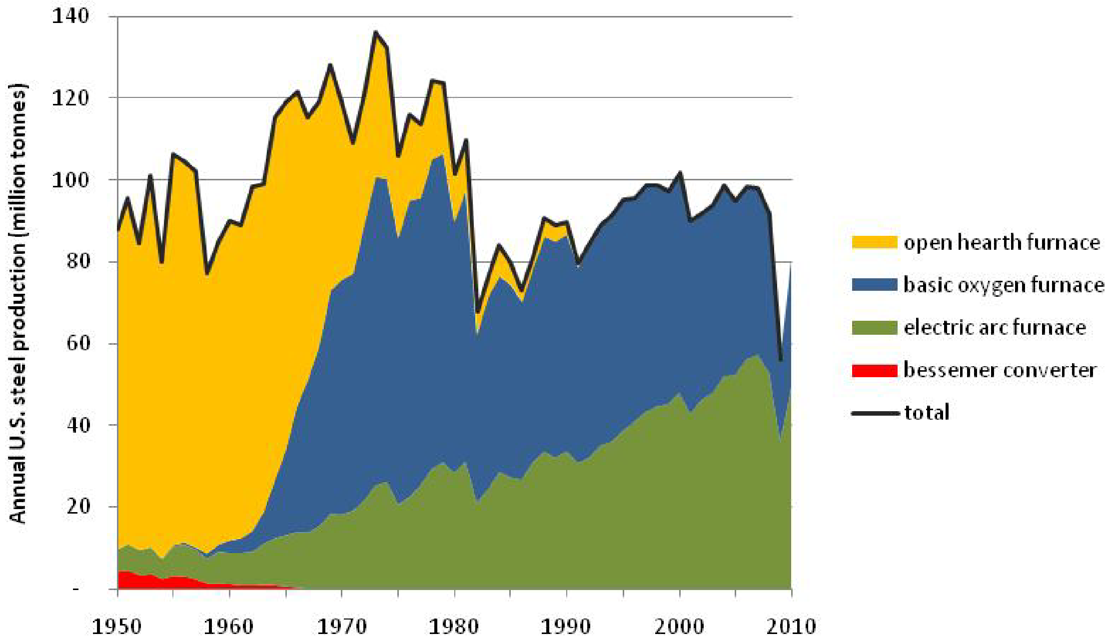
Notes: (1) Data in the table are from member companies of the China Iron and Steel Association.
(2) In the reported statistics, a primary energy conversion factor of 0.404 kgce/kWh was used for electricity during 1900-2005; and final energy conversion factor of 0.1228 kgce/kWh was used for electricity during 2006-2008. This is the primary reason for the large difference between the 2005 and 2006 data.
(3) Since 2006, the refining process of the BOF energy consumption is calculated separately.
(4) To convert units from kgce/t to GJ/t, multiply the values by 0.02931.

2.2. The Iron and Steel Industry in the U.S.

In the U.S., steel production peaked in 1973 at a level of 137 Mt (USGS, 2010a). As total production declined, the U.S. steel industry phased out open hearth furnaces and increased the share of electric arc furnace production from 18% in 1973 to 57% in 2006, growing to 64% in 2009 (worldsteel, 2009). Figure 2 shows total U.S. steel production by technology type. After 2000, the level of U.S. steel production hovered below 100 Mt, with total production of 98 Mt in 2006. U.S. steel production in 2009 dropped to 56 Mt - a 19 Mt drop in crude steel production in one year (USGS, 2010b), but rebound to about 80 Mt in 2010 (worldsteel, 2011).[6]

[6] Note that USGS 2011 reports 2010 steel production of 90 Mt.

Figure 2: U.S. Crude Steel Production by Technology Type (1950-2010)



Source: AISI, 2008; USGS, 2010a; worldsteel, 2011

The energy intensity and energy efficiency of American steel production continuously improved due to industry restructuring in the 1970s and 1980s, an increase in production of steel in electric arc furnaces, adoption of continuous casting, use of direct hot rolling, and feedstock process improvements (Ruth, 2000; Tornell, 1997).

In 2000, an analysis found that the energy intensity of steel production in the U.S. dropped from 20 to 18 MBtu/t (23.3 to 20.9 GJ/tonne, respectively) between 1990 and 1998 (Stubbles, 2000). The American Iron and Steel Institute (AISI) reported that the energy intensity of U.S. shipped steel production improved by 15% between 2002 and 2006 (AISI, 2008).

2.3. Previous Comparisons of China and U.S. Steel Industry Energy Use and Intensity

Previous comparisons of international steel industry energy use and intensity have employed a range of methods. Worrell et al. (1997) found that physical-based indicators provided a more robust basis for international comparison than economic indicators of steel sector energy efficiency and intensity. Within the range of physical-based analyses, a variety of study boundaries, units of analysis, and conversion factors are used. For example, whereas Worrell et al. (1997) use crude steel production as their unit of analysis, Stubbles (2000) calculated energy use and emissions per ton of shipped steel. Likewise, whereas Andersen and Hyman (2001) include coke-making energy use, Kim and Worrell (2002) omit coke making.

International comparisons of steel production energy efficiency and CO_2 emissions were published in the early 2000s with data through the 1990s. Worrell et al. (1997) used physical production index (PPI) decomposition analysis to identify process and product mix factors in overall energy intensity changes. Over the period from 1980 to 1991, Worrell et al. found the specific energy consumption (energy use per tonne of steel) of iron and steel production to be approximately 60% higher in China than the United States.

This comparative research was updated in 2002 when Kim and Worrell (2002) used CO2 intensity index decomposition analysis to examine the CO2 intensity of steel production in seven countries, including China and the United States. The analysis found that increased activity levels, structural demand shifts to a more energy-intensive steel product mix, and increased use of coal counterbalanced process efficiency improvements, thereby slowing the reduction of Chinese steel production CO2 intensity between 1980 and 1996. In their U.S. analysis, Kim and Worrell (2002) found that process efficiency improvements were the most important factor for explaining the reduced overall CO2 intensity of steel production. The carbon intensity given for China in 1994 is 0.85 tC/ton and for the U.S. is 0.55 tC/ton which is 35% lower than that on in China (Kim and Worrell 2000). The energy intensity and CO_2 intensity differences between two countries are not quite the same, as CO_2 intensity depends also to the grid CO_2 emission factor, EAF ratio, etc.

The International Energy Agency (IEA) also includes country-specific steel sector energy analysis in their overview of potential energy efficiency savings to 2050 (IEA, 2010). Based on 2007 data, the IEA found that China could save 6.1 GJ/tonne crude steel and the U.S. could save 2.4 GJ/tonne of crude steel through adoption of best available technologies. While the IEA does not present an explicit comparison of steel production in China and the U.S., its analysis implies that U.S. steel production was on average 3.7 GJ/tonne crude steel less energy intensive than Chinese production in 2007.

A review of the above comparison studies found that boundary and conversion factor assumptions are not always explicitly stated, but appear to vary widely, especially for characterizing imported or off-site produced inputs. Published studies indicate that consensus has yet to form on boundaries and conversion factors for international comparison of steel production energy efficiency, resulting in widely disparate results which are difficult to interpret and compare.

3. Methodology

This study uses a bottom-up, physical-based methodology to compare the energy intensity of China and U.S. crude steel production in 2006. This year was chosen in order to maximize the availability of comparable steel-sector data. However, data published in China and the U.S. are not always consistent in terms of analytical scope, conversion factors, and information on adoption of energy-saving technologies. This study is primarily based on published annual data from the China Iron and Steel Association and National Bureau of Statistics in China and the Energy Information Agency in the U.S.

3.1 Data Availability and Base Year for Analysis

3.1.1. Data Availability - China

There are two meaningful sources of total energy consumption data for China's iron and steel industry: one is from former Ministry of Metallurgical Industry (or current China Iron and Steel Association); and the other one is National Bureau of Statistics (see Table **3**). The *China Steel Industry Yearbook* and *China Steel Statistics* are managed by the China Iron and Steel Association, and only provide national energy consumption data up to 2003. The *China Energy Statistical Yearbook* is published by the Chinese National Bureau of Statistics, and has more comprehensive data for the steel industry's energy consumption. However, because the *China Energy Statistical Yearbook* only collects data for the larger category of smelting and pressing of ferrous metals, it includes steel production enterprises as well as ferroalloy production enterprises.[7]

The sources listed in Table 3 have been the main sources of the statistical data on China energy use for many years. Of the three sources, the two most meaningful are the data from the former Ministry of Metallurgical Industry, currently renamed the China Iron and Steel Association, and the National Bureau of Statistics of China.

Both the *China Steel Industry Yearbook* and the *China Steel Statistics* are managed by the China Iron and Steel Association, and data on national energy consumption are provided by these sources only up to 2003. The *China Energy Statistical Yearbook* is published by the National Bureau of Statistics of China and has more comprehensive data on energy use by the iron and steel industry. However, the *China Energy Statistical Yearbook* provides data on energy use by the larger category of ferrous metal smelting and rolling processing industry which includes iron and steel production enterprises as well as ferrous alloy production.

It should also be noted that Chinese government energy use statistics for the iron and steel industry are based on enterprise information, as stipulated in the corporate law, while energy use statistics gathered by other countries are normally based on the categorization of products, based on product laws. This can be seen in the *China Energy Statistical Yearbook* produced by the National Statistics Bureau of China, in which corporations' enterprise energy use does not

[7] Final (or site) electricity is the electricity consumed at the production facility. This value, however, does not include the primary energy used to generate, transmit, and distribute electricity to the site. To convert final electricity to primary energy, the average efficiency of power generation and transmission and distribution losses must be taken into account. This is discussed further below.

correspond to products. This includes not only energy use by the manufacture of iron and steel products but energy use in dealing with other businesses (such as construction, machine repair, transportation, chemical engineering, etc.) conducted by enterprises. In other words, the scope of energy use statistics covered by the *China Energy Statistical Yearbook* is broad and complicated. For example, a company may have been registered as an iron and steel enterprise, but its business lines may cover other industries, such as mining, hotels, construction materials, chemical engineering, transportation, machine repair, schools, restaurants, or hospitals.

In addition, a double-counting occurred in the calculation of the energy use in the Chinese steel industry by National Bureau of Statistics of China. The double-counting involves the accounting for heat and on-site power generation. Section 4.2.2 of this report provides an explanation of the adjustments that were made to the Chinese energy data to account for these issues.

Table 3: Main Data Sources of the Chinese Steel Industry

Main Sources of Energy Data	Main Authorities	Coverage	Contents
China Steel Industry Yearbooks	Managed by Ministry of Metallurgical Industry, National Bureau of Metallurgical Industry and China Iron and Steel Association, successively	Steel industry, key medium-large steel enterprises	• Total energy consumption: national steel industry consumption up to 2003; energy consumption of key steel enterprises for each year, except no data for 2000 and no data collection after 2005 • Energy consumption data by process in key medium-large steel enterprises (source of the data for Table 2) • Production, exports and imports of main products (crude steel, steel products, pig iron, steel billets and steel ingots)
China Steel Statistics (Edited by China Iron and Steel Association, China Steel Statistics, 1991-2009)	Managed by Ministry of Metallurgical Industry, National Bureau of Metallurgical Industry, Metallurgical Information and Standard Research Institute and China Iron and Steel Association, successively	Steel industry	• Total energy consumption data: new version of China Steel Statistics started from 1994, with the same total energy consumption data as China Steel Industry Yearbook. But data only provided through 1999. • Production, exports and imports of main products (crude steel, steel products, pig iron, steel billets and steel ingots)
China Energy Statistical Yearbooks	Dept of Industry and Transport, NBS, NEA of NDRC	Smelting and pressing of ferrous metals	• Total energy consumption data: started in 1986, have data collection of energy use in smelting and pressing of ferrous-metals • Imports and exports of steel products

3.1.2. Data Availability – U.S.

The most comprehensive and complete dataset available for iron and steel industry energy use in the U.S is provided in the *Manufacturing Energy Consumption Survey* (MECS) published by the U.S. Department of Energy's Energy Information Administration (EIA) (U.S. DOE/EIA, 2010a-k). The MECS data provide electricity and fossil fuels used in different U.S. manufacturing sectors, including the iron and steel industry. MECS provides energy use of the entire iron and steel industry by fuel type. MECS also disaggregates total energy use by the purpose of the use, i.e. fuel or nonfuel (feedstock).

The MECS data are not disaggregated by the type of steel production technology; hence energy use of EAF steel production and blast furnace - basic oxygen furnace (BF-BOF) steel production cannot be directly obtained from the MECS data. Also, MECS does not provide disaggregated data for energy use in each process step of iron and steel production such as coke making, iron making, steel making, and casting/rolling/finishing. Therefore, it is not possible to calculate the energy intensity for each process step for the whole U.S. iron and steel industry from the MECS data. There are some studies that provide the energy intensity of the U.S. iron and steel industry by process step or by type of technologies used, such as Stubbles (2000). These studies are useful, but the energy intensities provided in them are based on several case studies and not the actual energy use of all the steel plants in U.S.

Production data for the U.S. iron and steel industry are available in the U.S. Geological Survey (USGS) *Minerals Yearbook - Iron and Steel*, which are available for each year. Production data for pig iron, crude steel, finished steel as well as different types of the steel products are available in these reports. American Iron and Steel Institute (AISI) also publishes the *Annual Statistical Report* in which steel production as well as energy use and other data for the U.S. steel industry are given.

Recent information on the overall penetration of different technologies, including energy-efficient technologies, in the U.S. iron and steel industry is not available. MECS does provide information on the number of iron and steel plants that have waste heat recovery, computer control systems for process or major energy-using equipment, and adjustable speed motors. The most recent detailed process-level study of the U.S. iron and steel industry that is publicly available is Stubbles (2000). After this study there are only a few general or industry-level studies that are published, such as AISI (2005).

Recent time series data on the U.S. steel industry are published by the U.S. Department of Energy, the U.S. Geological Survey (USGS), and the American Iron and Steel Institute (AISI). The AISI publishes periodic industry analyses with useful data such as the *Saving One Barrel of Oil per Ton* roadmap (AISI, 2005).

3.1.3. Base Year for Analysis

Based on the available data, this study focuses comparing energy use and energy intensity of the iron and steel industry in China and the U.S. in 2006.

3.2. Boundaries

In order to make an accurate and fair comparison of the energy intensity of the iron and steel industries in China and the U.S., analytical boundaries must be clearly and accurately defined based on available data in both countries.

There are a number of issues related to defining the boundaries used in this study, including whether to include smelting and pressing of ferrous metals within the iron and steel industry analysis and how to account for imported and exported products.

3.2.1. Smelting and Pressing of Ferrous Metals

In Chinese statistics, energy use for the smelting and pressing of ferrous metals is included in the overall steel industry energy statistics (category 32 in the NBS industrial categorization (NBS, 2010b). This category is broken down into iron-making (3210), steel-making (3220), steel pressing (3230), and ferroalloy smelting (3240). In the U.S., the *Manufacturing Energy Consumption Survey* (MECS) reports the energy use of iron and steel mills under NAICS category 331111, while the energy use for electrometallurgical ferroalloy products is reported under NAICS category 331112, and the energy use of steel products from purchased steel is reported under NAICS category 3312. Thus, the main difference between the steel industry energy consumption statistics of the two countries is that China's system includes ferroalloy smelting while energy use for this activity is provided separately in the U.S. statistics (see Table 4).

Currently the international community only recognizes the steel industry as steel production enterprises. As such, for China this report will be based on energy consumption data in the category of "smelting and pressing of ferrous metals" as published in China Energy Statistical Yearbook in 2006, with the energy consumption of ferroalloy smelting deducted from the total. For the U.S., this report will use the energy consumption of iron and steel mills (NAICS 331111) and steel products from purchased steel (NAICS 3312) since they are within the boundary of this study. The energy use of electrometallurgical ferroalloy products (NAICS 331112) is not included in the calculation of the energy intensity in this study.

Table 4: Comparison of the Definitions and Scope of the Iron and Steel Industry in China and the U.S.

<table>
<tr><th>Country</th><th>Steel Industry</th><th colspan="4">Scope</th></tr>
<tr><td>China</td><td>Smelting and pressing of ferrous metals
(Industry code 32)</td><td>Iron-making
(Industry code 3210)</td><td>Steel-making
(Industry code 3220)</td><td colspan="2">Steel pressing
(Industry code 3230)</td></tr>
<tr><td>US</td><td>Iron and steel mills
(NAICS 331111)</td><td>Iron-making
(DRI, blast furnace)</td><td>Steel-making</td><td>Steel rolling</td><td>Steel products from purchased steel
(NAICS 3312)</td></tr>
</table>

3.2.2. Accounting for Imported and Exported Products

In China, about two thirds of consumed coke in the steel industry is produced separately by independent coking plants, and another third of the coke is produced by steel mills themselves. Net exports of main steel products (pig iron, steel billets, and steel products) are about 8% of total crude steel production (after converting them to crude steel production).

In the U.S., the net imported (import minus export) pig iron in 2006 was 5.92 Mt, net imported Direct-Reduced Iron (DRI) in 2006 was 2.61 Mt, and net imported ingots, blooms, billets and slabs in 2006 was 8.26 Mt. The total net imported steel mill products were about 32.27 Mt in 2006 (USGS 2008).

When one enterprise or one country does not have enough upstream production capacity, it needs to purchase upstream products such as pig iron, coke, and DRI. Energy consumption for production of these products is also counted in the total energy consumption in this study. On the other hand, when there is a surplus in upstream production capacity and a portion of the products are sold, the energy consumption of these sold products is deducted from total energy consumption in this study.

Besides the main processes, Chinese steel enterprises also include auxiliary systems, such as oxygen preparation, while most U.S. steel companies do not include auxiliary systems but instead purchase oxygen and other gases. However, the energy use for the production of purchased oxygen is taken into account in the calculation of energy intensity in both countries.

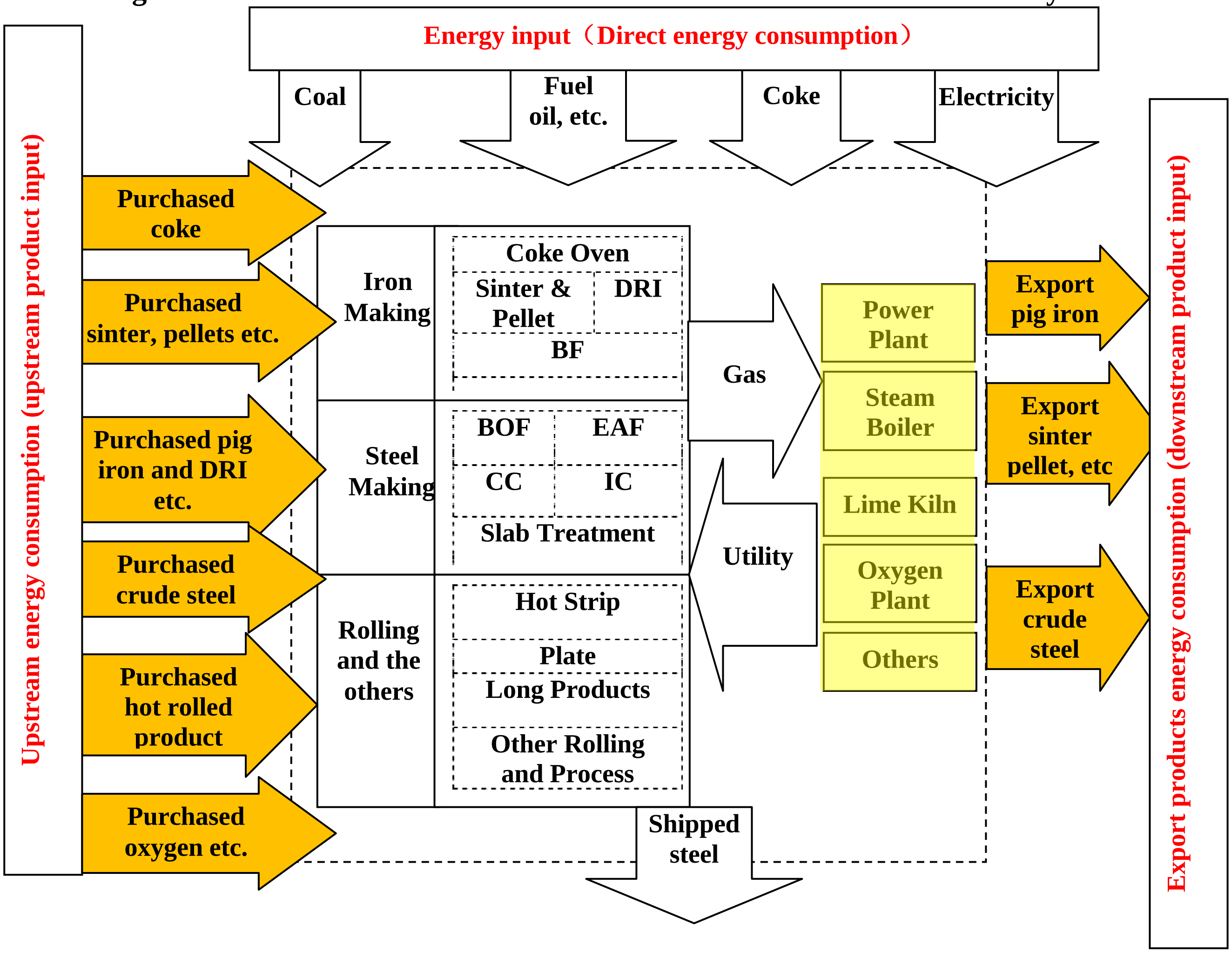
3.2.3. Boundaries Used in This Study

In this study, the boundaries of the iron and steel industry include all coke making, pelletizing, sintering, iron making, steel making, steel casting, hot rolling, cold rolling, and processing such as galvanizing or coating (Figure 3). This boundary definition is used for the calculations of energy use and energy intensity for both the Chinese and U.S iron and steel industries.

Regarding accounting for energy used for coke production within the iron and steel industry, there are a few special considerations. This study includes the total coal input used as a feedstock for coke making and also as a fuel in other parts of the steel making process. Only net imported coke (either produced in other domestic industries or imported from other countries) is included as a source of input energy to the iron and steel industry. Net imported coke is total imported coke minus total exported coke. The energy value of the coke produced in the coke making process within the iron and steel industry and used in the iron making process is not included since the coal initially used to produce the coke is already accounted for within the boundary. This study does not count the coke trade that occurs within the boundary, as the total coal input to the industry is already taken into account.

This study takes net imported (to the boundary of the industry defined in Figure 3) pig iron, direct-reduced iron (DRI), pellets, lime, oxygen, and ingots, blooms, billets, and slabs into account by adding the energy used for production of these products to the total energy input to the iron and steel industry.

Figure 3: Flowchart of Iron and Steel Sector Boundaries Used in this Study



In addition, this study does not include energy consumption associated with other energy-intensive products manufactured for the industry (e.g., electrodes, ferroalloys, refractories, etc.). These products could be included in a more extensive, life-cycle analysis study of the industry, but are excluded here because the focus of this study is on iron and steel production. This is the approach taken by Stubbles (2000). This study also does not take into account the embodied energy of the scrap used in the iron and steel industry. In other words, the embodied energy of the scrap is not added to the energy use of the EAF process. Also, energy demand for mining and beneficiation of iron ores is not included in this analysis. Finally, the energy use in further processing of the steel by steel foundries is not included in this analysis.

3.3. Conversion Factors

In order to calculate comparable energy use and energy intensity values, common conversion factors must be used to convert the physical quantities of fuels consumed to produce steel to energy values. In addition, common conversion factors must also be used to calculate electricity values. These conversion factors are explained below.

3.3.1. Fuel Conversion Factors

The heating value or calorific value of a fuel source represents the amount of heat released during combustion. This study uses the lower heating value – or net calorific value (NCV) – to convert physical quantities of fuel to a common energy unit. NCV conversion factors for China are provided in the *China Energy Statistics Yearbook* (2007, 2009) and for the U.S. are provided in the U.S. Energy Information Administration's *Annual Energy Review* (2007, 2009). Where available, the NCV of the fuels in 2006 is used. In addition, the typical NCVs for fuels are also provided in various IEA publications. Table 5 provides the NCV conversion factors for different fuels for China and the U.S. Figure 4 shows a graphical comparison of the NCVs from the different sources.

From Table 5 it can be seen that the fuel conversion factors in the two countries are different, especially those for other bituminous coal and coking coal. Small differences in conversion factors might cause great differences in total energy consumption. For example, China's steel industry consumed 104.07 Mt of washed/cleaned coal (wet-base, with ~10% moisture). Based on the Chinese conversion factor of 1.0143 kgce/kg (29.727 MJ/kg), cleaned coal (dry-base), energy consumption is 95 Mtce (3093.66 PJ). If converted using the U.S. conversion factor of 1.039 kgce/kg (30.451 MJ/kg) cleaned coal, energy consumption is 97.32 Mtce (3168.998 PJ). The difference between the calculated energy consumption is 2.32 Mtce (75.338 PJ).

Table 5 shows that:

1. The IEA recognizes that energy quality in different countries varies, and to reconcile the difference and compare internationally, IEA proposes a unified system of energy conversion factors. These average values are applicable to all countries. Since one of the goals of this study is to develop a methodology that can be used to compare the iron and steel industries of different countries in the world, one scenario is developed in which the IEA typical fuel NCVs are used.

2. The main difference between the energy conversion factors in the U.S. and China is for other bituminous coal and clean coal. The NCV used in the U.S. is for dry-base coal, but the NCV used in China is for wet-base coal. For this analysis, however, the dry-base conversion factor is used for China.

Table 5: Fuel Conversion Factors for China and the U.S.

Fuel	IEA-Typical		Country-Specific				Unit
	IEA-Typical	Source	China	Source	U.S.	Source	
Other Bituminous coal (used as fuel)	24.05	IEA 2005	20.91	NBS 2007	25.65	EIA 2009	MJ/kg
Coking coal	28.20	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	IEA 2008c	38.93	NBS 2007	38.33	EIA 2009	MJ/m3
Residual Fuel oil	42.18 [h]	IEA 2005	---		44.18	EIA 2007	MJ/kg
Distillate Fuel Oil	40.19	IEA 2008c	41.82	NBS 2007	40.94	EIA 2007	MJ/kg
LPG	46.15	IEA 2005	50.18	NBS 2007	45.81	EIA 2009	MJ/kg
Other washed coal	-		10.47	NBS 2007			MJ/kg
Crude oil	42.85	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 2009			MJ/kg
Benzene			41.82	NBS 2009			MJ/kg

[a] NCV of distillate fuel oil

[b] IEA value for LPG is a typical value and is the same for both countries.

[c] 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.

[d] 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.

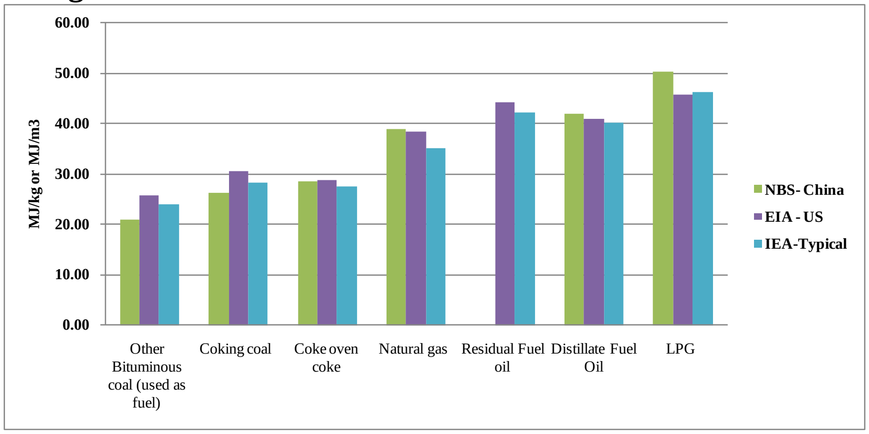
[e] Natural gas as supplied contains gases in addition to methane (usually ethane and propane). As the heavier gases raise the calorific value per cubic meter, the gross calorific values can vary quite widely. Therefore, the average NCV of natural gas of the top ten largest producers in 2008 is used in the table above.

[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 0.2857 to 0.4286 kgce/kg.

[h] This is for low sulfur fuel oil.

Figure 4: Fuel Conversion Factors for China and the U.S.



For this study, the international average energy conversion factors are used for products that are purchased externally and imported or exported by the iron and steel industry 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. The energy conversion factors for external products in this study are provided by the World Steel Association (worldsteel) (worldsteel, n.d.; worldsteel, 2008b). The energy conversion factors for all products except for crude steel provided by the worldsteel.org are in primary energy[8], and hence are converted into final energy for the final energy intensity calculation. For this purpose, the share of electricity use in the production of auxiliary and intermediary products and the conversion factor for electricity to primary energy is used.

Table 6 provides energy conversion factors for purchased fuels and materials as well as imported auxiliary/intermediary products along with the share of electricity use for production of each product. The values provided by worldsteel are assumed to be the international average; thus these values are used for the base case of this study. However, there are also U.S. country-specific values mostly from Stubbles (2000).

Table 6: Conversion Factors for Purchased Fuels & Auxiliary/Intermediary Products

	Coke [a]	Pig Iron [a]	Coal based [a] DRI	Gas based [a] DRI	Pellets [a]	Crude Steel [b]	Lime [a]	Oxygen [a]
	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/m³
worldsteel Factors (Primary Energy)	4.0	20.9	17.9	14.1	2.1	18.9	4.5	6.9
China-specific value						18.54		
worldsteel Factors (Final Energy)[c]	3.7	19.8	17.0	13.4	2.1	16.5	4.1	2.5
China-specific value						17.4		
Electricity share in total Primary Energy	11%	8%	8%	8%	0	20%	15%	100%
China-specific value					0	10%		

[a] worldsteel, n.d. [b] worldsteel, 2008a

[c] The 9.8 MJ/kWh conversion from worldsteel was used to convert the worldsteel conversion factors for Purchased Fuels & Auxiliary/Intermediary Products from primary to final energy using the percentages of electricity use for the production of each product given in the table above.

[8] Primary energy use is the sum of fuel use and the electricity use that is converted to primary energy by taking into account the power generation efficiency and transmission and distribution (T&D) losses. However, it should be noted that worldsteel does not take into account the T&D losses when converting electricity from final to primary energy.

3.3.2. Electricity Conversion Factors

Final (or site) electricity is the electricity consumed at the production facility. This value, however, does not include the primary energy used to generate electricity (both offsite and onsite) and transmit and distribute (only by offsite power producers) electricity to the site. To convert final electricity to primary energy, the average efficiency of power generation and transmission and distribution (T&D) losses must be taken into account. Primary energy is used in the energy conversion system (power sector) to produce electricity. Since the electricity generation has a certain efficiency which is often in the range of 25% - 40%, one unit of electricity in final energy terms is always less than the actual primary energy used to produce that unit of electricity. Total primary energy use is the sum of fuel use and the electricity use that is converted to primary energy by taking into account the power generation efficiency and T&D losses.

Presenting energy intensity in primary energy terms is especially important for the iron and steel industry because the EAF process uses mostly electricity, whereas the BF-BOF process uses mostly fossil fuels. Hence, if energy intensity is just compared in terms of final energy, it underestimates the actual primary energy needs of the industry since it ignores the large energy losses during electricity generation and the losses associated with T&D of electricity from offsite sources. EAF steel accounted for 56.9% of the steel produced in the U.S in 2006, whereas it accounted for just 10.5% of the steel produced in China in the same year (worldsteel, 2009). Therefore, comparing the energy intensities in primary energy is important since there is such a difference in the share of EAFs in China and the U.S.

In this study, the average heat rate of fossil fuel-fired power generation is used to convert electricity from final to primary energy since fossil fuels are the dominant sources of energy used for power generation in both China and the U.S. Heat rates can be expressed as either gross or net heat rates, depending whether the electricity output is gross or net generation. Net electricity output is the electricity after the deduction of power plant self-use. Heat rates are typically expressed as net heat rates; hence in this study the net heat rate is used. The average net heat rate of fossil fuel-fired power generation in China and U.S in 2006 is given in Table 7. A significant amount of electricity is also lost in the transmission and distribution (T&D) grid, which should be included when converting electricity from final to primary energy. Table 8 provides the grid T&D losses in China and the U.S. in 2006.

Table 7: Average Net Heat Rates of Fossil Fuel-Fired Power Plants in 2006

	Net Generation Heat Rate	Unit	Source
China	0.350	kgce/kWh	NBS 2009
U.S	0.354	kgce/kWh	EIA 2010a
worldsteel	0.334	kgce/kWh	worldsteel 2008b

Note: Coal-fired power generation in China is calculated based on thermal power generation standard coal and thermal capacity provided in the *China Energy Statistical Yearbook* 2009.

Table 8: Grid Transmission & Distribution Losses in China and the U.S. in 2006 [9]

Country	Grid Transmission & Distribution Losses	Source
China	7.0%	Anhua and Xingshu, 2006
U.S	6.7%	EIA 2008

Using the net generation heat rate and T&D losses from the tables above, electricity can be converted from final to primary energy using the following formula:

$$CF = NHR / (1 - T\&D\ losses)$$

Where:
CF: Conversion factor to convert electricity from final to primary energy (kgce/kWh)
NHR: Average net heat rates of fossil fuel-fired power plants (kgce/kWh)
T&D losses: Grid T&D losses (%)

The conversion factors to convert electricity from final to primary energy for the U.S. and China in 2006 that are calculated using the above tables and formula are presented in Table 9. By multiplying the final electricity by this conversion factor, the electricity in primary energy terms can be obtained. As can be seen from Table 9, the electricity conversion factors for the two countries are close to each other.

Table 9: Final to Primary Energy Conversion Factor in 2006

	China	U.S
Final Conversion Factor with T&D losses (kgce/kWh)	0.376	0.379
Final Conversion Factor without T&D losses (kgce/kWh)	0.350	0.354

[9] The values given in Table 8 are national grid T&D losses. It should be noted that sometimes plants obtain power at high or medium voltages directly from transmission lines; thus the distribution losses for them might be different.

4. Base Year Production, Trade and Energy Use Data

4.1. Production and Trade Data

4.1.1. Production Data for the U.S.

Table 10 shows the production data for pig iron, DRI, crude steel, ingots, blooms, billets, slabs, and steel products (finished steel). The trade data for pig iron are also presented since it is used in the analysis as explained above. As can be seen from this table, net import of pig iron accounts for 13.5% of the total pig iron used in the U.S. This is a substantial amount which cannot be neglected. For the calculation of the energy intensities, crude steel production is used as the denominator. However, it should be noted that the casting, rolling and finishing processes that happen after the crude steel production are also within the boundary of the analysis.

Table 10: Production and Trade Data for Pig Iron, DRI, Crude Steel, Ingot, Blooms, Billets, and Slabs, and Steel Products in U.S in 2006 (Mt)

	Production	Exports	Imports	Net Imports	Use
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	-

Source: USGS, 2008.

4.1.2. Production and Trade Data for China

Table 11 lists China's production, exports and imports of pig iron, DRI, crude steel, and steel products in 2006. Net exports are 0.7 Mt of pig iron and 8.67 Mt of steel billets. Net imports are 0.3 Mt of DRI, and 0.1 Mt of steel ingots.

Table 11: Production, Imports and Exports of Pig Iron, DRI, Crude Steel, Ingots, Billets, and Steel Products in China, 2006 (Mt)

Product	Production	Imports	Exports	Net Trade	Domestic Use
Pig Iron	413.64	0.17	0.87	-0.70	412.94
DRI	0.21	0.31	0.01	0.30	0.51
Crude Steel	421.02	-	-	-	-
Steel Ingots	-	0.14	0.04	0.10	-
Steel Billets	-	0.37	9.04	-8.67	-
Finished Steel Products	399.97*	18.51	43.01	-24.50	375.47

Source: Editorial Board of the China Iron and Steel Industry Association Yearbook, 2006.
* In order to avoid double-counting of steel products, this number was calculated as 95% of crude steel.

4.2. Energy Use Data

4.2.1. Energy Use of the U.S. Iron and Steel Industry Based on EIA Reported Data

U.S. energy use data in *physical units* are presented in Table 12. This table provides energy use for fuel and nonfuel (e.g. a feedstock such as coke), defined as "first use" of energy by the EIA (U.S. DOE/EIA, 2010b). Table 13 provides first use of energy for all purposes (fuel and nonfuel) in *energy units* for the U.S. iron and steel industry in 2006 based on the EIA fuel conversion factors from U.S. DOE/EIA (2010e, f, g). It should be noted that the data in Tables 12 and 13 are in final energy. Therefore, the electricity data given in these two tables do not include the primary energy used to generate electricity (both offsite and onsite) and transmit and distribute (only by offsite power producers) electricity to the site.

In addition to the first use of energy, which is the energy used as fuel and nonfuel (feedstock), the energy use for the production of net imported coke, lime, pellets, pig iron, DRI, oxygen, and ingots, blooms, billets, and slabs will also be included in the calculation of energy intensity for this study in order to have a more accurate and fair comparison of the energy intensity of the industry in both countries. This is done to eliminate the effect of differences in the share of imported coke, lime, DRI, and pig iron on the energy intensity of the industry in the two countries. For the base case scenario of this study, the worldsteel conversion factors for these auxiliary/intermediary products used in the iron and steel industry is used. The 9.8 MJ/kWh conversion factor from worldsteel (n.d.) is used to convert the worldsteel conversion factors for purchased fuels and auxiliary/intermediary products from primary to final energy using the percentages of electricity use for the production of each product given in Table 6.

worldsteel (n.d.) provides an energy intensity of 3.7 GJ/tonne for the production of coke, 4.1 GJ/tonne for lime, and 19.8 GJ/tonne for pig iron. These values were assumed to be world average energy intensities for the production of coke, lime, and pig iron and are used in the base case scenario of this study. By multiplying the net imported coke from both outside of the U.S. as well as from other industries in the U.S. into the steel industry (3,108,669 tonnes) and lime (1,956,000 tonnes) by the energy intensity of coke and lime production, the amount of energy that is associated with the production of net imported coke and lime are calculated. These values are added to the energy use before the final energy intensity calculation. It is assumed that 89% of total energy use for coke production is fuel, and 85% of total energy use for lime production is fuel. The amount of net imported lime (i.e. lime produced outside the iron and steel industry and used in the iron and steel industry) for the U.S. is obtained from USGS (2007).

Pelletizing is the primary ore agglomeration technology, but it normally takes place at the mine site. It is therefore not considered as part of the iron and steel industry according to the NAICS classification (US Census Bureau, 2007). Therefore, the energy use given for the iron and steel industry does not include pelletizing. To include the amount of energy used for the production of pellets, the following calculation is made. The amount of pellets used in the U.S. steel industry in 2006 was 49.30 Mt (USGS, 2008). The energy use for the pelletizing is 2.1 GJ/tonne (worldsteel, n.d.). Thus, energy use for the pellets used in the U.S. iron and steel industry is calculated and added to the fuel use. It is assumed that all the energy use for the pellet production is fuel, so this value is added to the total fuel consumption.

Based on NAICS, sintering is included in the iron and steel industry and, assuming there is no sinter imported from outside of the U.S., energy use for the sintering process is thus included in the energy use given by MECS. Sintering accounted for only 12% of iron oxide used in the U.S. iron and steel industry in 2006. The rest of the iron oxide used was pellets (USGS, 2008).

Furthermore, by multiplying the net imported pig iron and DRI by the energy intensity of pig iron and DRI production, the amount of energy that is associated with the net imported pig iron and DRI can be obtained, respectively. This value should be added to the first use energy use before the final energy intensity calculation. It is also assumed that around 92% of the energy use for pig iron as well as DRI production is fossil fuels and the remaining 8% is the electricity use (NDRC, 2007). There are two types of processes for DRI production: coal-based and natural gas-based. Based on Chukwuleke et al. (2009) it is assumed that 85% of the net imported DRI is produced by the natural gas-based process and 15% by the coal-based process. The calculated electricity and fossil fuel use for the production of net imported pig iron and DRI was added to the first use of electricity and fossil fuel in the U.S iron and steel industry given in Table 12. Also, the boundary of this study includes the energy consumption for the production of the net imported ingots, blooms, billets, and slabs as well as the energy use for rolling and finishing processes of net imported ingots, blooms, billets, and slabs. In 2006 the U.S. imported a net amount of 8.261 Mt ingots, blooms, billets, and slabs. These net imported ingots, blooms, billets, and slabs are taken into account in the analysis as described below.

In MECS 2006, the NAICS category 3312 represents the energy use for the steel products from purchased steel (i.e. imported ingots, blooms, billets, and slabs). This is the energy used for the rolling and finishing processes conducted on the imported ingots, blooms, billets, and slabs. The net imported ingots, blooms, billets, and slabs in 2006, were 8.261 Mt. Based on worldsteel (2008a, b) the final average energy intensity of steel production is 20.6 GJ/tonne crude steel. This includes the entire finished steel production process, i.e. crude steel production as well as rolling and finishing processes. Since only the energy intensity of crude steel production is needed, the portion of the energy intensity related to crude steel production (excluding rolling and finishing processes) can be calculated from the value given above (20.6 GJ/tonne crude steel). Based on Stubbles (2000), around 80% of the total energy use for the production of finished steel is for crude steel production in both EAF and BF-BOF production lines. By multiplying the 20.6 GJ/tonne crude steel by 80%, the energy use for the production of crude steel is calculated to be 16.5 GJ/tonne crude steel.

In addition, having the EAF ratio of the countries from worldsteel (2009) and the amount of ingots, blooms, billets, and slabs imported from each country in 2006 from USGS (2008) the weighted average ratio of EAF production in the countries from which the U.S. imported ingots, blooms, billets, and slabs in 2006 was calculated and is equal to 37.1%. Based on data provided in Stubbles (2000) it is assumed that 95% of the total energy use in BF-BOF plants is fuel, while in EAF plants around 55% of the total final energy use is fuel. Having the share of fuel used in BF-BOF and EAF production lines and the ratio of each, the combined share of fuel for the imported ingots, blooms, billets, and slabs was calculated to be around 80% and the other 20% is the electricity use. These shares are used for the calculating the embodied energy of the imported ingots, blooms, billets, and slabs into electricity and fuel.

Table 12: Energy Use (Fuel and Nonfuel) in Physical and Energy Units for the U.S. Iron and Steel Industry, 2006

NAICS	Industry	Electricity[1]	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	Coal used as fuel (calculated from EIA, 2010b)[2]	Coal used for coking (calculated from EIA, 2010b)[2]	Coke and Breeze	Other[3]	Shipments of Energy Sources Produced Onsite[4]	Total[5]
		million kWh	**million liters**	**million liters**	**billion m^3**	**million tonnes**	**million tonnes**	**million tonnes**	**TJ**	**TJ**	**TJ**
331111	**Iron and Steel Mills**	51,198	477	159	10	0.7	14.1	8.2	41,147	152,983	1,096,936
3312	**Steel Products from Purchased Steel**	4396	7.5	0	0.7	0.02	0	0.01	14,771	0	59,083

Source: U.S. DOE/EIA, 2010b. Note: Energy data are for the North American Industry Classification System (NAICS) categories of 331111 and 3312.

[1] Electricity use data are in final energy. That is, the electricity use is not converted to the primary energy use by taking into account the power generation efficiency and transmission and distribution losses.

[2] Total first use of coal is 16 million short tons in U.S. DOE/EIA (2010b). "Coal use for fuel" in U.S. DOE/EIA (2010c) is 1 million short tons and coal use as nonfuel (for coking) in U.S. DOE/EIA (2010d) is 16 million short tons, giving a total of 17 million short tons. This value is higher than the total value given in U.S. DOE/EIA (2010b) due to rounding. However, since 1 million short tons is a significant amount of coal, this difference is not acceptable for the analysis conducted in this study. To get the same rounded values as those given in U.S. DOE/EIA (2010b, c, d), total coal use was recalculated using the energy values (U.S. DOE/EIA, 2010 e, f) and the NCV for each type of coal used (coal used as fuel and coal used for coking[10]). The values calculated in this manner for coal used as fuel were 0.8 million short tons (0.7 million metric tonnes) and for coal used as nonfuel (for coking) were 15.6 million short tons (14.1 million metric tonnes), for a total value of 16.4 million short tons, or 14.8 million metric tonnes.

[3] The unit used for the category "Other" is an energy unit instead of a physical unit since this category is comprised of several fossil fuels which are not specified in U.S. DOE/EIA (2010b). Also, for the category "Shipments of Energy Sources Produced Onsite", EIA (2010b) gives the values in energy units.

[4] The category "Shipments of Energy Sources Produced Onsite" is for those shipments produced or transformed onsite from the nonfuel use of other energy sources. For example, at an establishment that processes coal to make coke for later use, the entire quantity of coal is counted as first use. Any onsite consumption of coke is not counted as first use because it would duplicate the coal use. If some of the coke is then sold to another establishment, then that second establishment will consider this coke to be a shipment of an offsite-produced energy source. Hence, the second establishment will count this coke as its first use, thereby resulting in double counting. In order to eliminate double counting, the energy equivalent of the coke shipment must be subtracted from first use. In other words, the total first use energy consumption of the U.S. iron and steel industry in Table 12 and Table 13 can be obtained by summing up the energy value of the electricity and all the fossil fuel used and then subtracting the "Shipments of Energy Sources Produced Onsite".

[5] Total energy consumption is calculated by EIA using the energy used in physical units and multiplying it by the net calorific value (NCV) of each fossil fuel. For electricity, only the unit conversion factor is used to convert electricity from million kWh to terajoules (TJ).

[10] Coal use for coking (nonfuel) accounted for about 95% of total coal use in the U.S iron and steel industry

Table 13: Energy Use for All Purposes (Fuel and Nonfuel) for the U.S. Iron and Steel Industry Using EIA Fuel Conversion Factors, 2006 (TJ)

NAICS	Industry	Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	Coal used as Fuel[1]	Coal used for Coking[1]	Coke and Breeze	Other	Shipments of Energy Sources Produced Onsite	Total
331111	**Iron and Steel Mills**	184,313	20,046	3,165	378,765	14,771	365,049	242,663	41,147	152,983	1,096,936
3312	**Steel Products from Purchased Steel**	15,826	317	0	27,431	422	0.0	317	14,771	0	59,083

[1] Calculated from EIA, 2010b.

In 2006, the U.S. steel industry purchased 6,786 million m^3 of oxygen and produced 194 million m^3, for a total oxygen use of 6,980 million m^3 (AISI, 2008).
Table **14** below shows the production, consumption and purchased oxygen in the U.S. iron and steel industry by process. worldsteel (n.d.) gives an energy intensity of 0.7 kWh/m^3 of oxygen. Having the amount of purchased oxygen and the energy intensity of the oxygen production, the energy consumption for the production of purchased oxygen was calculated and added to the energy use of the iron and steel industry.

The total electricity and fuel consumption for the production of iron and steel in U.S. based on the defined boundary of this study is presented in **Table 15**.

Table 14: Production, Consumption and Purchases of Oxygen in the U.S. Iron and Steel Industry in 2006

	2006 (Million m^3 in gaseous form)
Purchased	6,786
Produced	194
Total	6,980
Used in:	
Blast Furnace	2,329
Steelmaking:	
BOF	2,458
EAF	1,966
Total BF-BOF	4,786
Total EAF	1,966
All other	227
Total iron and steel industry	**6,980**

Source: AISI (2008).

Table 15 Total Electricity and Fuel Consumption for Iron and Steel Production in the U.S. Based on the Study Boundary

Item	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	117,157	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 based on EIA fuel conversion factor	**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.

4.2.2. Energy Use Data for the Chinese Iron and Steel Industry

Table 16 provides the end-use final energy consumption in physical units of the category of Smelting and Pressing of Ferrous Metals which also includes the energy use of ferroalloys production in China in 2006. The energy consumption shown in this table also includes double-counted secondary energy for heating.

In order to derive the energy use of the primary fuels used by China's iron and steel industry as reported in Table 17 below, the following adjustments to the data must be made:

- *Remove On-Site Generated Electricity.* The electricity use shown in Table 16 is the total electricity use in the industry, but not all of it is the purchased electricity. Iron and steel corporations tend to install electric voltage themselves and are equipped with energy efficiency technologies such as CDQ and TRT, as well as generate electricity on their own up to a certain percentage.[11] To avoid double counting, the onsite generation of electricity is taken out of the total electricity use and the resulting purchased electricity amount is shown in Table 17.

[11] NBS (through personal communication) stated that the percentage was 21.61% in 2006.

Table 16: End-Use Final Energy Consumption (Physical Amount) of Smelting & Pressing of Ferrous Metals (including Ferroalloys) in 2006

Energy type	Unit	Ferrous metal smelting and rolling processing industry
Raw coal	Mt	58.18
Cleaned coal	Mt	6.82
Other washed coal	Mt	1.58
Coke	Mt	235.86
Crude oil	Mt	0.001
Gasoline	Mt	0.25
Kerosene	Mt	0.02
Diesel	Mt	0.92
Fuel oil	Mt	1.51
LPG	Mt	0.13
Other petroleum products	Mt	0.09
Natural gas	10^9 m^3	1.12
Electricity	10^9 kWh	303.90
Coke oven gas (COG)	10^9 m^3	31.38
Other coal gas	10^9 m^3	79.14
Other coking products	Mt	1.48
Heating	10^9 kJ	162,209.1

Source: NBS, 2010a. Note: Mt = million tonnes.

- *Convert Non-Purchased Coke to Cleaned Coal.* In Table 16 the total coke used in the Chinese Smelting & Pressing of Ferrous Metals (including ferroalloys) in 2006 is given. Part of this coke is produced within the iron and steel industry boundary defined in this study and the rest is purchased from outside of the industry. The portion that is purchased from outside of the industry boundary (137.19 Mt) is given in Table 17 and the portion of coke that is produced within the boundary (98.67 Mt) is converted back to cleaned coal (coking coal) and added to the rest of the clean coal used in the industry and presented in Table 17.
- *Convert Coke Oven Gas (COG) and Other Coal Gas back to Cleaned Coal*. Table 16 provides information on the end use of the by-products of cleaned coal produced by the iron and steel industry, such as coke oven gas and other coal gas, which are normally produced by the iron and steel enterprises and then are used internally, rather than being purchased from external vendors. The China Energy Statistical Yearbook presents only the physical quantity of energy use by end-users (steel plants) for these by-products, not the cleaned coal initially consumed for their production. Thus, these by-products are converted back to cleaned coal and added to the reported clean coal used as a fuel in the calculation of the iron and steel industry's energy use presented in Table 17. Thus, the values of 31.38 billion m^3 for COG, 79.14 billion m^3 for other coal gas, and 1.48 Mt for other coking products are converted to cleaned coal and added to the reported end-use

value of 6.82 Mt of cleaned coal and the calculated value for clean coal used to produce coke (explained above) for a total of 135.79 Mt of cleaned coal in Table 17.

- *Remove Double-Counted Heating Energy*. The amount of heating energy reported separately in Table 16 is the by-product of other processes for which the coal or coke used is already accounted for. Therefore, the heating reported in Table 16 is deducted from the total energy use reported in Table 17.
- *Remove Energy for Ferrous Alloy Production.* Since the smelting and pressing of ferrous metals industry in China includes enterprises of iron and steel production and ferrous alloy production, the energy use by the ferrous alloy enterprises is deducted from the total energy use given in Table 16. This energy use is based on statistics provided to the China Iron and Steel Research Institute (CISRI) by China's National Bureau of Statistics (NBS) which show the energy use by China's ferrous alloy industry equal to 1,142,704 TJ. This energy use is deducted from the total energy use shown in Table 16.This value has been confirmed by Chinese experts from the ferrous alloy industry and been deemed reasonable.[12]

After the adjustments described above are made, the revised physical quantity of energy use by the iron and steel industry in China is shown in Table 17.

Table 17: Physical Quantity and Related Energy of Energy Use by the Iron and Steel Industry in China (2006)

Fuel Type	Unit	Physical Quantity	Energy (TJ)
Raw Coal	Mt	53.43	1,117,198.17
Cleaned Coal	Mt	135.79	3,576,761.16
Other Cleaned Coal	Mt	1.27	13,245.42
Purchased Coke	Mt	137.19	3,901,671.83
Crude Oil	Mt	0.0013	54.53
Gasoline	Mt	0.24	10,452.86
Kerosene	Mt	0.02	723.58
Diesel	Mt	0.89	37,879.13
Fuel oil	Mt	1.49	62,477.21
LPG	Mt	12.73	6,385.79
Other petroleum products	Mt	0.03	1,179.04
Natural gas	10^9 m^3	1.08	42,011.60
Tar Oil	Mt	4.00	-42,659.89
Benzene	Mt	1.02	-133,822.36
Purchased electricity (final)	TWh	174.29	627,456.39
Total (final)			**9,221,014.46**

Source: China Iron and Steel Research Institute (CISRI) calculations.
Notes: (1) The energy values reflect the deduction of ferroalloy energy use, double-counted heating energy use, and on-site electricity production.
(2) The fuel conversion factors used to calculate this energy values in table are based on Chinese NCVs
(3) Mt = million tonnes

[12] Personal communication with Zhang Chunxia from CISRI. December 2010.

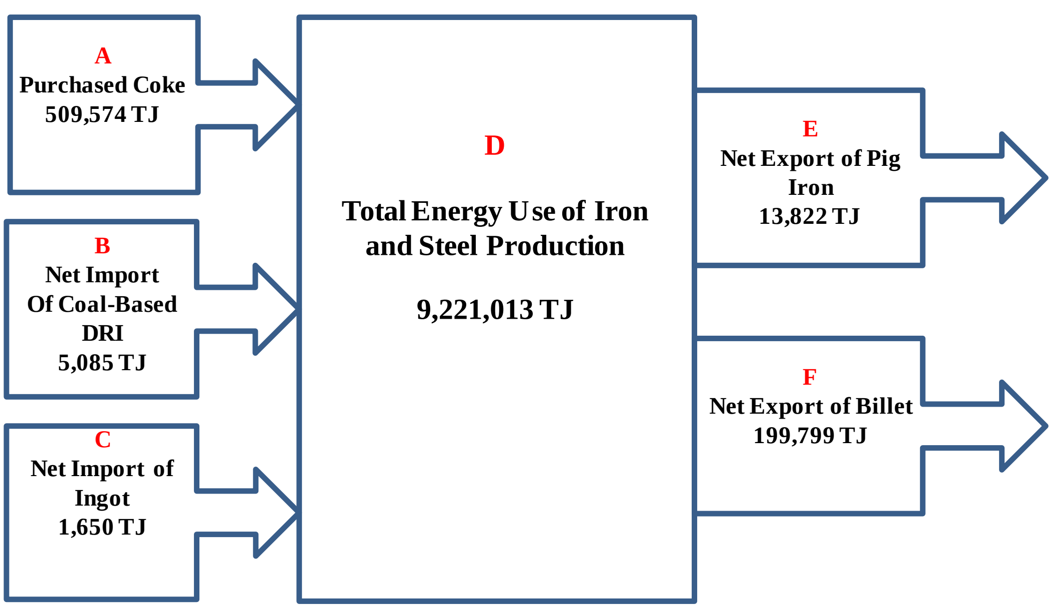
According to the boundaries presented in Figure 3, the energy consumption of steel production is calculated and included in this analysis. The upstream energy consumption of net imported coke, pig iron, DRI, steel ingots and steel billets is presented in Table 18. Total energy use is adjusted for net trade in auxiliary and intermediate products. Figure 5 provides an illustration of these calculations.

Table 18: Total Energy Consumption of China's Steel Industry Production in 2006

Component	Electricity Use (GWh)	Fuel Use (TJ)	Final (TJ)	Primary (TJ) *
Reported energy consumption	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 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 in table 18) and there is no import or export of these two products.

Figure 5: Final Energy Use of China's Iron and Steel Industry in 2006



Total Final Energy = A+B+C+D-E-F= 9,523,701 TJ

5. Comparison of Energy Intensity of Iron and Steel Production in China and the U.S.

In this study, "energy intensity" is chosen as the index for comparison of the Chinese and U.S. iron and steel industries. It presents, within the prescribed boundary (as illustrated in Figure 3), the energy consumption per tonne of crude steel during production.

$$\text{Energy intensity} = \frac{\text{Energy Consumption of the iron and steel industry within the prescribed boundary}}{\text{Crude steel production within the prescribed boundary}}$$

The energy intensity of steel production is influenced by industry structure, technology, fuel choice, and materials--e.g., availability of scrap steel. The effects of these variables are isolated in this study's scenario analyses. Section 5.3 presents six scenarios to compare a range of effects within the steel industry of China and the U.S.

5.1. Energy Intensity of Iron and Steel Production in the U.S.

Final energy intensity (energy use per tonne of crude steel) for the U.S. iron and steel industry in 2006 is provided in Table 19. This value is calculated using the production data from Table 10 and the electricity and fuel consumption data from Table 15. Crude steel production in the U.S. in 2006 was 98.2 Mt. In addition, there were 8.261 Mt of net imported ingots, blooms, billets, and slabs in 2006. Thus, total crude steel production used for the calculation of energy intensities in 2006 in this analysis was 106.461 Mt. As explained in section 3.3.1 above, energy use for 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 (worldsteel, n.d.; worldsteel, 2008b).[13]

Under the base case scenario, the total electricity and fuel consumption in the iron and steel industry in the U.S. in 2006 based on the defined boundary of this study are 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 final electricity to primary energy intensity using the average power generation efficiency of fossil-fuel power plants in the U.S. as well as transmission and distribution losses. By multiplying the final electricity intensity by the conversion factor given in Table 5 for the U.S., 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 19 presents the various energy intensities explained above.

[13] Total final energy intensity of the US iron and steel industry using the U.S. country-specific energy conversion factors for the purchased coke and auxiliary/intermediary products instead of worldsteel conversion factor would be 14.5 GJ/tonne crude steel, which is around 2.7% less than the intensity calculated using worldsteel conversion factors.

Table 19: Base Case - Energy Intensity of the U.S. Iron and Steel Industry in 2006

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity[1]		Primary Energy Intensity with T&D [2]		Primary Energy Intensity without T&D [3]	
		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
Base	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 U.S. country-specific energy conversion factors for the purchased coke and auxiliary/intermediary products instead of worldsteel conversion factor would be 14.5 GJ/tonne crude steel which is around 2.7% less than the intensity calculated using worldsteel conversion factors.

[2] In 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.

[3] 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.

Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

5.2. Energy Intensity of Iron and Steel Production in China

Table 20 shows the energy intensity (energy consumption per tonne crude steel) calculated based on the 2006 revised energy data for China, as presented in Section 4.2.2 above. Final energy intensity for the Chinese iron and steel industry in 2006 is provided in Table 20. This value is calculated using the Chinese production data from Table 11 and the electricity and fuel consumption data from Table 18. Crude steel production in China in 2006 was 421.02 Mt. In addition, there were 8.57 Mt of net exported ingots, blooms, billets, and slabs in 2006. Thus, total crude steel production used for the calculation of energy intensities in 2006 in this analysis was 412.45 Mt. Total electricity and fuel consumption of steel industry in China with embodied energy of net imported/exported auxiliary/intermediary products included are 178,039 GWh and 8,882,760 TJ, respectively. By dividing these energy consumption values by the production values, the energy intensities presented in Table 20 are obtained.

Table 20: Base Case - Energy Intensity of the Chinese Iron and Steel Industry in 2006

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity[1]		Primary Energy Intensity with T&D [2]		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
Base	China	431.66	53.02	21.54	734.96	23.11	788.53	26.30	897.38	25.97	886.12

[1] In 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.

5.3. Scenario Analyses

In addition to the base case presented above, six variations to the base case were calculated to examine the impact of different assumptions on the iron and steel production energy intensity value for each country. The purpose of this scenario analysis is to determine which variables are most important for explaining energy intensity differences between China and the U.S.

The first scenario uses IEA typical fuel conversion factors (instead of country-specific fuel conversion factors used in the base case), country-specific electricity conversion factors, and worldsteel conversion factors for auxiliary/intermediary products. This scenario is intended to isolate the impact of the use of country-specific conversion factors on the overall comparative intensity.

The second scenario uses the country-specific fuel conversion factors, worldsteel electricity conversion factors for converting electricity from final to primary energy (9.8 MJ/kWh) (instead of country-specific electricity conversion factors used on the base case), and worldsteel conversion factors for auxiliary/intermediary products. This scenario is intended to analyze the impact on energy intensity caused by change of electric power conversion factor.

The third scenario uses the IEA typical fuel conversion factors (instead of country-specific fuel conversion factors used in the base case), worldsteel electricity conversion factors (9.8 MJ/kWh) ((instead of country-specific electricity conversion factors used on the base case), and the worldsteel conversion factors for auxiliary/intermediary products. The purpose of this scenario is to remove the effect of country-specific conversion factors and focus the intensity comparison on structural and efficiency effects.

The fourth scenario uses the country-specific fuel conversion factors, country-specific electricity conversion factors, worldsteel conversion factors for auxiliary/intermediary products, and China's EAF ratio in 2006 used for U.S. energy intensity calculation. This scenario is intended to analyze the impact on energy consumption caused by a change of the EAF ratio.

The fifth scenario uses the IEA typical fuel conversion factors, worldsteel electricity conversion factors (9.8MJ/kWh), worldsteel conversion factors for auxiliary/intermediary products, and China's EAF ratio in 2006 used for U.S. energy intensity calculation. This scenario is the same as the third scenario, but takes into account the impact on energy consumption caused by a change of EAF ratio.

Finally, the sixth scenario uses the country-specific fuel conversion factors, worldsteel conversion factors for auxiliary/intermediary products, and China's final to primary electricity conversion factor for U.S. energy intensity calculation. This scenario shows the impact of the different power generation efficiencies in each country on the primary energy intensity.

5.3.1 U.S. Iron and Steel Industry

Scenario 1: Energy intensity of each country's iron and steel industry using the IEA typical fuel conversion factors, country-specific electricity conversion factors, and worldsteel conversion factors for auxiliary/intermediary products

In order to develop a scenario in which a similar fuel conversion factor is used for both China and U.S. to understand the effect of differences in country-specific fuel conversion factors on the calculated energy intensities, the IEA typical fuel conversion factor is used for both countries. Table 21 provides the use of energy for all purposes (fuel and nonfuel) for the U.S. iron and steel industry in 2006 based on the use of energy in physical units given in Table 12 and the IEA's typical fuel conversion factors given in Table 5. The same methodology explained for the base case is used for the calculation of the energy intensity using the IEA typical fuel conversion factors for this scenario. The results of the analysis are shown in Table 22. As can be seen, for the U.S. iron and steel industry, the energy intensity using the IEA typical fuel conversion factors is almost the same as the intensities using the country-specific fuel conversion factors.

Scenario 2: Energy intensity of each country's iron and steel industry using country-specific fuel conversion factors, worldsteel electricity conversion factors for converting electricity from final to primary energy, and worldsteel conversion factors for auxiliary/intermediary products

In order to develop a scenario in which a similar conversion factor to convert electricity from final to primary energy is used for both China and U.S. to understand the effect of differences in country-specific electricity conversion factors on the calculated primary energy intensities, the worldsteel electricity conversion factor which is 9.8 MJ/kWh (0.334 kgce/kWh) is used for both countries (worldsteel, n.d.).

The results of the analysis are shown in Table 23. As can be seen, for the U.S. iron and steel industry, the primary energy intensity using the worldsteel electricity conversion factors is lower than that of using the U.S. country specific conversion factor for electricity. There is no change in electricity, fuel, and final energy intensities compared to the base case scenario since the change in this scenario was only the conversion factor that used to convert electricity from final to primary energy.

Scenario 3: Energy intensity of each country's iron and steel industry using IEA typical fuel conversion factors, worldsteel electricity conversion factors, and worldsteel conversion factors for auxiliary/intermediary products

This scenario is similar to scenario 2 with the difference that in this scenario the IEA typical fuel conversion factors are used instead of country-specific conversion factors. Therefore, the results of this scenario can be compared to scenario 2. The purpose of this scenario is to use a similar fuel conversion factor or both China and the U.S. while assessing the impact of the electricity conversion factor. The results of the analysis are shown in Table 24. As can be seen, the primary energy intensity of scenario 3 is lower than scenario 1 in which the IEA typical fuel conversion factor was used with the country-specific electricity conversion factor. Also, the results show that the primary energy intensities of scenario 2 and 3 are very close to each other.

Table 21: Energy Use for All Purposes (Fuel and Nonfuel) for the U.S. Iron and Steel Industry Using IEA Typical Fuel Conversion Factors, 2006 (TJ)

NAICS	Industry	Electricity	Residual Fuel Oil	Distillate Fuel Oil	Natural Gas	Coal used as Fuel[1]	Coal used for Coking[1]	Coke and Breeze	Other[2]	Shipments of Energy Sources Produced Onsite[3]	Total
331111	Iron and Steel Mills	184,313	18,997	6,034	346,276	17,887	398,496	224,074	41,147	145,568	1,091,655
3312	Steel Products from Purchased Steel	15,826	300	0	25,797	511	0.0	292	14,771	0	57,497

[1] Calculated from EIA, 2010b.
[2] Energy use of the category "Other" is based on IEA fuel conversion factors, since the energy use in physical units for this category was not available (only the first use of energy in energy units was available from U.S. DOE/EIA 2010b). Thus, the value used for this scenario is the same as for the base case. The share of energy use of the category "Other" is less than 4% of the total energy used; hence the impact of this assumption is minimal.
[3] For the category "Shipments of Energy Sources Produced Onsite", only the energy use value is provided by the EIA. However, this value is for the coke that is traded within the U.S iron and steel industry. Therefore, the ratio of the fuel conversion factor for coke from the IEA to fuel conversion factor for coke from the EIA was multiplied by the energy use of this category (in energy units) to determine the energy use of this category based on the IEA's fuel conversion factor for coke.

Table 22: Scenario 1 - Energy Intensity of the U.S. Iron and Steel Industry in 2006 Using IEA Typical Fuel Conversion Factors, Country-Specific Electricity Conversion Factors, and worldsteel Conversion Factors for Auxiliary/Intermediary Products

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
1	U.S.	675.84	83.44	12.40	423.05	14.83	506.49	19.91	679.48	19.41	663.51

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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
[2] In primary energy without transmission and distribution (T&D) losses, 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.
Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

Table 23: Scenario 2 - Energy Intensity of the U.S. Iron and Steel Industry in 2006 Using Country-Specific Fuel Conversion Factors, worldsteel Electricity Conversion Factors, and worldsteel Conversion Factors for Auxiliary/Intermediary Products

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
2	U.S.	675.84	83.44	12.46	425.25	14.90	508.69			19.09	651.24

[1]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. Since the worldsteel electricity conversion factor used in Scenario 2 excludes T&D losses, the primary energy intensity with T&D losses based on worldsteel conversion factor is not available. [14]

[2] In primary energy without T&D losses, 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.

Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

Table 24: Scenario 3 - Energy Intensity of the U.S. Iron and Steel Industry in 2006 Using IEA Typical Fuel Conversion factors, worldsteel Electricity Conversion Factors, and worldsteel Conversion Factors for Auxiliary Products

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
3	U.S.	675.84	83.44	12.40	423.05	14.83	506.49			19.02	649.04

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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. Since the worldsteel electricity conversion factor used in Scenario 2 excludes T&D losses, the primary energy intensity with T&D losses based on worldsteel conversion factor is not available.

[2] In primary energy without transmission and distribution (T&D) losses, 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.

Conversions: GJ to kgce = 34.1208, kWh to kgce (in final energy) = 0.1235.

[14] This calculation will be included if the worldsteel conversion factor for electricity with T&D losses can be identified.

Scenario 4: Energy intensity of each country's iron and steel industry using country-specific fuel conversion factors, country-specific electricity conversion factors, worldsteel conversion factors for auxiliary/intermediary products, and China's EAF ratio in 2006 used for U.S. energy intensity calculation

A key factor influencing the energy intensity of a country's iron and steel industry is the share of steel that is produced by the more energy-intensive BF-BOF route compared to the share produced by the less energy-intensive EAF route. The iron and steel industry in the U.S. reflects the country's mature, industrialized economy that has an ample supply of scrap steel and that produced 56.9% of total steel by recycling this scrap steel in an EAF in 2006. China, on the other hand, is a developing country and due to scrap availability limitations only produced 10.5% of its total steel using the EAF route in 2006.[15] In order to account for this difference in the structure of the steel industry in China and the U.S., a scenario is presented in which the U.S. steel industry energy intensity is calculated using the share of EAF steel in China to illustrate how this structural difference changes the energy intensity value for the U.S. In order to calculate this scenario, the energy use and energy intensity by EAF and BF-BOF process routes is required. However, the EIA does not provide information on energy use by EAF and BF-BOF process routes for the U.S. Thus, an estimate of the breakdown of energy use by these two processes must be undertaken for the U.S.

The American Iron and Steel Institute (AISI) provides total final energy intensity for the production of one tonne of shipped steel by EAF technology and by BF-BOF technology in 2003 (Table 25) (AISI, 2005). To convert the energy intensities from units of per tonne of shipped steel to units of per tonne of crude steel in 2003, the ratio of the production of crude steel and shipped steel in 2003 from USGS (2004) is used (Table 25). These intensities are for the complete production line which includes casting, rolling and finishing for both EAF and BF-BOF production lines. Also, these intensity values for EAF and BF-BOF production lines include the energy use for net imported auxiliary products such as the energy use for the production of pellet, lime, coke, and oxygen. However, these energy intensities do not include the embodied energy of the net imported pig iron, DRI, and ingots, blooms, billets, and slabs as well as the energy use for rolling and finishing of the net imported ingots, blooms, billets, and slabs to the U.S. iron and steel industry.

Table 25: Final Energy Intensity of the U.S Iron and Steel Industry in 2003

	Final Energy with auxiliary products energy use included except for embodied energy of imported pig iron, DRI, and ingot, slabs and billets (GJ/t shipped steel)	Final Energy with all auxiliary products energy use and embodied energy of imported pig iron, DRI, and ingot, slabs and billets included (GJ/t crude steel)
Final Energy Intensity of EAF production	6.1	7.5
Final Energy Intensity of BF-BOF production	22.7	25.3
Combined Final Energy Intensity of U.S steel industry*	14.3	16.2

Source: 2003 energy intensities: AISI, 2005.

* The combined final energy intensity is the total energy intensity of the iron and steel industry taking into account the share of EAF and BF-BOF production lines and their intensities.

[15] Note, however, that even at this smaller overall share, China produced 44.22 Mt EAF crude steel compared to 56.10 Mt EAF crude steel produced in the U.S. in 2006.

The energy use for the production of net imported pig iron, DRI, and ingots, blooms, billets, and slabs is included in the calculation of the energy intensity from the MECS data for iron and steel industry. Hence, here also, this energy use must be included. It is explained above how the amount of crude steel required for the production of net imported ingots, blooms, billets, and slabs is calculated. Having this amount of crude steel and the energy intensity for the production of crude steel, the total energy use for the production of crude steel required for the production of net imported ingots, blooms, billets, and slabs can be calculated. Then, this total energy use can be divided by the crude steel production in 2006 to find out the energy intensity in GJ/tonne crude steel. The calculated intensities for the net imported ingots, blooms, billets, and slabs as well as the energy use given for the rolling and finishing processes of the net imported ingots, blooms, billets, and slabs (in MECS 2006, NAICS 3312) are then added to the energy intensities given in AISI (2005) for EAF and BF-BOF production lines in the U.S. The same approach is taken for net imported pig iron and DRI using the amount of imported material and their energy conversion factor from Table 6. At the end, the energy intensities that include the energy use of net imported auxiliary products (coke, lime, pellets, and oxygen) as well as pig iron, DRI, and ingots, blooms, billets, and slabs can be calculated.

Having the final energy intensities for each type of production line and the ratio of each type of production line (EAF and BF-BOF), the combined final energy intensity can be calculated using the following formula:

Combined EI = EI of EAF * EAF ratio + EI of BF-BOF * BF-BOF ratio

Where:

Combined EI: combined energy intensity of U.S steel industry (GJ/tonne **crude** steel)
EI of EAF: energy intensity of EAF production (GJ/tonne **crude** steel)
EI of BF-BOF: energy intensity of BF-BOF production (GJ/tonne **crude** steel)
EAF ratio: EAF ratio in U.S
BF-BOF ratio: BF-BOF ratio in U.S

The intensities in AISI (2005) are for 2003 and should be converted to 2006 values since this is the base year for this study. Table 26 provides the EAF ratio for the U.S. for 2003 and 2006 (worldsteel, 2009). Based on AISI (2005), it is assumed that the energy efficiency of the U.S. iron and steel industry improved at the rate of 0.7% per year from 2003 to 2006. This is used to calculate the 2006 intensity values from the 2003 values, as shown in Table 27.

Table 26: EAF Ratio in the U.S. in 2003 and 2006

	2003	2006
U.S. EAF ratio	51.0%	56.9%
U.S. BF - BOF ratio	49.0%	43.1%

Source: worldsteel, 2008

In addition, to assign a share of EAF and BF-BOF production lines from the energy use of the net imported ingots, blooms, billets, and slabs, the share of EAF and BF-BOF in the steel production in the US in 2006 is used. These shares are used to divide the energy intensity of the imported ingots, blooms, billets, and slabs as well as the energy use given for rolling and finishing of them between EAF and BF-BOF steel production (see Table 27).

The 2006 final energy intensity presented earlier using the EIA's fuel conversion factors and worldsteel conversion factors for the net imported auxiliary and intermediary products is 14.9 GJ/tonne crude steel (Table 23). As can be seen in Table 27, the calculated combined final energy intensity for 2006 matches the value presented in Table 23. Therefore, the assumptions taken are reasonable since the energy intensity of the industry calculated from the EIA data and the AISI (2005) match.

Table 27: Final Energy Intensity of the U.S Iron and Steel Industry in 2006

	Final Energy with all auxiliary products energy use and embodied energy of imported pig iron, DRI, and ingot, slabs and billets included (GJ/t crude steel)
Final Energy Intensity of EAF production	7.3
Final Energy Intensity of BF-BOF production	24.8
Combined Final Energy Intensity of U.S steel industry*	14.9

Source: 2003 energy intensities: AISI, 2005.

* The combined final energy intensity is the total energy intensity of the iron and steel industry taking into account the share of EAF and BF-BOF production lines and their intensities. The formula for the calculation of the combined final energy intensity is given above.

Now that the energy intensities for the EAF and BF-BOF routes have been calculated for the U.S iron and steel industry in 2006, Scenario 4 can be developed using the same calculation methodology but different EAF and BF-BOF ratios. In this scenario, the EAF and BF-BOF ratios of the Chinese steel industry in 2006 are used instead of the U.S ratios. In 2006, China produced 10.5% of its steel using the EAF route and 89.5% using the BF-BOF route.

To calculate the combined primary energy intensity from the calculated final energy intensity, the electricity and fuel intensity of each of the EAF and BF-BOF production routes must be calculated separately. Based on Stubbles (2000) it is assumed that around 45% of the final energy used in the EAF production line is electricity and the rest is fuel. Based on this share and the total final energy intensity of the EAF production line from Table 27 (7.3 GJ/tonne crude steel), the electricity intensity of the EAF production line is calculated to be 917.6 kWh/tonne crude steel. This value is in an acceptable range based on the Stubbles (2000) and Kirschen (2009). The fuel intensity is then calculated by subtracting the electricity intensity from the total final energy intensity.

Having the combined total electricity intensity of the U.S iron and steel industry from the base case scenario (Table 19) (675.8 kWh/tonne crude steel), the electricity intensity of the EAF production line from Table 25, and the EAF and BF-BOF ratios in U.S. in 2006, the electricity intensity of the BF-BOF production line can be calculated using the formula presented below. The fuel intensity of the BF-BOF production line can also be calculated using the same method.

$$EI\ BF\text{-}BOF = (EI\ U.S\ industry - EI\ EAF * EAF\ ratio)/BF\text{-}BOF\ ratio$$

Where:

EI BF-BOF: electricity intensity of the BF-BOF production line (kWh/tonne crude steel)

EI U.S industry: combined total electricity intensity of the U.S iron and steel industry from Table 19

EI EAF: electricity intensity of the EAF production line (kWh/tonne crude steel)

Table 28 presents the results for Scenario 4 showing that if the U.S. iron and steel industry had the same structure as the Chinese iron and steel industry in terms of the shares of EAF and BF-BOF steel, the final energy intensity of U.S. steel production would be 22.96 GJ/tonne crude steel. This is a 54% increase in final energy intensity compared to the 14.9 GJ/tonne crude steel that was calculated for the base case in U.S. This is an important finding that shows that comparing only the total final energy intensity of the U.S and Chinese steel industry could be misleading and may not represent the real energy efficiency of the iron and steel industry in both countries since the difference in the EAF ratios of the two countries is large.

Scenario 5: Energy intensity of each country's iron and steel industry using the IEA typical fuel conversion factors, worldsteel electricity conversion factors, worldsteel conversion factors for auxiliary/intermediary products, and China's EAF ratio in 2006 used for U.S. energy intensity calculation.

The purpose of developing this scenario is to assess the impact of the share of EAF production while keeping all the conversion factors similar for both countries. The results of this scenario are presented in Table 29. As can be seen, the results of Scenario 5 are very close to the results of Scenario 4.

Scenario 6: Energy intensity of each country's iron and steel industry using the country-specific fuel conversion factors, worldsteel conversion factors for auxiliary/intermediary products, and China's final to primary electricity conversion factor for U.S. energy intensity calculation

Another key difference between countries that has an effect on the primary energy consumption level and hence the primary energy intensity is the efficiency of electricity generation, transmission, and distribution in each country. A sixth scenario is constructed to illustrate the impact of using the Chinese electricity conversion factor to calculate primary energy use of the U.S. iron and steel industry.

In this scenario, the electricity, fuel, and final energy intensities are the same as the base case. However, to convert the final energy intensities to primary energy intensities for the U.S. iron and steel industry, the Chinese electricity conversion factor of 0.376 kgce/kWh from Table 9 is used instead of the U.S. electricity conversion factor of 0.379 kgce/kWh. This scenario is used to highlight the effect of power generation efficiency and T&D losses. The electricity conversion factor for China is almost same as the one in the U.S.; therefore, the total primary energy intensity of the U.S. iron and steel industry using the Chinese electricity conversion factor is about the same as the actual value using the U.S electricity conversion factor (base case scenario). The result for Scenario 6 is presented in Table 30.

Table 28: Scenario 4 - Energy Intensity of the U.S. Iron and Steel Industry in 2006 Using Country-Specific Fuel Conversion Factors, Country-Specific Electricity Conversion Factors, worldsteel Conversion Factors for Auxiliary/Intermediary Products, and China's EAF Ratio in 2006 Used for U.S. Energy Intensity Calculation

Scenario	Country	Item	Electricity Intensity		Fuel Intensity		Total Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
4	U.S.	Energy Intensity of EAF production line	917.64	112.72	4.04	137.77	7.34	250.48	14.24	485.94	13.56	462.61
		Energy Intensity of BF-BOF production line	356.63	43.81	23.51	802.02	24.79	845.83	27.47	937.34	27.21	928.27
		Combined Energy Intensity of U.S. steel industry [3]	**415.54**	**51.04**	**21.46**	**732.28**	**22.96**	**783.32**	**26.08**	**889.94**	**25.77**	**879.38**

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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

[2] In primary energy without transmission and distribution (T&D) losses, 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.[3] The combined final energy intensity is the total energy intensity of the iron and steel industry taking into account the share of EAF and BF-BOF production lines and their intensities. The formula for the calculation of the combined final energy intensity is given above.

Table 29: Scenario 5 - Energy Intensity of the U.S. Iron and Steel Industry in 2006 Using IEA Typical Fuel Conversion Factors, worldsteel Electricity Conversion Factors, worldsteel Conversion Factors for Auxiliary/Intermediary Products, and China's EAF Ratio in 2006 Used for U.S. Energy Intensity Calculation

Scenario	Country	Item	Electricity Intensity		Fuel Intensity		Total Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
5	U.S.	Energy Intensity of EAF production line	926.25	113.78	4.08	139.06	7.41	252.84	N/A	N/A	13.15	448.78
		Energy Intensity of BF-BOF production line	345.26	42.41	23.63	806.17	24.87	848.58	N/A	N/A	27.01	921.62
		Combined Energy Intensity of U.S. steel industry [3]	**406.26**	**49.90**	**21.57**	**736.13**	**23.04**	**786.03**	N/A	N/A	**25.56**	**871.98**

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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. Since the worldsteel electricity conversion factor used in Scenario 5 excludes T&D losses, the primary energy intensity with T&D losses based on worldsteel conversion factor is not available.[16]

[2] In primary energy without transmission and distribution (T&D) losses, 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.[3] The combined final energy intensity is the total energy intensity of the iron and steel industry taking into account the share of EAF and BF-BOF production lines and their intensities. The formula for the calculation of the combined final energy intensity is given above.

Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

[16] This calculation will be included if the worldsteel conversion factor for electricity with T&D losses can be identified.

Table 30: Scenario 6 - Energy Intensity of the U.S. Iron and Steel Industry Using Country-Specific Fuel Conversion Factors, worldsteel Conversion Factors for Auxiliary/Intermediary Products, and China's Final to Primary Electricity Conversion Factor for U.S. Energy Intensity Calculation

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
6	U.S.	675.84	83.44	12.46	425.25	14.90	508.69	19.92	679.60	19.40	662.99

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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.
[2] In primary energy without transmission and distribution (T&D) losses, 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.
Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

5.3.2. Chinese Iron and Steel Industry

<u>Scenario 1</u>: Energy intensity of each country's iron and steel industry using the IEA typical fuel conversion factors, country-specific electricity conversion factors, and worldsteel conversion factors for auxiliary/intermediary products

As discussed in Section 3.3.1, the IEA typical coefficient for fuel is for dry-based fuel, but energy consumption data published by the *China Energy Statistical Yearbook* is wet-based. Thus, under this scenario, the Chinese coal consumption data is converted to dry-based coal use, based on a 10% moisture content conversion factor. In addition, the results from this scenario can be used to analyze the impact of fuel conversion coefficient on China's energy consumption in iron and steel industry.

The analysis shows that if the IEA typical energy conversion factors are used to calculate the energy consumption of China's iron and steel industry, the energy consumption values are slightly lower (about 2%) than the resulting value when using China's country-specific energy conversion factors (see Table 31).

<u>Scenario 2</u>: Energy intensity of each country's iron and steel industry using country-specific fuel conversion factors, worldsteel electricity conversion factors for converting electricity from final to primary energy, and worldsteel conversion factors for auxiliary/intermediary products

The results of this scenario are presented in Table 32. This scenario can be used to analyze the impact of electric power conversion coefficient on China's energy consumption in iron and steel industry. The energy consumption per tonne of crude steel calculated based on the electric power conversion coefficient from worldsteel shows no change in final energy intensity as expected but reduces the primary energy intensity by 0.75% compared to the base case. This is the result of electric power equivalent coefficient at 9.8 MJ/kWh (0.334 kgce/kWh), which is lower than China country-specific coefficient of 10.26 MJ/kWh (0.3505 kgce/kWh).

<u>Scenario 3</u>: Energy intensity of each country's iron and steel industry using IEA typical fuel conversion factors, worldsteel electricity conversion factors, and worldsteel conversion factors for auxiliary/intermediary products

It needs to be noted that the analysis conducted in Scenarios 1 and 2 can describe the impact on the energy consumption of China's iron and steel industry as a result of the changes of conversion coefficient for fuel and electricity. In other words, the results can only be used to analyze changes in energy consumption within each individual country, not between countries. The comparison between countries can be made possible only when the conversion coefficient for fuel, electricity, and net imported auxiliary products power is set the same. Accordingly, the analysis of Scenario 3 serves as a foundation for comparison between countries (Table 33).

Table 31: Scenario 1 - Energy Intensity of China's Iron and Steel Industry in 2006 Using IEA Typical Fuel Conversion Factors, Country-Specific Electricity Conversion Factors, and worldsteel Conversion Factors for Intermediary Products

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
1	China	429.43	53.09	21.01	719.27	22.65	769.87	25.75	878.49	25.41	867.18

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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.
[2] In primary energy without transmission and distribution (T&D) losses, 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.
Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

Table 32: Scenario 2 - Energy Intensity of China's Iron and Steel Industry in 2006 Using Country-Specific Fuel Conversion Factors, worldsteel Electricity Conversion Factors, and worldsteel Conversion Factors for Auxiliary/Intermediary Products

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
2	China	429.03	53.08	21.57	718.93	23.11	788.69	N/A	N/A	25.77	879.45

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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. Since the worldsteel electricity conversion factor used in Scenario 2 excludes T&D losses, the primary energy intensity with T&D losses based on worldsteel conversion factor is not available.[17]
[2] In primary energy without transmission and distribution (T&D) losses, 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.
Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

[17] This calculation will be included if the worldsteel conversion factor for electricity with T&D losses can be identified.

Table 33: Scenario 3 - Energy Intensity of China's Iron and Steel Industry in 2006 Using IEA Typical Fuel Conversion factors, worldsteel Electricity Conversion Factors, and worldsteel Conversion Factors for Auxiliary/Intermediary Products

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
3	China	430.65	53.09	21.01	719.27	22.65	769.87	N/A	N/A	25.23	860.88

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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. Since the worldsteel electricity conversion factor used in Scenario 3 excludes T&D losses, the primary energy intensity with T&D losses based on worldsteel conversion factor is not available.[18]

[2] In primary energy without transmission and distribution (T&D) losses, 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.

[18] This calculation will be included if the worldsteel conversion factor for electricity with T&D losses can be identified.

<u>Scenario 4</u>: Energy intensity of each country's iron and steel industry using country-specific fuel conversion factors, country-specific electricity conversion factors, worldsteel conversion factors for auxiliary/intermediary products, and US EAF ratio in 2006 used for China's energy intensity calculation

China's iron and steel industry is at different development stage from the U.S. steel industry. With production growth remaining upward, scrap steel is still in short supply. The ratio of EAF steel production in total production in China has not increased, but instead has declined in recent years due to the rapid growth of BF-BOF steel production. However, China's iron and steel industry has been working to eliminate inefficient facilities, to restructure, and has been actively adopting energy-efficient techniques and technology. These actions have led to the downward trend of the industry's unit energy consumption. In other words, China's steel industry has improved energy efficiency through measures other than increased EAF production. Given China's ongoing economic growth, demand is likely to remain robust, limiting the availability of scrap steel and the ability to produce more EAF steel.

The increase in the EAF steel production ratio leads to the decline in the BOF steel production ratio from total steel produced. This also corresponds to the decline in the blast furnace production ratio in the iron-making process. The formula for calculation of energy consumption by the industry is as follows:

Energy consumption per ton steel = energy consumption of the iron-making process × iron to steel ratio + energy consumption of BOF steel-making process × BOF steel ratio + energy consumption of EAF steel-making process × EAF steel ratio + energy consumption of rolling steel-making process + others

Iron to steel ratio =

$$\frac{\text{raw iron used by BOF} \times \text{BOF steel production} + \text{raw iron used by EAF} \times \text{EAF steel production} + \text{export raw iron}}{\text{crude steel production}}$$

The energy consumption of individual processes in 2006 is shown in Table 34.

Table 34: Energy Consumption of Individual Iron and Steel Industry Processes in China, 2006

Process	Coking	Sintering	Iron-making	BOF	EAF
2006 Process Energy Consumption (kgce/t)	126.12	54.65	436.67	11.49	105.6

The iron to steel ratio of China's iron and steel industry in 2006 is 0.98 (Editorial Board of China Iron and Steel Industry Yearbook, 2007). China's EAF steel ratio is 10.5% while BOF steel ratio reached 89.5% of total steel production in 2006. Accordingly, the ratio of exported raw iron to crude steel production is 0.0017. Raw iron used by BOF is 1.054~1.061t/t. In 2006, the relation between iron to steel ratio, EAF steel ratio and BOF steel ratio for the industry is as follows:

Iron to steel ratio= (1.054~1.061) × BOF steel ratio + (0.275~0.33) ×EAF steel ratio + 0.0017

Other conditions being equal, with 1% increase in EAF steel ratio, the iron to steel ratio decreases by 0.0073~0.0080. Based on calorific coefficient, the energy consumption in the process before iron-making in 2006 is 572.03 kgce/t. With 1% increase in EAF steel ratio, the energy consumption per ton steel decreases 3.26 ~ 3.61 kgce/t steel, with an average of 3.43 kgce/t. Based on equivalent coefficient, with 1% increase in EAF steel ratio, the energy consumption per ton steel decreases by 2.64 ~ 3.01 kgce/t steel, with an average of 2.83 kgce/t.

Table 35 shows the energy consumption of China's iron and steel industry under Scenario 4 when China's EAF steel ratio reaches the US level of 56.9% in 2006, which is calculated based on the above information. According to this table, when China's EAF steel ratio reaches the US level of 56.9% in 2006, the final energy intensity of China's iron and steel industry decreases significantly by 20.2%, and the primary energy intensity drops by 14.8% compared to the base case. Thus, the ratio of EAF has significant impact on energy consumption per ton of steel.

Scenario 5: Energy intensity of each country's iron and steel industry using the IEA typical fuel conversion factors, worldsteel electricity conversion factors, worldsteel conversion factors for auxiliary/intermediary products, and U.S. EAF ratio in 2006 used for China's energy intensity calculation

The analysis of energy consumption of per ton steel in Scenario 5 is based on IEA fuel conversion coefficients and the worldsteel electric power conversion coefficient, with both coefficients close to the international level. The fuel conversion coefficients used by each country will be different due to variances in fuel quality. Similarly, electricity conversion coefficient from final to primary energy will be different due to different development stage of power generation of each country. It is thus fair to use the world average for international comparisons. The results of this analysis are presented in Table 36. The analysis result of Scenario 5 is based on the world average conversion factors, while taking into account the difference in the EAF steel ratio.

Scenario 6: Energy intensity of each country's iron and steel industry using the country-specific fuel conversion factors, worldsteel conversion factors for auxiliary/intermediary products, and the U.S. final to primary electricity conversion factor for China's energy intensity calculation

The results of this scenario are only applicable to the comparison analysis of power generation efficiencies of different countries. In this scenario, the electricity, fuel, and final energy intensities are the same as the base case. However, to convert the final energy intensities to primary energy intensities for the China iron and steel industry, the U.S. electricity conversion factor from Table 7 is used instead of the Chinese electricity conversion factor.

Table 35: Scenario 4 - Energy Intensity of the China's Iron and Steel Industry in 2006 Using Country-Specific Fuel Conversion Factors, Country-Specific Electricity Conversion Factors, worldsteel Conversion Factors for Auxiliary/Intermediary Products, and the U.S. EAF Ratio in 2006 Used for China's Energy Intensity Calculation

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
4	China	552.55	67.87	16.45	561.29	18.44	629.19	22.54	769.24	22.12	754.75

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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.

[2] In primary energy without transmission and distribution (T&D) losses, 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.

Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

Table 36: 2006 Scenario 5 - Energy Intensity of the China's Iron and Steel Industry in 2006 Using IEA Typical Fuel Conversion Factors, worldsteel Electricity Conversion Factors, worldsteel Conversion Factors for Auxiliary/Intermediary Products, and the U.S. EAF Ratio in 2006 Used for China's Energy Intensity Calculation

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
5	China	561.29	68.95	15.88	541.84	17.90	610.76	N/A	N/A	21.38	729.50

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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. Since the worldsteel electricity conversion factor used in Scenario 5 excludes T&D losses, the primary energy intensity with T&D losses based on worldsteel conversion factor is not available.[19]

[2] In primary energy without transmission and distribution (T&D) losses, 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.

[19] This calculation will be included if the worldsteel conversion factor for electricity with T&D losses can be identified.

Table 37: Scenario 6 - Energy Intensity of the China's Iron and Steel Industry Using Country-Specific Fuel Conversion Factors, worldsteel Conversion Factors for Auxiliary/Intermediary Products, and the U.S. Final to Primary Electricity Conversion Factor for China's Energy Intensity Calculation

Scenario	Country	Electricity Intensity		Fuel Intensity		Final Energy Intensity		Primary Energy Intensity with T&D losses [1]		Primary Energy Intensity without T&D losses [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
6	China	428.36	52.62	21.57	735.99	23.11	788.53	26.33	898.51	26.01	887.48

[1] In final energy, electricity use is equal to the electricity consumption at the end-use. In primary energy with transmission and distribution (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.

[2] In primary energy without transmission and distribution (T&D) losses, 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.

Conversions: GJ to kgce = 34.1208, kWh to kgce (final energy) = 0.1235.

5.3.3. Summary of Scenario Results

Table 38 and Figure 6 present the results of the base case and the six scenarios, providing information on the calculated electricity intensity, fuel intensity, final energy intensity, and primary energy intensity for the U.S. and China.

Table 38: Energy Intensity for the Iron and Steel Industry in China and the U.S. (2006)

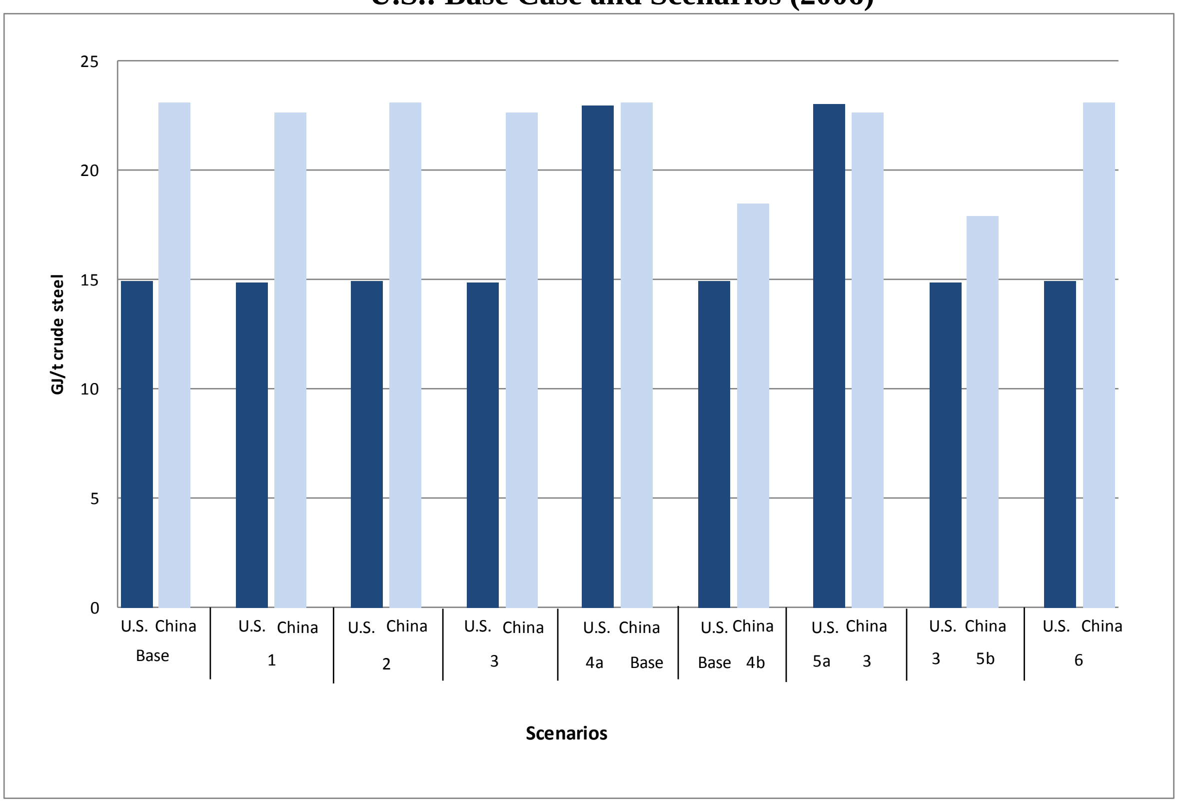
No.	Scenarios	Country	Final Energy Intensity		Primary Energy Intensity*	
			GJ/t	kgce/t	GJ/t	kgce/t
Base	Country-specific fuel conversion factors Country-specific electricity conversion factors worldsteel conversion factors aux/intermediary products	U.S.	14.90	508.69	19.98	681.68
		China	23.11	788.53	26.30	897.29
1	IEA typical fuel conversion factors Country-specific electricity conversion factors worldsteel conversion factors aux/intermediary products	U.S.	14.83	506.49	19.91	679.48
		China	22.56	769.87	25.75	878.49
2	Country-specific fuel conversion factors worldsteel electricity conversion factors worldsteel conversion factors aux/intermediary products	U.S.	14.90	508.69	19.09	651.24
		China	23.11	788.69	25.77	879.45
3	IEA typical fuel conversion factors worldsteel electricity conversion factors worldsteel conversion factors aux/intermediary products	U.S.	14.83	506.49	19.02	649.04
		China	22.65	769.87	25.23	860.88
4a	Country-specific fuel conversion factors Country-specific electricity conversion factors worldsteel conversion factors aux/intermediary products China 2006 EAF ratio used for U.S.	U.S.	22.96	783.32	26.08	889.94
	(Base Scenario) Country-specific fuel conversion factors Country-specific electricity conversion factors worldsteel conversion factors aux/intermediary products	China	23.11	788.53	26.30	897.29
4b	(Base Scenario) Country-specific fuel conversion factors Country-specific electricity conversion factors worldsteel conversion factors aux/intermediary products	U.S.	14.90	508.69	19.98	681.68
	Country-specific fuel conversion factors Country-specific electricity conversion factors worldsteel conversion factors aux/intermediary products U.S. 2006 EAF ratio used for China	China	18.44	629.19	22.54	769.24
5a	IEA typical fuel conversion factors worldsteel electricity conversion factors worldsteel conversion factors aux/intermediary products China 2006 EAF ratio used for U.S.	U.S.	23.04	786.03	26.09	890.27
	(Scenario 3) IEA typical fuel conversion factors worldsteel electricity conversion factors worldsteel conversion factors aux/intermediary products	China	22.65	769.87	25.23	860.88

No.	Scenarios	Country	Final Energy Intensity GJ/t	Final Energy Intensity kgce/t	Primary Energy Intensity* GJ/t	Primary Energy Intensity* kgce/t
5b	(Scenario 3) IEA typical fuel conversion factors worldsteel electricity conversion factors worldsteel conversion factors aux/intermediary products	U.S.	14.83	506.49	19.02	649.04
	IEA typical fuel conversion factors worldsteel electricity conversion factors worldsteel conversion factors aux/intermediary products U.S. 2006 EAF ratio used for China	China	17.90	610.76	21.38	729.50
6	Country-specific fuel conversion factors worldsteel conversion factors aux/intermediary products China final to primary electricity conversion factor for U.S. energy intensity calculation	U.S.	14.90	508.69	19.92	679.60
	Country-specific fuel conversion factors worldsteel conversion factors aux/intermediary products U.S. final to primary electricity conversion factor for China energy intensity calculation	China	23.11	788.53	26.33	898.51

* For the base Scenario and Scenarios 1, 4 and 6 the primary energy value includes T&D losses, whereas for Scenarios 2, 3, and 5 the primary energy value is calculated based on the worldsteel conversion factor which excludes T&D losses.

** Values are in metric tons of crude steel.

Figure 6: Comparison of Energy Intensity for the Iron and Steel Industry in China and the U.S.: Base Case and Scenarios (2006)



Note: For the base Scenario and Scenarios 1, 4 and 6 the primary energy value includes T&D losses, whereas for Scenarios 2, 3, and 5 the primary energy value is calculated based on the worldsteel conversion factor which excludes T&D losses.

5.3.4 Uncertainty and Unresolved Issues

- **Fuel consumption data for China's steel industry**: In Table 16 *Final Energy Consumption (Physical Amount) of Smelting & Pressing of Ferrous Metals (including ferroalloys) in 2006*, energy consumption in physical values is provided from the 2009 China Energy Statistical Yearbook. However, these values include energy use for ferroalloys which should be deducted for this analysis since ferroalloys are not within the boundary of this study. The energy use of ferroalloys industry is based on statistics provided to the China Iron and Steel Research Institute (CISRI) by China's National Bureau of Statistics (NBS). The energy use by China's ferrous alloy industry equal is to 1,142,704 TJ. This energy use is deducted from the total energy use shown in Table 16. This value has been confirmed by Chinese experts from the ferrous alloy industry, but there is not a published reference for this value.

- **The IEA fuel conversion factors for other bituminous coal and clean coal**: The country-specific fuel conversion factors for these coals used in the U.S. are for dry base coal, but CISRI has explained that the country-specific coal consumption data in China are for wet base coal. Thus, for the calculation of the Scenarios in which the IEA conversion factors are used, China's reported wet base coal value was multiplied by 0.9 to convert to dry base coal. As a result, the overall coal energy use in China is reduced as well as the resulting energy intensity. The choice of 0.9 depends on the moisture content of the coal in China compared to that used by IEA for defining the fuel conversion factor. There is uncertainty about this value which adds minor uncertainty to the results for scenarios that use the IEA fuel conversion factors.

- **Results of Scenario 5a**: There are two factors that contribute to the result of Scenario 5a where the U.S. steel intensity is slightly higher than the Chinese steel intensity. First, this scenario normalizes the comparison by using the IEA typical fuel conversion factors instead of country-specific fuel conversion factors. The main difference between the actual, country-specific energy conversion factors in the U.S. and China is for other bituminous coal and clean coal. As discussed above, the country-specific fuel conversion factors for these coals used in the U.S. are for dry base coal, but the country-specific fuel conversion factors used in China are for wet base coal. For the calculation of Scenario 5a, however, China's reported wet base coal value was multiplied by 0.9 to convert to dry base coal. As a result, the overall coal energy use in China is reduced as well as the resulting energy intensity. Secondly, the amount of pig iron used in the EAF also varies between the two countries. In the U.S., about 10% of the feed to the EAF is pig iron which is produced in a blast furnace and is highly fuel intensive while about 28% of the feed to the EAF in China is pig iron (Stubbles 2000; CISRI and CISA 2010). In Scenario 5a, where the EAF ratio for the U.S. value is decreased from the actual U.S. EAF ratio of 56.9% to the Chinese EAF ratio of 10.5%, the effect of the increase in pig iron is reflected in the overall energy intensity value.

- **Breakdown of energy use of Chinese steel industry by BOF and EAF production lines**: The energy intensities of the EAF and BF-BOF production lines in China could not be calculated separately from China's scenario 4b results. This was because it is very difficult to separate the EAF production route and BF-BOF production route in China, as the situation in China is very different from the U.S. Unlike in the U.S., in China the EAF production route and BF-BOF production route are often included in an integrated plant, which also means that they share the auxiliary equipment and materials. The following analysis has been undertaken to indirectly calculate the energy intensities of the EAF and BF-BOF production lines in China separately:

The energy intensities calculated for China in the base year (using the Chinese EAF ratio) and the energy intensities calculated for China in scenario 4b (using US EAF ratio) were used. Having the EAF ratios in China and US and the intensities from these two scenarios, the energy intensities of EAF and BF-BOF can be calculated separately from the following equation:

1. Chinese EAF final energy intensity * EAF ratio in China + Chinese BF-BOF final energy intensity * BF-BOF ratio in China = Final Energy intensity in base case
2. Chinese EAF final energy intensity * EAF ratio in US + Chinese BF-BOF final energy intensity * BF-BOF ratio in US = Final Energy intensity in scenario 4b

Then:

1. Chinese EAF final energy intensity * 10.5% + Chinese BF-BOF final energy intensity * 89.5% = 23.11 (GJ/t crude steel)
2. Chinese EAF final energy intensity * 56.9% + Chinese BF-BOF final energy intensity * 43.1% = 18.44 (GJ/t crude steel)

By solving these two equations with two unknown variables, the Chinese EAF final energy intensity and Chinese BF-BOF final energy intensity can be calculated. The results are:

- Chinese EAF final energy intensity = 14.11 (GJ/t crude steel)
- Chinese BF-BOF final energy intensity = 24.17 (GJ/t crude steel)

Table 39. Comparison of calculated final energy intensities for EAF and BF-BOF production lines in China and the U.S in 2006

	Final energy intensity (GJ/t crude steel)		Primary energy intensity (GJ/t crude steel)	
	China	U.S.	China	U.S.
EAF production line	14.11	7.34	19.01	14.24
BF-BOF production line	24.17	24.79	27.17	27.47

It can be seen that the final energy intensity for EAF steel production in China is significantly higher than that in the U.S., while the intensity of BF-BOF steel production in China is slightly lower than that of in the U.S. One reason for this could be the higher share of pig iron used in EAFs in China compared to the U.S. As mentioned above, in the U.S., about 10% of the feed to the EAF is pig iron which is produced in a blast furnace and is highly fuel intensive while about 28% of the feed to the EAF in China is pig iron. The higher the share of pig iron, the lower the electricity use in EAF, yet the higher the fuel used for the production of crude steel by EAF production line. However, the significantly higher intensity for EAF in China might not be all explained by the higher share of pig iron in the charge mix and requires further investigation. However, the difference in primary energy intensity of EAF is not as significant as the final energy intensity value. The reason for this is that in U.S. the EAF production lines use more scrap as input and less pig iron and thus use more electricity which is presented in final energy. When converting electricity from final to primary energy, the gap between energy intensity of EAF production lines in two countries decreases. It would be best if the Chinese could calculate directly the EAF and BF-BOF energy intensities separately from the energy used in those production lines as it is done for the U.S. in scenario 4a of this report.

- Values for the energy intensity of EAF and BF-BOF production lines in U.S. were obtained from AISI (2005). The intensities given in AISI (2005) were for the year 2003. However, the base year for this study is 2006. Thus, a 0.7% improvement in energy efficiency per year was assumed which was also obtained from AISI (2005) and applied to the 2003 intensities in order to get the 2006 energy intensities. The other issues with AISI intensities for EAF and BF-BOF used is that it was assumed for this study that these intensities include the energy use for the production of auxiliary products but exclude the embodied energy of imported ingot, slabs and billets, DRI, and pig iron. These assumptions could also add uncertainty to the results and should be verified.

- As mentioned in the calculation of scenario 4a for the U.S., it was assumed that 45% of the final energy use in a EAF production line (as defined in this study) is electricity and the rest is fuel, while only 5% of the final energy use in BF-BOF production line (as defined) is electricity and 95% is fuel. These shares could also vary slightly from one plant to another and may add uncertainty to the results.

5.4. Explanatory Variables

The purpose of the analysis presented in this report is to develop and test a methodology for quantifying and comparing the energy intensity of steel production in China and the U.S. with defined boundaries and conversion factors. This section provides a discussion of some possible reasons that the energy intensity values differ in the two countries. Six explanatory variables are discussed: 1) the age of steel manufacturing facilities in each country, 2) the share of EAF steel in total steel production, 3) the level of penetration of energy-efficient technologies, 4) the scale of production equipment, 5) fuel shares in the iron and steel industry, and 6) the final steel product mix in both countries.

5.4.1. Age of Steel Manufacturing Facilities

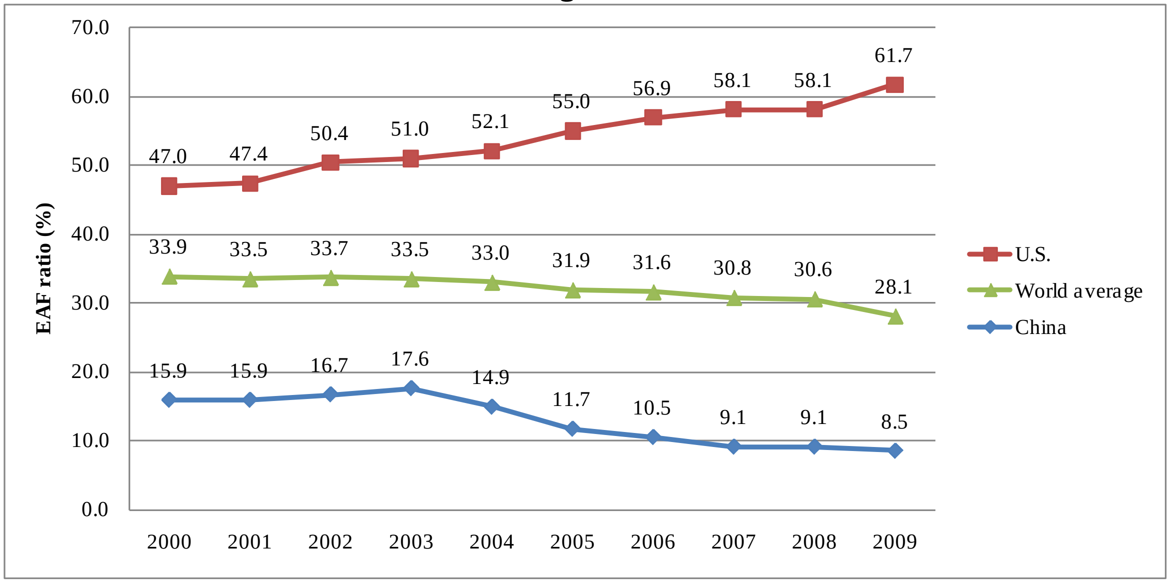
As is evident from Figure 1, most of China's steel production capacity has been constructed since 2000, when annual production jumped from 129 Mt to 627 Mt in 2010. During that same time, production in the U.S. dropped from 102 Mt to 80 Mt.

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%) is from plants that are 10 years old or younger. In contrast, the average age of BOF vessels in the U.S. is 31.5 years (AIST, 2010a) and the average age of EAF furnaces in the U.S. is 30.9 years (AIST, 2010b). Even though the vessels have been relined and other upgrades have been made to the U.S. 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.

5.4.2 Structure of the 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 U.S. since EAF steel production uses significantly less energy for the production of one tonne of steel. In 2006, the share of EAF steel production in total steel production was 10.5% in China and 56.9% in the U.S. The world average EAF production in 2006 was 31.6% (see Figure 7).

Figure 7: Share of EAF in Total Steel Production in China and the U.S. and World Average Values



Source: World Steel Association, 2009

Scenarios 4 and 5 calculate the total U.S. energy intensity using the share of EAFs in China and the total Chinese energy intensity using the share of EAFs in the U.S., respectively.

Scenario 4a, which relies on country-specific fuel and electricity conversion factors and worldsteel conversion factors for auxiliary and intermediate products, found that if the U.S. iron and steel industry had the same structure as the Chinese iron and steel industry in terms of the shares of EAF steel, the final energy intensity of U.S. steel production would be 22.96 GJ/tonne crude steel using the same conversion factors. This value should be compared to the Base Scenario for China which resulted in a final energy intensity of 23.11 GJ/tonne crude steel using the same conversion factors. Conversely, Scenario 4b shows that if the Chinese steel industry had the same structure as the U.S. steel industry in terms of shares of EAF steel, the final energy intensity of Chinese steel production would be 18.44 GJ/tonne crude steel using the same conversion factors. This value should be compared to the Base Scenario for the U.S which resulted in a final energy intensity of 14.9 GJ/tonne crude steel.

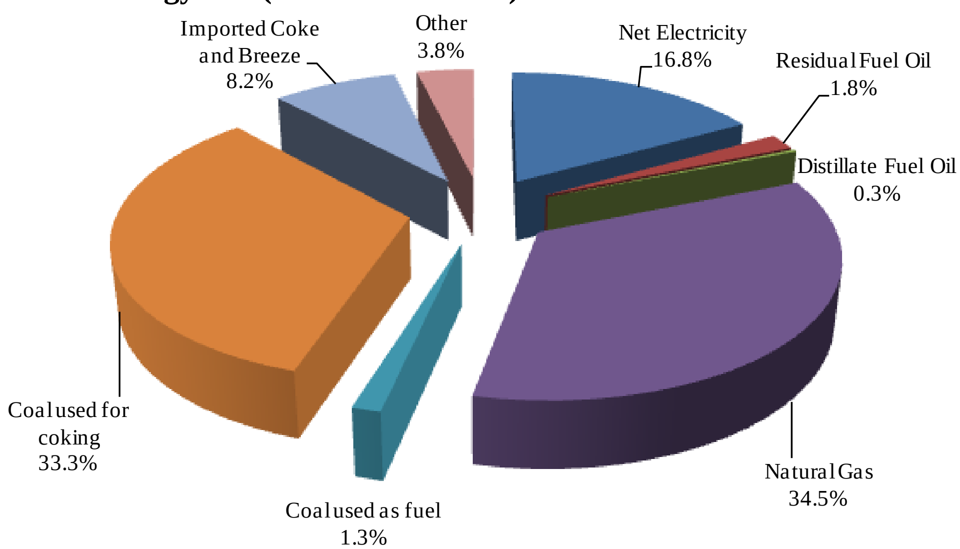
Scenario 5a, which uses IEA typical fuel conversion factors and v conversion factors for electricity and auxiliary and intermediate products, found that if the U.S. iron and steel industry had the same structure as the Chinese iron and steel industry in terms of the shares of EAF steel, the final energy intensity of U.S. steel production would be 23.04 GJ/tonne crude steel. This value should be compared to Scenario 3 for China, in which the resulting steel energy intensity was calculated to be 22.65 GJ/tonne crude steel using the same conversion factors. Conversely, Scenaro 5b shows that if the Chinese steel industry had the same structure as the U.S. steel industry in terms of shares of EAF steel, the final energy intensity of Chinese steel production would be 17.9 GJ/tonne crude steel using the same conversion factors. This value should be compared to Scenario 3 for the U.S which resulted in a final energy intensity of 14.83 GJ/tonne crude steel using the same conversion factors.

5.4.2. Fuel Shares

The share of different fuels used in the iron and steel industry in both countries is also another 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. Figures 8 and 9 show the shares of different fuels used (both as fuel and nonfuel) in the U.S. 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, in the U.S. natural gas accounts for 34.5% of final energy use, while only accounting for 0.45% in China.

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 emissions 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 U.S. Since the share of EAF steel production in the U.S. 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.

Figure 8: Total Energy Use (Fuel and Nonfuel) in the U.S. Iron and Steel Industry, 2006

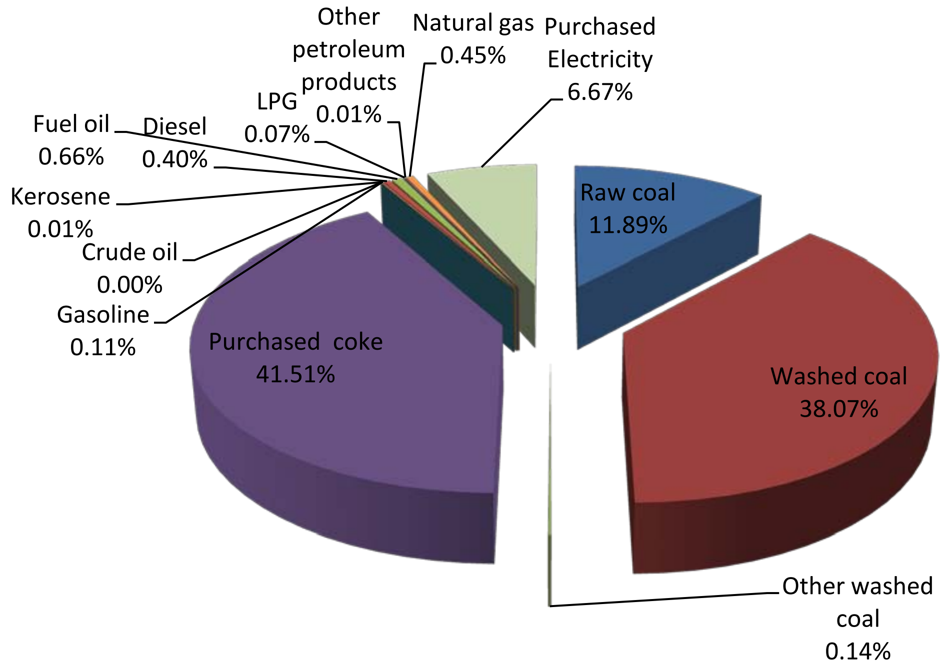


Source: U.S. DOE/EIA, 2010f

Notes:

1. These are fuel inputs to the U.S. iron and steel industry given the boundary defined in section 3.1.2. Therefore, the fuel conversion (e.g. from coal to coke) within the industry is not included in the figure above.
2. Electricity is in final energy and is not converted to primary energy.

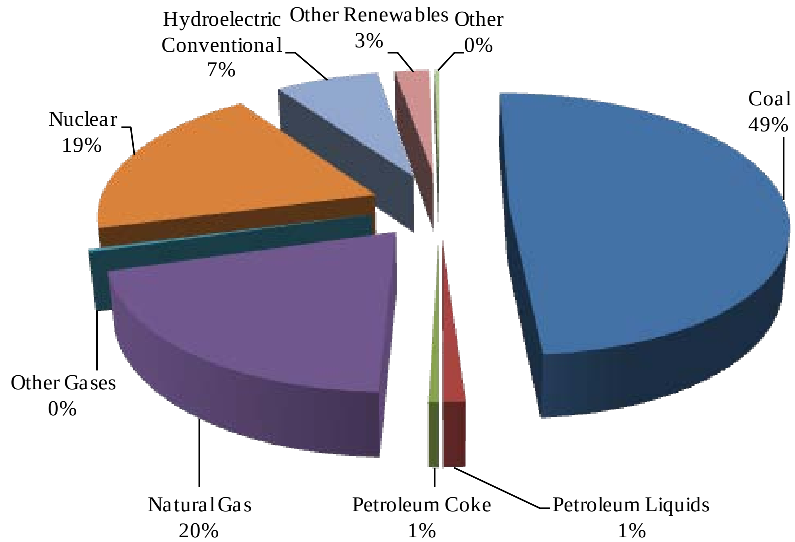
Figure 9: China 2006 Primary Energy Use (Fuel and Non-fuel) of Iron and Steel Industry



Source: China Iron and Steel Research Institute (CISRI) calculations based on NBS, 2010a.

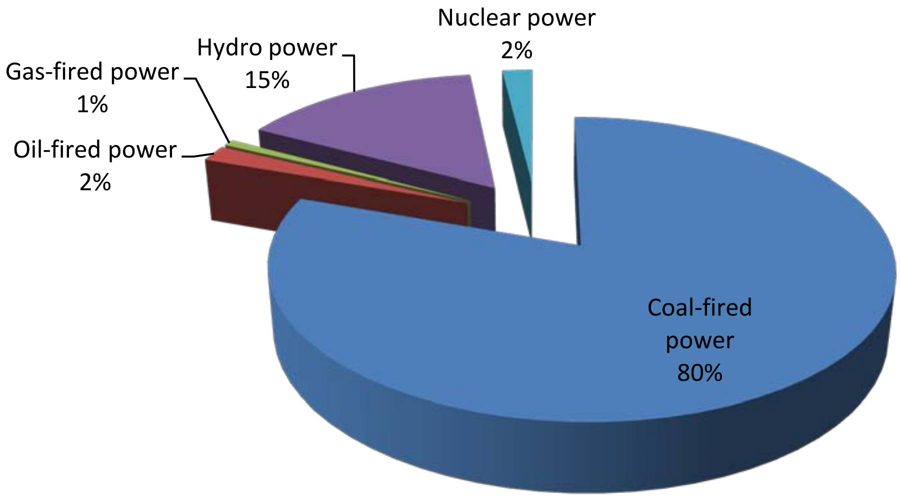
Figure 10 shows the fuel shares for electricity generation in the U.S. in 2006. Coal is the major source for power generation, accounting for about 49%, with around 20% of the electricity in the U.S. generated from natural gas, 19% from nuclear energy, and around 10% from hydroelectric and other sources of renewable energy. In contrast, 80% of electricity in China was generated by coal in 2006.

Figure 10: Electricity Generation Fuel Shares in the U.S. in 2006



Source: U.S. DOE/EIA, 2010g

Figure 11: Electricity Generation Fuel Shares in China in 2006



Source: NBS, 2010a

The comparison of fuel shares in 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). Power generation efficiency (coal consumption of net power supply, including plant self use) in both countries are similar.

5.4.3. Product Mix

Various final steel products have different energy requirements in the rolling/casting/finishing processes. Therefore, the final product mix is another key variable that should be considered when reviewing the results of the energy intensity comparison of the two countries. Table 40 and Table 41 show the final product mix of the iron and steel industry in the U.S. and China, respectively.

Table 40: Final Product Mix of the Iron and Steel Industry in the U.S. in 2005 and 2006

	Quantity (thousand metric tons)		Percentage	
	2005	2006	2005	2006
Shipments by steel type:				
Carbon steel	88,800	92,700	93.25	93.33
Alloy steel	4,700	4,740	4.94	4.77
Stainless steel	1,730	1,890	1.81	1.90
Total	95,200	99,300	100.00	100.00
Steel mill products:				
Ingots, blooms, billets and slabs	1,160	1,500	1.22	1.51
Wire rods	1,760	1,840	1.84	1.86
Structural shapes, heavy	6,730	7,220	7.07	7.26
Steel piling	582	582	0.61	0.59
Plates, cut lengths	5,830	6,490	6.12	6.53
Plates, in coils	3,470	3,150	3.64	3.17
Rails	633	726	0.66	0.73
Railroad accessories	196	225	0.21	0.23
Bars, hot-rolled	6,300	7,060	6.61	7.11
Bars, light-shaped	1,470	1,490	1.54	1.50
Bars, reinforcing	6,350	6,830	6.67	6.87
Bars, cold finished	1,470	1,420	1.55	1.43
Tool steel	20	16	0.02	0.02
Pipe and tubing, standard pipe	1,030	1,140	1.08	1.15
Pipe and tubing, oil country goods	2,030	2,100	2.14	2.12
Pipe and tubing, line pipe	366	503	0.38	0.51
Pipe and tubing, mechanical tubing	998	966	1.05	0.97
Pipe and tubing, pressure tubing	38	43	0.04	0.04
Pipe and tubing, stainless	14	15	0.01	0.01
Pipe and tubing, structural	130	141	0.14	0.14
Pipe for piling	11	10	0.01	0.01
Wire	607	681	0.64	0.69
Tin mill products, blackplate	163	136	0.17	0.14
Tin mill products, tinplate	1,860	1,840	1.95	1.85
Tin mill products, tin-free steel	493	544	0.52	0.55
Tin mill products, tin coated sheets	96	93	0.10	0.09
Sheets, hot-rolled	20,300	19,400	21.30	19.55
Sheets, cold-rolled	11,600	12,000	12.19	12.13
Sheets and strip, hot dip galvanized	13,600	14,800	14.29	14.94
Sheets and strip, electrogalvanized	2,240	2,370	2.35	2.39
Sheets and strip, other metallic coated	1,710	1,890	1.80	1.90
Sheets and strip, electrical	424	481	0.45	0.48
Strip, hot rolled	36	38	0.04	0.04
Strip, cold rolled	1,520	1,500	1.59	1.51
Total	95,200	99,300	100.00	100.00

Source: U.S. Geological Survey (USGS), 2008

Table 41: Final Product Mix of the Iron and Steel Industry in the China in 2005 and 2006

Year	2005	2006
Steel production, Mt/year	325.90	390.77
Bars, Mt/year	187.83	217.59
Plates, Mt/year	109.45	135.36
Pipes and tubes, Mt/year	26.14	35.52
Percentage of bars, %	57.63	55.68
Percentage of plates, %	33.59	34.64
Percentage of pipes and tubes, %	8.02	9.09

Source: Editorial Board of the China Iron and Steel Industry Association Yearbook, 2006.

5.4.4. Penetration of Energy-Efficient Technologies and Practices

Data on penetration of energy-efficient technologies and practices in China and the U.S. are not fully comparable. The types of information available regarding the penetration of energy-efficiency technologies in these two countries are different. Therefore, a direct comparison of the penetration of certain technologies is not possible. The only technology that can be compared directly is the penetration of EAF steel production technology that was presented above. The application of energy-efficient technologies depends on various factors such as raw materials, energy sources, cost, availability, product mix, and the regulatory regime in the country.

Penetration of energy-efficient technologies and practices in the U.S. iron and steel industry
In 2006, out of 348 establishments[20] in the U.S. iron and steel industry, only 17 use cogeneration technology[21] (U.S. DOE/EIA, 2010k). Also, 40 establishments report using computer control of the building-wide environment (e.g. space-heating equipment, cooling equipment, lights), 199 use adjustable speed motors, and 88 use oxy-fuel firing (U.S. DOE/EIA, 2010j). In 2002, plants provided additional information regarding their energy management activities (Table 42).

Table 42: Energy Management in U.S. Iron and Steel Industry (NAICS 331111**)**

Item	# of plants [a, b]
Participation in One or More of the Following Types of Activities	412
Energy Audits	287
Direct Electricity Load Control	214
Special Rate Schedule [c]	118
Standby Generation Program	55
Equipment Rebates	30
Power Factor Correction or Improvement	213
Interval Metering (to manage energy use for programs such as real-time pricing)	69
U.S. Environmental Protection Agency's Energy Star Program	-
U.S. Environmental Protection Agency's Green Lights Program	12
Other Federally Sponsored Energy or Environmental Management Program	5
Equipment Installation or Retrofit for the Primary Purpose of Improving Energy Efficiency Affecting:	
Steam Production/System	172
Compressed Air Systems	110
Direct/Indirect Process Heating	131
Direct Process Cooling, Refrigeration	47
Direct Machine Drive	199
Facility HVAC	150
Facility Lighting	148
Equipment Installation or Retrofit for the Primary Purpose of Using a Different Energy Source	49
Other	7
Full-Time Energy Manager	17

[a] 2006 information is not available.
[b] This count includes only those establishments that reported this activity in 2002.
[c] Examples are interruptible rates and time-of-use rates.
Source: U.S. DOE/EIA, 2010i

[20] "Establishments" includes those units which reported any of the five energy-saving technologies listed by MECS in use any time in 2006, plus those units where usage of those technologies was not ascertained (U.S. DOE/EIA, 2010k).
[21] This count includes only those establishments that reported this cogeneration technology in use any time in 2006 (U.S. DOE/EIA, 2010k).

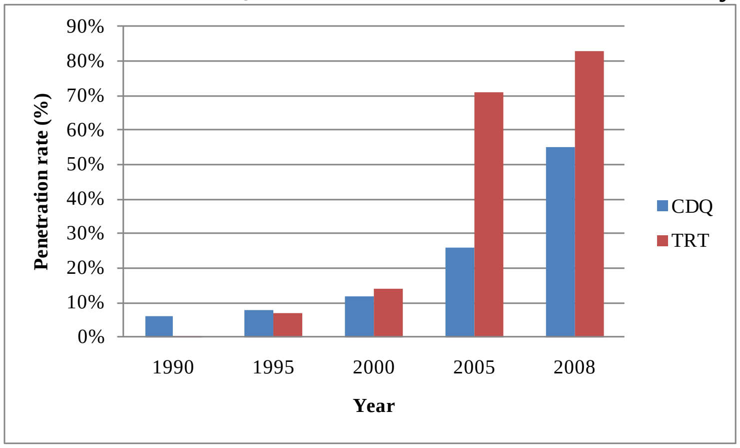
Penetration of energy-efficient technologies and practices in the China's iron and steel industry

With the rapid development of China's iron and steel industry, energy-efficient technologies and processes have also greatly improved. Penetration of equipment as well as technologies for waste heat and waste energy recycling has increased. The main technologies that are utilized include: coke dry quenching (CDQ) for the coking process, top-pressure recovery (TRT) for blast furnaces, pulverized coal injection, and comprehensive energy management and utilization technologies. Other technologies, such as low temperature waste heat recovery, are also being used gradually. The application and popularization of these energy-saving technologies have helped China to improve its energy efficiency in iron and steel industry. Many Chinese steel companies have benefited from the Kyoto Protocol's Clean Development Mechanism for additional funding for implementing CDQ and TRT projects in their plants, whereas the U.S. steel plants did not have such opportunities for outside investment-related funding.

1) CDQ and TRT technologies

Figure 12 shows the penetration levels of CDQ and TRT in China's iron and steel industry since the 1990s, showing that they have increased significantly in recent years. Both CDQ and TRT have great energy-saving impacts. For example, CDQ can recycle more than 80% of the sensible heat of the heated coke. By quenching every ton of coke, it can recycle 0.45~0.6 ton of steam (at 4.5 MPa) on average (Shangguan, et al., 2009).The recycled steam can be fed into the streaming pipelines directly, or can be used for power generation as well. If using pure condensing steam turbines, on average 95~110kWh of electricity can be generated for quenching every ton of coke.

Figure 12: Use of CDQ and TRT in China's Steel Industry



Sources: Gao and Gao, 2004; ISD-CISIA and ISIMI, 1991; Zheng, et al., 2005; Shan, 2008; Xue, 2007; EDRC, 2009; ISD-CISIA and ISIMI, 1996; Zhao and Jiang, 1999; EDRC, 2006; Zhang, 2006.

Note: Penetration ratio of CDQ is the ratio at internal coking factories of steel mills.

TRT can recycle large amounts of fuel to produce electricity without consuming any fuel. According to statistical reports, if operated under good conditions, it can recycle 25~50 kWh per ton of steel, which can meet 30% electricity demand of the blast furnace. From 2000 to 2007, the number of blast furnaces with TRT in the Chinese steel plants increased from 33 to more than 400. By the end of 2007, all the blast furnaces with a capacity larger than 2000 m^3 are equipped with TRT, and 95% of the blast furnaces with a capacity larger than 1000 m^3 have TRT as well.

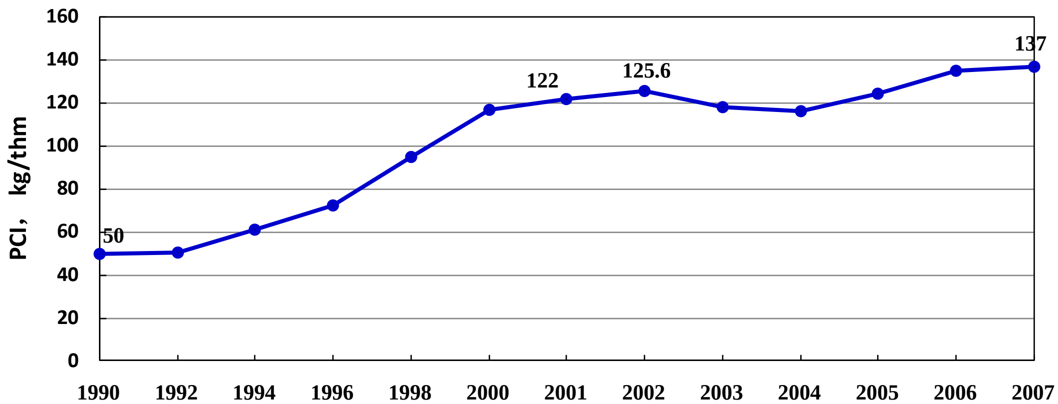
In addition, all of the TRT on blast furnaces (smaller than 1000 m^3) are dry-dust removal. Dry-dust removal has also been promoted into larger blast furnace (larger than 1000m^3). For instance, the TRT on two large blast furnaces (5500 m^3) in Tangshan Steel Mill (in Cao Pei Dian, China) utilize dry-dust removal. TRT with dry-dust removal can improve its efficiency by 30~40%, if compared to wet-dust removal, and reaches to 54kWh/t of steel (Shangguan, et al., 2009; ECERTF, 2008).

Considering the scale of China's iron and steel industry, the energy-saving impacts of both CDQ and TRT are significant. These technologies can contribute greatly to energy conservation and CO_2 emission reduction in the Chinese iron and steel industry.

2) Pulverized Coal Injection

Pulverized coal injection can reduce coke consumption in the blast furnace. Recently, the level of pulverized coal injection in the Chinese iron and steel industry has increased to 134 kg/t iron, which reaches the advanced international level (world average: 125 kg/t iron),[22] as presented in Figure 13.

Figure 13: PCI (Pulverized Coal Injection) Use in the Chinese Steel Industry, 1990-2007



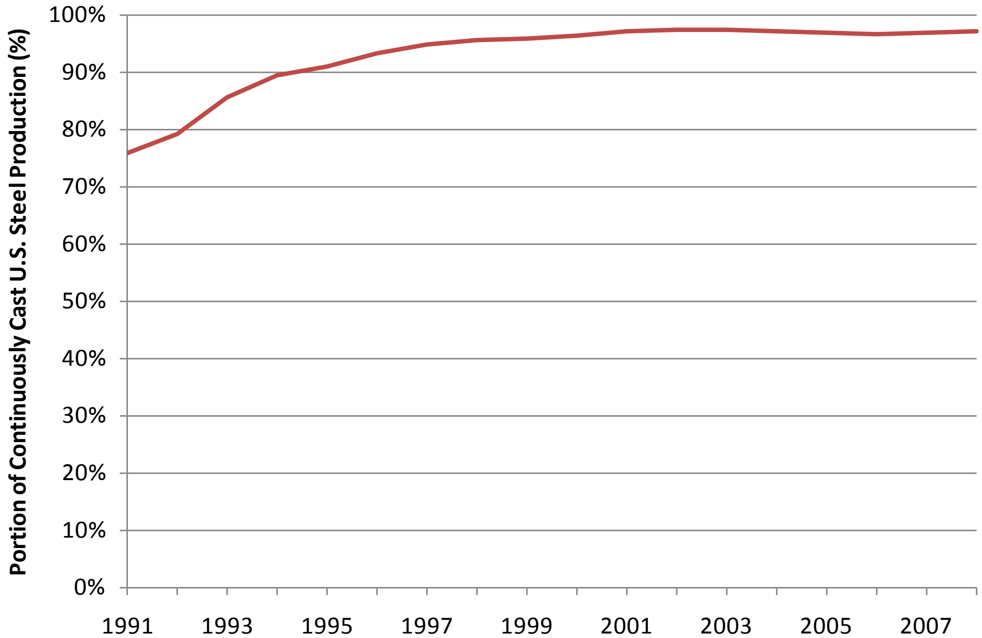
Source: Yin R, 2009.

3) Continuous casting

The ratios of continuous casting in the U.S. and China since 1990s are displayed in Figure 14 and Figure 15. Figure 14 shows that the continuous casting ratio in the U.S. had already reached a high level in the 1990s (about 76% in 1991). But the ratio in China during the same period was low, only 25% in 1990. With the development of China's iron and steel industry, the ratio of continuous casting increased rapidly, reaching 86.97% in 2000, and 98.57% in 2006. Currently, the continuous casting ratios in China and the U.S. are very close, with 97% in the U.S. in 2006. The improvement of the continuous casting ratio in China has had positive impacts on energy conservation and emission reduction in the Chinese iron and steel industry.

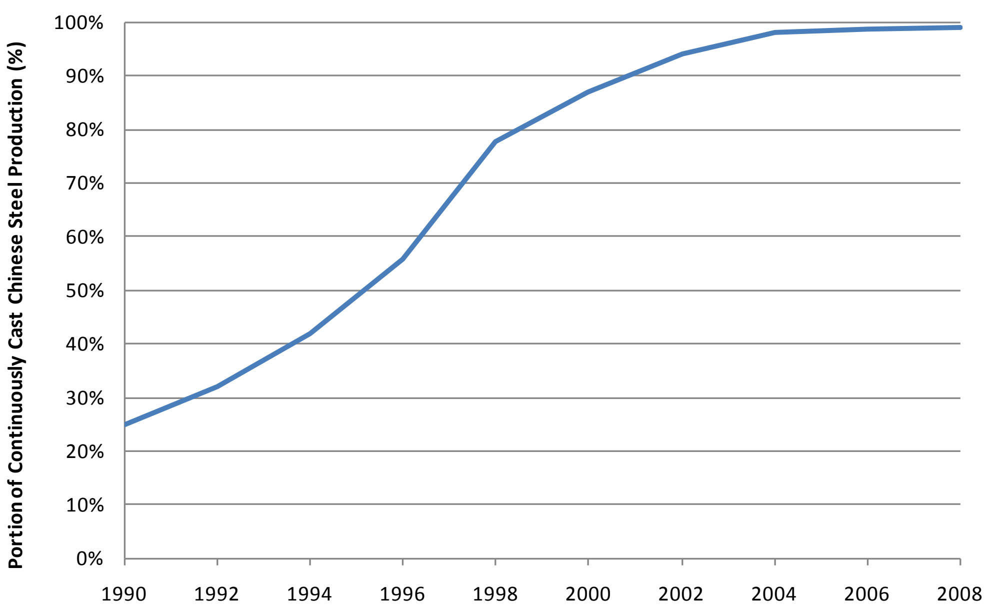
[22] The world average is 125 kg/t iron (IEA, 2007).

Figure 14: Portion of Continuously-Cast U.S. Steel Production (1991-2008)



Source: USGS, 2010b.

Figure 15: Portion of Continuously-Cast Chinese Steel Production (1990-2008)



Source: Yin R, 2009.

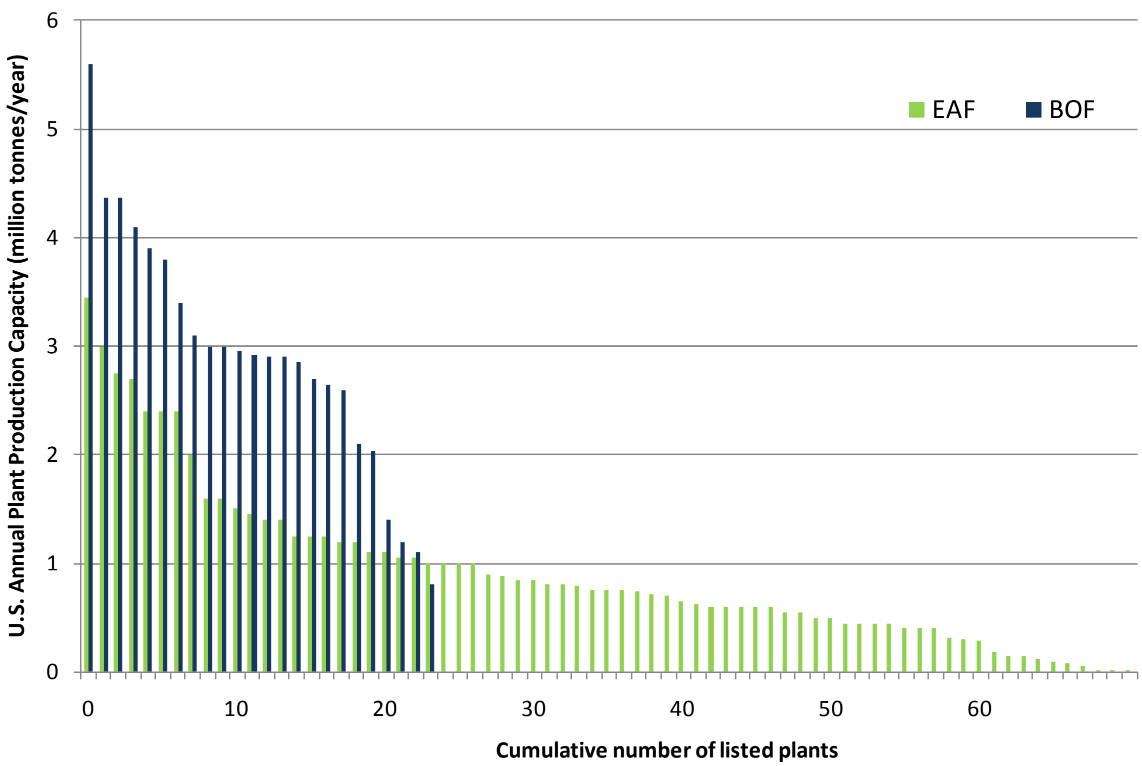
The analysis on the penetration and energy savings of energy-efficient technologies shows that the U.S. and China have their own characteristics in applying energy-saving technologies.

Energy management related technologies are emphasized more in the US. China has adopted more waste heat/energy recovery technologies, in addition to energy management related technologies.

5.4.5. Scale of Equipment

The U.S. steel industry is characterized by consolidated, large-scale integrated steel producers and largely fragmented, mini-mill secondary producers. Figure 16 illustrates the distribution of self-registered U.S. steel production facilities by annual capacity. The average capacity of integrated BOF plants in the registry was 2.9 Mt per year and 0.93 Mt for the EAF plants.

Figure 16: Distribution of Listed US Plant Facilities by Production Capacity (2007)



Source: Association for Iron and Steel Technology (AIST), 2008.

Overall, the Chinese iron and steel industry still has many small and inefficient enterprises or plants. There are many different types of steel enterprises in China as well, including large-scaled integrated steel enterprises, independent rolling enterprises, and even independent iron-making enterprises. Thus, the total number of iron and steel enterprises in China at the national level is quite large, and it is almost impossible to have the production and capacity information for every enterprise. But as the production from the key enterprises (medium-and-large sized) represents 82.9% of the national crude steel production (421 Mt in 2006), these plants can represent the level of major production equipment.

In 2006, China had 85 key medium-and-large sized enterprises, with a total crude steel production of 349 Mt. The average annual production capacity of each key enterprise was 4.1 Mt. From the perspective of average annual production capacity, China is larger than the U.S. Since 2006, China has been implementing a policy focused on phasing out inefficient capacities in energy intensive sectors. The overall level of the Chinese iron and steel industry is increasing gradually, along with the implementation of the phasing-out policy. From 2006 to 2009, China has phased out 82 Mt of iron-making production capacity and 60 Mt of steel-making production capacity (MIIT, 2010).

The key issue in China is the large share of small blast furnaces. The total number of blast furnaces in key enterprises in China in 2007 was 483 (EBCISIY, 1992-2009) among which 363 blast furnaces had a capacity under 1000 m^3. However, there were around 30 blast furnaces in the U.S. in 2007 with average capacity of 1500 m^3.

6. Findings

A key finding of this analysis is that it is possible to develop a methodology in which the energy intensity of steel production of different countries can be compared. The methodology must clearly define the boundaries and energy conversion factors used in the analysis. The boundary definition must address how to account for imported and exported inputs and intermediate products.

Another key finding is that it is not possible to accurately compare the energy intensity of steel production of different countries without considering multiple scenarios. There is no single scenario that best compares different countries; each scenario presents different issues in terms of the accuracy and "fairness" of the comparison. For example, for this comparison of the U.S. and Chinese steel industries, the results change when the difference in production structure is taken into account when comparing the energy intensity values. For other countries, key differences might be found in the fuel or electricity conversion factors. Thus, it is necessary to present multiple scenarios to accurately convey the reasons behind the calculated energy intensities.

Thus, the base case 2006 comparison of U.S. and Chinese steel industries using identical boundary definitions for the steel industry, country-specific fuel and electricity conversion factors, and world average intensity values for net imported products, found that the final energy intensity of the Chinese steel industry is 23.11 GJ/t crude steel while that of the U.S. steel industry is 14.90 GJ/t crude steel (36% lower) and the primary energy intensity of the Chinese steel industry is 26.3 GJ/t crude steel while that of the U.S. steel industry is 19.98 GJ/t crude steel (24% lower).

A number of scenarios were also analyzed to identify which variables had the largest impact on the base case energy intensity values. First, the effect of the fuel conversion factors was examined in Scenario 1. Instead of using country-specific fuel conversion factors, IEA typical fuel conversion factors were used. All other variables were the same as in the base case. For this scenario, the final energy intensity of the Chinese steel industry is 22.65 GJ/t crude steel while that of the U.S. steel industry is 14.83 GJ/t crude steel (35% lower) and the primary energy intensity of the Chinese steel industry is 25.85 GJ/t crude steel while that of the U.S. steel industry is 19.91 GJ/t crude steel (23% lower). Thus, Scenario 1 shows that for these two countries, there is very little impact on the energy intensity values if standardized fuel conversion factors are used instead of country-specific factors.

Next, the impact of the electricity conversion factors was examined. For Scenario 2, world average electricity conversion factors were used instead of country-specific factors. All other variables are the same as in the base case. For this scenario, the final energy intensity of the Chinese steel industry is 23.11 GJ/t crude steel while that of the U.S. steel industry is 14.90 GJ/t crude steel (36% lower), which is identical to the base case. The primary energy intensity of the Chinese steel industry in this scenario is 25.77 GJ/t crude steel while that of the U.S. steel industry is 19.09 GJ/t crude steel (26% lower). Electricity conversion factors have more of an influence on the calculation of primary energy, which accounts for electricity generation, transmission, and distribution losses. Using the world average electricity values lowered the overall primary energy intensity in both countries, but the reduction was greatest on the U.S. value due to the larger share of EAF steel in the U.S.

A 3rd Scenario was developed to evaluate the combined impact of using average fuel and electricity conversion factors. For this scenario, the final energy intensity of the Chinese steel industry is 22.65 GJ/t crude steel while that of the U.S. steel industry is 14.83 GJ/t crude steel (35% lower) and the primary energy intensity of the Chinese steel industry is 25.32 GJ/t crude steel while that of the U.S. steel industry is 19.02 GJ/t crude steel (25% lower). Comparison of Scenario 3 and the Base Scenario indicates that variation among country-specific fuel and electricity conversion factors does not account for a large portion of the energy intensity difference.

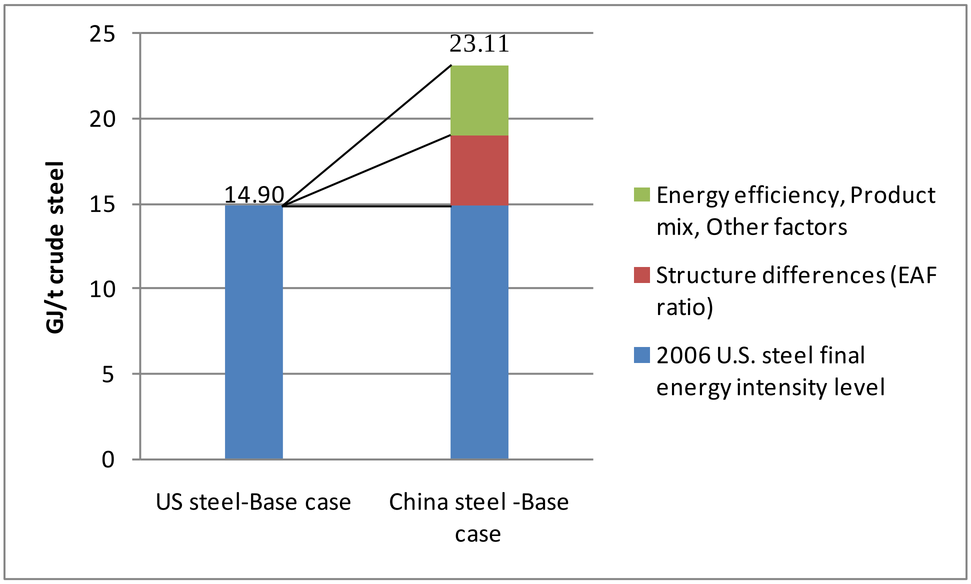
In order to evaluate the impact of the different structures of the steel industry in the two countries, Scenarios 4 and 5 were developed. Scenario 4 is the same as the base case, but each country's energy intensity is calculated using the EAF share in the other country. In 2006, the share of EAF steel production in total steel production was 10.5% in China and 56.9% in the U.S. When the U.S. energy intensity is calculated using the share of EAF steel production in China, the final energy intensity is 22.96 GJ/t crude steel and the primary energy intensity is 26.08 GJ/t crude steel. When the Chinese energy intensity is calculated using the share of EAF steel production in the U.S., the final energy intensity is 18.44 GJ/t crude steel and the primary energy intensity is 22.8 GJ/t crude steel. This calculation shows that the structure of the steel industry heavily influences the energy intensity and that if the U.S. steel industry was structured the same as the Chinese steel industry, the U.S. steel industry would be only 0.6% less energy-intensive than China in terms of the base case final energy and 0.84% less energy-intensive in terms of primary energy. It also shows that if the Chinese steel industry was structured the same as the U.S. steel industry, it would still be 19.2% more energy-intensive than the U.S. in terms of final energy and 12.37% more energy-intensive in terms of primary energy.

Scenario 5 is similar to Scenario 4, except that instead of country-specific fuel and electricity conversion factors, the IEA and v conversion factors used in Scenario 3 are used. Like Scenario 4, this scenario evaluates the impact of different structures on the energy intensity value. When the U.S. energy intensity is calculated using the share of EAF steel production in China, the final energy intensity is 23.04 GJ/t crude steel and the primary energy intensity is 26.09 GJ/t crude steel. When the Chinese energy intensity is calculated using the share of EAF steel production in the U.S., the final energy intensity is 17.99 GJ/t crude steel and the primary energy intensity is 22.48 GJ/t crude steel. This calculation shows that the structure of the steel industry heavily influences the energy intensity and that if the U.S. steel industry was structured the same as the Chinese steel industry, the U.S. steel industry would be only 0.3% less energy-intensive than China in terms of final energy and the Chinese steel industry is 0.4% less energy-intensive than the U.S. in terms of primary energy. It also shows that if the Chinese steel industry was structured the same as the U.S. steel industry, it would still be 17.2% more energy intensive than the U.S. in terms of final energy and 7% more energy-intensive in terms of primary energy. These higher differences could be because of the fact that the energy intensity of EAF steel production in China is significantly higher than that of in the U.S. (see Table 39).

The final scenario developed for this analysis, Scenario 6, evaluated the impact of the different electricity final to primary conversion factors in each country. All other variables are the same as in the base case. This analysis reflects the difference in the generation, transmission, and distribution losses experienced in each country. As explained earlier, the final to primary conversion factors used in this analysis for 2006 are 0.376 kgce/kWh and 0.379 kgce/kWh for China and the U.S., respectively. This calculation shows that the there is little impact on the energy intensity value for each country if the final to primary conversion factor of the other country is used because the electricity conversion factors in two countries are similar.

Figure 17 shows the effect of various factors on the differences in energy intensity of iron and steel industry in China and the U.S. It should be noted that this figure is just for illustration purpose. The magnitude of each factor could not be determined because of the lack of data. However, it is found that the structural difference (i.e. difference in EAF ratio) between the steel industries in two countries has the highest contribution to the energy intensity difference.

Figure 17: Qualitative Effect of Key Factors on the Energy Intensity of Iron and Steel Production in China and the U.S.



(Note: This figure is the representative of the rough calculation for the contribution of different factors in the differences in energy intensity based on the scenario analysis done in this study. Further research is required to determine the exact magnitude of each factor.)

7. Discussion, Policy Implications, and Future Research

7.1. Discussion

The findings presented above indicate that using a series of scenarios to evaluate the impact of different variables on the calculated energy intensity value for the steel industry in China and the U.S. 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 U.S. steel industry. This is primarily, but not only, due to the difference in the structural composition of the two industries, with the U.S. producing a significantly greater share of the less energy-intensive EAF steel.

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

The comparisons of energy consumption of 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 which represent the advanced level in the world (i.e. Baosteel Co., Ltd). If this analysis focused only 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/tonne crude steel more than that of the key steel enterprises).

On the other hand, much of China's steel production facilities have been constructed in recent years while most of the US steel production capacity is 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.

It is also important to note that during this analysis problems were discovered related to the availability and reliability of the data provided for the Chinese and U.S. iron and steel industries. Hence, both countries should make efforts to improve data collection and management.

7.2. Policy Implications

A number of policy implications result from this study. First, it should be noted that even with the use of a common methodology, it is difficult to provide policy-makers with a single energy intensity value for steel production for each country to be used to compare energy intensity across countries. Such values are often sought by policy-makers when making decisions related to energy, greenhouse gases, and competitiveness issues. This analysis illustrates that such a single indicator does not provide enough information to fully explain country-specific conditions.

In the case of the U.S. and China comparison, the key explanatory variable is the share of EAF steel. When comparing other countries, there may be other explanatory variables that are important. Thus, when providing policy-makers with a single indicator value for international comparisons, it is essential that explanatory variables also be evaluated and key results conveyed to policy-makers to accompany the single energy-intensity value.

This analysis also found that both countries could strengthen data collection for the iron and steel industry in order to both better understand trends in the industry and to more easily allow for the use of the methodology outlined in this report. For China, a number of adjustments had to be made to the data reported by the National Bureau of Statistics in order to make the comparison with the U.S. based on the outlined methodology. China could strengthen energy data collection and data management and consider adopting a system more similar to the system in the U.S. in which a census of manufacturing industries is conducted every four years. The U.S. could strengthen data collection and reporting related to facility and technology-level adoption of energy-efficient technologies and measures, such as CDQ and TRT.

During this study, it was also found that there is a lack of research-level communication and exchange between the Chinese and U.S. iron and steel industries, especially in the areas of iron and steel technologies, energy efficiency, and environmental protection. Since the Steel Sector Task Force of the Asia Pacific Partnership will move to the Global Superior Energy Performance (GSEP) effort at the U.S. Department of Energy, there is potential for GSEP to establish a stronger, research-level sectoral communication platform among different countries, to learn from each other and to promote the mutual exchange of technical expertise as well as energy-efficient and environmental-protection technologies.

7.3. Future Research

Based on this analysis, there are three recommendations for future research. The first involves improving the analysis of the difference of application of energy-efficiency technology in iron and steel industry in both China and United States. This work may involve working with iron and steel research institutions or associations in both countries, or conducting surveys of key steel enterprises. Better information on both the penetration of energy-efficiency technologies as well as the barriers to the implementation of such options would be useful for both countries.

The second future area of research involves extending the current methodology and analysis to cover energy-related carbon dioxide emissions from steel production. Both the U.S. and China have committed to 2020 greenhouse gas emissions reduction targets under the Copenhagen Accord. In addition, China's 12^{th} Five Year Plan includes a carbon dioxide emission reduction target of reduction of CO_2 emissions per unit of GDP by 17% between 2011 and 2015. Such an analysis will require additional methodological definitions and data, but could provide interesting and useful comparative information.

Finally, the third area of future research involved extending this analysis to include other key steel producing countries, such as Japan, India, Germany, and Brazil. Policymakers in both China and the U.S. may gain additional insights in how to improve domestic energy efficiency through further comparison with other countries which identifies not only the differences in energy intensity, but the key variables that explain the differences.

Different regulatory regimes in China and the U.S. can also influence the energy intensity of the steel industry in these two countries. For example, compliance with environmental regulations sometimes causes significant energy expenditures (e.g. in baghouse fans and filtration systems). Environmental regulations in the U.S. and some other developed countries are stringently enforced, while this may not always be the case in China. While the detailed comparison of the environmental regulations for the steel industry in China and the U.S. and quantifying the amount of energy used to meet those environmental regulations are beyond the scope of this study, this could be a subject for future research.

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Appendix

Table 43: Unit conversion factors

From this unit	Multiply by	To get this unit
1gce	0.0081	kwh
1MJ	0.0341208	kgce
1toe	1.4286	tce
1 million Btu	1055.056	MJ
1short ton	0.907	metric tonne
1 ft3	0.028316847	m3
1 barrel [US, petroleum]	158.987	liter
1lb	0.4536	kg