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AN INITIAL VIEW ON METHODOLOGIES FOR EMISSION BASELINES: IRON AND STEEL CASE STUDY

INFORMATION PAPER

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FOREWORD

This document was prepared in June 2000 at the request of the Annex I Expert Group on the United Nations Framework Convention on Climate Change. The Annex I Expert Group oversees development of analytical papers for the purpose of providing useful and timely input to the climate change negotiations. These papers may also be useful to national policy makers and other decision-makers. In a collaborative effort, authors work with the Annex I Expert Group to develop these papers. However, the papers do not necessarily represent the views of the OECD or the IEA, nor are they intended to prejudge the views of countries participating in the Annex I Expert Group. Rather, they are Secretariat information papers intended to inform Member countries, as well as the UNFCCC audience.

The Annex I Parties or countries referred to in this document refer to those listed in Annex I to the UNFCCC (as amended at the 3rd Conference of the Parties in December 1997): Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, the European Community, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Luxembourg, Monaco, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russian Federation, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom of Great Britain and Northern Ireland, and United States of America. Where this document refers to "countries" or "governments" it is also intended to include "regional economic organisations", if appropriate.

This case study is part of a larger analytical project undertaken by the Annex I Experts Group to evaluate emission baselines issues for project-based mechanisms in a variety of sectors. Additional work will seek to address further the issues raised in this and other case studies.

ACKNOWLEDGEMENTS

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IRON AND STEEL CASE STUDY

1. Executive summary

The iron and steel industry is the largest energy consuming manufacturing sector in the world. In 1990, its global energy consumption was estimated to be 18-19 exajoules (EJ), or 10-15% of total annual industrial energy consumption. The associated CO_2 emissions are estimated to be 1425 Mt. In 1995 this amount increased to 1442 Mt CO_2, equalling about 7% of global anthropogenic CO_2 emissions.

Before an international regime for Joint Implementation (JI) or the Clean Development Mechanism (CDM) can be implemented, the problem of setting baselines needs to be solved in a satisfactory way.

This report examines the possibilities for establishing multi-project baselines in the iron and steel sector and is based on a general assessment of the iron and steel sector with examples from India, Brazil and Poland. The report concludes that it is possible to define multi-project baselines in the iron and steel sector using standardised energy intensities for different production routes. The standardised baselines would apply to the production of crude steel (the intermediate product in steel making), as final products differ in energy intensity. Baselines may also need to take the product mix and quality of coal and iron ore inputs into account when determining the credits available for potential projects in the sector. Given the international homogeneity of the sector, it is suggested that standardised energy intensities could apply to similar projects across countries.

1.1 The iron and steel process and potential for emission savings

The iron and steel making process may be divided into five different steps:

1. treatment of raw materials;
2. iron making;
3. steel making;
4. casting; and
5. rolling and finishing.

Emissions (predominantly CO_2) from iron and steel production are caused by the combustion of fossil fuels, the use of electrical energy and the use of coal and lime as feedstock.

There are different production routes with substantially different energy intensities in which steel can be manufactured from iron ore or scrap. However, as step 2 (iron making) is the most energy intensive, steel production from minimills is generally much less energy and GHG intensive than steel production from an integrated steel mill.

Production is primarily undertaken through three different processes:

- Integrated Steel Plants (ISPs);
- Scrap based Electric Arc Furnaces (scrap-EAF); and
- Direct Reduced Iron Electric Arc Furnaces (DRI-EAF).

The dominant steel production processes are the integrated steel mill (where steel is produced from iron ore by following steps 1 - 5 above) and the minimill (where steel is produced from scrap steel or substitutes by following steps 3 - 5 above).

The greenhouse gas emissions associated with iron and steel production depend on how much energy is used and the greenhouse gas intensity of that energy. Energy intensities are used as the standardised component of emission baselines instead of CO_2 intensities because there is lower variation in the former. Using energy intensities avoids having to effectively proscribe which fuel should be used, the relative proportions of fuel and electricity and the GHG-intensity of electricity used in the steel production process.

There are a number of potential energy-related JI/CDM project types in the iron and steel sector. These include:

- increasing the energy efficiency of steel production (*e.g.* by installing more efficient equipment and/or implementing good housekeeping measures);
- changing the manufacturing process (*e.g.* by installing new equipment); or
- changing the fuel used for the direct reduction of iron (*e.g.* from coal to gas).

1.2 Benchmarking versus technology matrix

Several methods for multi-project baseline development have been described in the literature. This analysis considers two: benchmarking (setting a standardised value for energy use for a particular process) and technology matrix (setting a standardised value for energy use for a particular technology).

The differences in the environmental credibility (additionality requirement) between the two baseline types are relatively small. However, the data requirements for the latter are large, particularly for the inclusion of technologies that do not cause step change difference in performance. Such data requirements translate into substantially higher costs for development. Given the increased transparency possible with a benchmarking approach and the difficult data demands of the matrix approach, a baseline based on standardised energy values for different production processes (“benchmarks”) is recommended.

1.3 Stringency of baselines

This report proposes setting different standardised energy intensities for the different major steel production routes, *i.e.*:

- Integrated Steel Plants (ISPs);
- Scrap based Electric Arc Furnaces (scrap-EAF); and
- Direct Reduced Iron Electric Arc Furnaces (DRI-EAF).

The benchmark value in the benchmarking approach, or the standard set of technologies in a technology matrix, can be determined based on various assumptions. These different assumptions result in baselines that are more or less stringent.

The levels of stringency studied are:

1. best practice world wide level;
2. world wide average level (with and without an autonomous energy efficiency improvement);
3. country level (average and “better than average”); and
4. a “graduated crediting” level, which takes into account both technological best practice and country average levels.

This analysis evaluates the stringency options against a set of selected criteria, including environmental additionality, potential volume of projects, transparency and verifiability and baseline costs (Table ES). This analysis indicates that any particular baseline approach involves trade-offs between factors, with no single option emerging as a unique “best” solution in all cases.

However, for refurbishment of existing plants, a benchmark on the world-wide average is considered to be a good trade-off between environmental credibility and the potential volume of projects.

For new capacity, a benchmark based on the world-wide best practice (which is equal to marginal technology addition) is considered the most suitable.

1.4 Potential for JI/CDM projects

Potential project volumes under each level of stringency are quantified in three case study countries. The analysis suggests that the likely number of that would meet minimum standards is not high, whichever approach is used.

One potential method to increase the potential volume of projects while still preserving the environmental credibility may be to provide credit in a progressive way. For example, refurbishing plants so that they perform better than the country or production process average may result in these projects being eligible for some credits even if the refurbished performance does not reach BAT standards. Shortening the emissions timeline for such “intermediate level” projects would have a similar effect on the number of credits they generate.

1.5 Data availability and other issues

In general, data availability is limited with respect to the iron and steel sectors. However, the detailed research undertaken for the India case study suggests that the necessary data may be available, but that their collection may require additional research (and cost).

It is difficult to give general rules regarding emission timelines, mainly because the average lifetime of an industrial technology is very difficult to determine, as it can vary substantially from site to site (depending on its operation, maintenance and thus, indirectly, on the availability of funds). This also means that the current age of the stock is therefore not considered to be a useful indicator for determining the additionality of CDM/JI projects.

Table ES

Scoring the proposed baselines for refurbishment projects in the iron and steel sector against selected criteria

Criteria	Benchmarking[1]					Technology matrix[2]		
	World-wide best practice	World-wide average	World-wide average with AEEI	Country average	Graduated crediting	World-wide best practice	World-wide mode	Country mode
Environmental	++	- to +[5]	-- to +	-- to ++[6]	- to +	++	++[5]	-- to ++[6]
Additionality[3]								
Potential volume of projects	--	+	+	0 to ++[7]	0 to +	--	+	0 to ++ [7]
Transparency and verifiability	++	++	++	+	-/+	++	+	+
Costs to draw up the baseline system[4]	++	+	+	+	+/-	-	--	-
	[low cost]						[high cost]	

2 Introduction

This analysis proposes methodologies for developing multi-project baselines in the iron and steel industry and suggests potentially appropriate values for these baselines. The potential volume of projects under these different baselines is also estimated. Based on these inputs, conclusions and recommendations with regard to the possibilities for multi-project baselines in the iron and steel industry are given.

This section gives an overview of the global iron and steel sector, including the important players and the different processes and production routes. Also, an overview of energy consumption, carbon dioxide emissions and regional distribution thereof is discussed. This section ends with a description of the iron and steel sector in India, Brazil and Poland.

2.1 Iron and steel production processes

The iron and steel industry is the largest energy consuming manufacturing sector in the world. In 1990, its global energy consumption was estimated to be 18-19 exajoules (EJ), or 10-15% of the annual world industrial energy consumption (WEC, 1995). The associated CO_2 emissions are estimated to be 1425 Mt (De Beer *et. al.*, 1999). In 1995 this amount increased to 1442 Mt CO_2, equalling about 7% of global anthropogenic CO_2 emissions[1]. When mining and transportation of ore and coal are included, this share is near 10% of total emissions. Fossil fuel combustion is the primary source of GHG emissions from iron and steel production and energy costs represent 15-20% of steel manufacturing costs.

Currently, two processes dominate the global steel production. These may be generally be described as:

(a) the integrated steel mill, where steel is made by reducing iron ore in a blast furnace to make pig iron which is subsequently processed in an oxy-steel plant; and

(b) the minimill, in which steel is made by melting scrap or scrap substitutes in an electric arc furnace (EAF).

Other processes that are in use are either outdated, *e.g.* the open-hearth furnace, or so new that their share in the world steel production is still small, *e.g.* smelt reduction processes and direct reduction processes (*e.g.* Corex).

[1] These include energy related emissions as well as process emissions (Olivier *et. al.*, 1996).

The iron and steel making process may be divided into 5 different steps (see Figure 1):

1. treatment of raw materials;
2. iron making;
3. steel making;
4. casting; and
5. rolling and finishing.

At the end of step 3, an intermediate product (molten steel) is common to all production routes. The technologies and fuels used in the two main steel production processes can be used to further disaggregate steel production. This report examines how emission baselines could be standardised for four “process routes” to produce molten steel:

1. Blast Furnace - Basic Oxygen Furnace (BF-BOF);
2. Blast Furnace - Open Hearth Furnace (BF-OHF);
3. Scrap-based Electric Arc Furnace; and
4. Direct Reduced Iron - Electric Arc Furnace (either coal based or gas based).

The energy intensity of final steel products can vary substantially, but adjustments to emission baselines to take into account product differences are beyond the scope of this analysis.

The GHG emissions from iron and steel production in integrated steel mills are mainly from the combustion of fossil fuels for energy (heat), electrical energy and the use of coal and lime as feedstock. These emissions are primarily of CO_2, although very small amounts of CH_4 and N_2O may also be emitted. Only emissions of CO_2 are assessed in this case study. Emissions from feedstock use is mainly from step 2 and 3 and some from step 1.

The blast furnace is the most energy-intensive step in an integrated steel mill and requires about 11-15 GJ per tonne of pig iron produced. Of this amount approximately 7 GJ is used for the chemical reduction of iron ore to pig iron. In addition, energy input is required to raise the temperature to a level at which the chemical reduction can thermodynamically proceed at a sufficient rate. Carbon (from energy sources such as coal or coke) is used both as the reducing agent and as the energy input. The reducing agent (feedstock energy use) may constitute up to 50% of the total energy demand of an integrated steel mill. Accounting for which proportion of energy input results in energy-related emissions and which results in process-related emissions is ongoing.

Description of the steel production process

The integrated steel mill process starts with the production of coke (step 1) by heating metallurgical coal in the absence of air in coke ovens*. The coke oven gas is fed into the blast furnace (step 2) and the energy in the gas is used for the iron making. In some cases coke is (partially) purchased. Iron ore is agglomerated in sinter plants or pellets plants[2]. Coke, ore and lime are fed alternately in the blast furnace (step 2). A hot compressed stream of air, the blast, is blown from the bottom into the furnace. A gas is produced that reduces iron ore. Molten pig iron, rich in carbon, is tapped from the bottom and transferred in isolated vessels to the oxy-steel plant (step 3). Here carbon and other impurities are removed by oxygen blowing. Usually part of the input into the oxy-steel plant is scrap or other iron-bearing materials. The characteristics of the crude steel are adjusted in a series of ladle treatment processes. The casting of steel can either be continuous or batch (ingot casting) (step 4). The cast steel is reheated, rolled and sent to a number of finishing operations. These final operations depend largely on the type of steel that is produced. Integrated steel mills may use the Open Heart (OHF) furnace or the Basic Oxygen Furnace (BOF). The electric arc furnace mainly uses electrical energy. The largest part of the world steel production is made in integrated steel mills.

* This step and associated capital expenditure, energy use and GHG emissions, are avoided in the Corex process.

The ranges in energy use to produce molten steel for a given technology type are influenced by the quality of fuel and iron/scrap inputs, but also by variations in the relative proportion of fuel input used. The share of electricity in the total energy demand varies from plant to plant but is not reported separately. Based on statistics published by IISI (IISI, 1996) this share is estimated to range from 2.5 to 7% of the final energy use in an integrated steel plant. Integrated steel mills may generate (part of) their electricity use and purchase the remainder. Electricity can account for between 50-85% of total energy inputs to an EAF[3]. The GHG-intensity of steel produced by the same production route in different plants will vary according to the fuel used and to differences in GHG-intensity of electricity.

The lay-out of the energy system varies considerably from plant to plant. The potential to recover energy contained in process gases, heat and pressure energy will also vary from site to site, depending on its layout.

A minimill uses scrap (or scrap substitutes) rather than iron ore as its material input. The scrap is melted in an electric arc furnace to produce crude steel, which is cast, rolled and given a final treatment. However, due to contaminants in the scrap the quality of the steel produced in an EAF may be lower than that of oxy-steel. The demand for high-quality scrap, *i.e.* low in contaminants, has increased significantly and has pushed up the market prices for such scrap. Therefore, minimill steel producers also use other iron-bearing materials as raw material. These materials are usually sponge iron, produced in direct reduction plants, or (hot) pig iron, produced in a blast furnace. The electricity consumption from an electric arc furnace has come down from about 550 kWh/tonne liquid steel in 1970 to 350 kWh/tonne liquid steel in the late 1990s. The theoretical minimum is 300 kWh/t. Obviously, the CO_2 emissions associated with such energy use

[2] Pellet plants are more frequently located near the ore mine than at the site of the integrated mill.

[3] Jeremy Jones, *Electric Arc Furnace Steelmaking,*(www.steel.org/learning/howmade/eaf.htm)

depends on the way the electricity is produced. The range of products produced by minimills used to be limited to long products only, because the quality of the scrap was not high enough to produce flat products[4]. Moreover, the investment costs for a hot strip mill are high. However, with the availability of scrap substitutes and, more important, with the introduction of new casting techniques, minimills have entered the market of flat products.

The energy demand for direct reduction varies from 13 to 18 GJ per tonne of sponge iron. Energy in the form of natural gas or coal is used. Scrap preparation requires different amounts of energy, depending on the quality of the scrap.

2.2 Production and expected growth

The iron and steel industry has an annual global production of 775 Mt of crude steel in 1998 (IISI, 1999). Table 1 gives a listing of the 20 largest steel producing countries in 1999, which combined account for 87% of global steel production.

Demand for steel is growing at a moderate pace (+2% in 1998/99 and projected to average 1.6% p.a. to 2005 - IISI 1999). However, steel demand can vary widely from country to country and year to year, depending on economic conditions. Demand for steel is linked to demand in construction and for automobiles. The growth in EU and NAFTA countries is expected to be small, whereas in South America a large growth is expected. The development in China is hard to predict, but in general a large growth is expected. A recovery of production (with levels returning to pre-1990 volumes) is expected in the former Soviet Union.

The three countries that are selected as cases in this study, *i.e.* Brazil, India and Poland, are all among the world's top 20 steel producers. Since 1992, the largest growth in steel production has been in Mexico, Taiwan, Republic of Korea and China, where production jumped more than 40% between 1992 and 1999. In the former Soviet Union and Japan the steel production declined over the same period.

[4] Flat products are used in the production of automobiles and appliances, such as refrigerators. Long products are used in infrastructure

Figure 1: Processes for steel production

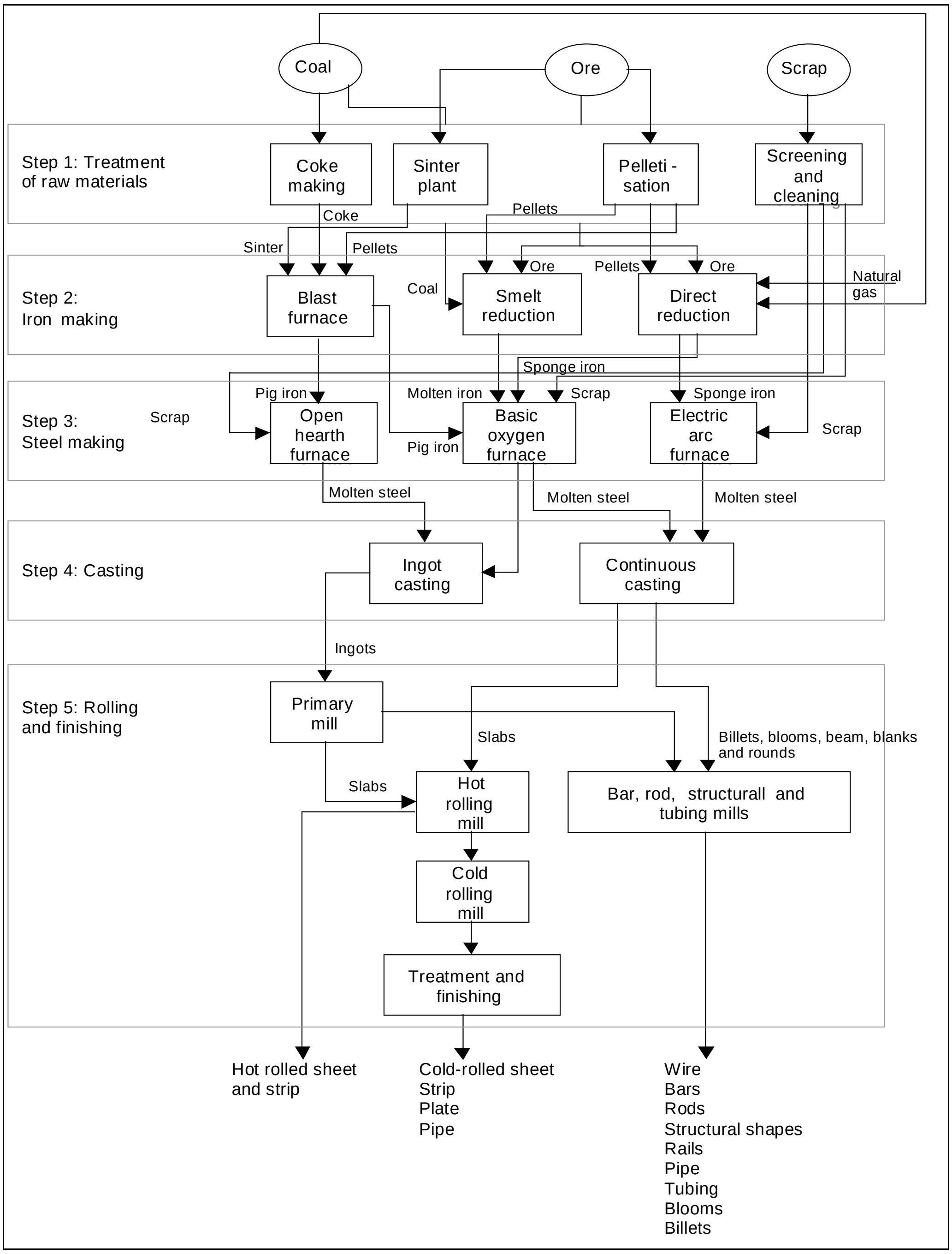


Table 1: The 20 largest steel producing countries and their change in production in 1999 relative to 1992

	Production 1999 (provisional) (Mt crude steel)	Production 1992 (Mt crude steel)	Change 92/99 (%)		Production 1999 (provisional) (Mt crude steel)	Production 1992 (Mt crude steel)	Change 92/99 (%)
China	123.3	80.9	52	France	20.2	18.2	11
US	97.2	84.3	15	UK	16.3	16.2	1
Japan	94.2	98.1	-4	Canada	16.3	13.9	17
Russia	49.8	67	-26	Chinese Taipei	15.4	10.7	44
Germany	42.1	39.7	6	Mexico	15.3	8.5	80
S. Korea	41	28.1	46	Spain	14.6	12.3	19
Ukraine	27	41.8	-35	Turkey	14.4	10.3	40
Italy	25	24.8	1	Belgium	11	10.3	7
BRAZIL	**25**	**23.9**	**5**	**POLAND**	**8.8**	**9.9**	**-11**
INDIA	**24.3**	**18.1**	**34**	Australia	8.2	6.8	21

Source: IISI, 2000

N.B. The countries written in bold capital letters are those which have been selected as cases in this study.

2.3 Major players

The 20 largest steel companies world wide produced about a third of global steel production in 1998 (Table 2). The largest producers are in Asia and Europe. However, market share is susceptible to changes. For example, the recent merger between British Steel and Hoogovens brings the new company Corus at the third place of largest producers.

Table 2

The twenty largest steel producing companies in the world in 1998

Rank	Production (Mt)	Company	Country	Rank	Production (Mt)	Company	Country
1	28.1	Nippon Steel	JAP	11	10.9	SAIL	IND
2	26.4	POSCO	ROK	12	10.9	Kawasaki	JAP
3	18.8	Arbed	LUX	13	10.6	Sumitomo	JAP
4	17.4	Thyssen Krupp[1]		14	9.6	Bethlehem Steel	USA
5	17.0	British Steel	GBR	15	8.9	BHP	AUS
6	16.1	Usinor	FRA	16	8.9	Cherepovets	RUS
7	14.8	Riva[2]	ITA	17	8.8	Nucor	USA
8	12.0	NKK	JAP	18	8.7	China Steel	TAI
9	12.0	USX	USA	19	8.6	Baoshan	PRC
10	11.4	LNM	GBR	20	8.3	Anshan	PRC

Source: IISI, 1999

[1] includes 50% of HKM
[2] includes ILVA LP

2.4 Regional production trends

Over the 1990s, the distribution of the CO_2 emissions from the iron and steel industry shifted considerably over the world regions. This is due to a decline in production and emissions in the countries of the former Soviet Union and Eastern Europe on the one hand and to a rapid increase of production and emissions in China and other developing countries on the other hand.

The energy consumption per ton steel produced is typically 19 to 40 GJ/tcs for an integrated steel mill using a BOF and 30-45 GJ/tcs for an integrated steel mill using open hearth furnaces (De Beer *et. al.*, 1999). A scrap based minimill uses typically 7.7-12.5 GJ/tcs, a DRI (gas)-EAF typically 22-30 GJ/tcs and a DRI (coal)-EAF typically 30-40 GJ/tcs (De Beer *et. al.*, 1999; IISI, 1998).

Iron and steel plants (especially integrated steel plants) often generate part of their own electricity consumption. Fuel input data (*e.g.* as given in the following sections for each of the countries) do not give an indication about the fraction of electricity generated within the plants, nor how these fuels are used within the plant.

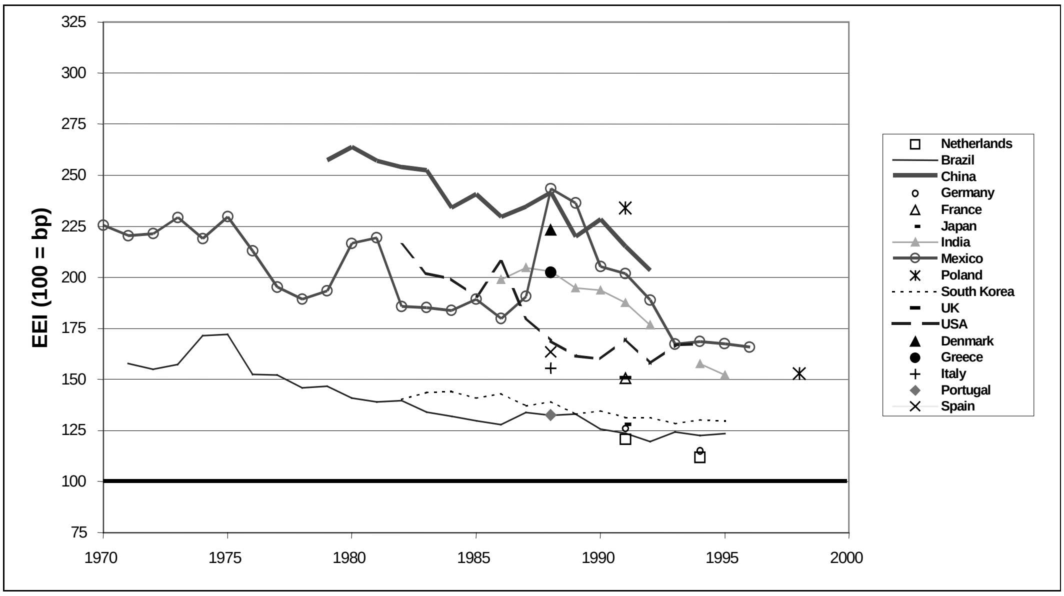
There are large regional differences between energy performance of steel making. This is due to differences in operation and maintenance of the processes, the fuel input and the different use of new technologies. The outdated open-hearth furnace has been completely replaced by the oxy-steel process (first introduced in the 1950s) in the developed countries. In the former Soviet Union, however, this process is still in operation. India also operates open hearth furnaces. China also still operates open hearth furnaces, but intends to have them all closed in 2000.

A new process, Corex, has been developed that avoids the need for the coke processing step (and a coke plant). This means that the Corex process is less energy, emission (and capital) intensive than traditional steel-making routes. It also allows lower grade coals and ores to be used, which are more readily available worldwide. Corex plants are currently installed in only a few countries (*e.g.* US, India, Japan and South Africa), although are planned in more (*e.g.* Thailand). Because of its limited use to date, this production route is not taken into account on a detailed level here. Future analysis of the uptake of this process will need to assess to what extent its lower GHG emissions should influence the suggested standardised energy values presented here.

An indication of the energy efficiency changes in iron and steel production of the processes in a number of selected countries is given in Figure 2[5] (adapted from Phylipsen, 2000). This includes the energy use from the reducing agent. The figure presents data at a national level (*i.e.* including all process routes) and therefore gives an indication of the efficiency of the iron and steel industry in the different countries. As can be seen from this figure, Brazil is relatively efficient and has a lower energy efficiency index than many OECD countries. The reforms in the Polish iron and steel sector are also visible, with an energy efficiency index of around 230 in 1991 and slightly more than 150 in 1998. Substantial improvements in the Indian energy efficiency index (EEI) are also noted between 1985 - 1995.

[5] Since specific energy consumption depends on sector structure, cross-country comparisons cannot be made based solely on trends in the absolute value of the energy efficiency indicator for each individual country. In the methodology used, the actual energy efficiency levels (or rather SECs) are compared with a reference energy efficiency level (accompanying best practice SEC) at the given sector structure. This means that both the actual SEC and the reference SEC are similarly affected by changes in sector structure. The sectoral SEC is established by calculating a weighed average of the reference SECs of individual processes and/or products. The Energy efficiency index, as shown in Figure 5.2 is the result of dividing the current SEC (corrected for the structure of the sector) by the accompanying best practice SEC.

Figure 2: Energy efficiency index trends for iron and steel production in selected countries



2.5 Case studies: India, Poland and Brazil

Three countries: India; Poland; and Brazil, were chosen for more in-depth study. These countries vary substantially in national circumstances and sectoral structure, thus providing an indication of some of the possible global variations in the sector. Moreover, data availability, though patchy, is relatively good (compared to other countries). India is representative of a large country with a large share OHF, a mixture of large ISPs, small EAFs, substantial production under the DR process and some advanced technology (Corex) production. Brazil has relatively low GHG intensities, largely due to the use of charcoal and hydro electricity. India and Brazil are also important players in global steel production. In contrast, Poland has significant over-capacity, is facing reductions in demand and has very old facilities. Each of these is reviewed in greater detail below.

The iron and steel sector in India

In India, three routes for iron and steel production are under operation:

- Integrated Steel Plants (ISPs), using blast furnace-open hearth (BF-OHF) or blast furnace/basic oxygen furnace (BF-BOF);
- Mini Steel Plants, scrap based Electric Arc Furnaces (scrap-EAF);
- Mini Steel Plants, sponge iron based Electric Arc Furnaces, iron from direct reduction (DRI-EAF). These can be either gas-based, or coal-based.

One or two Corex plants are currently being built.

There have been significant changes in the Indian iron and steel sector over the last few decades. Although the government owns 6 of the 7 large-scale integrated steel plants, there are many smaller-scale and privately owned steel plants in operation (estimated at 160 in 1998 (Kanjilal 1998) and 180 in 1999

(Sathaye and Gadgil). Demand is growing rapidly and the government's emphasis on increasing capacity is to expand and modernise existing facilities (rather than to build new ones).

Table 3 gives an overview of the number of plants, total capacity and production.

Table 3

Production and number of large-scale plants in the Indian iron and steel industry in 1995/96

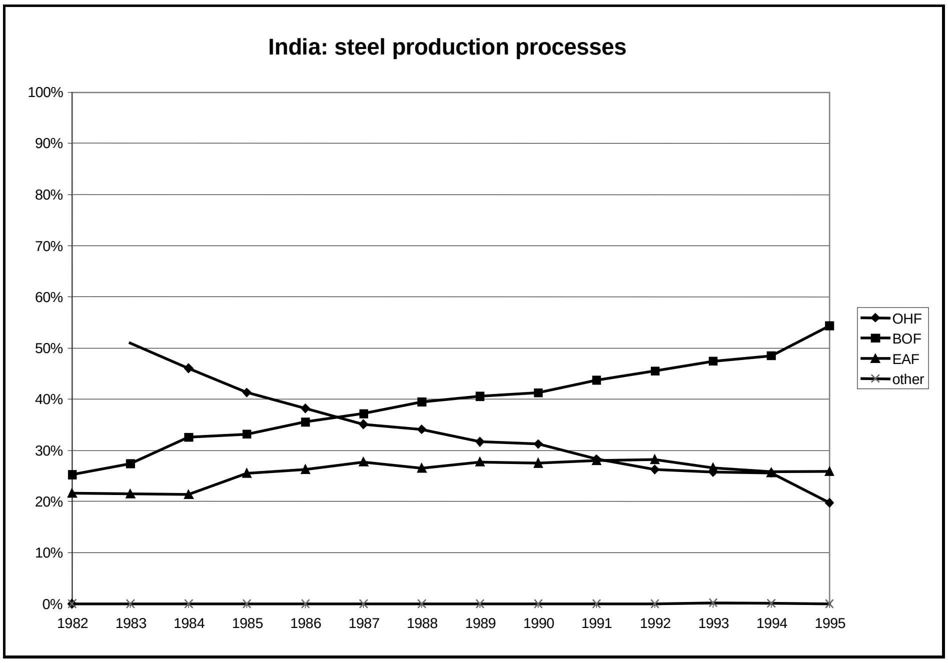
Type	Production (Mt/y)	Number of plants
ISP	15.7	7
Scrap-EAF	1.5	N/A
DRI-EAF (gas)	2.2	4
DRI-EAF (coal)	1.8	12[1]

[1] Since 1995/96, another 4 coal based DRI-EAF plants have been installed and are now in operation

The current production is largely dominated by integrated steel plants. However, new capacity is mainly found in the EAF route, both from scrap and DRI. It can be expected that new capacity will be added over the next decades and, as EAFs require less investment capital (partly as they are mostly smaller units), these are expected to dominate the new construction. Therefore, the relative share of the EAF in production is expected to increase continuously.

For primary steel production, if current trends continue, the OHF will probably be completely phased out by 2005. An overview of the relative share of the steel production processes is given in Figure 3.

Figure 3: Relative amount of steel produced by the different process routes in India from 1982 to 1995



Annual data for energy use are available for ISPs from 1983 through 1995, as well as total energy consumption for all steel plants in 1994/95, including and excluding coke production, are provided in Figure 4. (Note: The fiscal year in India runs from March to April. Data for 1994/5 are plotted as 1994 data.) The increase in overall ISP energy consumption is expected to continue, in line with increasing steel demand, for the next several decades.

The Specific Energy Consumption can be calculated from the energy consumption data and production figures per process (Table 4). The CO_2 emission factors for each of the production processes are also calculated. Caution should be taken in any interpretation of these figures, as these estimates are based on averages for the entire sector and disaggregation may not be appropriate.

Figure 4: Energy consumption for steel plants in India (PJp)

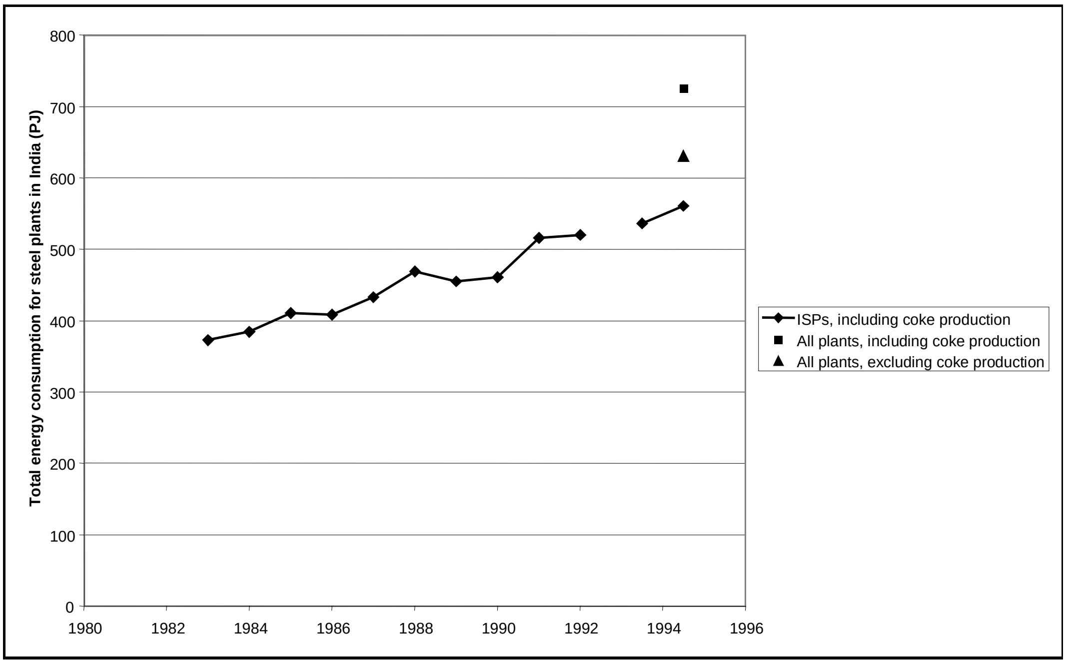


Table 4

Specific energy consumption and CO_2 emission factors for the different process routes in 1994/5, India

Process routes	Specific Energy Consumption (GJ/tcs)	CO_2 emission factor (tCO_2/tcs)[1]
ISP	36.4	3.7
Scrap-EAF	18.8	1.4
DRI-EAF (gas)	25.3	1.55
DRI-EAF (coal)	35.6	3.37

Source: (Phylipsen, 2000) and own calculations (CO_2 emission factors)

[1] For the electricity emission factor, an average of 74 kg/GJp is used, based on fuel mix and an electricity generating efficiency of 30%.

Table 5 gives an overview of the different energy inputs in the Indian iron and steel sector. Data on fuel inputs for different process routes are not available.

Table 5

Fuel inputs in the Indian iron and steel sector (1994/5)

Solids (PJ)	Liquids (PJ)	Electricity (PJe)	Total Final (PJ)
620 (90%)	30 (4%)	41 (6%)	692 (100%)

Source: LBNL, 1999

The iron and steel sector in Brazil

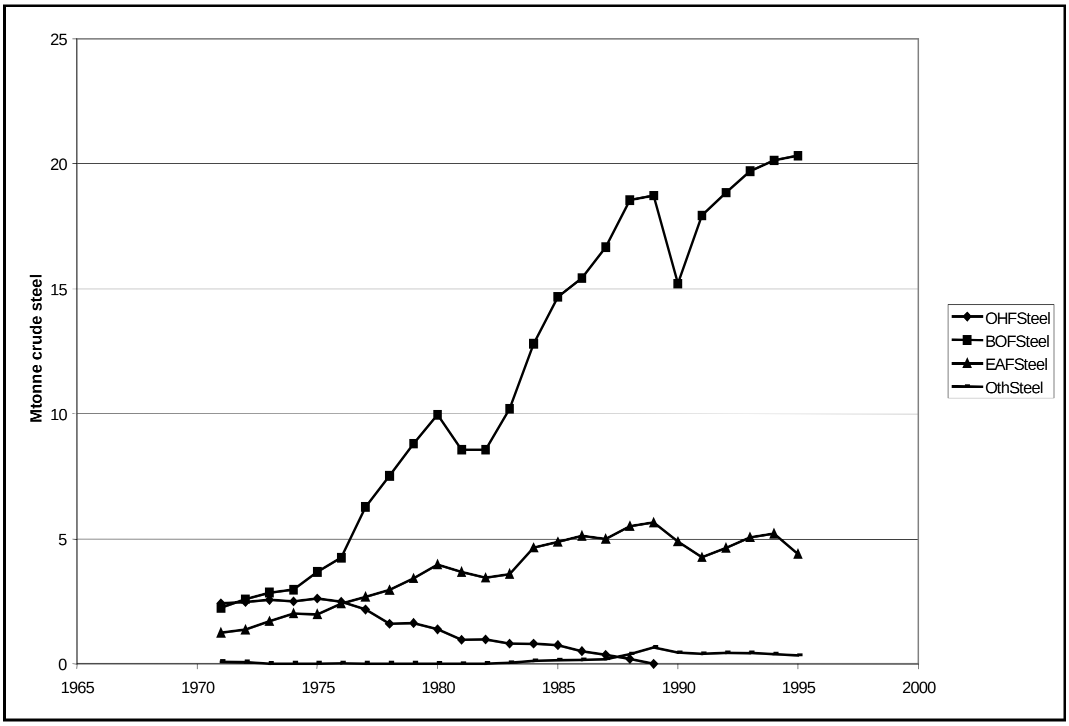
In Brazil, three processes for iron and steel production are in operation:

- Integrated Steel Plants (ISPs), using blast furnace/basic oxygen furnace (BF-BOF);
- Mini Steel Plants, scrap based Electric Arc Furnaces (scrap-EAF);
- Mini Steel Plants, sponge iron based Electric Arc Furnaces, iron from direct reduction (DRI-EAF). These can be either gas-based, or coal-based.

The blast furnace/open hearth route is no longer used.

An overview of Brazilian production in each process through the various steel making routes is given in Figure 5. Between 1971 and 1995 steel production in Brazil has increased approximately 5-fold and the shares of the different production routes has changed significantly over this time. While in the early 1970s BF-OHF and BF-BOF produced approximately equal amounts of steel, rapid increases in BF-BOF production in the 1980s now means that it is by far the most dominant method. The open hearth furnace production route was totally phased out in Brazil in 1989. Steel produced via the EAF process has approximately tripled between 1971 and 1995. However, its share in total steel production has decreased slightly since the 1970s, from around 25% in 1978 to about 20% in 1993 and 1994 and 18% in 1995 (LBNL, 1999). With a production of 0.32 Mt in 1997, the contribution of DRI-EAF is relatively limited (LBNL, 1999).

Figure 5: Crude steel production in Brazil



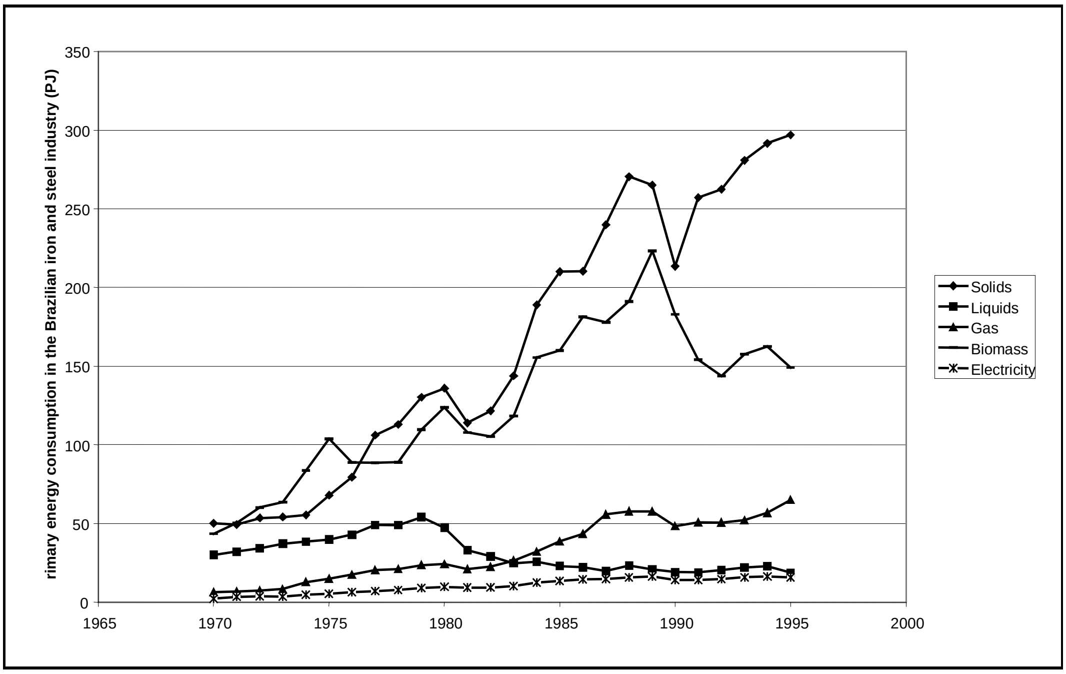
Source: LBNL, 1999

Figure 6 gives an overview of total energy consumption trends in the iron and steel sector in Brazil. Data on inputs for each of the process routes are not available.

An important characteristic of the Brazilian iron and steel industry is the large contribution of biomass (in the form of charcoal). Together with an electricity system that is largely based on hydro, the carbon intensity of iron and steel making in Brazil is therefore relatively low (Table 6), particularly when compared with either India or Poland, which are largely coal-based.

However, the low emissions intensity does not necessarily correlate to overall high efficiencies: due to the non-availability of SEC data on a plant or process route level, no conclusions on this issue can be drawn. As an indication, Table 7 gives an overview of the input of the different energy inputs in the Brazilian iron and steel sector. At a sectoral level, the SEC has decreased slightly since 1970, mainly due to the (autonomous) phase-out of the open hearth furnace, which accounted for approximately 40% of total production at that date (Figure 7).

Figure 6: Primary energy consumption in the Brazilian iron and steel industry



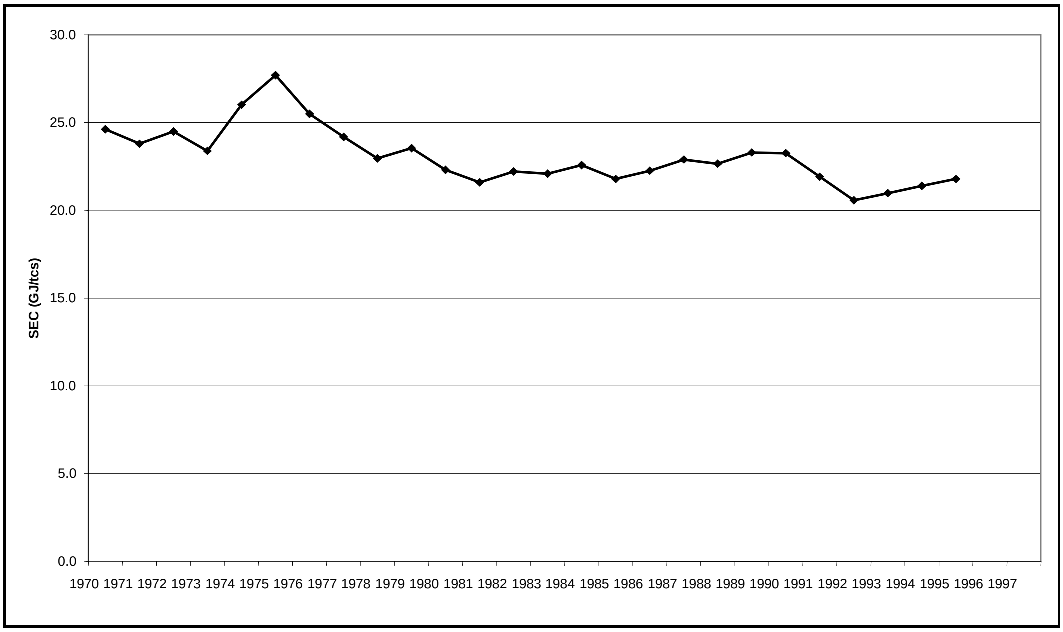
Source: LBNL, 1999

Table 6: The specific energy consumption and carbon intensity of the Brazilian iron and steel sector

	Specific Energy Consumption (GJp/tcs)	CO_2 emission factor (tCO_2/tcs)
Entire sector	23	1.32

Source: Phylipsen, 2000

Figure 7: SEC development of the iron and steel sector in Brazil



Source: LBNL, 1999

Table 7: Fuel inputs in the Brazilian iron and steel sector (1995)

Solids (PJ)	Liquids (PJ)	Gases (PJ)	Biomass (PJ)	Electricity (PJe)	Total Final (PJ)
297 (54%)	19 (3%)	65 (12%)	149 (27%)	16 (3%)	546 (100%)

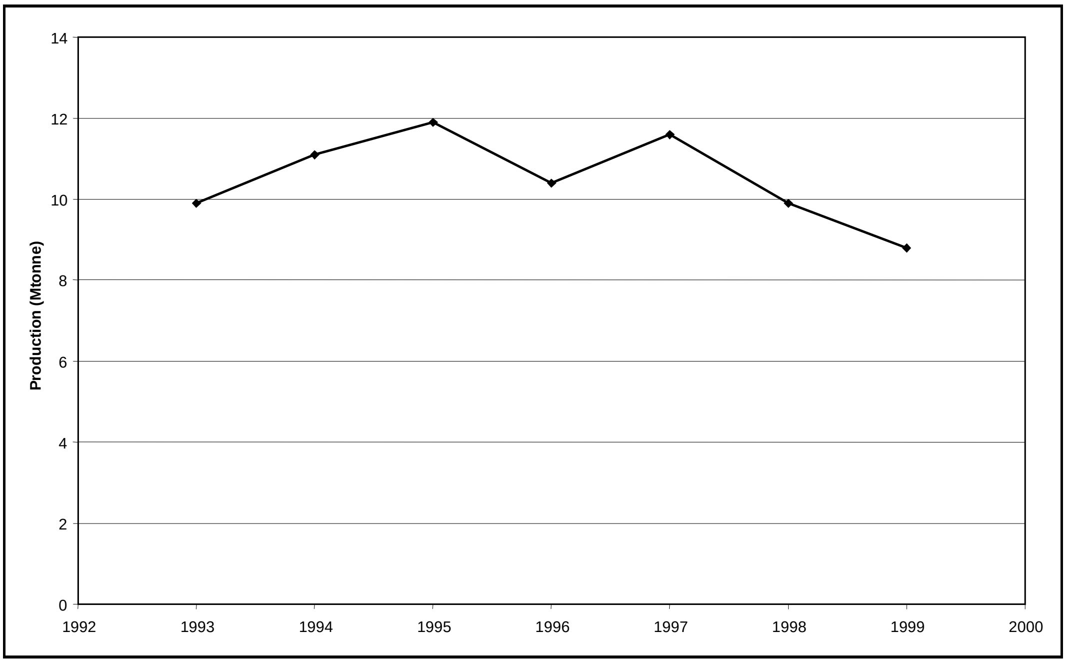
Source: LBNL, 1999

The iron and steel sector in Poland

Data on steel production in Poland by type and energy consumption are available only between 1993 to 1999 (see Figure 8).

Much existing Polish steel technology is old: of the 25 steel mills in operation, 18 started production before the first world war (Prus 1998). However, restructuring in the steel sector is underway as part of Poland's EU accession programme. The consequent modernisation of the sector has meant an influx of capital and a resulting rapid and substantial increase in the share of continuously cast steel (from 8% in 1992 to 70% in 1997 (Prus 1998). Significant changes have also occurred in the share of different process routes. BF-OHF accounted for 10% of total production in 1997, compared to 30% in 1990 and is set to fall further as all but two BF-OHF facilities have been earmarked for closure (Prus 1998).

Figure 8: Total production of crude steel in Poland (1999 data are provisional)



Source: IISI, 2000

The majority of steel production is in BF-BOF plants. In 1998, some sources indicate that 93% of the steel production was through a BOF and 7% through OHF (IISI, 2000). However, the Polish Energy Agency gives data on energy consumption for steel production by the EAF process, suggesting that this is used for at least some steel production. This inconsistency demonstrates that data availability is a problem.

Based on the data provided in (Worrell *et. al*., 1997), in combination with the data on continuous casting as given in (IISI, 2000) the current SEC of the iron and steel sector in Poland is estimated at around 26 GJ/tonne. No data on plant level are available.

The CO_2 emission factor is estimated assuming that the fuel that is used for the production of steel is 100% coal. The emission factor is then comparable to the emission factor for ISPs in India, 3.6 ton CO_2/tcs (1998). From the IEA energy balances, the following division for the Polish iron and steel sector was derived (Table 8):

Table 8: Fuel inputs in the Polish iron and steel sector (1995)

Coal and derivatives	Natural gas	Renewables	Electricity	Heat	Other	Total
179.4	3.0	23.0	2.9	27.1	7.7	240.2
75%	10%	1%	11%	3%	1%	100%

Source: IEA, 1998

N.B. Energy use in coke ovens and blast furnace are not included in these figures.

2.6 Comparison of the case study countries

A number of similarities and differences emerge from the analysis of these three countries. The difference in SEC values between India and Brazil is mainly caused by the fact that no BF-OHF furnaces remain in operation in Brazil, whereas 20% of capacity in India is still through this route. Furthermore, the DR-EAF route is virtually absent in Brazil (relatively more scrap used as input for the EAFs, thereby significantly reducing the energy consumption compared to India.

Table 9: Comparing CO_2-intensities for the different process routes

Process routes	India		Brazil		Poland	
	SEC (GJ/tcs)	CO_2 emission factor (tCO_2/tcs)[1]	SEC (GJ/tcs)	CO_2 emission factor (tCO_2/tcs)	SEC (GJ/tcs)	CO_2 emission factor (tCO_2/tcs)
ISP	36.4	3.7	23[2]	1.32[2]	26	3.6
Scrap-EAF	18.8	1.4	n/a	n/a	n/a	n/a
DRI-EAF (gas)	25.3	1.6	n/a	n/a	n/a	n/a

Source: Phylipsen, 2000

The estimate for Poland is based on (Worrell *et. al.*, 1997) and extrapolated using an overview of installed equipment.

[1] For the electricity emission factor, we used an average for the entire sector of 74 kg/GJp.
[2] For the entire iron and steel sector

The difference in energy and CO_2-intensities for the case study countries is summarised in Table 9. It is seen that, while energy intensities vary significantly between countries, the variation in CO_2-intensities per GJ fuel input is even greater.

3 Baseline construction: environmental performance

Based on both the specific case studies and on the broader review of the sector provided above, it is possible to develop a set of recommendations regarding baseline construction for potential steel projects. Several types of multi-project baselines are developed and discussed here; the analysis also indicates the kind and extent of the data required.

3.1 Input data

Obtaining energy consumption data useful for standardised baseline construction in iron and steel production is difficult. Highly aggregated data is available and this can be used to give general indications about a country's iron and steel sector, including the extent of the sector's autonomous energy efficiency improvements. However, as this data is aggregated for all plant types, it does not indicate whether improvements are as a result of a change in production routes, product mix or increased efficiency.

Some information is available on observed best practice plants. The data in Table 10 ("best actually observed" column) represent estimates based on plants that are currently running and of which energy consumption data are known. Data in this table must be treated with caution - plants listed here may be operating more or less efficiently than indicated in this table. The Corex process is more efficient than the ISP route. Plants operate typically at 19 GJ/ton, which is very near the design value (CEC, 1999).

Data on global average energy use by production route is scarce. Data might be estimated by extrapolating from a few important producing countries for which information is available (although, based on existing literature, even this data is difficult to come across):

1. China, Japan, US and Germany for ISP;
2. China, Japan, US, Mexico and Italy for scrap-based EAF; and
3. Mexico, Venezuela, Iran and Saudi-Arabia for DRI (gas).

Country-specific data on SEC per production route is also patchy. In theory it should be possible, albeit time-consuming, to gather the data for individual plants. Alternatively, a plant inventory could be carried out and national energy intensity inferred from weighted average production. For Brazil, only data for the entire iron and steel sector are available. As indicated before, according to (IISI, 2000) Poland did not produce any steel via the EAF route in 1998. However, Gilecki (2000) gives energy (electricity) consumption data for EAF steel production in the same year, thus indicating differences in data that cannot easily be explained.

The estimated averages used in this study are given in the following table. They should be interpreted with care and would need international review before being fixed as the values used in establishing baselines. In the short term, the values as given in the following table can be used as first estimates.

Table 10: Comparing energy intensities of steel production in selected countries and processes (GJ/tcs)

Process	Best actually observed[a]	Mid-point SEC	India [d]	Brazil [d]	Poland
ISP	22	26[b]	36.4	23	26
Scrap-EAF	7.7	10[c]	18.8		
DRI-EAF (gas)	22	26[c]	25.3		
DRI-EAF (coal)	25	36	35.6		
Corex	19				

[a] SEC values represent the lowest SEC observed in a fully operational plant world wide in 1995-1996. *Source:* (De Beer *et. al.*, 1999)

[b] Estimate based on the values of China, US, Japan and Germany.

[c] Estimate based on the average of the upper and lower values achieved in practice as indicated in (De Beer *et. al.*, 1999). Because a large share of the production is in developing and OPEC countries, this is expected to be an underestimate.

[d] *Source:* Pyhlipsen (2000).

Emission baselines may also need to take into account improvements in energy efficiency that have occurred as part of BAU practices in the past. However, such a calculation requires country-specific data for at least two years and is therefore also difficult to obtain. Some indications for the case study countries are outlined in Table 11.

As indicated in section 2 and Figure 1, several different final products can be produced from the intermediate product, crude steel. These final products have different energy intensities (Table 12) and also different end uses. For example, cold-rolled products are needed for applications such as car bodies or the outside of refrigerators and their production entails an extra step. To determine total energy consumption in a cold rolling process, the values for hot and cold rolling should be summed.

Table 11: Indication of past autonomous efficiency improvements

	India	Brazil	Poland
Primary steel production	~0.5-1% per year[c]	~0% per year[b]	-0.6% per year[a]

[a] *Source:* Worrell *et. al.* (1997). This figure indicates an increase in Specific Energy Consumption in the period 1980-1991. Energy efficiency continued to improve between 1991-1995, but at a lower rate (Price *et. al.* 1999).

[b] Both Worrell *et. al.* (1997) and LBNL (1999), indicate only a very small change in efficiency in the Brazilian iron and steel sector in the period 1980-1995.

[c] Based on (SAIL, 1996) with indications over the period 1990-1995

Table 12: The differences between hot rolling and cold rolling with regard to energy intensity on a best practice basis.

	Fuel consumption (GJ/tonne shaped steel)	Electricity consumption (GJ/tonne shaped steel)
Hot rolling	1.53	0.35
Cold rolling	1.10	0.53

Moreover, the quality of coal and iron ore inputs used can influence the energy consumption of steel production. Using high sulphur and/or high ash content coal increases the Specific Energy Consumption of the steel manufacturing process. The quantitative relationship between coal quality and energy consumption is not exactly known, but for specific cases a rough estimate can be made. In general, a higher ash content in the coal, or a lower iron content in the ore, will lead to a higher energy consumption (Worrell, 2000).

Data problems

For all countries studied, acquiring the necessary input data was difficult. In general, national bureaux of statistics have been the main source of data. The data for India are more complete than those of the other countries studied (drawing on extensive research as described in Phylipsen, 2000 and fieldwork carried out in 1998/9 by the main author). Difficulties experienced are production data for electric arc furnaces and energy consumption data for electric arc furnaces. Data on the product mix from electric arc furnaces are also difficult to obtain at a national level. On the plant level, these data are available, so this information could be supplied for a refurbishment CDM project is under development.

For Brazil, data have been gathered within the INEDIS network[6]. However, the distinction between the different process routes is relatively difficult to obtain both for production data and energy input data. On a national level, the product mix and energy inputs are relatively well known for the iron and steel sector as a whole.

For Poland, the production data from (IISI, 2000) are not in agreement with the data for energy use as given by the Polish national energy agency (Gilecki, 2000). It is beyond the scope of this case study to determine the “real” values, so extrapolations have been used.

Data on crude steel production are also not always readily available. However, the values for developing the baselines could be determined with additional research. Similarly, there are problems with obtaining the data required for the adjustment of benchmarks for product differences: data are available, but additional research in the countries is required to assess its accuracy.

[6] The Inedis network (International Network for Energy Demand Analysis in the Industrial Sector) is an international network of specialists in the area of industrial energy efficiency. Data on industrial energy use and accompanying indicators are collected and stored in a database (LBNL, 1999).

3.2 Aggregation

Based on data availability, comparability and sectoral variability, it is proposed that baselines be constructed on the basis of energy intensity in the manufacture a ton of crude steel at the international process routes level, *i.e.*:

1. Integrated Steel Plants (ISPs);
2. Scrap based Electric Arc Furnaces (scrap-EAF);
3. Direct Reduced Iron (gas-based) Electric Arc Furnaces (DRI (gas)-EAF); and
4. Direct Reduced Iron (coal-based) Electric Arc Furnaces (DRI (coal)-EAF).

No fuel separation is needed in categories 1 and 2 because in EAF the majority (more than 95%) of fuel used is electricity and in Integrated Steel Plants it is almost all coal. However for EAFs, it is important to examine the raw materials that used as iron-bearing materials (*i.e.* the proportion of scrap used) as these have a significant impact on the energy use.

It is not possible to aggregate baselines across process routes as they differ significantly in the amount of energy used to produce one ton of crude steel. Moreover, the different process routes use different feedstocks, energy inputs and produce and different products. Each of the different routes are used in most countries.

The DRI-EAF (coal-based) process route could be considered as an inefficient variation on the Integrated Steel Plants concept, implying that GHG emission reduction projects from coal-based DRI-EAF should not be credited at all. Therefore, this process route is excluded in the remainder of the report.

Since the technologies used for iron and steel production are internationally uniform, it is not necessary to distinguish between geographical regions for technical reasons and standardised baselines for different process routes may therefore be set up at an international (global) level. This level of disaggregation is also in line with the recommendations of other studies on the suitability of multi-project baselines, *e.g.* that recommend using global, disaggregated benchmarks for commodities that are traded internationally and products and feed stocks that are heterogeneous (Lazarus *et. al.*, 1999),. However, the energy consumption of the same technology in different places can differ substantially, reflecting the age of equipment, quality of raw material inputs, the degree of integration of the process and the level of implementation of energy efficient technologies.

It may be necessary to adjust for the specific characteristics of an individual plant or product mix within a process route. For example, Phylipsen *et al* (1998), recommend correcting for the amount of hot-rolled and cold-rolled steel produced.

In theory, standards could also be established at a higher degree of disaggregation. Thus, for example, it would be possible to set standards for the different process steps within each process route, *e.g.* the energy used in a blast furnace. However, such a disaggregation is not recommended as process integration is then not rewarded as an option for emission reduction.

Setting baselines with still greater disaggregation (*e.g.* at the level of individual technology components such as motors and pumps) would be extremely data intensive. Moreover, it would be difficult to assess the emission reductions from projects using this level of disaggregation, because it would require an assumption regarding individual component use (*e.g.* how long. an individual motor runs[7].

Differences in SEC for the same technology operating in different places are generally caused by differences in operation and maintenance, or the age of the technology. Other causes can be the quality of coal and iron ore, which differs between countries.

3.3 Proposed baselines

As with baselines set in other sectors, ideal emissions baselines in the iron and steel sectors should meet the following criteria (Ellis and Bosi, 1999):

- Be environmentally credible (to exclude projects that are not environmentally additional);
- Be transparent and verifiable by a third party;
- Be simple and inexpensive to draw up (low transaction costs/low costs for baseline development);
- Provide a reasonable level of crediting certainty for investors; and
- Have a potentially large volume of projects.

The variation in these criteria influences the number of projects that will be generated through JI and CDM. For the suitability of the baselines that will be described in the following pages, the potential large volume of projects is an important criterion.

Any baseline approach involves a trade-off between the criterion of environmental credibility and generating a potential large volume of projects. The baselines proposed in the following sections will first be described and then scored against these criteria.

Much of the following analysis mainly focuses on existing plants. New plants usually operate at a Specific Energy Consumption that is approximately equal to the world wide best practice and the SEC of worldwide best practice is thus considered the most suitable standardised baseline for new plants. This is particularly true as a number of plants in developing countries have been built and operated at a SEC that is at the world-wide best practice. However, exceptions do exist: for example, in the United States where it is not considered economically viable to build new plants with the lowest specific energy consumption due to low energy prices, lower efficiency plants are still being constructed. Thus, a baseline that incorporated these new facilities into the average might yield higher crediting levels.

Corex© plants too operate at approximately equal efficiencies world-wide, with most plants that are installed operate at a specific energy consumption near the best practice value. Thus, the best practice value of 19 GJ/ton crude steel is proposed to be a suitable baseline, both for new and refurbishment Corex plants.

Benchmarking energy use

Emission baselines could also be developed based on standardised (or "benchmarked") energy performance of a plant. In such cases, country specific GHG emission factors would need to be applied to

[7] Note that motors and lighting from such industries as iron and steel must be excluded from a general "motor project" if there also is a iron and steel project to avoid double counting.

the standardised energy value to calculate the accompanying GHG emissions reduction[8]. Separating the energy and GHG intensity of the process avoids the requirement to set default GHG intensity standards for electricity generation, significantly simplifying the baseline setting process.

Several possible baselines based on the concept of benchmarking can be generated, such as average, median or “better than average”. Average and “better than average” benchmarks can also be thought of in terms of the stringency of a baseline. A standardised baseline based on the energy intensity of different steel production routes would be very stringent if based on world-wide best practice values, but much more lax if based on world-wide average performance. A baseline based on the “national average” performance could be more or less stringent than a world-wide average, depending on the country.

Benchmarking based on recent technology additions is another option and indeed, one that is recommended in other sectors. However, for new plants, this option seems to be essentially the same as benchmarking on the world-wide best practice level (see *e.g.* the latest new iron and steel plants in South Korea) and so is not considered separately.

Five different possibilities for a standardised energy baseline for each of the production routes are discussed below:

1) A baseline based on the best practice energy performance world-wide.

Assuming that the plant operating with the best practice energy performance world-wide indicates the level above which environmental additionality is guaranteed, a baseline can be set at this level. In practice, adjustments to this level will need to be made in order to account for the amount of steel that is hot-rolled and cold-rolled (see Table 12) and for the quality of the coal and ore used. In such a case, only projects using advanced technology would generate emission credits.

2) A baseline based on the world-wide average SEC per process route.

Using this value would lead to a relatively lax baseline as plants that are responsible for approximately half of total iron and steel production world-wide would qualify as CDM/JI projects if the baseline “test” were the only additionality criteria.

3) A baseline based on “better than average” performance

Such a baseline would be between the values of the world average and best practice performance baselines outlined above. It would therefore also result in an intermediate level of stringency and an intermediate level of project numbers. It could be drawn up at an arbitrary level, such as 90% of the “average” level.

4) A baseline based on benchmarking on the country average SEC per production route

This option would result in baselines differentiated by country, as well as by production route. This type of baseline is not consistent with aggregation purely at a production route level, but it would have the advantage of being able to take into account widely differing national circumstances. As for baselines based on a worldwide average, this type of baseline could be drawn up at different levels of stringency (*e.g.* country average, 10% better than average).

5) A “graduated crediting” baseline

This alternative allows a percentage of the reductions to be counted - with the amount varied according to the stringency of the benchmark used (see Figure 9). The values could be set to take into account both

[8] The determination of the country specific emission factors is dependent on the developments in the power sector of a country. The Electricity Case Study suggests how such baselines could be established.

national performance and BAT performance. Such an approach is more stringent than one based on national average figures (because not all emission reductions would be credited at that level), but would allow a larger number of projects than a standard set at the BAT energy performance level.

Technology matrix

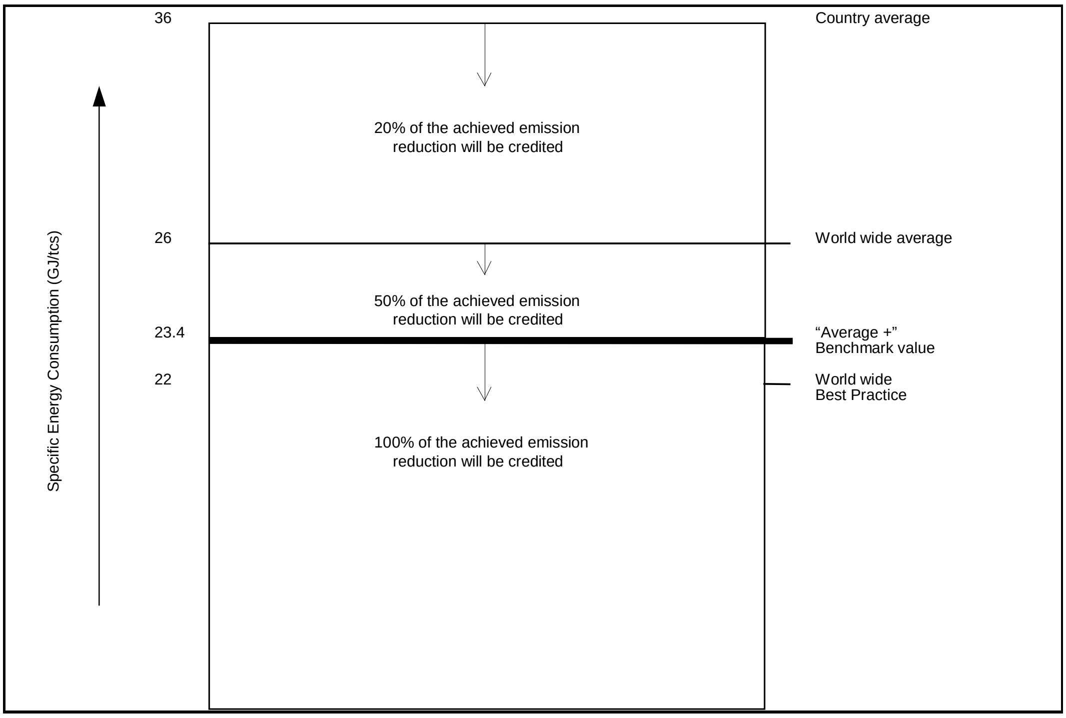
As for a multi-project baseline based on a standardised energy value for production process routes, there is no technical reason to distinguish between countries or regions for baselines drawn up using the technology matrix approach. A standardised energy consumption figure could be established for each piece of equipment in a "standard" plant for each of the production routes examined.

The basic principle is the same as for the benchmarking approach: compare the SEC of the standard technology with the alternative, lower GHG emission technology. The differences in SEC can then again be "translated" to GHG emissions using country specific emission factors.

The possible standard configurations can be determined in the following ways:

1. Based on the configuration of the world-wide best-practice plant: The technologies that are used in the plant performing with the lowest SEC in the world are taken as the reference technologies.
2. Based on inventory of all the technologies world-wide: An overview of all technologies world-wide is made and penetration figures for each of the options are collected. Then, the modal technology, *i.e.* the technology that is implemented most frequently, can be included in the configuration of the standard.
3. Based on the implementation of technologies in each country: Although this requires a higher level of disaggregation than that recommended in this report, it would enable national circumstances to be taken into account. However, establishing a baseline would require data collection at a country level in order to establish the modal technology.

Figure 9: An illustration of the "graduated crediting" concept (*e.g.* for BF-BOF production)



This is illustrated in Table 13. The estimated savings by adopting continuous casting in a plant using an ingot caster are 2 GJ/tcs (Price *et. al.*, 1999). A thin slab caster accounts for around an additional 0.4 GJ/tcs, derived from (De Beer *et. al.*, 1999). Because strip casting is an advanced technology, the savings are not exactly known. Additional savings compared to thin slab casting are indicated with X in Table 13. The data are the amount of GJ that will be saved per ton crude steel. The first number gives the amount of savings under a baseline based on world-wide best practice, the second is based on world-wide average, the third is based on country average.

For the iron and steel sector, these matrices would have to be developed for different steps, including the coke making process, the sinter plant, pelletisation, the oxygen plant, the iron making step, the steel making step, the casting process, the hot rolling mill and the cold rolling mill. Besides this, for the technologies that cannot be attributed to one of these processes, like heat recovery where the heat is used in another process step, another matrix would also need to be developed.

Developing a technology matrix may be difficult especially when technologies are included that do not cause a large step change difference in performance, such as heat exchangers, adjustable speed drives, high efficiency motors, *etc.* For these small technologies, it will be difficult to determine the accompanying change in specific energy consumption by examining plant-specific energy consumption data. In addition, the energy consumption of individual components (*e.g.* motors) is very much dependent on the amount of time they are used. To estimate the energy conservation and consequent GHG mitigation that is achieved by the implementation of energy efficient components, this amount of time also has to be estimated, as in a technology matrix no direct measurements are included. The effect of implementation of these smaller kind of technologies as a JI/CDM project is therefore almost impossible to monitor.

An example of the technology matrix approach for integrated steel plants

In the manufacture of flat products, a choice exists between ingot casting, continuous casting, thin slab casting and strip casting. Any of these routes would result in equivalent products being produced, but the energy used to produce these products would be different. Ingot casting is the “traditional” technology, continuous casting the standard in more than 80% of the installed plants, thin slab casting can be considered as best practice and strip casting as future technology.

Using the first technology matrix option, the standard “benchmark” technology would be thin slab casting (even though this technology is installed in not more than 3 or 4 plants). No GHG emissions will be credited when a continuous caster or an ingot caster is (partially) replaced by a thin slab caster. Strip casting will be credited, for the difference between thin slab and strip casting, but this is a future technology.

Using the second technology matrix option, the standard would be continuous casting. Replacing either an ingot caster or a continuous caster by a thin slab caster generates GHG emission credits for the difference between a thin slab caster and a continuous caster.

Under the third option, the ingot caster will be the standard. Installation of a continuous caster would be credited at the difference of continuous casting and ingot casting and the installation of a thin slab caster will be credited at the difference between thin slab and ingot casting.

Table 13: A technology matrix for the casting process

in an integrated steel plant that produces flat products

		Currently installed technology					
		Ingot caster	Continuous caster	Thin slab caster	Strip caster	*Etc.*	*Etc.*
Technology to be implemented in the JI/CDM project	Ingot caster						
	Continuous caster	0/0/2					
	Thin slab caster	0/0.4/2.4	0/0.4/2.4				
	Strip caster	X/X+0.4/X +2.4	X/X+0.4/X +2.4	X/X+0.4/X +2.4			
	Etc.						

3.4 Other issues: Fixed versus revisable baselines and timelines

The previous section outlined possible ways of standardising the starting point of baselines for potential iron and steel JI/CDM projects. If the value of the baseline remains constant for each year that the project receives credits, the baseline is fixed and static. However, given that the energy efficiency of iron and steel production has increased in many countries and that technology developments can make new investments highly energy-efficient, it may be more appropriate to assume some sort of autonomous energy efficiency improvement (*e.g.* 1% per year). This type of baseline, fixed at the start of a project’s life, but dynamic over that life, would increase the environmental additionality of the baseline by reducing the likelihood of it creating non-additional credits. Alternatively, baselines could be revised periodically, *e.g.* once every 5 years, in order to take into account technological development.

Regarding the length of time over which a project can generate emission credits (*i.e.* the emission timeline), this analysis recommends using the average economic lifetime of technologies as the most important indicator. These differ from one technology to another. A rule of thumb is that electro-mechanical equipment (*e.g.* pumps and motors) have a lifetime of 10-15 years and buildings and large installations 25-30 years. (Daniels *et. al.*, 1998) give 20 years for buildings and large installations, 15 years for electro-mechanical equipment, 40 years for the coke ovens and 30 years for sinter and pellet production.

The problem with determining crediting lifetimes for JI/CDM projects in the iron and steel industry is that it is very difficult to give good estimates, because it is very rare that an entire facility is replaced. It is much more common for a plant to undergo major revisions during its lifetime without ever being completely replaced. It is therefore difficult to determine when a piece of equipment is at the end of its lifetime. This also implies that the age of the current stock can not be considered to be a useful indicator for determining the additionality of a proposed CDM/JI project.

The practice of refurbishing different parts of the iron and steel production route at different times also means that improvements in a plant's SEC is likely to be steady and incremental rather than large step changes. Applying an autonomous efficiency improvement into account when developing a baseline for an iron and steel project is therefore recommended, as this effectively includes technology development into the baseline. It is advised to use a fixed improvement rate (based on world-wide average efficiency improvement) and check the thus derived generic baseline every 5 years to see if the SEC development still conforms to expectations.

3.5 Scoring the baselines

It is useful to consider the criteria discussed above to evaluate the advantages and disadvantages of the baseline methods.

Table 14 indicates that the environmental additionality of different baseline approaches and assumptions can differ substantially, sometimes even within a single approach. For example, using a country average energy benchmark for Brazil would lead to a stringent baseline because iron and steel production in Brazil is relatively efficient. The risk of any projects under such a baseline not being additional is small. However, using a baseline drawn up using the same methodology (*i.e.* country average) for India would lead to a lax baseline because India has an old and relatively inefficient iron and steel sector.

The costs of setting up the different baselines can also differ substantially. A baseline predicated on a smaller number of data points, such as "best practice" data, will be cheaper and easier to set up than a baseline drawn up using a larger number of data points, such as the world average for a particular production route. Similarly, the "graduated crediting" approach, essentially drawn up using both country average and world wide average baselines will be more expensive than either of these baselines singly. The costs of baselines drawn up using a technology matrix approach are generally higher than those drawn up using a benchmarking approach, because one JI/CDM project could involve installing many different technologies. The mitigation effect of such a project would therefore need to be assessed by summing the individual effect of each technology change.

The transparency and verifiability of the different potential baselines also varies with different baseline approaches and assumptions, although to a smaller degree than the other criteria examined. Any standardised and documented baseline should be relatively transparent. However, the calculations of a more complex baseline (such as one based on "graduated crediting" are likely to be more difficult to follow than those of a simpler baseline, such as that based on best practice performance.

Table 14 also gives a rough indication of the numbers of projects likely to qualify for credits under different baseline assumptions. This is assessed in more detail in the following section.

Table 14: Scoring the proposed baselines for the iron and steel sector against the criteria

Criteria	**Benchmarking**[1]					**Technology matrix**[2]		
	World-wide best practice	World-wide average	World-wide average with AEEI	Country average	Graduated crediting	World-wide best practice	World-wide mode	Country mode
Environmental Additionality[3]	++	- to +[5]	-- to +	-- to ++[6]	- to +	++	++[5]	-- to ++[6]
Potential volume of projects	--	+	+	0 to ++[7]	0 to +	--	+	0 to ++ [7]
Transparency and verifiability	++	++	++	+	-/+	++	+	+
Costs to draw up the baseline system[4]	++	+	+	+	+/-	-	--	-

[1] With regard to benchmarking, monitoring and measuring the JI/CDM project remains an important issue to determine the achieved CO_2 emission reduction. Benchmarking only gives an indication on the additionality of projects.

[2] Using the technology matrix approach, the GHG emission that is credited is fixed and is thus not a real representation of the GHG emission achieved. The monitoring requirements are lower than in the project based or the benchmarking case, due to standardisation on technology level.

[3] Environmental additionality is defined as the credibility of the achieved emissions in projects being truly additional, which, of course, does not equal the environmental effect that is the result of the implemented projects.

[4] ++ means low costs, -- means high cost.

[5] Because world wide averages are used in the benchmarking baseline and modal technologies are used in the case of a technology matrix, the environmental additionality in the technology matrix is expected to be slightly better guaranteed in the latter case.

[6] If a country is relatively inefficient (in the case of benchmarking) or relatively old technologies are installed (in the case of a technology matrix) the environmental additionality is low. This is generally the case. If a country has efficient new, technologies (*e.g.* South Korea), the environmental additionality is large.

[7] If a country is relatively inefficient (in the case of benchmarking) or relatively old technologies are installed (in the case of a technology matrix) the potential volume of projects is large. If a country has efficient new, technologies (*e.g.* South Korea), the potential volum
e of projects is small.

4. Baseline construction: potential volume of projects

The potential volume of refurbishment projects under each of the proposed baselines is estimated for each of the process routes in the countries under consideration (Table 15). These are general indications and have not been adjusted for the effect of product mix on energy consumption. The actual potential may therefore differ from the estimations overleaf.

In the context of project volumes, it is also useful to draw a distinction between new plants and retrofits. Given the magnitude of investment needed for new plants and the potentially long life of iron and steel plants, retrofit is more common than greenfield additions, especially when integrated steel plants are considered. New plants that have recently been built, in general show a specific energy consumption is of the same order of magnitude as in best practice plants - allowing the best practice standard to serve as the baseline. The high degree of variability in existing plants requires a more complex baseline structure for this group - leading to the distinction between greenfield and refurbishment plants.

The potential volume for GHG emissions reduction in new plants is difficult to determine, because estimates of capacity additions from new plants are difficult to make and have large uncertainties. As a first indication, it could be expected that the specific energy consumption of new plants in 10 years would be up to 2 GJ/tcs lower than the current world-wide best practice SEC for integrated steel plants and DRI-EAF plants, but less for scrap based EAF plants.

It is very data and time intensive to calculate the potential volume of projects using the technology matrix. A simple estimate of the total volume can be made if it is assumed that the standard configuration of technologies is represented by the accompanying SEC values. Under this assumption, the SEC of the standard configuration defined by the world modal technologies would be equivalent to the world average SEC. Of course, in such a case, the total potential volume of projects would then be the same for technology matrix as for benchmarking using the world average. However, inasmuch as the data requirements for a technology matrix are more extensive, it can also be assumed that fewer projects would be undertaken - as the sheer difficulty of this approach would increased transaction costs and reduce project volumes. Such an assumption might apply to any technology matrix approach versus a benchmark approach of comparable stringency. In the subsequent analysis, only benchmark approaches are therefore considered.

The potential volume of projects that can be undertaken with benchmarking baselines is provided for India in Table 15. The data are derived as follows:

- It is assumed that plants that operate at a SEC that is less than 10% higher than the benchmark would be suitable for CO2 emission reduction measures. This number of plants is indicated in the first column of the table.
- For each plant, the potential volume of projects is calculated by subtracting the Best Practice value from the benchmark value, or the SEC of the plant (whichever is lower) and then multiplying the result by the process route specific CO2 emission indicator.
- The total volume (*i.e.* the sum of the first two steps for the country) is given in the third column.

It should be noted that the result is likely to be an over-estimate of potential volumes as, in practice, plants would not be expected in any single retrofit, to reach best practice performance levels. For Brazil and Poland, comprehensive plant data are not available. However, potential project numbers will be largest using the world-wide average, but likely to be no more than 6 for Brazil and 5 for Poland. Phylipsen (2000) calculated a reference Best Practice SEC for the Brazilian situation (*i.e.* 20% EAF and 36% cold-rolled), *i.e.* 18.7 GJ/ton. This value is used as the best practice world wide value.

Whereas the country average SEC in India is above the world-wide average SEC, this is not the case for Brazil and Poland. This does not imply that a benchmark on a world-wide average is not stringent enough for Brazil or Poland, but only that the plants in Brazil and Poland are already more efficient than Indian plants on average.

Table 15: Potential volume of refurbishment projects in the iron and steel plants in India

Baseline approach	Number of plants near the benchmark value	Potential volume of projects in selected plants (Mt CO_2)	Potential volume of projects in all plants (Mt CO_2)
Integrated Steel Plants			
World-wide Best practice (22 GJ/tcs)	0	~0	~0
World-wide average (26 GJ/tcs)	2	3	6
Country average	4	16	20
Scrap-EAF			
World-wide Best practice (7.7 GJ/tcs)[1]	0	~0	~0
World-wide average (10 GJ/tcs)	N/a	N/a	0.3
Country average	N/a	N/a	1
DRI-EAF (gas)			
World-wide Best practice (7.7 GJ/tcs)[1]	0	~0	~0
World-wide average (10 GJ/tcs)	N/a	N/a	0.5
Country average	N/a	N/a	0.5

* Graduated crediting would result in greater potential project numbers than baselines based on worldwide best practice, but lower potential project numbers than baselines based on world-wide average or country averages.

From Table 15 it becomes clear that there is a tradeoff between environmental additionality and the potential volume of projects. That automatically generates the question if it is possible to generate a larger potential volume of projects, while not losing on the additionality criteria. The "graduated crediting" approach outlined in section 3 and Figure 9 could be one way of achieving a satisfactory tradeoff - although, as discussed above, it imposes potentially significant data requirements and costs.

5. Conclusions and recommendations

There are a number of potential energy-related JI/CDM project types in the iron and steel sector. These include:

- increasing the energy efficiency of steel production (*e.g.* by installing more efficient equipment, implementing good housekeeping measures);
- changing the manufacturing process (*e.g.* by installing new equipment like thin slab casters); or
- changing the input fuel for direct reduction (*e.g.* from coal to gas).

It is possible to define multi-project baselines in the iron and steel sector. The component of these baselines that could be standardised is that of the energy consumption of different process routes per ton of crude steel output. Further adjustments would need to be made to take into account the different energy intensity of different iron and steel products. Adjustments may also need to be made to take into account the quality of fuel and ore inputs used. A standardised "translation" of these energy values to GHG equivalents is not practical given the variability in fuels used in iron and steel production between countries and the fuel mix of central electricity production. CH_4 and N_2O emissions are almost absent in the production of iron and steel and thus need not be included in the baseline.

Internationally standardised baselines for iron and steel projects based on energy intensities could be aggregated to the level of different process routes, *i.e.*:

1. Integrated Steel Plants;
2. Scrap based Electric Arc Furnaces;
3. Direct reduced iron (gas based) Electric Arc Furnaces;
4. Direct reduced iron (coal based) Electric Arc Furnaces.

As the direct reduced iron (coal based) route is as an inefficient and outdated process, it is recommended that projects using this process should not be considered eligible for JI/CDM status. Energy intensities could be used for projects worldwide. However, some corrections may need to be made to account for country specific circumstances, *i.e.* coal and iron ore quality and product mix, *i.e.* the fraction of cold-rolled steel *versus* hot-rolled steel.

In general data availability at the level of aggregation needed to develop baselines is limited in international publications. Thus, for example, while the analysis of India reviewed in this case study shows that the necessary data are available, even this information would require additional verification and are not sufficiently comprehensive to fully develop country specific sectoral baselines. Reviewing national data also yields conflicting information: this is the case in the Polish case study. Establishing robust baselines in these countries will require additional data to be collected bottom-up (in the country and compared with international statistics.

Two types of baselines have been evaluated in this report, *i.e.* benchmarking and technology matrix. They both have advantages and disadvantages.

Neither approach is not inherently better than the other with respect to environmental credibility: both could provide stringent or lax baselines, depending on the assumptions used. Moreover, the environmental additionality, or not, of a single baseline assumption can vary substantially depending on national circumstances. For example, using a baseline derived from country average data would lead to a lax baseline for India, but a stringent baseline for Brazil.

Overall, it is recommended that baselines be set using a standardised energy value for an individual iron and steel process route. Such a benchmarking-type system is easier to develop than a system based on the technology matrix. Moreover, the data requirements for the latter are large and the inclusion of technologies that do not cause step change difference in performance is expected to be very data intensive and very difficult to develop.

It is also recommended that separate baselines be developed for greenfield and refurbishment projects. For greenfield projects (new capacity), a benchmark based on the world-wide best practice energy intensities for different production routes is the most suitable, as it reflects recent capacity additions under BAU conditions, including in both developed and developing countries (*e.g.* in India and South Korea). Indeed some of the most advanced iron and steel production technology (*e.g.* the Corex process) is already in place or is planned in developing countries.

For refurbishment of existing plants, a benchmark based on a “better than world-wide average” is considered to be a good trade-off between environmental credibility and the potential volume of projects. However, determining what is “better than average” is likely to be an arbitrary decision, particularly given the lack of data on plant performances.

Given the improvements in energy efficiency noted over the past two decades, an autonomous energy efficiency improvement should be factored into a standardised emission baseline (for both greenfield and refurbishment plants). This baseline is likely to need evaluating every 5 years to check if the SEC development conforms to previous expectations.

Another method to increase the potential volume of projects while still preserving the environmental credibility is to allow credits for projects that improve currently operating plants to below the national average energy intensity, even if the performance of such plants does not achieve the “better than average” baseline. This type of baseline is more stringent than one based on national average performance (because not all emission reductions would be credited at that level), but would encourage more projects than projects judged against baselines drawn up using BAT energy performance.

It is difficult to give general rules regarding the standardisation of emission timelines for JI/CDM projects in the iron and steel sector, mainly because the average lifetime of the industrial technology used is very difficult to determine. The current age of the stock is therefore not considered to be a useful indicator for determining the additionality of CDM/JI projects.

Glossary

additive (or extender)	material(s) added to clinker to make cement
AEEI	autonomous energy efficiency improvement
AIJ	activities implemented jointly
AIXG	Annex I Experts Group on the United Nations Framework Convention on Climate Change (UNFCCC)
audit-based programmes	Programmes that rely on the systematic collection of data on building and energy system performance characteristics at the customer site. The goal of these programmes is typically to identify and quantify energy efficiency improvement opportunities in combination with an implementation plan.
baseload	The minimum amount of electric power delivered or required over a given period of time at a steady rate.
BAU	business as usual
bench tests	Tests of equipment performance characteristics conducted in a controlled environment such as a laboratory or manufacturer's test facility.
BF	blast furnace
blast furnace slag	One of the common additives used in cement. It is the by-product of iron and steel manufacture and grinding this additive for use in cement is energy intensive.
BOF	basic oxygen furnace
CDM	Clean Development Mechanism (project-based mechanism introduced in Article 12 of the Kyoto Protocol)
CFL	compact fluorescent lamp
CH_4	Methane
CHP	Combined heat and power. A plant that is designed to produce both heat and electricity
cli	Clinker
clinker	The key component of cement and the most GHG-intensive.
CO	coke oven
CO_2	carbon dioxide
combined cycle	An electric generating technology in which electricity is produced from otherwise lost waste heat exiting from one or more gas (combustion) turbines. This process increases the efficiency of the electric generating unit.

conversion efficiency	Efficiency at which a thermal power plant converts input fossil fuel (*i.e.* coal, gas, or oil) into electricity.
crediting lifetime	Length of time (in years) during which a project can generate emission credits.
demand-side management (DSM)	Utility programmes designed to control, limit or alter Energy consumption by the end user. DSM objectives may include energy conservation, load management, fuel substitution and load building.
diversity factor	The ratio of the peak demand of a population of energy-consuming equipment to the sum of the non-coincident peak demands of the individual equipment.
DR	direct reduction
DRI	direct reduced iron
dry process	A process whereby the raw materials for cement production are ground and then mixed (as a dry powder).
EAF	electric arc furnace
EEI	energy efficiency index
EIT	countries with economies in transition
EJ	exajoule (= 10^{18} Joule)
emission credits	Unit used for the measurement (*e.g.* in tonnes of CO_2-equivalent), transfer and acquisition of emission reductions associated with JI and CDM projects.
end-use indices (EUI)	The ratio of the energy use of a building, system or end-use over a given time period to a commonly recognised index of size or capacity. Examples include lighting energy use per square foot of floor area and motor energy use per unit of production output.
environmental credibility	Quality of a baseline with respect to realistically reflecting the emission level that would likely occur without the JI or CDM project(s).
environmental effectiveness	Extent to which the project-based mechanisms result in maximum emission reductions and maximum participation through JI and CDM projects, thereby contributing to achieving the objectives of the Kyoto Protocol.
EU or EU15	The 15 members states of the EU.
fluorescent lamps	A discharge lamp whereby a phosphor coating transforms ultraviolet light into visible light. Fluorescent lamps require a ballast that controls the starting and operation of the lamp.

free riding	A situation whereby a project generates emission credits, even though it is believed that the same project would have gone ahead, even in the absence of JI or CDM. The emission reductions claimed by the project would thus not really be "additional". Free riding therefore affects the number of projects obtaining credits under JI and CDM.
gaming	Actions or assumptions taken by the project developer and/or project host that would artificially inflate the baseline and therefore the emission reductions. Gaming therefore affects the amount of emission credits claimed by a JI or CDM project.
GHG	greenhouse gas
GJ	gigajoule (= 10^9 Joule)
greenfield projects	New projects (as opposed to existing plants that are refurbished)
grid	The layout of an electrical distribution system.
GWh	gigawatt hour, *i.e.* 10^9 Wh.
GWP	global warming potential
hp	horsepower
HPS	High pressure sodium lamps.
HVAC	Mechanical heating, ventilating and air-conditioning of buildings.
IEA	International Energy Agency
incandescent lamps	A lamp that produces visible light by heating a filament to incandescence by an electric current.
ISP	integrated steel plant
JI	Joint implementation (project-based mechanism introduced in article 6 of the Kyoto Protocol).
kWh_e	kilowatt hours of electricity use
leakage	Leakage occurs if actual emission reductions (or sink enhancements) from a CDM or JI project lead to increases in emissions (or sink decreasing) elsewhere.
load curve	A plot of the demand placed on an energy system during an hour, day, year or other specified time period.
load factor	Number of hours in a year during which a power plant is generating electricity.
market segment	A segment of a customer or end-user market identified by common demographic, firmographic or energy use characteristics. Examples include the single-family detached home segment in the residential sector; and the office building segment in the commercial sector.

MJ	megajoule (= 10^6 Joule)
Mt	million metric tons
mtoe	million tons of oil equivalent
multi-project baselines	Emission baselines (also referred to as “benchmarks” or “activity standards” in the literature) that can be applied to a number of similar projects, *e.g.* to all electricity generation CDM or JI projects in the same country.
nameplate data	Data provided by equipment manufacturers that identify the make, model and performance characteristics of the equipment. These data are published in the manufacturer’s product literature and key data elements are affixed to the equipment on the nameplate. Often the equipment nameplate itself does not provide sufficient information for energy analysis.
N_2O	nitrous oxide
OECD	Organisation for Economic Co-operation and Development
off-peak load	The demand that occurs during the time period when the load is not at or near the maximum demand.
OHF	open hearth furnace
peak load	The maximum demand or load over a stated period of time. The peak load may be stated by category or period such as annual system peak, customer class peak, or daily peak.
peaking plants	Power plants normally reserved for operation during the hours of highest daily, weekly, or seasonal loads.
PJ	petajoule (= 10^{15} Joule)
PJe	petajoules electricity
PJp	petajoules calculated back to primary energy
PJf	petajoules final energy
Pozzolana	A natural cementious material that can be ground and used as a cement additive.
Process emissions	For cement production this refers to the CO_2 emitted from decarbonisation of limestone. It takes place during the pyro-processing step.
Production process change	Refurbishment of an existing plant that would change the process by which clinker is manufactured to a more efficient process (*e.g.* wet to dry, or semi-dry to dry)
Pyro-processing	This is the process of turning the raw materials into clinker (and takes place in the cement kiln).
Refurbishment projects	Projects in which existing equipment/processes are upgraded or replaced.

rpm	revs per minute
Run-time monitoring	Recording equipment or system runtime over a specific monitoring period. Often conducted with devices specifically designed for recording operating hours.
SAE	statistically adjusted engineering analysis
SEC	specific energy consumption
shaft kiln	The kiln, where clinker is produced, is vertical (whereas in other cement processes the kiln is slightly tilted, *e.g.* 1-3 degrees from the horizontal).
spot-watt measurements	One-time or instantaneous measurements of input wattage to a system or piece of equipment.
tcs	tonne of crude steel
thermal power plant	Power plants that burn fuel directly to produce steam.
TJ	terajoule (= 10^{12} Joule)
transaction costs	The costs associated with the process of obtaining JI or CDM recognition for a project and obtaining the resulting emission credits. Transaction costs would include, for example, costs of developing a baseline and assessing the “additionality” of a project, costs of obtaining host country approval, monitoring and reporting, *etc.* Transaction costs would not include the direct investment, maintenance and operational costs of the project.
UNFCCC	United Nations Framework Convention on Climate Change
update of baselines	Updating multi-project baselines, at regular intervals, in order to continue to reflect business-as-usual electricity investments. CDM or JI electricity projects would need to use the most recently updated multi-project baseline.
USAID	US Agency for International Development
USEA	US Energy Association
wet process	A process whereby the raw materials are ground, with water added, and mixed (as a slurry). The wet process is more energy-intensive than the dry process as energy is needed to evaporate the water in the raw material mix.

References

De Beer, J., J. Harnisch, M. Kerssemeeckers, 1999. *Greenhouse Gas Emissions from Iron and Steel Production*, Ecofys, The Netherlands.

CEC, 1999. Integrated Pollution Prevention and Control (IPPC). *Best available techniques reference document on the production of iron and steel*, European Commission, Directorate-General Joint Research Centre, Seville, Spain.

Daniels, B.W. and H.C. Moll, 1998. *The base metal industry: Technological descriptions of processes and production routes; status quo and prospects*. Center for Energy and Environmental Studies, Research Paper no 92, University of Groningen, Groningen, The Netherlands.

Ellis, J. and M. Bosi, 1999. *Options for Project Emission Baselines*. OECD and IEA information paper, Paris.

Gilecki, 2000. Personal communication with Ryszanol Gilecki, Agencja Rynku Energii S.A., Warsaw, Poland, on 14 March 2000.

Lawrence Berkeley National Laboratory, 1999. *International Network on Energy Demand in the Industrial Sector (INEDIS) Database*. Berkeley, CA: LBNL.

IISI, 1992. *Steel Statistical Yearbook 1992.* International Iron and Steel Institute, Brussels, Belgium.

IISI, 1998. *Energy use in the steel industry*, IISI, Committee on Energy, Brussels, Belgium

IISI, 1999. *World Steel in Figures Online, 1998.* Statistics published on the Internet (www.worldsteel.org), International Iron and Steel Institute, Brussels, Belgium.

IISI, 2000. *World Steel in Figures Online, 1999*. Statistics published on the Internet (www.worldsteel.org), International Iron and Steel Institute, Brussels, Belgium.

Kanjilal, Ashoke, 1998, *India Iron and Steel Plant Equipment*, US Foreign Commercial Service and US Department of State (www.tradeport.org/ts/countries/india/isa/isar0051.html)

Lazarus, M, S. Kartha, M. Ruth, S. Bernow, C. Dunmire, 1999. *Evaluation of Benchmarking as an Approach for Establishing Clean Development Baselines*, Tellus Institute, Boston, Stockholm Environmental Institute, Boston.

Olivier, J.G.J., A.F. Bouwman, C.W.M. van der Maas, J.J.M. Berdowski, C. Veldt, J.P.J. Bloos, A.J.H. Visschedijk and J.L. Zandveld (1996), *Description of EDGAR Version 2.0: A set of global emission inventories of greenhouse gases and ozone depletion substances for all anthropogenic and most natural sources on a per country basis and on 1°x1° grid*, RIVM, Bilthoven, The Netherlands.

Phylipsen, D., 2000. *International comparisons and national commitments*, PhD Thesis. Dept of Science, Technology and Society, Utrecht University, Utrecht, The Netherlands.

Price, L., D. Phylipsen, E. Worrell, 1999. *Energy Use and Carbon Dioxide Emissions in the Steel Sector in Key Developing Countries: Preliminary Sector Analysis*, Lawrence Berkeley National Laboratory, Berkeley.

Prus, Aleksandra, 1998, *Poland: Steel Industry*, US and Foreign Commercial Service and US Department of State (www.tradeport.org/ts/countries/poland/isa/isar0019.html)

Puhl, 1998. *Status of Research on Project Baselines under the FCCC and the Kyoto Protocol,* OECD Environment Directorate, Paris.

Sathaye, Jayant and Ashok Gadgil, LBL 1999, *Role of Development Banks in Promoting Industrial Energy Efficiency* (www.lbl.gov)

Steel Authority of India (SAIL), 1996. *Statistics for Iron & Steel Industry in India*, New Delhi: Steel Authority of India Ltd.

WEC, 1995. Energy Efficiency Improvement Utilizing High Technology - An Assessment of Energy Use in Industry and Buildings, World Energy Council, London.

Worrell, E., L. Price, N. Martin, J. Farla and R. Schaeffer, 1997. Energy intensity in the iron and steel industry: a comparison of physical and economic indicators, in: Energy Policy, V 25, Nos 7-9, pp 727-744.

Worrell, E., 2000. Personal communication with Dr E. Worrell, Lawrence Berkeley National Lab, Berkeley, CA, USA.