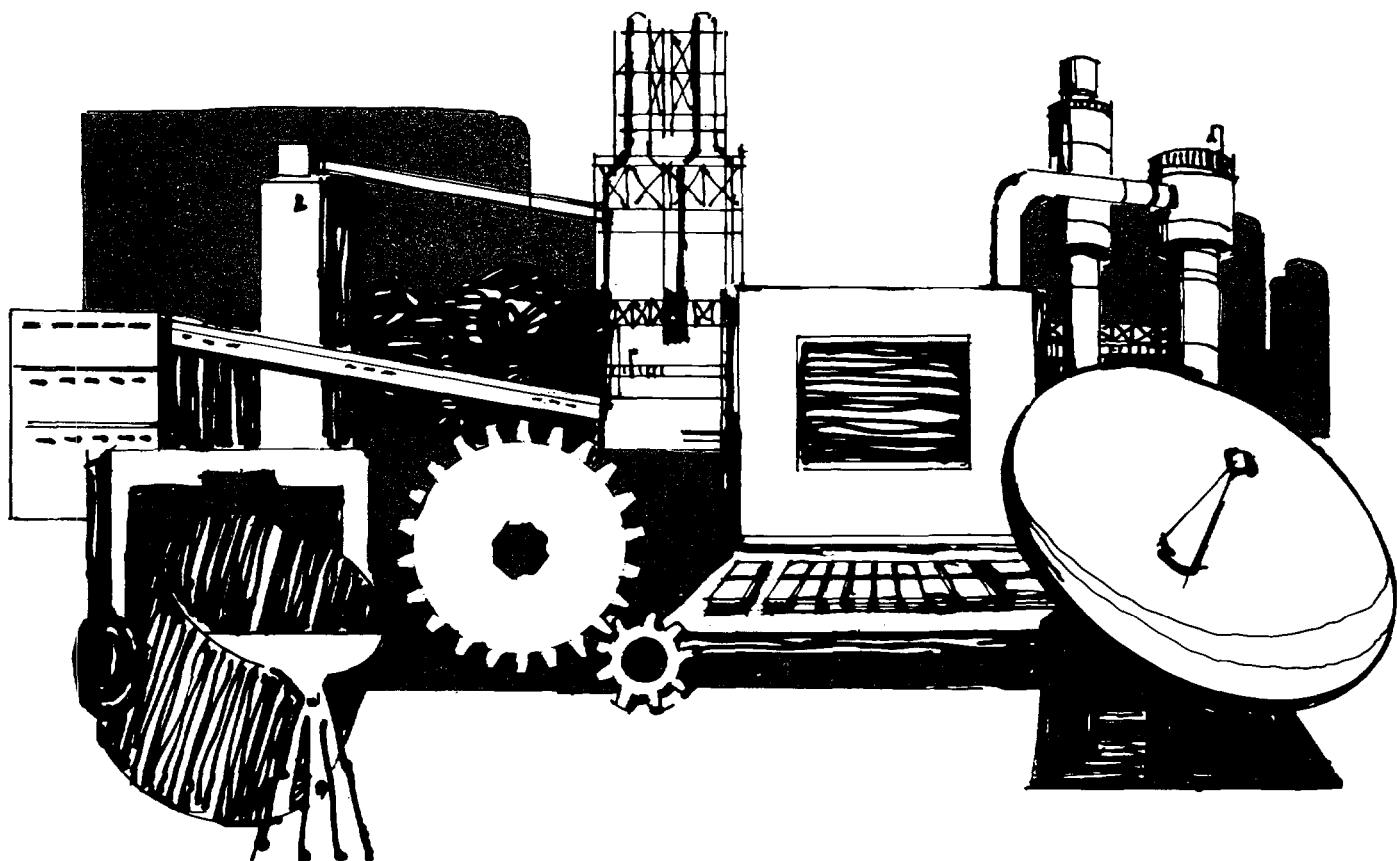


Energy Efficiency in the Steel Industry with Emphasis on Developing Countries

Maurice Y. Meunier and Oscar de Bruyn Kops



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**Energy Efficiency in the Steel Industry
with Emphasis on Developing Countries**

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ABSTRACT

As a result of the sharp increase in the price of energy during the 1970s and the associated changes in the relative costs of alternative energy resources, all countries need to conserve energy and to replace expensive sources of energy with cheaper ones. The subject of energy efficiency improvement has therefore assumed increasing importance worldwide. The steel industry is one of the most energy-intensive industries with energy-related costs accounting for a major portion of the costs of producing steel. The recent experience of the industrialized countries has shown that energy costs per unit of output of steel can be reduced significantly through a variety of measures ranging from energy management and improvement of operating conditions through better housekeeping, to more capital-intensive investments in modifications to existing plant and equipment and conversion to more energy-efficient processes.

This report aims at a broad presentation of concepts, measures and issues relevant to achieving such improvements in energy efficiency in the steel industry based on experience in both industrialized and developing countries. In so doing, it identifies possible constraints to the successful execution of energy efficiency programs that can be found in many developing countries, and indicates some measures that can be taken at the government, industry and plant levels to stimulate the achievement of increased energy efficiency in the steel industry.

ABSTRAIT

La forte hausse des prix de l'énergie des années 70 et les modifications qu'elle a apportées aux coûts relatifs des ressources énergétiques de substitution ont obligé tous les pays à remplacer des ressources coûteuses par une énergie à meilleur marché. C'est pourquoi la question de l'amélioration du rendement énergétique a pris une importance croissante dans le monde entier. La sidérurgie est l'une des industries les plus vulnérables à cet égard car l'énergie entre pour une large part dans les coûts de production de l'acier. L'expérience récente des pays industriels a montré que l'on pouvait réduire sensiblement les coûts énergétiques par unité de production d'acier grâce à une variété de mesures allant d'une gestion plus saine de l'énergie et de l'amélioration des conditions d'exploitation par un meilleur entretien à une orientation plus capitaliste par des investissements dans des modifications des installations et équipements existants et par une conversion à des procédés plus économes en énergie.

Ce rapport s'efforce de donner une présentation générale des concepts, des mesures et des questions intéressant la mise en oeuvre de telles améliorations du rendement énergétique dans la sidérurgie sur la base de l'expérience des pays industriels et des pays en développement. En même temps, il indique les obstacles auxquels peut se heurter la bonne exécution de programmes d'économies d'énergie dans de nombreux pays en développement, et certaines mesures à prendre aux niveaux de l'Etat, de l'industrie et de l'usine pour favoriser l'amélioration du rendement énergétique dans l'industrie sidérurgique.

EXTRACTO

Como resultado del alza pronunciada del precio de la energía durante la década de 1970 y los consiguientes cambios en los costos relativos de otros recursos energéticos, todos los países deben conservar energía y reemplazar las fuentes costosas por otras más económicas. Por lo tanto, el tema de la mejora de la eficiencia energética ha asumido cada vez más importancia en el mundo entero. La industria siderúrgica es una de las que usa energía en forma más intensiva y los costos relacionados con ella son una parte importante de todos los que intervienen en la elaboración del acero. La experiencia reciente de los países industrializados ha demostrado que los costos de la energía por unidad de producción de acero pueden rebajarse mucho aplicando diversas medidas que van desde su administración y condiciones más adecuadas de funcionamiento, a mejores prácticas de organización interna y más inversiones con utilización intensa del capital en modificaciones de la planta y equipo existentes y conversión a procesos más eficientes en lo relativo a la energía.

El objetivo de este informe es presentar con amplitud los conceptos, medidas y cuestiones pertinentes para lograr tales mejoras de la eficiencia energética en la industria siderúrgica, con arreglo a la experiencia de los países industrializados y en desarrollo. Al hacerlo, identifica posibles limitaciones para alcanzar el éxito en la ejecución de los programas pertinentes e indica algunas medidas que pueden tomarse en el plano oficial, industrial y de planta para procurar que se logre una mayor eficiencia energética en la industria siderúrgica.

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ABBREVIATIONS AND ACRONYMS

ACC	-	Automatic combustion control
BF	-	Blast furnace
BFG	-	Blast furnace gas
BOF	-	Basic oxygen furnace
BTU	-	British Thermal Unit
C	-	Celsius
CC	-	Continuous casting
CDQ	-	Coke dry quenching
COG	-	Coke oven gas
CPE	-	Centrally planned economy
DC	-	Developing country
DR	-	Direct reduction
EAF	-	Electric arc furnace
Gcal	-	Gigacalories (10^9 calories)
IISI	-	International Iron and Steel Institute
IME	-	Industrialized market economy
Kcal	-	Kilocalories (10^3 calories)
kg	-	Kilogram
KVA	-	Kilo Volt Ampere
Kwh	-	Kilowatt hours
LDG	-	Basic oxygen furnace off-gas
Mcal	-	Megacalories (10^6 calories)
MW	-	Mega Watt (10^6 Watt)
NSC	-	Nippon Steel Corporation
OECD	-	Organisation for Economic Co-operation and Development
OHF	-	Open hearth furnace
tce	-	Tons of coal equivalent
toe	-	Tons of oil equivalent
tpy	-	Tons per year
TRT	-	Top-pressure recovery turbine
UHP	-	Ultra high power
WHB	-	Waste heat boiler

ENERGY CONVERSION FACTORS

1 BTU	=	0.252 Kcal
1 Kwh	=	2,450 Kcal <u>a/</u>
1 tce	=	0.7×10^7 Kcal
1 toe	=	10^7 Kcal

a/ Based on energy conversion efficiency in modern power plants.

COUNTRY CLASSIFICATION a/

Industrialized Market Economies (IMEs)

All countries of Western Europe (except Greece, Portugal and Turkey), United States, Canada, Japan, Australia and New Zealand.

Centrally Planned Economies (CPEs)

Albania, Bulgaria, Cuba, Czechoslovakia, Democratic Republic of Korea, German Democratic Republic, Hungary, Poland, Romania, USSR and Viet Nam.

Developing Countries (DCs)

All countries other than IMEs and CPEs.

a/ Unless specified otherwise.

SUMMARY AND CONCLUSIONS

1. The improvement of energy efficiency in steelmaking is of widespread concern since the steel industry is one of the largest consumers of energy both in industrialized and developing countries. Not only does steelmaking use great amounts of energy per ton of product (6-10 Gcal or 0.6-1.0 ton of oil equivalent (toe) are used per ton of crude steel to produce finished steel from iron ore and coal), but levels of output are also relatively high (world production in 1982 totalled 645 million tons of crude steel). As a result of this intensive use of energy, the steel industry accounts for up to 10 percent or more of total energy consumption in steel producing countries. Whatever energy can be conserved in steelmaking, then, will significantly affect a country's overall energy consumption and thus its balance of payments. Furthermore, such savings will enhance the cost competitiveness of the industry owing to the large share of energy in production costs.

2. The steel industry in developing countries presents a significant potential for energy saving. As demonstrated in this report, well-designed energy efficiency programs can quickly yield impressive results in realizing this potential. Contrary to common belief, significant savings can be realized with a limited investment outlay that promises high economic returns and short payback periods. The report demonstrates that over the medium term, the energy consumed by developing countries in steelmaking--particularly in the form of fuel oil, metallurgical coal, and electricity--can be reduced by 10-15%. If these savings could be achieved,

overall energy consumption in the steel-producing DCs could drop by about 10-20 million toe a year by 1990, and total savings could amount to about US\$2-4 billion a year (1982 prices). Based on experience in the Japanese steel industry, an investment of about US\$2-4 billion (1982 prices) would be required in the developing countries to achieve these savings. Such savings, however, hinge upon specific energy efficiency measures and policies at both the plant and country level.

3. At the plant level, successful energy efficiency programs begin with comprehensive energy audits and the establishment of an adequate energy management and control organization. These measures should normally be followed by minimal investments in improving operating conditions and subsequently by larger projects directed at installation of energy saving hardware and equipment modernization. A number of proven energy saving measures are currently available and can be readily adapted for application to the steel industry in the developing countries. These measures are briefly explored in the report for each steelmaking process and for each stage of steel production.

4. Effective measures at the country/industry level are necessary to stimulate energy efficiency at the plant level. These measures include appropriate pricing of energy inputs, fiscal and financial incentives for energy conservation, energy-use target-setting and monitoring schemes, promotion of energy audits and appropriate technical assistance/training. The lack of such measures has, in the past, contributed to impeding the implementation of energy efficiency programs in a number of developing countries.

I. INTRODUCTION

1.01 The steel industry is one of the largest consumers of energy both in industrialized and developing countries (DCs). Not only does the steel industry use great amounts of energy per ton of product (6-10 Gcal or 0.6-1.0 tons of oil equivalent (toe) are used for every ton of crude steel to produce finished steel from iron ore and coal), but levels of output are also relatively high (world production in 1982 totalled 645 million tons of crude steel). As a result of this intensive use of energy, the steel industry accounts for up to 10% or more of total energy consumption in steel producing countries. The improvement of energy consumption in the steel industry will therefore significantly affect a country's overall energy consumption and as a result its balance of payments. Furthermore, such savings will enhance the cost competitiveness of the industry due to the large share of energy in production costs.

1.02 This report provides an assessment of the potential for improving energy efficiency in the steel industry, particularly in DCs, and of the measures required at plant and country level to achieve such improvements. Chapter II gives an introductory overview of recent production and technology trends in the steel industry. Chapter III contains a detailed analysis of energy consumption in the steel industry, including its share in overall energy consumption, specific energy consumption by various steelmaking processes, and the costs of energy in steel production. Furthermore, it describes energy efficiency improvements realized in selected countries and estimates the potential for such improvements in the DCs. Chapter IV reviews energy efficiency measures at the plant level, and

is followed in Chapter V by a brief overview of measures at the industry and country level to promote energy efficiency.

1.03 Concerning the technical aspects related to the energy consumption of various production processes and energy efficiency measures at the plant level, the report is based largely on a report prepared for the Bank by Nippon Steel Corporation. Therefore, most of the data in this respect used in Chapters III and IV reflect Japanese steelmaking conditions.

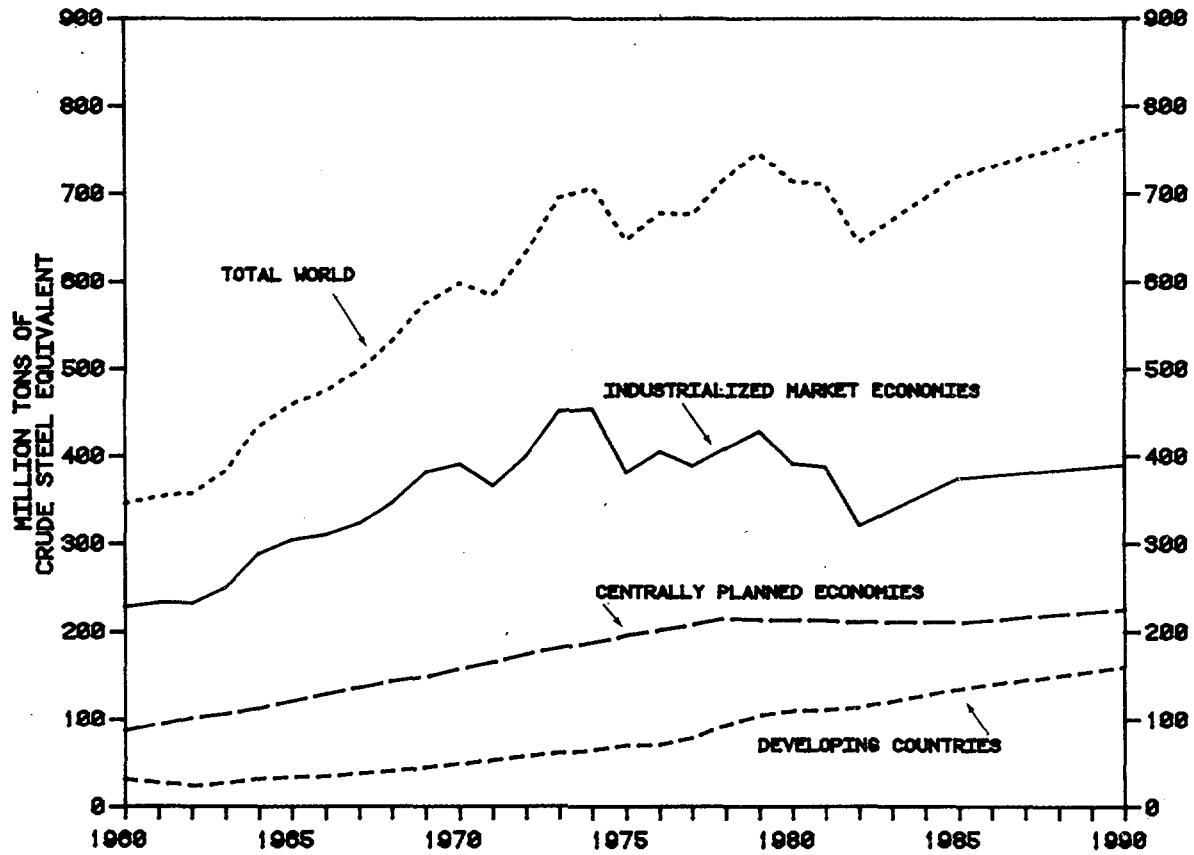
II. THE STEEL INDUSTRY - AN OVERVIEW

A. Trends in Production

2.01 Since the mid-1970s, world production of crude steel ^{1/} has stagnated at around 700 million tons per year (tpy) despite rapid growth in the DCs and a steady, though less remarkable, increase in the centrally planned economies (CPEs), as shown in Figure 1. The stagnation results largely from steel production trends in the industrialized market economies (IMEs) where production declined sharply from the high levels of 1973 and 1974, and has yet to recover to these levels. Steady production increases during the 1960s and early 1970s led the steel industry in the IMEs to expect a greater demand for steel and thus to implement substantial net additions to capacity. Production had to be cut back after 1974, however, when the industry was hard hit by the recessions of the mid-1970s and early 1980s and demand dropped. Subsequently, capacity utilization in the IMEs fell sharply and it has not recovered since that time (in 1982 it stood at about 64%).

^{1/} Crude steel: first solid state after the steelmaking stage which includes ingots, continuously cast semi-finished products and castings (para 2.05).

Figure 1: World Steel Production, 1960-90 a/



a/ 1960-1982 actual; 1983-90 projected.

Source: World Bank data.

2.02 Because of the slow economic growth in IMEs and external debt problems in many DCs, world demand for steel is expected to show only a slight increase between 1980 and 1985, when demand should reach an estimated 720 million tons. By 1990, when the world economies are expected to have returned to a moderate growth, demand should reach a level of about

775 million tons, or an increase of about 1.5% per year between 1985-90. The increase of demand will be partly met by an increase of production in IMEs, which presently have substantial excess capacity. Their production is expected to reach 375 million tons by 1985 and 390 million tons by 1990.

2.03 The situation in the DCs (including China), on the other hand, has been somewhat different. Because of a steady growth in demand, steel production in the DCs increased by an average of 7.3% during 1974-82. Capacity utilization reached 92% in 1981 and reduced to 84% in 1982. Despite lower expected growth rates in some DCs than in the late 1970s, steel production should nonetheless increase at a relatively high annual rate (estimated at about 3.8% a year between 1980 and 1990) because of the continued growth in local demand and the suitability of DCs in producing certain types of steel products (para 2.07). The DC share in total production should therefore increase to about 21% in 1990, which is more than double its share in 1970 (8.2%). This share is expected to increase further in line with the increasing share of the DCs in world steel consumption and some addition of production capacity.

2.04 Steel production in the DCs is highly concentrated. In 1982, for example, some fifty DCs were producing steel, of which the top five DC producers accounted for about 71% of total DC production. In the same year, the top ten produced 89%,^{2/} and only twelve DCs produced more than one million tons each. Details of world steel production and production in DCs are provided in Annex 1.

^{2/} The top ten DC steel producers in 1982 were: China; Brazil; Republic of Korea; India; South Africa; Mexico; Taiwan, China; Yugoslavia; Argentina; and Turkey.

B. Trends in Technology

2.05 Simplified flow diagrams of the steelmaking process are given in the following chart (figure 2) for a conventional integrated steel plant and a mini steel plant, while the main features of steelmaking are summarized in Table 1 according to the four most common methods of producing steel: blast furnace and open hearth furnace (BF-OHF); blast furnace and basic oxygen furnace (BF-BOF); direct reduction furnace and electric arc furnace (DR-EAF); and scrap-based electric arc furnace (Scrap-EAF).

Figure 2: Simplified Flow Diagrams of Conventional and Mini Steel Plants

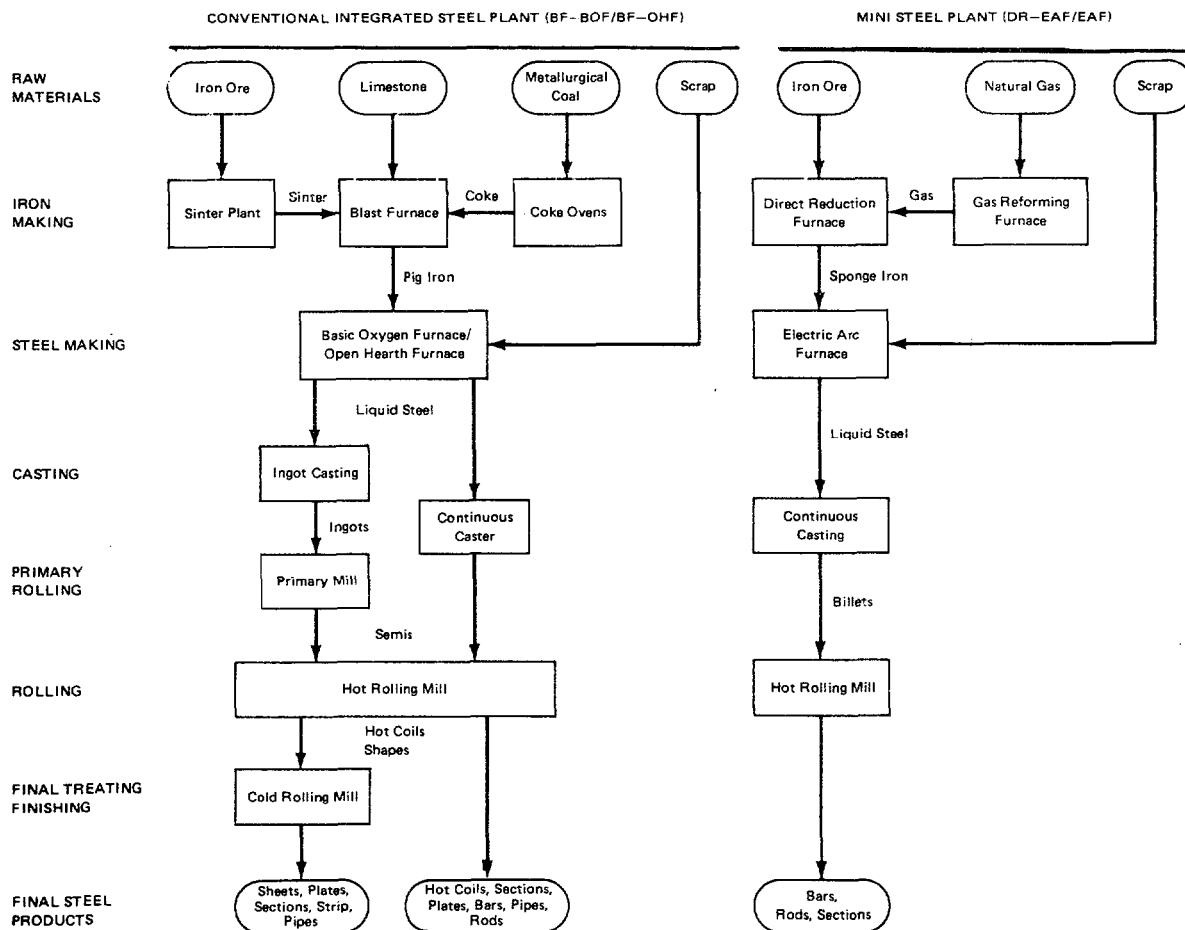


Table 1: Characteristics of Principal Methods of Producing Steel

	Conventional Integrated Steel Plant		Mini Steel Plant	
	BF-OHF	BF-BOF	DR-EAF	Scrap-EAF
<u>Type of Furnace</u>				
Ironmaking stage	Blast furnace (BF)	Blast furnace (BF)	Direct reduction (DR) furnace	-
Steelmaking stage	Open hearth furnace (OHF)	Basic oxygen furnace (BOF)	Electric arc furnace (EAF)	Electric arc furnace (EAF)
<u>Capacity Range a/</u> (million tpy)	0.5-2.0	0.5-3.7	0.2-1.0	0.2-0.8
<u>Investment Cost b/</u> (US\$ per ton installed in 1982 prices)	1,700-2,000 c/	1,500-1,800	500-900 d/	350-550
<u>Main Material Inputs</u>	Iron ore, scrap	Iron ore, scrap	Iron ore, scrap	Scrap
<u>Main Energy Inputs</u>	Coking coal, oil, electricity	Coking coal, oil, electricity	Natural gas, e/ electricity	Electricity

a/ Typical range (crude steel).

b/ Includes working capital and interest during construction.

c/ Rough estimate because new capacity addition by this route has been abandoned.

d/ Does not include pellet plant.

e/ Coal-based DR processes are currently being developed.

Source: Nippon Steel Corporation, hereafter referred to as NSC.

2.06 At present the most favored method among modern large integrated steel plants is the BF-BOF combination which is rapidly replacing the older OHF-based process because of its higher productivity and lower energy consumption. In the IMEs, the BOF steelmaking process accounted for more than two-thirds of total production in 1982; OHF's share fell to about 3% during the same period. Table 2 compares the trends in steelmaking processes favored by selected IMEs and CPEs between 1960 and 1982. In DCs, the share of BOF steelmaking in 1982 was about 51%, while the OHF process accounted for about 20%. Annex 2 gives details of DC production by main steelmaking process.

Table 2: Trends in Steelmaking Processes in Selected Areas
(% of total production)

	1960				1982			
	Basic Oxygen Furnace	Open Hearth Furnace	Electric Furnace	Other ^{a/}	Basic Oxygen Furnace	Open Hearth Furnace	Electric Furnace	Other ^{a/}
<u>Western Europe</u> ^{b/}	3.4	48.8	11.2	36.6	69.2	2.2	28.6	-
EEC	2.2	37.8	10.4	49.6	73.6	0.5	25.9	-
Other	5.9	72.4	13.1	8.6	52.4	11.6	36.0	-
<u>North America</u> ^{c/}	3.2	87.0	8.7	1.1	60.8	9.0	30.2	-
United States	3.4	87.0	8.4	1.2	60.7	8.2	31.1	-
<u>Japan</u>	<u>11.9</u>	<u>67.9</u>	<u>20.2</u>	<u>-</u>	<u>73.4</u>	<u>-</u>	<u>26.6</u>	<u>-</u>
Subtotal	4.1	67.5	11.0	17.4	68.4	3.2	28.4	-
<u>Eastern Europe</u> ^{d/}	3.1	85.0	9.1	2.8	30.5	56.5	12.5	0.5
USSR	3.8	84.4	8.9	2.9	29.5	59.1	10.9	0.5
Other	<u>0.1</u>	<u>87.3</u>	<u>9.7</u>	<u>2.9</u>	<u>33.9</u>	<u>47.1</u>	<u>18.3</u>	<u>0.7</u>
Total	<u>3.8</u>	<u>71.8</u>	<u>10.5</u>	<u>13.9</u>	<u>54.4</u>	<u>22.9</u>	<u>22.5</u>	<u>0.2</u>

a/ Including Thomas steelmaking process.

b/ Excluding Switzerland.

c/ Canada and United States.

d/ Excluding Czechoslovakia, 1982 data based on 1981.

Sources: For 1960 data: United Nations Economic Commission for Europe, Structural Changes in the Iron and Steel Industry (1979); for 1982 data: International Iron and Steel Institute.

2.07 Recently, the so-called minimills have become strong competitors of the larger integrated steel plants for the common grade of steel products. At present, the typical integrated minimill consists of a direct reduction (DR) plant, an electric arc furnace (EAF) shop with continuous billet casting, and one or two rolling mills for the production of non-flat products (the DR-EAF process). There are indications that minimills may

soon be able to produce flat products also, if development work in the field of continuous casting of thin slabs proves successful. Of the various direct reduction (DR) processes, those based on natural gas account for about 90% of total DR sponge iron production throughout the world (estimated at 8.2 million tons in 1982). They will no doubt continue to hold this place in the near future, but new coal-based DR processes (those using gasified coal are already well advanced and some of the kiln type are already producing at industrial scale) could become important competitors of BF ironmaking, since they would make the DR process accessible to countries that do not have supplies of natural gas. A nonintegrated minimill uses scrap to charge the electric arc furnace (the scrap-EAF process). The minimill is especially attractive to the DCs because of four main advantages: its lower economies of scale than the BOF-based process allows it to serve smaller markets; the investment cost per ton installed is relatively low; a minimill can be constructed faster and the production buildup is generally more rapid than in other types of mills; and it has substantially lower specific energy consumption in the case of a scrap-EAF plant (para 3.05). The main drawbacks of the minimills are currently the restrictions on product mix; the relatively high cost of its main energy source, electricity; the fluctuating prices of scrap; and the dependence of DRI production on natural gas supplies and high quality iron ore. As noted above, however, the installation of more coal-based plants is expected in the future which could produce either DRI or hot metal. The latter would permit converter steelmaking, and reduce the substantial dependence of the DR-EAF process on electricity. Its favorable features are expected to ensure the continued growth of DR-based ironmaking and the EAF share in

steelmaking. The DR share in ironmaking is expected to increase from 2% in 1982 (12% in DCs) to 6% in 1990 (28% in DCs); and the EAF share (DCs and IMEs combined) from 27% in 1982 to 31% in 1990. Details are given in Annex 3.

III. ENERGY CONSUMPTION IN STEELMAKING

A. Share of the Steel Industry in Total Energy Consumption

3.01 The steel industry ranks high among the industrial users of energy, both in terms of its size and specific energy consumption. Even an energy efficient steel producer such as Japan, uses about 6-8 Gcal (0.6-0.8 toe) per ton of crude steel to produce finished steel in its integrated plants, as compared with other energy intensive industries such as aluminum (17-22 Gcal per ton), ammonia (8-11 Gcal per ton), pulp and paper (5-11 Gcal per ton), and cement (0.8-1.4 Gcal per ton). Because the output of steel is also high and constitutes a significant portion of total industrial output in steel producing countries, this industry accounts for a substantial share of total energy consumption. In 1981 in the OECD countries, for example, steel accounted for an average of 20% of industrial energy consumption and 7% of total commercial energy consumption. The industry's share in total commercial energy consumption ranged from 5% for the United States to 15% for Japan. Typically, the steel industry accounts for almost half of an industrialized country's consumption of solid fuels (mainly metallurgical coal), and around 5-6% of gas and electricity. These amounts can differ considerably from country to country, depending on the structure of the economy, the size of the steel industry, the types of steelmaking processes employed, and the efficiency with which energy is used in the industry. Table 3 shows the energy consumption in the steel industry for selected OECD countries for 1981.

Table 3: Energy Consumption in the Steel Industry in Selected OECD Countries, 1981

	Crude Steel Production (million tons)	Total Commercial Energy Consumption (million tons of oil equivalent)	Share of Steel Industry in Energy Consumption		Share of Steel Industry in Total Consumption of Specific Types of Energy			
			Industry Sector Consump- tion (%)	Commercial Energy Consump- tion (%)	Solid Fuels (%)	Petroleum Products (%)	Gas (%)	Elec- tricity (%)
United States	108.8	1,266.4	17.0	4.8	46.4	0.5	5.3	3.9
Japan	101.7	254.5	28.9	15.0	73.7	2.0	-	13.7
France	21.3	136.4	17.9	6.5	47.0	0.6	7.1	7.0
Germany, F.R.	41.6	191.3	24.5	9.1	51.0	0.7	7.9	7.3
Italy	24.8	102.7	19.1	7.7	60.0	1.4	9.4	11.7
United Kingdom	15.6	134.5	17.2	5.6	28.8	2.1	2.4	5.1
EEC Total	126.3	681.8	20.6	7.5	46.9	1.1	5.7	7.2
OECD Total	388.0	2,602.1	19.6	6.7	46.3	1.0	5.2	6.1

Sources: For energy consumption data: OECD, Energy Balances of OECD Countries, 1971-81, 1983; for steel production: IISI, Steel Statistical Yearbook, 1982.

3.02 Although accurate comparable information is less readily available for DCs, estimates for selected steel producing DCs suggest similar average shares of the steel industry in industrial and total energy consumption as in the OECD countries. For example, it is estimated that in China (the main DC steel producer) in 1981 the steel industry accounted for 11% of total energy consumption, and 18% of industry sector consumption. For India, these shares are estimated at about 13% and 23% respectively, and for Turkey at about 6% and 22% respectively.

B. Specific Energy Consumption in Steelmaking ^{3/}

1. Consumption by Source of Energy

3.03 The sources of energy used at a steel plant can be classified into primary sources that are purchased from outside the plant and secondary sources that are generated in various parts of the steel plant and that can be recovered for re-use. One of the objectives of energy efficiency improvement is to expand the use of these secondary sources as much as possible and thereby reduce the requirements for purchased energy. The main primary sources of energy for steelmaking are metallurgical or coking coal, fuel oil, electricity, and natural gas. Coking coal and natural gas are mainly used for transforming iron ore into iron by removing oxygen (reduction of iron ore); fuel oil for heating, carbonization, and firing; and electricity for rolling, oxygen production, air blowing, and transportation. The shares of the primary purchased energy sources in total primary energy consumption are summarized in Table 4.

Table 4: Energy Consumption by Steelmaking Process
and Type of Purchased Energy
(% of calorific value)

Energy Sources	Steelmaking Process			
	BF-BOF	BF-OHF	DR-EAF	Scrap-EAF
Metallurgical coal	71	62	-	-
Natural gas	-	-	53	-
Electricity	16	14	32	59
Fuel oil and other	<u>13</u>	<u>24</u>	<u>15</u>	<u>41</u>
Total	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>

Source: NSC

^{3/} This section is based on a report prepared by Nippon Steel Corporation for the Bank. The specific energy consumption levels used in this section therefore reflect Japanese steelmaking conditions and not necessarily those of other countries.

3.04 The main secondary sources of energy in an integrated BF-BOF steel plant are: (i) coke oven gas (COG) from carbonization ^{4/} of coal; (ii) blast furnace gas (BFG) from the reduction of iron ore with coke; and (iii) basic oxygen furnace off-gas (LDG) from the decarburization ^{4/} of molten iron. In such a plant, BFG accounts (by calorific value) for about 50% of the energy content of by-product gases, COG for 42%, and LDG for 8%. In minimills, top-gas from direct reduction and the electric arc furnace can also be recycled. The by-product gases can be used to fuel various furnaces, or to generate steam and electric power. In some plants, these gases are flared off when excess amounts are produced as a result of the high fuel rates in the BF, or when recycling facilities are inadequate or ineffective. Figure 3 illustrates the energy flow in an integrated BF/BOF steel plant, distinguishing between primary and secondary energy sources.

2. Consumption by Steelmaking Process

3.05 Steelmaking processes can be compared on the basis of the energy required to produce one ton of finished product as shown in Table 5.^{5/} As seen, in fully integrated steel plants most of the energy is used during the ironmaking stage (BF-BOF: 71.6%, BF-OHF: 63.2%, DR-EAF: 57.6%). Since familiarity with these processes can be helpful in understanding the potential for improving energy efficiency, each production stage of the different processes is discussed in the following paragraphs.

^{4/} Carbonization: process of carbonizing (destructive distillation).
Decarburization: process of removing the carbon from the molten iron.
^{5/} Total energy consumption has been defined as: energy content of total energy purchased minus energy content of total energy sold.

Figure 3: Example of Energy Flow in BF-BOF Integrated Steel Plant
(unit of energy: percentage of total purchased energy)

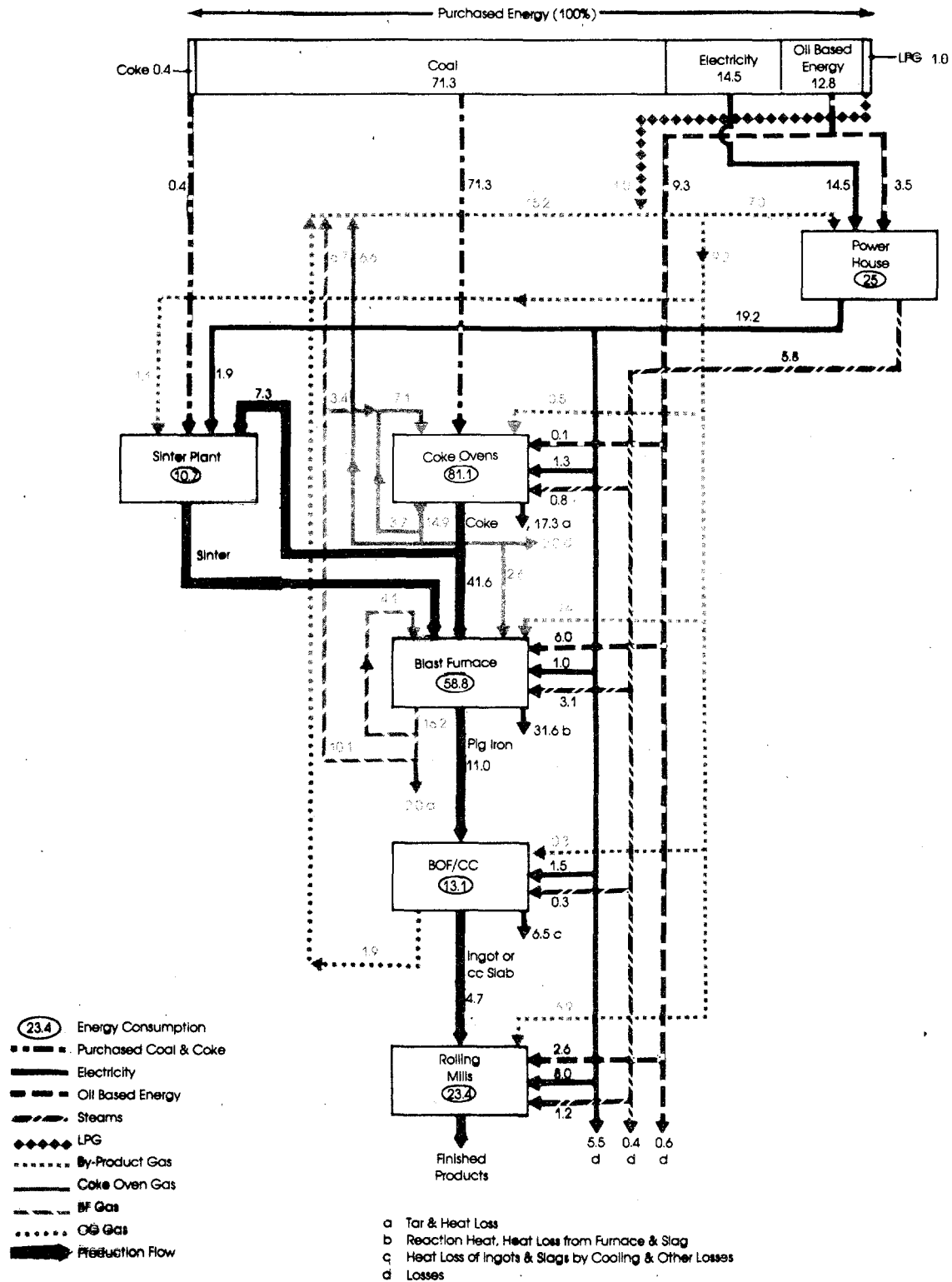


Table 5: Energy Consumption by Steelmaking Process
(Gcal per ton of crude steel)

	<u>BF-BOF</u>		<u>BF-OHF</u>		<u>DR-EAF</u>		<u>Scrap-EAF</u>	
	Gcal	%	Gcal	%	Gcal	%	Gcal	%
<u>Ironmaking</u>								
Sinter and pellet plant	0.7	11.6	0.7	10.3	-	-	-	-
Coke ovens	0.4	6.6	0.4	5.9	-	-	-	-
Blast furnace/DR unit	<u>3.2</u>	<u>53.4</u>	<u>3.0</u>	<u>47.0</u>	<u>3.4</u>	<u>57.6</u>	-	-
Sub-total	4.3	71.6	4.1	63.2	3.4	57.6	-	-
<u>Steelmaking</u> ^{a/}								
BOF/OHF/EAF	0.2	3.4	1.1	14.7	1.4	23.7	1.4	56.0
<u>Rolling mills</u>	1.0	16.6	1.0	14.7	1.0	16.9	1.0	40.0
<u>Power plant & others</u>	<u>0.5</u>	<u>8.4</u>	<u>0.5</u>	<u>7.4</u>	<u>0.1</u>	<u>1.8</u>	<u>0.1</u>	<u>4.0</u>
Total	<u>6.0</u>	<u>100.0</u>	<u>6.7</u>	<u>100.0</u>	<u>5.9</u>	<u>100.0</u>	<u>2.5</u>	<u>100.0</u>

a/ Including the primary rolling stage and continuous casting to produce semi-finished steel products such as slabs, blooms and billets.

Source: NSC

a. Ironmaking

3.06 The ironmaking stage, by far the most energy intensive stage in the BF-BOF, BF-OHF and DR-EAF processes, accounts for about 58% to 72% of total energy consumption. In the blast furnace (BF) alone, the gross energy consumption ranges from 4.2 to 5.3 Gcal per ton of pig iron produced, or 450-600 kg of fuel (coke and fuel oil), to which must be added the energy required to produce the hot blast used to generate reducing gas through partial combustion of coke (the reducing gas is used to reduce iron ore into iron). After the unused blast furnace gas (BFG) that can be recycled is deducted, the net energy requirement of the blast furnace amounts to 3.2-3.7 Gcal per ton of pig iron, which accounts for about half

of the total energy consumed at an integrated BF-BOF or BF-OHF steel plant. In addition, the coke ovens, sinter and pellet plants (which prepare coke, sinter and pellets which are fed into the BF) consume considerable amounts of energy. Because of both the high energy consumption and potential for savings in the ironmaking stage, energy efficiency measures tend to concentrate initially on this stage of production (para 4.02).

3.07 In the scrap-EAF process, purchased steel scrap is fed into the EAF so that no energy input is needed to reduce the iron ore; the energy is already present in the steel scrap. In the gaseous DR processes used in the integrated DR-EAF plants, 90 to 94% of the iron contained in the iron ore is reduced in the solid state. The reducing gas blown into the DR furnace is prepared by reforming natural gas with steam or carbon dioxide in the recycled top gas from the DR furnace. Theoretically, the energy required to reduce the iron ore is 1.7 Gcal per ton of DRI (direct reduced iron) produced, but because of losses in the reformer and the reducing furnace, actual energy requirements range from 3.0 to 3.8 Gcal, which can be supplied from about 280-350 Nm³ of natural gas (2.8 to 3.5 Gcal), and 80-120 Kwh of electric power (0.2-0.3 Gcal).

b. Steelmaking

3.08 In an efficient BF-BOF steel plant, net energy consumption in the steelmaking stage -- which is carried out in the basic oxygen furnace (BOF) -- is minimal and can be reduced to zero. The incoming molten iron, which represents 75-95% of the material inputs in steelmaking (the balance being mostly steel scrap, lime and oxygen), has a greater energy content than the

outgoing steel^{6/}. This excess energy can be taken out as off-gas (LDG, para 4.09) at the rate of about 0.2 Gcal per ton of steel produced, which equals the 0.2 Gcal of energy (mostly in the form of electricity and oxygen) required for BOF refining. Thus, when LDG is recycled, net energy consumption in the BOF can be reduced to zero, and the total energy required to produce molten steel from iron ore amounts to 4.0-4.6 Gcal per ton of crude steel.

3.09 In the OHF process, the hot metal ratio (the share of molten pig iron in the material inputs in steelmaking) is different from the BOF process. Optimum hot metal ratios for BOF and OHF are 70-90% and 30-60% respectively (the balance being, as noted previously, steel scrap, lime or flux and oxygen). The energy input required for the OHF varies between 0.6 and 1.4 Gcal per ton of crude steel. The higher energy consumption in comparison with the BOF process is mainly due to the energy required to melt the high share of steel scrap charged with the hot metal; also the OHF has a lower steelmaking yield than the BOF.

3.10 In the DR-EAF and scrap-EAF process, steelmaking takes place in the electric arc furnace (EAF) charged with either 80% of direct reduced iron (DRI) plus 20% steel scrap in the DR-EAF process, or 100% scrap in the scrap-EAF process. The energy required varies between 550 and 600 Kwh of electricity (1.4-1.5 Gcal) per ton of liquid steel plus some fuel and oxygen. However, recent improvements in electrodes, power supply equipment and water cooled furnaces have led to the development of ultra high power

^{6/} The molten pig iron produced in the BF has an energy content of 450 Mcal per ton, composed of a sensible heat at a temperature of 1,400°C and a latent heat of the solid-dissolved carbon in the iron. This energy is greater than the energy of 340 Mcal possessed by each ton of molten steel.

(UHP) EAFs, which, in turn, have reduced the consumption of power by raising the melting rate and improving productivity and heat efficiency (para 4.12,c). Some UHP EAFs consume as little as 450-500 Kwh of electricity per ton of steel based on scrap. Thus, total energy requirements for the steelmaking stage fall somewhere between 1.1 and 1.25 Gcal per ton of steel, which is supplied mainly from electricity, plus some oxygen and fuel.

3.11 In the next stage of the production, semifinished steel products (semis) such as billets, blooms, and slabs were traditionally produced from liquid steel in two steps: (i) ingots cast from liquid steel, and (ii) billets and slabs rolled from ingots. The energy used during this stage amounts to about 0.3 Gcal per ton of ingot. Significant amounts of energy can be saved at this point through the use of continuous billet or slab casting technology, which requires only about 90 Mcal (0.09 Gcal) per ton of continuously cast billets, blooms or slabs (para 4.13). Almost all recently constructed steel plants incorporate the continuous casting process.

3.12 A comparison of the steelmaking processes summarizing the energy required in the iron and steelmaking production stages is shown in Table 6.

Table 6: Energy Consumption in Crude Steel Production
(Gcal per ton of crude steel)

	BF-BOF	BF-OHF	DR-EAF	Scrap-EAF
Ironmaking	4.3	4.1	3.4	-
Steelmaking	0.2	1.1	1.4	1.4
Total	<u>4.5</u>	<u>5.2</u>	<u>4.8</u>	<u>1.4</u>

Source: NSC

c. Rolling mills

3.13 After the primary rolling stage or the continuous casting stage comes the final rolling stage which converts the semis into different finished products. The major categories of finished products are:

(i) non-flat products such as rebars, bars, wire rods, profiles, and rails; (ii) flat products such as plates, hot rolled coils, hot rolled sheets, cold rolled coils, and cold rolled sheets; (iii) coated products such as galvanized sheets (corrugated or flat), tinplate and enamelled sheets; (iv) tubes and pipes; and (v) special steel products such as stainless steel, and high tensile steel. The energy used in rolling amounts to about 0.5-1.0 Gcal per ton of crude steel rolled for each rolling stage. When rolling is accomplished in a number of stages, the energy required between the semis and the final product can be as high as 4.0 Gcal/ton of crude steel processed (e.g. tinplate).

3.14 In the rolling stage, energy is consumed in the reheating furnaces (fuel oil or gas) for heating the semis before rolling, and in the rolling mills (electricity).

3. Main Factors Affecting Energy Consumption in an Integrated Plant

3.15 In an integrated BF-BOF/OHF steel plant, the main factors influencing energy consumption are:

- (i) The fuel rate in the blast furnace;
- (ii) The hot metal ratio in the BOF/OHF steel shop;
- (iii) The production load or the degree of stabilization of the production flow and equipment performance; and
- (iv) The cold products ratio, or the extent of rolling of finished steel products.

C. Cost of Energy in Steelmaking

1. Share of Energy in Production Costs

3.16 Depending on the specific technology and steelmaking process, plant size, and efficiency with which energy is used, energy costs (valued at economic opportunity costs) usually range between 16% to 26% of production costs. Production costs for the different steelmaking processes are summarized in Table 7. It shows that the cost of energy for the scrap-based electric arc furnace steel plant is substantially lower than for the other processes since the energy intensive ironmaking stage is deleted. As mentioned earlier, for this process the energy is already present in the purchased scrap that is melted and refined into steel in the electric arc furnace.

3.17 The analysis of steel production costs in Table 7 is based on energy prices at international economic levels. Energy prices vary considerably among countries, however, and in some cases substantial differences exist between the actual energy prices (in financial terms) charged to the steel plants and the corresponding economic opportunity costs. In view of the high share of energy costs in total steel production costs, such differences between financial and economic costs--which are often accompanied by controls over steel prices--can cause substantial distortions in the use of particular energy sources and perpetuate energy-inefficient steel production. Appropriate pricing of both inputs (including energy) and outputs is therefore essential if overall production and efficiency (including energy efficiency) are to be improved in the steel industry (para 5.02).

Table 7: Analysis of Liquid Steel Production Costs by Steelmaking Process ^{a/}

Cost Item	BF-BOF		BF-OHF		DR-EAF		Scrap-EAF	
	US\$/ton	%	US\$/ton	%	US\$/ton	%	US\$/ton	%
<u>Energy</u>								
Fuel Oil	-	-	19.8	9.7	-	-	6.6	3.7
Metallurgical Coal	58.4	35.6	46.4	22.7	-	-	-	-
Electricity	5.5	3.4	4.4	2.1	29.6	16.3	22.0	12.5
Natural Gas	-	-	-	-	12.6	7.0	-	-
Recovered Energy	(20.8)	(12.7)	(16.6)	(8.1)	(-)	(-)	(-)	(-)
Subtotal	43.1	26.3	54.0	26.4	42.2	23.3	28.6	16.2
<u>Raw Materials</u>								
Scrap	18.7	11.4	40.0	19.6	21.3	11.8	102.0	57.7
Ore	30.1	18.4	24.3	11.9	63.9	35.2	-	-
Subtotal	48.8	29.8	64.3	31.5	85.2	47.0	102.0	57.7
<u>Labor</u>	6.0	3.7	6.0	2.9	7.0	3.8	4.0	2.3
<u>Other Costs</u>	66.0	40.2	80.0	39.2	47.0	25.9	42.0	23.8
Total	163.9	100.0	204.3	100.0	181.4	100.0	176.6	100.0

a/ Following assumptions were used in calculating production costs:

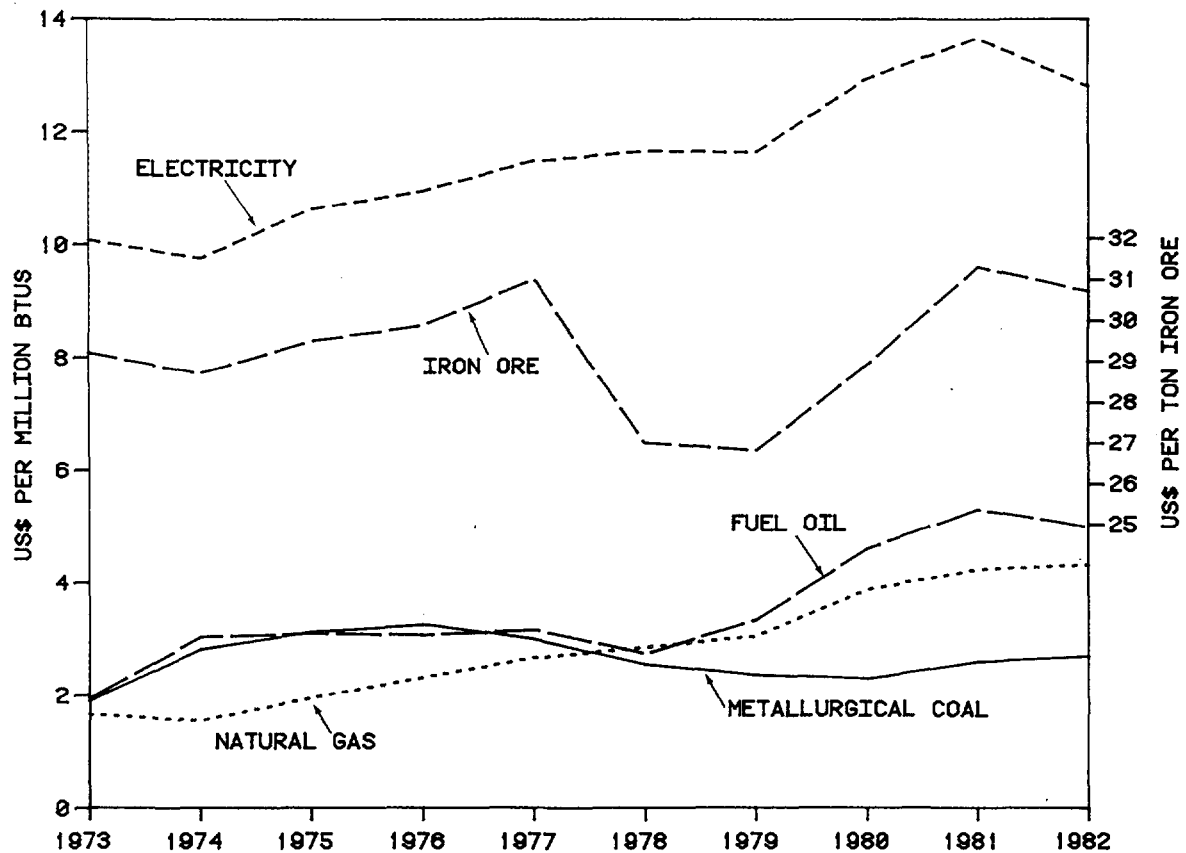
- (i) Unit costs - fuel oil: US\$250/ton; metallurgical coal: US\$80/ton; electricity: US\$0.04/kwh; natural gas: US\$4/Gcal (assumed price for gas producing countries which are most likely to use the DR process); scrap: US\$85/ton; lump ore: US\$25/ton; fine ore: US\$20/ton; oxide pellet: US\$45/ton; and labor: US\$15,000/man year.
- (ii) BF-BOF process:
BF-sinter ratio: 80%; fuel ratio: 500 kg/ton of hot metal; all coke operation; BOF-hot metal ratio: 80%.
- (iii) BF-OHF process:
BF-sinter ratio: 80%; fuel ratio: 500 kg/ton of hot metal; all coke operation; OHF-hot metal ratio: 60%.
- (iv) DR-EAF process:
DR-100% pellets.
EAF charge - DRI: 80%, scrap: 20%.
- (v) Scrap-EAF process:
EAF charge - scrap: 100%.

Source: NSC

2. Trends in Energy Costs in Steelmaking

3.18 The cost of energy in steelmaking has increased substantially since the early 1970s as a result of the sharp rise in international oil prices and the effect of this change on other energy prices, particularly for electricity and natural gas. Figure 5 compares prices for the main energy inputs of the steel industry in major steel producing countries (Japan, United States, Federal Republic of Germany, France, and United Kingdom) with the price of iron ore during the period 1973-82.

Figure 5: Price Trends of Energy Inputs and Iron Ore, 1973-82 ^{a/}
(US\$ in 1981 prices)



^{a/} Average of prices in Japan, United States, United Kingdom, France and Federal Republic of Germany.

Source: Paine Webber Mitchell Hutchins Inc.: WSD Steel Strategist No. 7, January 1983.

3.19 As a result of these increases, energy costs have become more important in the steel industry's production cost structure. Table 8 illustrates this trend for the major integrated steel plants in the United States, Japan, and Federal Republic of Germany.

Table 8: Production Cost Structure
of Major Integrated Steel Plants 1970-80 a/
(% of total)

	USA		Japan		F.R. Germany	
	1970	1980	1970	1980	1970	1980
Metallurgical coal, coke	11.1	11.9	18.8	18.1	15.9	17.1
Fuel oil	1.1	1.9	5.4	5.0	2.9	3.7
Electricity	2.7	3.4	3.8	7.6	2.4	3.0
Natural gas	1.8	6.1	0.7	1.3	1.9	4.2
Subtotal	16.7	23.3	28.7	32.0	23.1	28.0
Materials and consumables	43.6	38.6	45.9	41.6	43.7	36.0
Labor and others	39.7	38.1	25.4	26.4	33.2	36.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

a/ The table is based on actual production costs and has not been adjusted for economic prices of operating inputs. No conclusions can therefore be drawn about the relative energy efficiency of the three countries shown since energy prices among the countries vary considerably.

Source: Paine Webber Mitchell Hutchins Inc., World Steel Dynamics, September 1981.

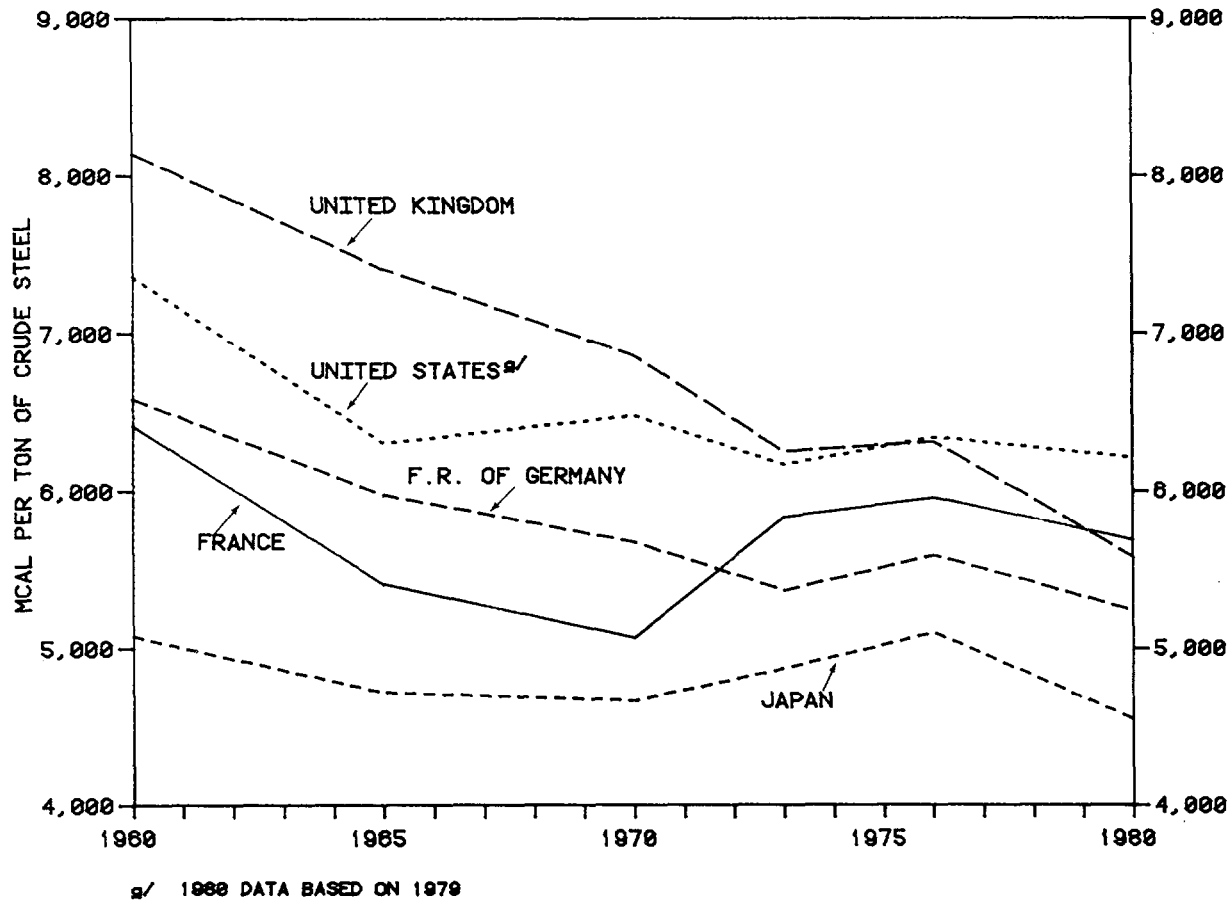
D. Improvements in Energy Efficiency in the Steel Industry

1. Overall Trends in Energy Consumption

3.20 Average energy consumption in the steel industry has dropped considerably over the last two decades as Figure 6 illustrates for some large IME steel producers. The decline in energy consumption between 1960 and 1980 is largely the result of technological developments such as improved blast furnace operations, the change in steelmaking from open hearths to basic oxygen furnaces, the introduction of ultra high power electric arc furnaces, the introduction of continuous casting, and the

higher speed of rolling mills. In addition, after the first major oil price increase in 1973, many countries placed increasing emphasis on energy efficiency by improving operating conditions and by introducing energy saving and recycling facilities (para 4.01). The slight increase in specific energy consumption during the mid-1970s, apparent in Figure 6, is probably mostly due to the conversion in that period of many integrated steel plants to oil-free operations, particularly in the blast furnace, which reduces overall energy costs but increases energy consumption (para 4.05).

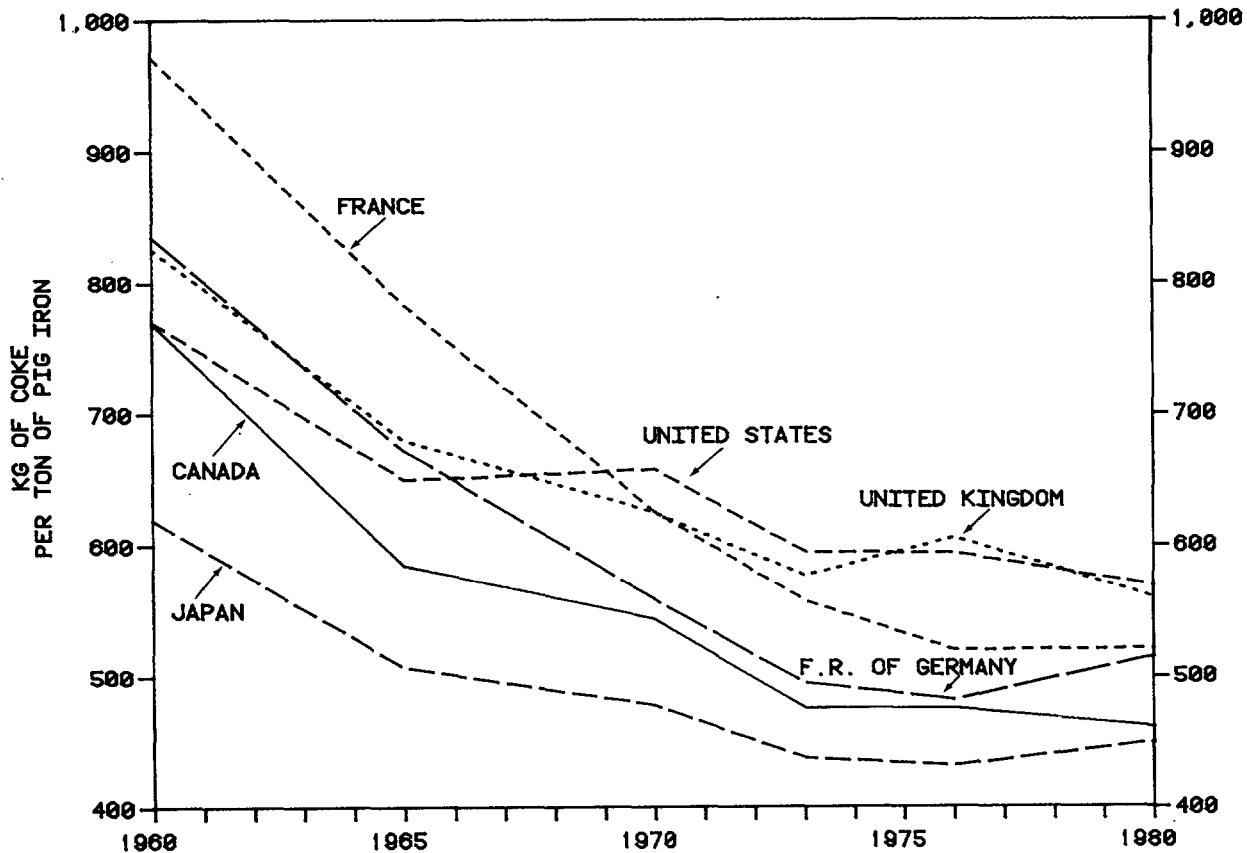
Figure 6: Steel Energy Consumption Trends in Selected Countries, 1960-80
(Mcal per ton of crude steel)



Sources: IISI, Steel Statistical Yearbook, 1980; NSC.

3.21 Probably the most important reason for the overall drop in specific energy consumption in the steel industry has been the improved efficiency of blast furnace operations, which constitute the most energy intensive stage in steelmaking (para 3.06). In the IMEs this improvement is reflected in a sharp decrease in the consumption of coke per ton of pig iron produced (coke rate), as shown in Figure 7.

Figure 7: Specific Coke Consumption in Selected Countries, 1960-80
(Kg of coke per ton of pig iron)



Sources: IISI, Steel Statistical Yearbook, 1980; and NSC.

2. Examples of Energy Efficiency Improvements

3.22 Several countries, as mentioned earlier, have initiated programs to improve energy efficiency in the steel industry. Many of these programs were developed after the first oil crisis in 1973. The steel industry in Japan has been one of the most successful in this respect. In a stringent energy efficiency program (more details are given in para 4.14), Nippon Steel Corporation (NSC), for example, decreased its specific energy

consumption between 1973-80 by 13%, that is, from 6.8 Gcal to 5.9 Gcal per ton of crude steel. Energy savings achieved by NSC in 1980 compared with 1973 energy consumption totaled about 28.4 million Gcal, or an estimated US\$570 million (1982 prices). A key factor in improving energy cost efficiency in NSC was its move to oil-free operation of BFs, which caused oil consumption to be almost eliminated from its BFs. Annex 4 shows some details of the energy efficiency improvements realized by NSC.

3.23 Brazil's steel industry, too, has been quite successful in improving its energy efficiency. Following a program of modernization, SIDERBRAS, which represents seven of the major steel companies in Brazil and which accounts for almost two-thirds of Brazil's steel production, realized a substantial reduction in specific energy consumption. Between 1975 and 1979, energy consumption was reduced by 22% from 8.2 Gcal to 6.4 Gcal per ton of crude steel. This represents, at 1981 production levels for SIDERBRAS (7.7 million tons), a total energy saving of about 13.7 million Gcal per year, or an estimated US\$270 million (1982 prices). Some details of these achievements in SIDERBRAS appear in Annex 5.

E. Potential for Improving Energy Efficiency in the Developing Countries

3.24 Energy consumption of the DC steel industries is difficult to compare, because data on specific energy consumption per ton of steel are scarce in these countries. Nonetheless, some other factors--such as coke consumption in the blast furnace, the share of open hearth steelmaking, and the extent of continuous casting--can be used to evaluate the likely energy efficiency of DC steel producers. Table 9 presents specific energy consumption, where available, and these other factors for selected IMEs and DCs.

Table 9: Comparison of Energy Efficiency in Selected Countries, 1980

Country	Steel Production (million tons of crude steel equivalent)	Gcal per ton of Crude Steel	Blast Furnace Coke Rate (Kg/ton of pig iron)	Share of OHF Steelmaking (%)	Continuous Casting Ratio (% of crude steel)
<u>IMEs</u>					
Japan	111.4	4.5	449	-	59
United States	103.8	6.2a/	588	12	20
Germany, F.R.	43.8	5.2	515	7	46
Italy	26.5	4.2a/	463	2	50
France	21.2	5.7	520	1	41
Spain	12.6	4.4	530	5	36
United Kingdom	11.3	5.6	588	-	27
<u>DCs</u>					
China	37.0	9.1	585b/	32	7
Brazil	15.2	5.7	480	9	33
Korea, Rep.	8.6	n.a.	n.a.	1	32
India	9.5	9.8	n.a.	58	-
Mexico	7.1	n.a.	n.a.	19	30
Yugoslavia	3.6	7.5	706	40	37
Turkey	2.5	n.a.	690	23	7
Portugal	0.6	7.5	620	-	43
Colombia	0.4	9.4a/	740	-	n.a.

a/ Based on 1979 data.

b/ Based on China's key plants which account for over 75% of steel production.

Sources: World Bank data; International Iron and Steel Institute;
UN Economic Commission for Europe.

3.25 As the table indicates, specific data on energy consumption were available for only a few DCs. In China, the largest DC producer, the average amount consumed (about 9.1 Gcal per ton of crude steel) is almost twice the amount consumed by energy efficient IME steel producers. India and Colombia, with 9.8 Gcal and 9.4 Gcal respectively per ton of crude steel, also consume considerably more energy than the IMEs. By comparison, Brazil's relatively modern and well-run steel industry uses 5.7 Gcal per

ton, which is in line with the major IME producers. Some of the factors that influence energy consumption (blast furnace coke rate, OHF share in steelmaking, and continuous casting ratio) indicate that most of the DCs lag behind the large IME steel producers in energy efficiency (the DCs have higher coke rates and OHF shares, and make less use of continuous casting). Consequently, there is room for substantial improvement in energy efficiency in most DCs. The experience of Japan and Brazil, briefly described above (para 3.22), demonstrates that such improvements can be achieved in a short time through the implementation of specific energy efficiency programs (para 4.01).

3.26 Since most DCs must start from a less efficient base than that of Japan or Brazil, they should be able to realize at least a 10-15% decrease in specific energy consumption in the steel industry. For the DCs combined, therefore, energy consumption could be reduced by about 100-200 million Gcal (10-20 million toe) per year by 1990 (according to projected steel production for 1990 in the DCs). Savings would be in the form of a reduced consumption of primary energy inputs, particularly fuel oil, metallurgical coal, and electricity. Total savings could amount to around US\$2-4 billion equivalent (1982 prices), or an average US\$12-24 per ton of steel. Based on experience in the Japanese steel industry (para 4.15), an investment of about US\$2-4 billion (1982 prices) would be required to achieve such savings. These savings would not only increase the competitiveness of steel producing DCs by reducing production costs, but would also have a favorable effect on their balance of payments by reducing overall energy consumption.

IV. ENERGY EFFICIENCY MEASURES

A. Introduction

4.01 The primary objective of energy efficiency measures in the steel industry is to lower energy costs by reducing the need for purchased energy or by using least-cost energy sources. Energy efficiency measures have often been narrowly defined as hardware measures at the plant level including installation of modern energy saving equipment. Energy efficiency measures are actually much broader in scope, however, including measures to improve operating procedures and control over energy distribution. Energy efficiency measures can be divided into two types:

(i) measures which help to increase the reaction and heat transfer efficiency within the industry's processes (ironmaking, steelmaking and rolling); and (ii) measures which help to reduce and recover waste energy.

The cost of energy can also be reduced by substituting less costly energy inputs for relatively costly ones, that is, by fuel substitution. The implementation of specific energy efficiency measures should be preceded by detailed energy audits, on the basis of which the actual energy balance of the plant can be assessed and a program of measures formulated.

Implementation of an energy program at the plant level should comprise the following steps:

- (i) conduct an energy audit;
- (ii) set up an appropriate energy management organization;
- (iii) improve operating conditions;
- (iv) introduce fuel substitution measures;
- (v) introduce energy saving facilities;
- (vi) modernize production equipment.

Since these steps call for progressively increasing capital investment, longer gestation/implementation periods, and less attractive economic returns, it is advisable to follow them in the order shown. These measures at the plant level are discussed hereafter, followed by a brief description of energy efficiency programs implemented by the steel industry in Japan and Brazil.

B. Specific Energy Efficiency Measures at the Plant Level

1. Energy Audits

4.02 The first step in an efficiency program at the plant level, as indicated above, is to conduct an energy audit, which calculates the energy flow (energy balance) in the steel plant both for individual furnaces and equipment, and for the overall plant. The results can be compared with the energy balances of energy-efficient plants in order to identify areas that need corrective measures. While interpreting the results of an energy audit, corrections should be made for country and plant-specific conditions such as quality of raw materials, capacity utilization, product mix, and workers' skills. The next important step of the energy audit is to design an energy efficiency program for the plant. Such a program should focus on the establishment of an energy management function (if one does not already exist), the definition of plant-wide energy saving targets, and the identification of operational measures (including training programs) and specific equipment investments. The program should initially concentrate on low cost operational improvements, as well as improvements in the ironmaking stage (through measures for coke ovens, sinter plants, BF's, and DR ironmaking furnaces), because of its large share in energy consumption (about 72 percent in a BF/BOF plant, and 58 percent in a DR/EAF plant), and

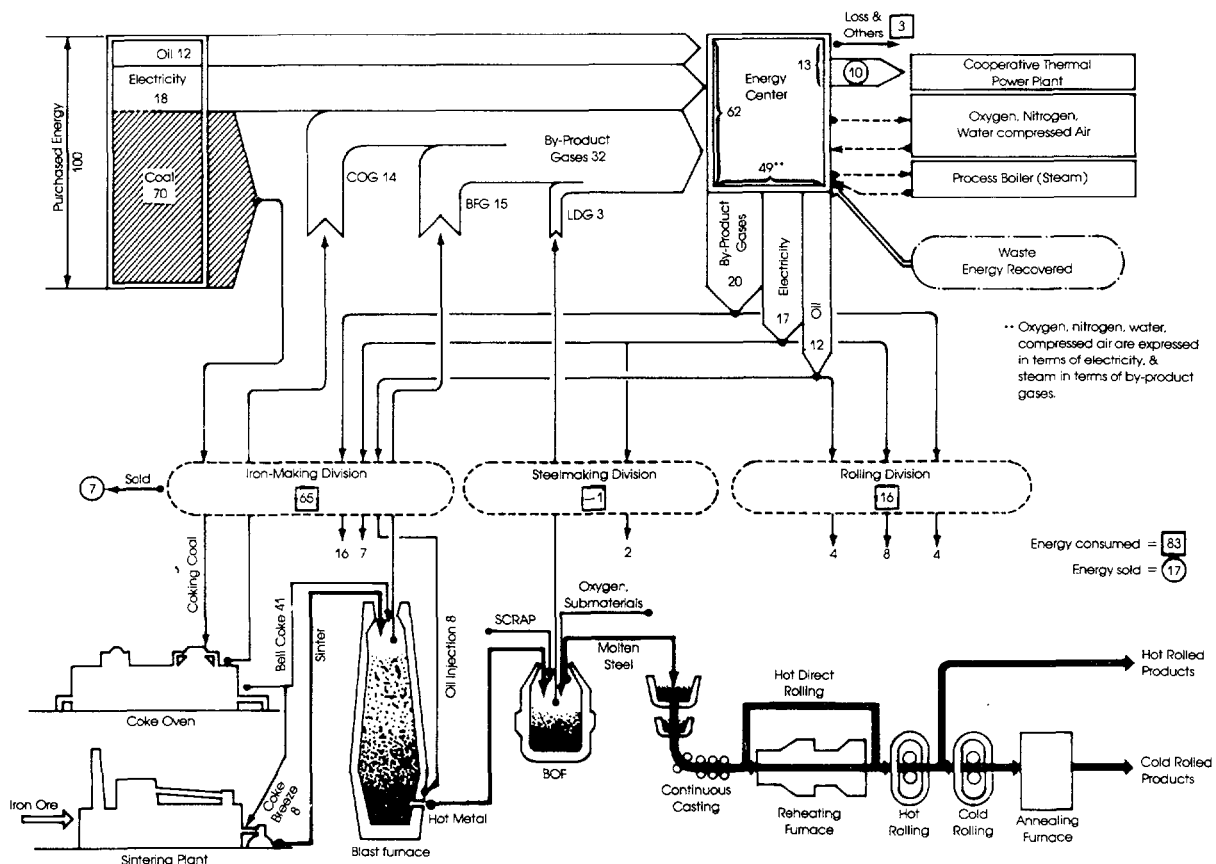
the large scope for savings. A number of engineering firms are now available to undertake energy audits in the steel industry. During such audits basic data are collected, areas for improvement identified, and an energy efficiency program designed. These steps normally take about 6-60 manmonths of consultants' time over a period of 2-12 months at an overall cost of US\$0.1-1.0 million. A brief outline of a typical energy audit for a steel plant is given in Annex 6.

2. Organizing the Energy Management Function

4.03 An effective energy efficiency program requires an appropriate organization at the plant level. A well-designed energy center in the steel plant plays a particularly important role in promoting energy efficiency through improved energy distribution control. Such a center can be established at the same time that measures for operational improvements are implemented and energy saving facilities installed. The energy center provides centralized control over the supply and demand of both purchased primary energy sources (except metallurgical coal which normally is controlled by the ironmaking department) and recovered and converted energy sources in the various parts of the steel plant. It does so by monitoring the operating conditions of the various energy consuming facilities (for example, blast furnace, steel plant, and rolling mill), as well as the energy generation and distribution facilities (for example, the power substation, blower plant, oxygen plant, gasholder, heavy oil tank, process steam boiler, and water pump station), and by monitoring and adjusting the energy flow in the steel plant. Furthermore, the energy center can reduce energy costs by stabilizing the supply of energy to the various operating departments. As a result, the center can improve the operations of the

steel plant by maximizing the use of by-products through a reduction in gas flaring and oxygen releasing, and by making the best possible use of least cost energy sources available (the energy center therefore plays an important role in fuel substitution). Figure 8 illustrates the role of the energy center in channelling the energy flow in an integrated steel plant.

Figure 8: Role of Energy Center in Integrated Steel Plant
(Unit of Energy: percentage of purchased energy)



Source: NSC

The energy center can be set up as independent "operating" unit in the plant or as part of the plant's energy control department. The department, in collaboration with the operating departments of the plant and with the assistance of independent energy auditors, should be responsible for undertaking a comprehensive energy audit of the enterprise and thereafter preparing short-term (annual) and long-term (for example, five-year) plans for energy efficiency that both identify and evaluate energy efficiency projects. Together the energy control and operating departments should also develop specific operational targets for each major energy-consuming activity in the plant. The progress towards achievement of these targets should be monitored periodically and feedback provided to the operating departments. Furthermore, the energy control department could increase management and worker awareness of the benefits of major conservation and introduce the latest developments in the field of energy efficiency through seminars and training programs. The typical structure, functions and staffing of the energy organization in an integrated steel plant are shown in Annex 7.

3. Improvements in Operating Conditions

4.04 The energy audit is usually followed by measures to improve operating conditions in the plant. The aim at this stage is to reduce energy consumption and recovery without significant investments. A first step in this direction should be to stabilize equipment performance and operation. Since the raw materials and products used in steelmaking are transported from one production stage to another--being heated and cooled from time to time--a bottleneck at any point can have an adverse effect on the entire process by decreasing production and increasing energy

consumption. Accordingly, substantial energy savings can be realized by improving operating and maintenance techniques, ensuring the continuity of processes, and improving interprocess delivery conditions. Throughout the entire process of steel production--from iron ore reduction to finishing--metallurgical reactions and other operations (for example, casting or rolling) are repeated at high temperatures between 500°C and 2,000°C. Because of repeated heating and cooling, the heat contained in iron and steel can be carried to downstream processes (for example, hot DRI to EAF, hot metal to BOF, hot ingot to soaking pit, and hot slab or billet to reheating furnace), and can amount to significant savings of energy. Also, the quality of raw materials and fuels has a great bearing on energy consumption. For example, the efficiency of the BF improves considerably with the use of sinter and pellets. In some cases, however, good quality raw materials can raise total production costs (for example, oil injection in BF, scrap in BOF, and pellet oxide in DR). Finally, improvement in production yields can add another substantial contribution to energy saving. Scrapping or lowering the grade of finished products may merely lead to a high waste of energy. Examples of measures to improve operating conditions are: (i) stabilizing BF operations, so as to reduce the blast furnace fuel rate, (ii) reducing the track time of ingots, and (iii) improving the heat pattern and control of the air-fuel ratio in reheating furnaces.

4. Fuel Substitution Measures

4.05 The substitution of cheaper energy inputs for expensive ones is certainly a cost saving measure but does not necessarily lower energy consumption. The main fuel substitution measures to be carried out in the

steel plant are: (i) substitution of hot metal by scrap steel, and vice versa, in the BOF/OHF steel shop, and (ii) substitution of oil with other primary energy sources, particularly in the blast furnace. Switching from primary to secondary energy sources falls under the category of improved recovery and improved use of waste energy, and is accordingly described in para 4.07. The first measure (variation of the hot metal ratio in the steel shop) is an indirect measure as it does not directly involve the substitution of fuels but rather the substitution of hot metal and scrap. It can reduce operating costs by optimizing the ratio of hot metal and scrap, depending on the relative costs of these two material inputs at a given time. As noted above (para 3.09), the hot metal ratio (the ratio of molten iron to crude steel) in a BOF shop can vary from 70% to 90%, and in an OHF shop from 30% to 60%. Depending on the availability of steel scrap, there is therefore a considerable margin for substitution between hot metal and scrap. The second measure (oil substitution) was introduced after 1973 as a result of the sharp increase in the price of oil, compared with other energy sources (para 3.18). Between 1973 and 1981, for example, the relative prices of fuel oil and metallurgical coal per unit of energy increased from 1:1 to 2:1. Oil substitution measures in integrated steel plants have been concentrated on BF operations in which typically about 45% of total fuel oil of the steel plant is consumed. Fuel oil is injected in the BF alongside coke, at a rate of about 30-70 kg per ton of pig iron in energy efficient plants, as a fuel and as a reducing agent.

4.06 Various substitutes have been developed for oil injection in the blast furnace:

- (i) In all-coke operations of BFs, fuel oil is replaced by a corresponding amount of coke;

- (ii) Tar rather than fuel oil can be injected (tar is produced as a by-product in coke ovens);
- (iii) A coal oil mixture (COM) consisting of pulverized coal and oil in a 50:50 ratio can be injected (therefore only 50% of the oil can be replaced by this method);
- (iv) Pulverized coal, including steam coal, can be injected with carrier gas; and
- (v) The fuel oil can be replaced by natural gas and/or coke oven gas.

In Japan, the all-coke operation of the BF has been widely adopted as the main oil-free BF operating method. This measure should be regarded as cost saving, rather than energy saving, as it causes a decline in productivity in the BF, an increase in the BF fuel rate, and related higher coke oven production because of higher BF coke needs. Increased coke needs for the BF are estimated at 10-20 kg per 10 kg of fuel oil saved. This increase is offset to some extent, however, by the higher production of such by-products as coke oven gas, blast furnace gas, coke breeze, tar, and light oil, which can be used to replace fuel oil for reheating furnaces and boilers. Overall net energy consumption therefore increases by about 10-30 Mcal per 10 kg of fuel oil saved. Despite increased energy consumption, however, the all-coke BF operation saves about US\$1-3 (1982 prices) per 10 kg of oil saved, owing to the price differential between oil and coke.

5. Introduction of Energy Saving Facilities

4.07 Measures in this area are directed at the hardware for saving energy, in terms of both improving the efficiency of energy consumption, and recovering waste energy for effective use. Table 10 presents a summary of these types of measures, which are categorized according to whether they

increase energy efficiency or enhance recovery of waste energy. Some of the principal measures used in the three main stages of steel production (namely iron making, steelmaking, and rolling) are described below together with their costs and benefits.

4.08 For the iron making stage, some selected measures are as follows:

a. Waste heat recovery from sinter cooler

This measure recovers and utilizes the sensible heat of sinter. Sinter is usually cooled by an air cooler, and the resulting hot exhaust air discharged into the atmosphere. The hot-air temperature may reach as high as 300-350°C, and the energy content of its sensible heat is equivalent to approximately 30% of the energy input (coke breeze and fuel) into the sintering machine. Three methods have recently come into use for the recovery and utilization of the sensible heat of the hot air:

- (i) Recirculating fans introduce the hot air to the ignition furnaces for use as combustion air (energy saved: 5-10 Mcal/ton of sinter).
- (ii) Recirculating fans introduce the hot air to the raw material layer for preheating (energy saved: 10-20 Mcal/ton of sinter).
- (iii) The recovered hot air is sent to a waste heat boiler where it is converted into steam that is either used as process steam or further sent to turbines for power generation (steam recovery: 30-50 Mcal/ton of sinter).

b. Coke dry quenching

Coke dry quenching (CDQ) permits recovery of the sensible heat of hot coke produced in coke ovens (temperature of about 1,000°C). The conventional technique was to quench hot coke with a water spray, and to allow the sensible heat to be discharged into the atmosphere. The

Table 10: Selected Energy Efficiency Measures

Production Stage	Energy Efficiency Increasing Measures	Energy a/	Rank b/	Waste Heat Recovery Measures	Energy a/	Rank b/
Coke Plant	Automatic combustion control (ACC)	F	B	Recovery of coke sensible heat (CDQ)	SE	A
	Calorific value control of mixed gas	F	B	Charging of dried coal	F	B
	Optimized temperature distribution in combustion chamber	F	B	COG sensible heat recovery	S	B
	Automatic ignition of COG released	F	B	Exhaust gas heat recovery	F	C
Sinter Plant	Particle size distribution control of ore and coke breeze	F	B	Waste heat recovery from main exhaust gas	S	A
	ACC of ignition furnace (control of oxygen content in waste gases, temperature and pressure)	F	C	Cooler waste heat recovery - Combustion air preheating for ignition furnace	F	C
	Increased bed depth	F	B	- Sinter mix preheating	F	C
				- WHB and/or power generation	SE	A
Pellet Kiln	Adding dolomite (self-fluxing pellet)	F	B	Waste heat recovery from pellet cooler	F	B
	Increased efficiency of cooling zone	F	C			
DR	Preheating of recirculating gas	-	-	Waste heat recovery of reformer	F	B
	In-situ reforming	F	B	DRI latent heat recovery	-	-
	Preheating of combustion air	-	-	Hot DRI charging into EAF	E	B
	Gas flow pattern control in DR furnace	F	C			
	Increased reducing gas temperature	-	-			
BF	Burden distribution control	F	B	Top pressure recovery turbine (TRT)	E	A
	Furnace condition control system	F	B			
	Insulation of blast main	F	C	Recovery of BFG bled during charging	F	B
	Hot stove heating pattern control	F	C	Evaporative stove cooling	S	C
				Hot stove waste heat recovery	F	A
BOF CC	Automatic ignition of BOF-gas released	F	C	BOF-gas recovery	F	A
	Programmed control of ladle preheating	F	C	BOF-gas sensible heat recovery	S	A
	Improved insulation of CC tundish	F	C			
EAF	UHP	E	B	Scrap preheating by waste heat	E	C
	Oxygen blowing	E	B			
Hot Rolling	ACC	F	B	Modification of recuperator	F	B
	Optimized heating pattern	F	B	Slab preheating by waste gas impinging	F	B
	Extension of furnace length	F	C			
	Improved insulation of furnace wall and roof	F	C	Waste gas sensible heat recovery for steam	S	B
	Double insulation of skid	F	C	Steam recovery by evaporative cooling of skid	S	C
	Use of hot rolling oil	E	C			
	Higher speed rolling	F	B			
	Increase in hot slab charging ratio and the temperature	F	B			
	Increase in hot direct rolling ratio	F	A			
Cold Rolling	Steam saving by means of floats and well-sealed lids	S	C	Waste heat recovery from cooling water	S	C
	Dispensing with electrolytic cleaning	SE	B	Combustion air preheating from batch type furnace	F	C
	Programmed heating of coil	F	B	WHB of non-oxidizing furnace	S	B
	Extension of furnace length	F	B			
Others	Boiler combustion control	F	B	Use of back pressure turbine generator	E	B
	Improved mixed gas supply by calorific value control	F	B			
	Insulation of tank	S	C	Waste heat recovery of boiler	F	C
	Power saving for fan and pump operation by rotative speed control	E	B-C	Energy supply-demand control system	all	B

a/ Type of energy saved: F = fuel; E = electricity; S = steam

b/ Rank (effect of measure on energy savings): A = major; B = medium; C = slight

Source: NSC

principle of CDQ is to cool the hot coke by circulating non-oxidizing gas in a closed loop. The heat thus recovered is used to generate steam or electric power by means of a heat exchanger. Total net energy savings in the form of recovered steam, allowing for power usage by the CDQ equipment, amounts to about 80 Mcal per ton of coke, which is equivalent to about 40% of the total energy input of the coke plant, and 80% of the sensible heat of discharged hot coke. Other benefits of CDQ include improved coke quality and environmental protection. Investment in CDQ facilities for a 2 to 3 million tpy coke production, is about US\$20-30 million (1982 prices), with an estimated payback period of two to four years.

c. Blast furnace top-pressure recovery turbine (TRT)

This process uses the high top-pressure of BFs to generate power by a turbine. The power output depends on the capacity of the BF and ranges from 8 to 15 MW. Thus far, the process has been used primarily in large, high pressure BFs, but its application is now also being considered for relatively low-pressure BFs. Furthermore, a dry-type dust collection TRT system under development should help to improve the efficiency of power generation by use of the heat recovered from the BF top gas. At present, the sensible heat of the BF top gas is not effectively used. The BF TRT system costs about US\$5-10 million with an estimated payback period of one to two years.

d. Waste heat recovery in BF hot stove

Although the temperature of waste gas at the hot stove is rather low at about 50°C, the recovery of hot stove waste heat is important, because of the large volume of waste heat involved. The system recovers waste gas at high efficiency for re-use as energy to preheat combustion air

and fuel gas. The waste heat recovery system includes a heat exchanger installed in the pipe system that carries low temperature waste gas from hot stoves to preheat combustion air and fuel gas. Net energy savings amount to about 20-30 Mcal per ton of pig iron. The system costs about US\$2-4 million for a 2 to 3 million tpy BF, and has an estimated payback period of one to two years.

4.09 The following are some typical energy conservation measures for the steelmaking stage:

a. BOF gas recovery and utilization

Gas generated by the oxygen converter (LD gas) in the BOF steel shop has a total energy of about 240 Mcal per ton of crude steel (at a hot metal rate of 85%). Two methods of recovering this energy are: (i) waste heat boiler system (combustion-type steam recovery system), by which the carbon monoxide contained in the gas is completely burned using air, and the resulting sensible heat is recovered in the form of steam in the upper part of the converter stack (about 70 Mcal per ton of steel can be recovered in this way); and (ii) the OG system (suppressed combustion-type gas recovery system), by which the carbon monoxide contained in the gas is not burnt, but is recovered as latent heat (about 200 Mcal per ton of steel can be saved by this means, almost three times more than by the waste heat boiler system). Because of the better recovery of energy, the latter system is preferred over the former. The OG system also includes gas cooling and dust collection. The recovered gas volume is determined primarily by (i) steelmaking conditions (hot metal analysis, hot metal ratio, and so on), (ii) OG gas operating conditions, particularly time setting of gas recovery (recovery normally takes place from 1 to 2 minutes

after ignition of the converter, to 1 minute before the end of converter blowing), and (iii) conditions of recovered gas utilization equipment (such as gas holder capacity and consuming rate of recovered gas). The recovered LD gas, which accounts for about 8% of total by-product gases in an integrated steel plant (blast furnace gas 50%, and coke oven gas 42%), is used alone or may be mixed with blast furnace gas or coke oven gas as a fuel for low pressure boilers, power station boilers, hot stoves, soaking pits, reheating furnaces, and calcining furnaces. The cost of an OG gas recovery system is about US\$40-100 million, and the estimated payback period two to three years.

b. Selected measures for the electric arc furnace

Steelmaking in an EAF consists primarily of the melting and refining of the steel scrap and/or DRI charge, and the melting consumes about 90% of the electricity used in steelmaking. Ultra high power (UHP) EAFs have been introduced in the last decade to reduce melting time and thereby decrease consumption of power and increase furnace productivity (para 4.12,c). UHP EAFs are therefore gaining favor particularly among the larger minimills (para 2.07). This and other measures for the EAF are summarized in Table 11.

Table 11: Selected Energy Saving Measures for the Electric Arc Furnace

Energy Saving Measure	Mcal per ton of Crude Steel	As Percentage of EAF Energy Consumption <u>a/</u>
1. Introduction of UHP furnace	40	3.1
2. Use of oxygen lancing to assist melting	25	1.9
3. Preheating of scrap	30	2.3
4. Secondary refining of steel	17	1.3
5. Water cooled panels	3	0.2
6. Bottom pouring	10	0.8
7. Installation of electrode saver	<u>5</u>	<u>0.4</u>
Total	<u>130</u>	<u>10.0</u>

a/ Based on EAF energy consumption of 1,300 Mcal per ton of crude steel.

Source: SOFRESID (France)

4.10 In the rolling stage, energy saving measures are directed primarily at reheating furnaces, which account for about 70% of energy consumption in that stage. The overall objective here is to recover the re-usable heat of the exhaust gas, which, in conventional reheating furnaces, has a temperature of about 500-600°C after being used to preheat the air for combustion. Methods of recovering exhaust gas re-usable heat include: (i) jet flow preheating, by which retained exhaust gas is boosted by a high temperature blower, and is blown at high speed over the surface of cold slabs or billets in order to preheat them (the energy saving is 5% compared with conventional furnaces); (ii) extension of furnace length (conventional furnace length is extended by some 40%), by which the temperature of the exhaust gas is lowered to 350-400°C; and (iii) installation of exhaust heat boiler, by which steam is recovered from downstream exhaust gas by recuperator. Furnace length extension and steam recovery in combination can yield energy savings of about 30%. Other

measures that can be applied to the reheating furnace include combustion control of air-fuel ratios, lowering of the slab discharge temperature (para 4.12,d), improving the furnace operating rate, furnace insulation, double insulation of the skid pipe, and hot slab charging. Some of the above measures in combination can bring down the average energy consumption of reheating furnaces from about 450 Mcal per ton to 300 Mcal per ton of reheated steel, and even to 250 Mcal per ton in newly installed furnaces. Annex 4 shows the reduced fuel consumption of reheating furnaces at Nippon Steel Corporation.

6. Modernization of Production Facilities

4.11 Energy efficiency measures in this category are concerned with the long-term and more costly investment programs of steel plants. Energy savings in this case derive from the composite effects of these programs, such as improved productivity and yield. These modernization programs generally include: (i) measures to improve efficiency and performance of conventional processes; and (ii) measures to replace conventional processes by new ones. Both types of measures help to improve energy efficiency.

4.12 Some examples of gradual efficiency improvements through modernization of facilities that have taken place in the last two decades are:

a. Improved burden preparation of blast furnaces

BF performance has greatly improved with the introduction of high-grade beneficiated iron ore, the widespread use of sinter or pellets in the BF burden, and the application of refined techniques in BF furnace burden preparation (iron ore and coke) that aim to produce a carefully

sized burden and to avoid undersized materials. With the greater use of high quality iron ores and increased basicity of the burden, the quantity of gangue materials has been reduced, and thus BF productivity has increased significantly.

b. Introduction of larger, improved blast furnaces

Larger BFs and various technological developments in BFs have also helped to reduce energy consumption. Blast furnace capacity is now four to five times greater than in the mid-1960s. At the same time, BF performance has been enhanced by the use of oxygen-enriched blast operation, higher blast temperature and humidity control, computer process control, elevated top pressure operation, and the injection of auxiliary fuels (for example, coal-oil mixture, tar, and natural gas). These measures and improved BF burden preparation have raised BF productivity considerably and have reduced energy consumption, as reflected by the reduced coke rate in most countries (para 3.21).

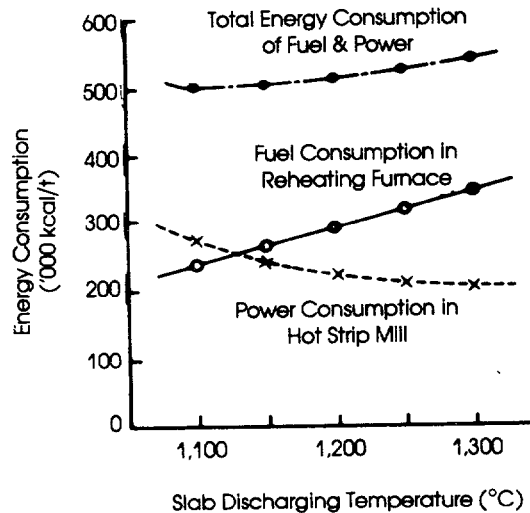
c. Introduction of ultra high power electric arc furnaces

The transformer capacity of steelmaking electric arc furnaces has gradually increased from 250-300 KVA per ton for conventional electric arc furnaces to 600-800 KVA for ultra high power (UHP) furnaces. The higher power input level has helped to reduce melting time, increase furnace productivity and lower the consumption of electricity (owing to reduced cycle time and loss of radiation). In the case of scrap based EAFs, the melting time may be further shortened and energy consumption lowered by scrap preheating using the hot waste gases to supply additional heat (para 4.09,b).

d. Introduction of high speed rolling mills

The most effective way to improve productivity and reduce production and energy costs at the rolling stage is to operate rolling mills at higher speed. The temperature at which billets, blooms, or slabs need to be discharged from reheating furnaces can be greatly lowered when these are processed in high-speed rolling mills with a large reduction capacity. This reduction in temperature together with the improved heat recovery capacity of recuperators can lower the energy consumption of reheating furnaces to 250-300 Mcal per ton. Lower discharge temperatures lead to reduced fuel consumption in the reheating furnace; at the same time, however, power consumption on the downstream rolling mill will increase, since semifinished steel discharged at a lower temperature has greater deformation resistance. The discharging temperature from reheating furnaces should therefore be set so as to minimize the total energy consumption of the reheating furnace and the rolling mill as much as possible without affecting the metallurgical aspects of the steel produced. In the hot strip mill, for example, the total energy consumption can be decreased simply by lowering the temperature of slabs from the ordinary level of 1,200°-1,300°C to 1,050°-1,100°C (see Figure 9). From the viewpoint of energy consumption, then, low temperature discharging is advantageous. When low-temperature discharging is adopted, a heavy reduction mill should be used in the subsequent rolling stage. From the viewpoint of energy cost, the point at which the total of fuel and power costs becomes optimal differs according to their relative costs.

Figure 9: Relationship between Slab Discharging Temperature from Reheating Furnace and Power Consumption in Hot Strip Mill



Source: NSC

4.13 Significant recent process innovations that had an impact on lowering energy consumption are:

a. Shift from OHF to BOF steelmaking

The BOF process has several advantages over the OHF process; for example, lower construction costs and higher productivity. Another feature in its favor is that the BOF process requires less energy (para 3.09). Finally, the BOF process allows the recovery of by-product energy from the off-gas (LDG) of the converters.

b. Shift from batch-type to continuous processes

Until recently, the steel industry has relied on batch production techniques for the production and processing of steel. The conventional method is to cast the molten steel into ingots, which are subsequently rolled into billets or slabs, and in the final stage are rolled into

finished steel products. Each stage of rolling requires heating to a high temperature (1,000-1,300°C) and cooling. As mentioned earlier (para 4.04), metallurgical changes or rolling can be accomplished by using the energy carried over from upstream processes. The great benefit of continuous operations or a combination of processes is their significant energy savings. An important development in this area is continuous casting, by which molten steel is directly processed into billets, blooms, or slabs without going through the ingot stage. With continuous casting, yields have risen by about 5-10%, and energy savings have amounted to 100-300 Mcal per ton of semis (billet, bloom, slab, para 3.11). The latest development, hot direct rolling, can be combined with continuous casting to permit, in certain cases, continuously cast semis to be directly rolled into the finished steel product in a hot state. Another such process, continuous annealing and processing, combines five cold rolling batch treatment processes into a single system, and thus reduces energy consumption by about 100-150 Mcal per ton of finished steel products. Apart from saving energy, these continuous processes can achieve drastic cuts in production time, improved yields, higher productivity and a reduction in the labor force.

C. Examples of Energy Efficiency Programs in Japan and Brazil

4.14 The experience of the steel industry in Japan and Brazil confirms that energy saving projects have high returns, short payback periods, and short implementation periods. Annexes 8 and 9 show some details of selected energy saving projects carried out by Nippon Steel Corporation (NSC) in Japan, and of projects planned by COSIPA in Brazil. Annex 10 shows the principal measures taken by NSC in its BF/BOF plants. As shown

in Annexes 8 and 9, the investment costs of projects tend to vary widely--in the NSC case, from US\$0.1-0.2 million for measures in the reheating furnaces to US\$40-100 million for a BOF gas recovery system, and in the COSIPA case, from US\$0.8 million for computer control of the slab furnace in the hot strip mill, to US\$41.9 million for recovery and use of surplus BF gas. At the same time, the rates of return are very favorable and payback periods short, ranging from 0.5 to 4.0 years. The more capital-intensive projects, which are concentrated in the ironmaking sector, tend to have lower returns, but they are nonetheless attractive since the amount of energy saved and recovered is far greater than in the smaller projects. Implementation periods for the various projects are relatively short, lasting from 2 to 3.5 years. Operational improvements such as better production planning and improvement of yields can be implemented in even shorter periods, normally within a year (para 4.04).

4.15 Japan's experience further demonstrates that operational improvements yield high returns in short periods of time. The outcome of the energy conservation program carried out by NSC after the first oil crisis of 1973 was a 10.9% energy saving between 1974 and mid-1978, of which 55% was due to operational improvements, 25% to the introduction of energy efficiency equipment, and 20% to the modernization of equipment. Initially, the savings achieved through improvements in day-to-day operations far surpassed those from changes in equipment. As these equipment measures began to take effect, however, the energy savings they generated gradually increased. In 1978, at the end of NSC's first five-year energy efficiency program, energy saving by equipment measures (both for energy saving and for modernization of equipment) accounted for

about 50% of savings achieved in that year. Thus, after a period of four to five years, equipment measures clearly became more important. At the same time, however, these measures required higher investments than the relatively inexpensive operational improvements. At NSC, for example, while the investment in energy efficiency measures has steadily increased since 1974, the return on such projects has gradually dropped and the payback period has increased from an average of 0.4 year in 1974 to 2.3 years in 1980. Table 12 gives some details of NSC annual investments in energy saving measures and their effect.

Table 12: Nippon Steel Corporation - Energy Efficiency Measures, 1974-80

	1974	1975	1976	1977	1978	1979	1980
<u>Crude Steel Production</u> (million tons)	37.4	32.8	35.0	32.3	32.7	34.3	32.4
<u>Investment in Energy</u> <u>Efficiency Measures</u>							
Total (US\$ million) <u>a/</u>	50.0	24.8	38.7	36.9	77.7	65.4	123.0
Per Ton of Crude Steel							
Production (US\$) <u>a/</u>	1.34	0.76	1.11	1.14	2.38	1.91	3.80
Average Payback Period							
(Years) <u>b/</u>	0.4	0.5	0.6	0.8	0.8	1.4	2.3
<u>Energy Saving (%)</u>	1.9	3.2	1.5	1.2	3.1	1.7	0.3
of which due to:							
Operational Improvements							
(% of Total)	95	63	20	17	51	42	n.a.
Energy Saving Equipment							
(% of Total)	-	11	61	63	25)	n.a.
Equipment Modernization) 58	
(% of Total)	5	26	19	20	24)	n.a.
Total (%)	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>	<u>100</u>

a/ Based on 1981 prices at yearly average exchange rates.

b/ Based on 1981 energy prices.

Source: NSC

V. PROMOTION OF ENERGY EFFICIENCY

A. Constraints on the Implementation of Energy Efficiency Programs

5.01 Despite the great potential for energy efficiency improvements in the steel industry in the DCs (para 3.24), many countries are not able to implement successful energy efficiency programs because of certain constraints. The principal factors that impede the development of such programs in the steel industry in DCs are: (i) the inappropriate pricing of energy inputs at levels that are too low compared to their economic opportunity costs, or do not adequately reflect the relative economic costs of the various energy inputs (for example, fuel oil as against metallurgical coal); (ii) a lack of awareness of the possible benefits of energy efficiency programs; (iii) a lack of technical know-how and manpower which are required for the preparation and implementation of energy efficiency projects; (iv) a conflict of investment priorities between energy efficiency and capacity expansion projects, the latter being usually more visible and therefore often favored; (v) financial constraints; (vi) a lack of motivation in certain enterprises; (vii) an inadequate energy management organization at the plant level; and (viii) a lack of clearly defined government policies for approving and financing energy efficiency projects. Any program aimed at promoting energy efficiency should address these constraints through measures at the country, industry, and plant levels. Specific measures at the plant level have been discussed above (para 4.01). A number of measures at the country and industry levels are described below. They provide a framework for the successful implementation of energy efficiency programs.

B. Measures at Country and Industry Levels

5.02 An appropriate energy pricing policy is the most important element in an energy efficiency program. The prices of energy inputs should reflect their real economic costs to the country; that is, the price of each form of energy should represent its full opportunity cost. Such a policy would help to reduce the distortions in the absolute and relative prices of different energy inputs and thereby stimulate both energy efficiency and the use of least cost energy inputs through fuel substitution. Experience in IMEs and some DCs has shown that steel producers are able to adapt quickly to changing energy prices; many have undertaken operational and technical measures that have significantly lowered specific energy consumption in steel production (para 3.20) and lowered the importance of their energy costs. In many DCs, however, pricing of energy inputs at economic levels is constrained by inappropriate government restrictions or government policies, which would have to be changed in order to promote energy conservation.

5.03 Many countries have introduced a number of other measures to complement the effect of energy prices and accelerate energy efficiency and fuel substitution. These measures vary among countries, depending on underlying philosophies or economic conditions. Some countries, for example, emphasize voluntary and indicative measures, whereas others stress mandatory schemes.

5.04 Fiscal and financial incentives for energy efficiency improvements can accelerate the introduction of energy saving equipment and technology. Various such measures have been successfully introduced in some countries and include: (1) grants and subsidies for energy efficiency

investments, energy research, and energy audits by energy consultants; (ii) tax incentives such as investment tax credits, tax write-offs, advanced or accelerated depreciation, elimination of sales tax on energy saving equipment; and (iii) access to credit on preferential terms (for example, lower interest rates, longer grace periods).

5.05 Targets can be useful in motivating both management and workers to save energy. Governments should encourage the setting of targets and their achievement at both the industry and company levels. Several countries (notably Japan and Brazil) have already introduced target setting schemes for the steel industry, while some others (for example, the United States, Canada, Japan, and Italy) have initiated mandatory periodic reporting schemes in order to monitor the progress of measures aimed at improving the energy efficiency of companies in energy intensive industrial sectors.

5.06 Energy audits are particularly valuable because of the information they provide on energy flows within facilities (para 4.02). Some countries are using energy auditing as a means of controlling the energy consumption in a specific branch of industry. Such audit schemes exist in varying degrees of comprehensiveness in the United States, Canada, Japan, the United Kingdom, Sweden, Spain, and Greece. Portugal, for example, introduced an energy management decree in early 1982 under which about 1,000 enterprises whose energy consumption levels exceed a specified limit will have to engage independent energy auditors to (i) undertake a comprehensive energy audit of each enterprise; and (ii) prepare a five-year energy conservation plan.

5.07 Suitable information and advisory assistance schemes offered through specialized agencies can help increase management's awareness of the benefits of energy efficiency programs and provide assistance in the development of the energy management function at plant level. These measures are particularly appropriate for small and medium sized firms. Specific institutional arrangements vary from country to country. In some cases, specific energy management, audit and training centers involving interagency collaboration are being set up, which functions include training and promotional seminars, technical and advisory services, as well as performing audits in selected enterprises. For larger firms, governments could encourage technical collaboration and consultancy arrangements that would facilitate the transfer of technology and know-how on energy efficiency from suitably qualified sources. Such technical assistance should start with an in-depth energy audit of the plant, followed by the development of an energy efficiency program that should include recommendations for improving the energy management function, operations and equipment of the plant.

ANNEX 1.

WORLD STEEL PRODUCTION WITH DETAILS ON
DEVELOPING COUNTRIES, 1960-82
('000 tons of crude steel equivalent)

Economy ^{a/}	1960	1970	1974	1982
<u>Developing Economies</u>				
China	18,449	18,000	24,000	37,000
Brazil	2,283	5,390	7,502	13,000
Korea	20	481	1,954	11,750
India	3,287	6,271	7,068	11,000
South Africa	2,181	4,757	5,838	8,320
Mexico	1,540	3,881	5,138	7,060
Taiwan, China	120	294	450	4,080
Yugoslavia	1,442	2,228	2,836	3,860
Argentina	277	1,823	2,354	2,900
Turkey	280	1,520	1,464	2,800
Venezuela	47	927	1,058	2,300
Iran, Islamic Rep.	-	-	400	1,200
Greece	65	348	700	933
Egypt	100	300	400	900
Zimbabwe	85	150	340	700
Algeria	-	330	450	550
Portugal	-	385	377	505
Chile	451	592	635	480
Qatar	-	-	-	450
Thailand	-	40	100	450
Colombia	172	310	333	400
Syria	-	-	120	400
Indonesia	-	10	20	380
Philippines	50	60	130	370
Peru	50	94	450	350
Singapore	-	30	50	330
Malaysia	-	50	230	210
Tunisia	-	70	100	175
Saudi Arabia	-	8	20	150
Pakistan	12	-	-	130
Jordan	-	65	185	120
Israel	70	120	120	115
Iraq	-	-	4	100
Other	-	136	206	364
Sub-total	30,981	48,670	65,032	113,832
<u>Industrialized Market Economies</u>				
Japan	22,138	93,322	117,131	99,550
United States	90,067	122,120	135,025	67,400
Germany, F.R. of	34,101	45,041	53,232	35,880
Italy	8,229	17,277	23,803	24,003
France	17,299	23,774	27,020	18,417
United Kingdom	24,695	28,316	22,426	13,601
Spain	1,920	7,429	11,646	13,160
Canada	5,253	11,212	13,623	11,865
Other	24,714	42,868	51,024	37,231
Sub-total	228,416	391,359	454,930	321,107
<u>Centrally Planned Economies</u>				
USSR	65,291	115,889	136,206	149,000
Czechoslovakia	6,768	11,480	13,640	15,000
Poland	6,681	11,750	14,556	14,000
Romania	1,806	6,517	8,840	12,900
Other	6,145	12,655	14,759	19,500
Sub-total	86,691	158,291	188,001	210,400
<u>World Total</u>	<u>346,088</u>	<u>598,320</u>	<u>707,963</u>	<u>645,339</u>

^{a/} Economies ranked by their 1982 crude steel production

Source: World Bank data.

ANNEX 2.

WORLD STEEL PRODUCTION BY STEELMAKING PROCESS

Economy	Production	Steel Making Process			
	1982	Basic	Open		Other
	('000 tons of crude steel equivalent)	Oxygen Furnace	Electric Furnace	Hearth Furnace	
			(% of total)		
<u>Developing Economies</u>					
China ^{a/}	37,000	50	19	31	-
Brazil	13,000	67	26	7	-
Korea	11,750	75	25	-	-
India	11,000	24	22	53	1
South Africa	8,320	73	27	-	-
Mexico	7,060	41	44	15	-
Taiwan, China	4,080	64	36	-	-
Yugoslavia	3,860	36	26	38	-
Argentina	2,900	23	53	22	2
Turkey	2,800	55	26	19	-
Venezuela	2,300	-	83	17	-
Iran, Islamic Rep. ^{b/}	1,200	100	-	-	-
Greece ^{b/}	933	n.a.	n.a.	n.a.	n.a.
Egypt ^{b/}	900	57	7	21	14
Zimbabwe ^{b/}	700	n.a.	n.a.	n.a.	n.a.
Algeria ^{b/}	550	79	17	4	-
Portugal ^{b/}	505	42	54	-	4
Chile ^{b/}	480	98	2	-	-
Qatar ^{b/}	450	-	100	-	-
Thailand ^{b/}	450	-	100	-	-
Colombia ^{b/}	400	-	44	-	56
Syria ^{b/}	400	-	100	-	-
Indonesia ^{b/}	380	10	90	-	-
Philippines ^{b/}	370	-	77	23	-
Peru ^{b/}	350	57	43	-	-
Singapore ^{b/}	330	-	100	-	-
Malaysia ^{b/}	210	76	24	-	-
Tunisia ^{b/}	175	100	-	-	-
Saudi Arabia ^{b/}	150	-	100	-	-
Pakistan ^{b/}	130	-	100	-	-
Jordan ^{b/}	120	-	100	-	-
Israel ^{b/}	115	-	100	-	-
Iraq ^{b/}	100	100	-	-	-
Other ^{b/}	364	-	99	1	-
Sub-total	113,832	51	28	20	1
(Excluding China)	(76,832)	(52)	(33)	(14)	(1)
<u>Industrialized Market Economies</u>					
Japan	99,550	73	27	-	-
United States	67,400	61	31	8	-
Germany, F.R. of	35,880	81	18	1	-
Italy	24,003	47	53	-	-
France	18,417	81	19	-	-
United Kingdom	13,601	66	34	-	-
Spain	13,160	45	52	3	-
Canada	11,865	61	25	14	-
Other	37,231	84	13	3	-
Sub-total	321,107	69	28	3	-
<u>Centrally Planned Economies</u>					
USSR	149,000	29	11	59	1
Czechoslovakia	15,000	n.a.	n.a.	n.a.	n.a.
Poland	14,000	38	14	48	-
Romania	12,900	44	20	36	-
Other	19,500	20	22	57	1
Sub-total	210,400	30	13	56	1
<u>World Total</u>	645,339	54	23	23	-

^{a/} Steelmaking process shares based on 1981 data

^{b/} Steelmaking process shares based on 1980 data

Sources: International Iron and Steel Institute; Stahl und Eisen 102 (1982) No. 7; and World Bank data.

ANNEX 3.

PROJECTED TRENDS IN IRON AND STEEL PRODUCTION BY PROCESSES
(% of Total)

	Ironmaking			Steelmaking		
	Blast Furnace	Direct Reduction Plant		Basic Oxygen Furnace	Open Hearth Furnace and Other	
1982 (actual)						
Developing Countries ^{a/}	87.5	12.5)	67.5	27.2	5.3
Industrialized Market Economies ^{b/}	99.2	0.8)			
Centrally Planned Economies ^{c/}	99.9	0.1		<u>n.a.</u>	<u>n.a.</u>	<u>n.a.</u>
World Total	<u>98.2</u>	<u>1.8</u>		<u>n.a.</u>	<u>n.a.</u>	<u>n.a.</u>
1990 (projected)						
Developing Countries ^{a/}	71.6	28.4)	65.7	31.3	3.0
Industrialized Market Economies ^{b/}	97.8	2.2)			
Centrally Planned Economies ^{c/}	98.5	1.5		<u>n.a.</u>	<u>n.a.</u>	<u>n.a.</u>
World Total	<u>94.4</u>	<u>5.6</u>		<u>n.a.</u>	<u>n.a.</u>	<u>n.a.</u>

a/ Including capital surplus oil exporting countries.

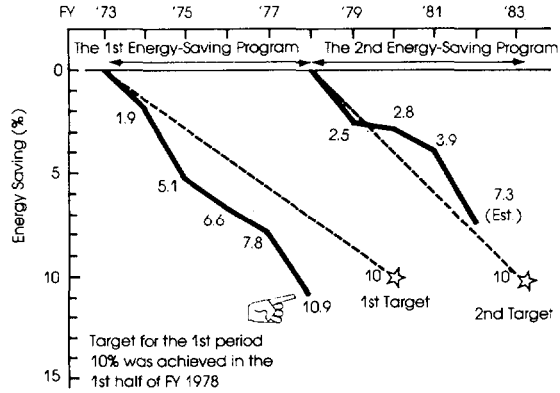
b/ Including Portugal, Turkey, Yugoslavia.

c/ Including China, Romania.

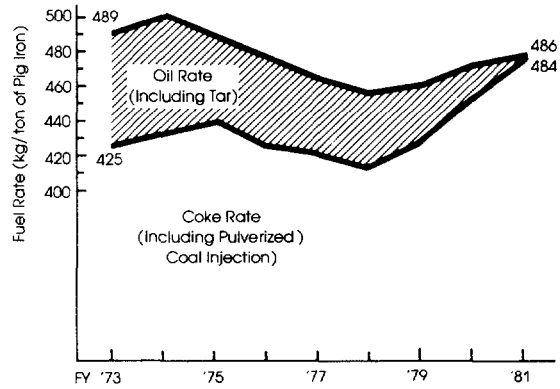
Sources: Paine Webber Mitchell Hutchins Inc., World Steel Dynamics, July 1983.

ANNEX 4.

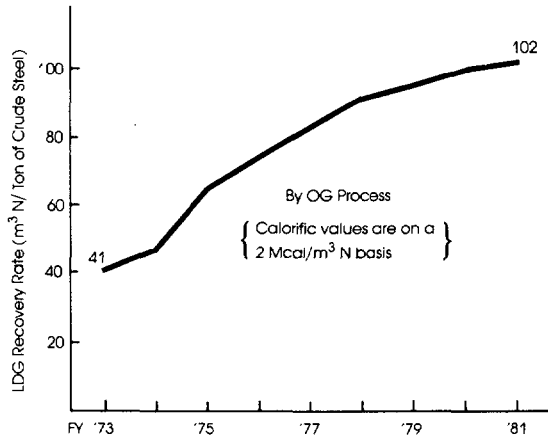
JAPAN Energy Efficiency Improvements at Nippon Steel Corporation, 1973 — 1981



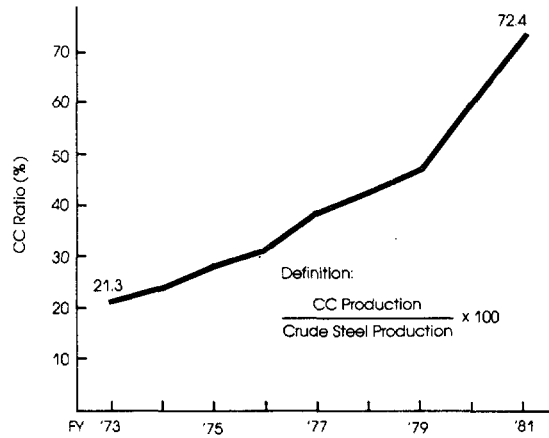
ENERGY-SAVING TARGETS
AND ACHIEVEMENTS



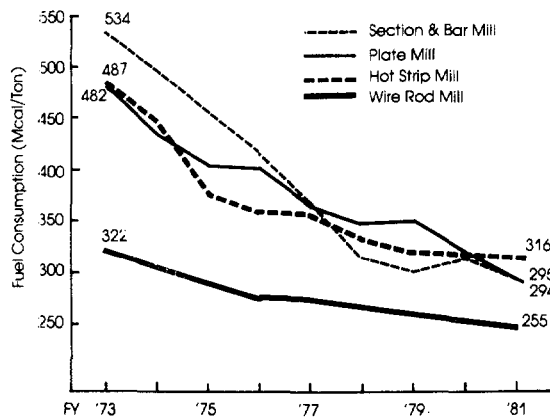
FUEL RATE FOR BLAST FURNACE (BF)
OPERATION



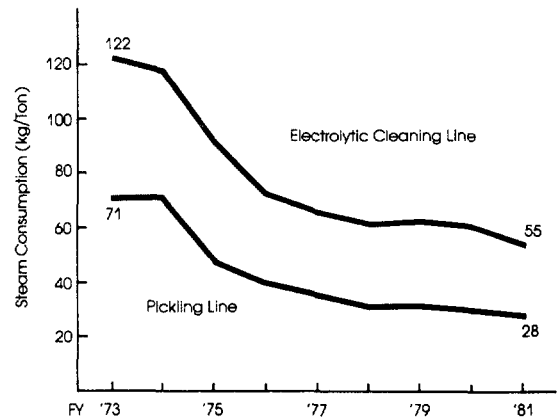
LD CONVERTER (BOF) OFF-GAS (LDG)
RECOVERY RATE



CONTINUOUS CASTING (CC) RATIO



FUEL CONSUMPTION OF REHEATING FURNACES



STEAM CONSUMPTION OF COLD ROLLING MILL

ANNEX 5.

BRAZIL: ENERGY EFFICIENCY IMPROVEMENTS AT SIDERBRAS, 1975-79

	1975	1979	% Change Per Year
<u>A. SIDERBRAS Overall</u>			
Production ('000 tons)	4,602	8,914	18.0
Share SIDERBRAS Production in Brazil (%)	54.8	64.2	
Total energy consumption ('000 Gcal)	37,756	57,293	11.0
Specific energy consumption (Gcal per ton of crude steel)	8.20	6.43	(5.9)
<u>B. SIDERBRAS Integrated BF/BOF Plants ^{a/}</u>			
Production ('000 tons)	4,123	8,189	18.7
Total energy consumption (Gcal per ton of crude steel)	8.23	6.49	(5.8)
Blast furnace fuel rate (kg per ton of pig iron):			
- Coke rate	532	478	(2.6)
- Oil rate	<u>37</u>	<u>34</u>	<u>(2.1)</u>
Total	569	512	(2.6)
Consumption of primary energy inputs:			
- Metallurgical coal (kg per ton of crude steel)	708	659	(1.8)
- Electricity (Kwh per ton of crude steel)	437	427	(0.6)
- Fuel oil (kg per ton of crude steel) ^{b/}	<u>151</u>	<u>72</u>	<u>(16.9)</u>

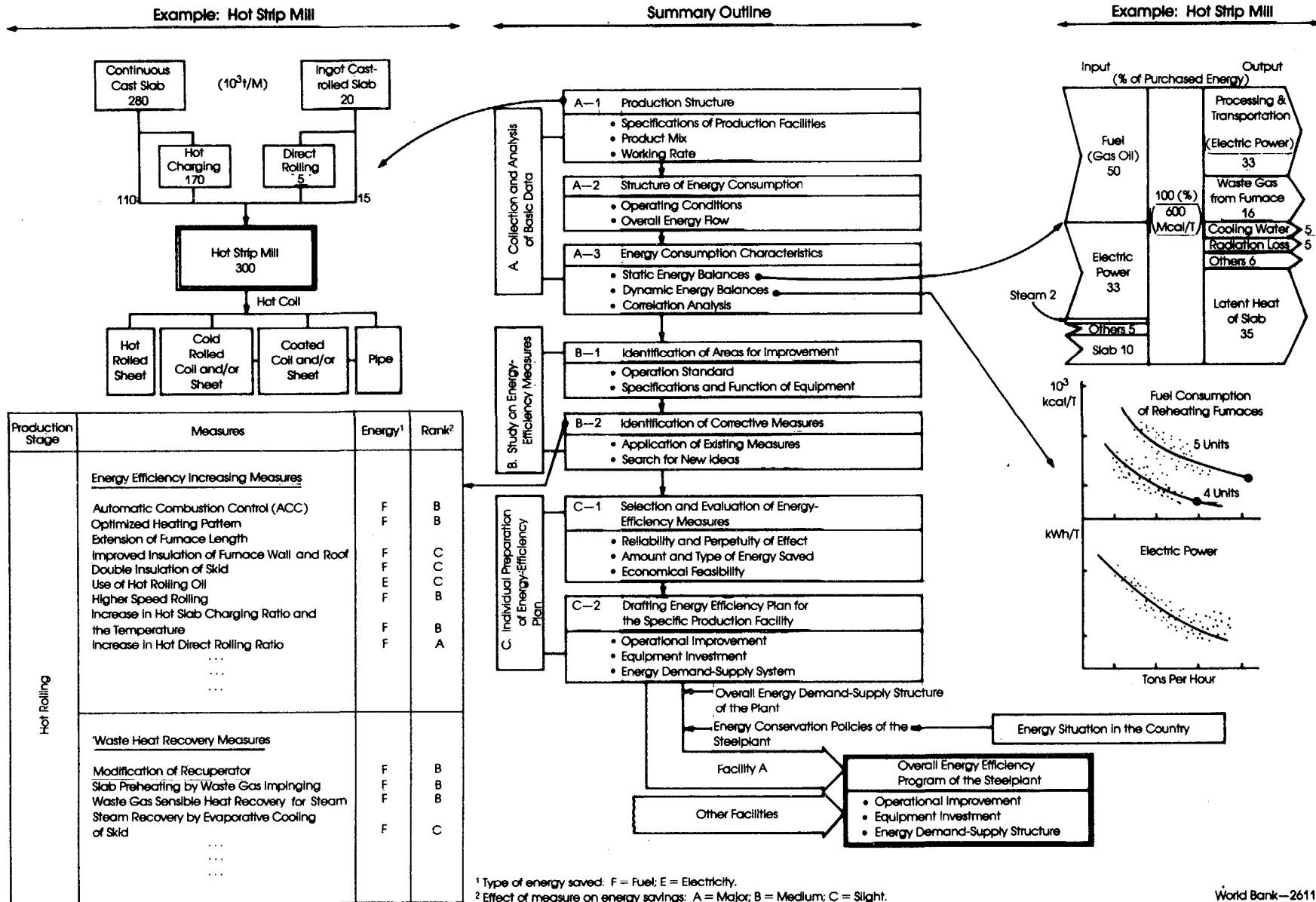
a/ COSIPA, CSN, USIMINAS.

b/ Including fuel for iron ore reduction in blast furnace and combustion.

Source: SIDERBRAS statistics.

ANNEX 6.

Summary Outline of Energy Audit at Steel Plant

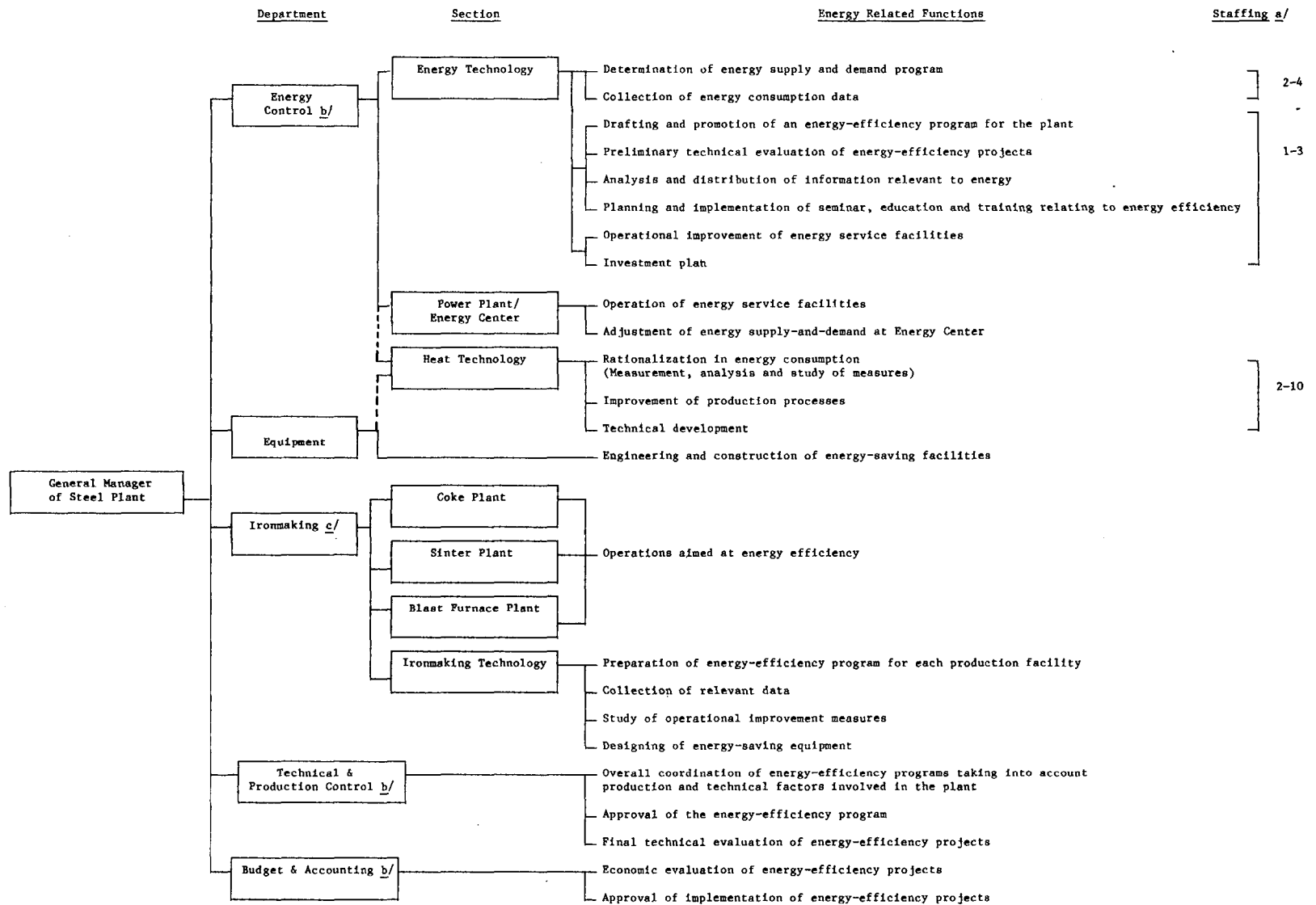


Source: NSC

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ANNEX 7.

ENERGY ORGANIZATION IN STEEL PLANT - STRUCTURE, FUNCTIONS AND STAFFING



a/ Figures in the column "Staffing" show numbers of personnel who are to be involved full-time in energy efficiency activities of a steel plant with steel production from 1-6 million tons per year.

b/ Managing departments for promotion of energy efficiency program.

c/ Similar organization structure exists for steel-making, and hot and cold rolling production departments.

Source: NSC

JAPAN: SELECTED ENERGY EFFICIENCY PROJECTS AT NIPPON STEEL CORPORATION

Type of Project	Investment ^{a/} (Million US\$)	Saved Energy ^{b/} (Mcal/ton of product)	Pay-Back Period ^{c/} (Years)
A. <u>Ironmaking Stage</u>			
1. Waste heat recovery system for sinter cooler			
1.1 Combustion air preheating	1-2	10-20	1-2
1.2 Steam generation	3-10	30-50	2-3
1.3 Power generation	10-20	10-30	3-4
2. Coke dry quenching	20-30	250-350	2-4
3. Automatic ignition device for coke oven gas released	0.2-0.4	10-20	0.5-1
4. Waste heat recovery system for hot stoves	2-4	20-30	1-2
5. Blast furnace top pressure recovery turbine	5-10	60-80	1-2
B. <u>Steelmaking Stage</u>			
6. BOF gas recovery system	40-100	170-200	2-3
C. <u>Rolling Stage</u>			
7. Double insulation of skids of reheating furnace	0.1-0.3	10-20	0.5-1
8. Installation of partition walls for reheating furnace	0.1-0.2	5-10	0.5-2
9. Modification of recuperator for reheating furnace	1-4	20-30	1-3
10. Waste heat recovery equipment for combustion-type non-oxidizing furnace	0.5-1	10-30	1-3
11. Steam saving for pickling tank	0.1-0.3	5-10	1-3
12. Installation of recuperator for bell-type annealing furnace	0.3-2	20-40	2-3
13. Power saving for descaling at hot rolling	0.5-2	5-10	1-3
D. <u>Miscellaneous</u>			
14. Control system for oxygen content in exhaust gas			
14.1 Soaking pits	0.5-1	5-10	1-2
14.2 Reheating furnaces	0.1-0.2	5-10	1-2

^{a/} At 1982 prices. The investment cost varies depending on the location, type, capacity, and other specifications of the facility to be installed and actual conditions of the existing equipment including the necessity of its modification.

^{b/} 1 Kwh of electric power is assumed to be equivalent to 2.45 Mcal of energy.

^{c/} Values obtained from investment cost divided by cost of energy saved per year, based on US\$3.1 per Mcal of energy saved which reflects Japanese conditions. In each specific case, the savings and pay-back period would depend on the types of energy saved and their local costs.

Source: NSC

ANNEX 9.

BRAZIL: SELECTED ENERGY EFFICIENCY PROJECTS AT COSIPA, 1981-85

Type of Project	Investment ^{a/} (US\$ '000)	Expected Annual Savings			Internal Rate of Return ^{b/} (%)	Implementation Period ^{c/} (years)
		Metallurgical	Fuel	Electricity		
		Coke	Oil			
		-- ('000 tons)	--	(Gwh)		
<u>A. Ironmaking Sector</u>						
1. Coal preheating in coke oven batteries	41,100	-	40.7	-	18.5	3.0
2. Coke dry quenching	34,992	31.6	18.7	-	11.0	3.0
3. Air blast dehumidifying for BF	10,506	47.4	1.7	-	39.9	3.0
4. Recovery and use of surplus BF gas	41,894	-	30.7	-	8.8 <u>d/</u>	3.5
<u>B. Steelmaking Sector</u>						
5. Recovery of BOF gas	3,730	-	8.7	-	31.8	2.5
<u>C. Rolling Sector</u>						
6. Computer control for slab furnace in hot strip mill	854	-	9.0	-	163.7	2.0
7. Combustion air recuperators for annealing furnaces	1,370	-	2.3	-	21.7	2.5
8. Energy center	<u>3,280</u>	<u>-</u>	<u>6.0</u>	<u>69.0</u>	<u>45.5</u>	<u>2.5</u>
Total	137,726	79.0	117.8	69.0	18.1	3.5

a/ June 1980 prices; excluding working capital and interest during construction; including 10% physical contingencies.

b/ Prices of energy inputs assumed as follows:

	US\$ per ton (June 1980 prices)	Real Price Increases 1980-84 (%)
Domestic Coal	47.30	1.0
Imported Coal	102.47	1.0
Heavy Oil	174.00	4.0-5.0
Light Oil	193.00	4.0-5.0

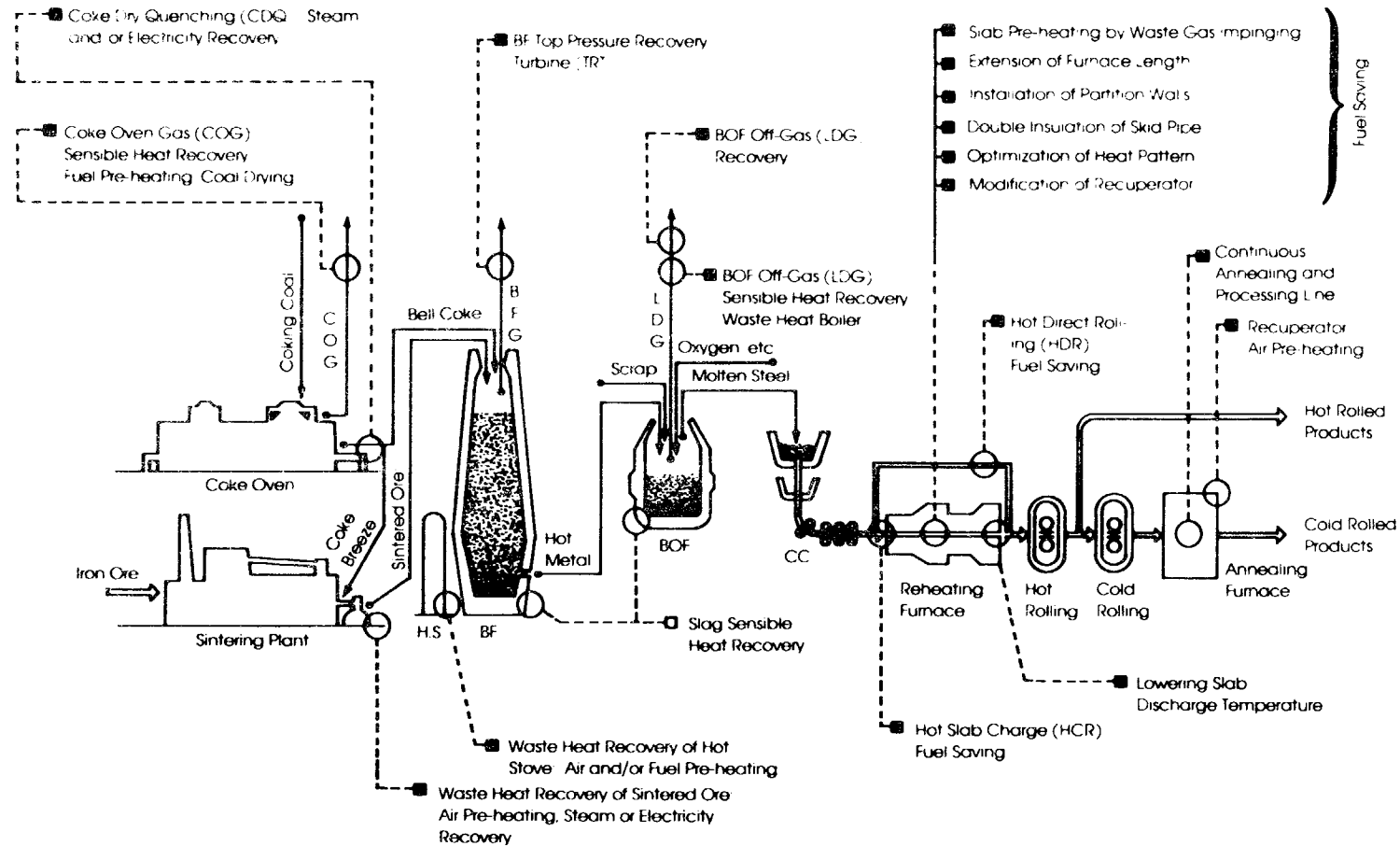
c/ From detailed engineering until completion of erection

d/ Low return due to costly (long) pipe connections of blast furnace with other furnaces.

Source: COSIPA Project data.

ANNEX 10.

JAPAN Selected Measures for BF/BOF Plants at Nippon Steel Corporation



Notes

Electricity and steam saving measures have been incorporated in all processes

- Adopted measures and installed equipment
- Under development

Source: NSC

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World Bank Publications of Related Interest

A Brief Review of the World Lube Oils Industry

A. Ceyhan, H. Kohli, L. Wijetilleke, and B.R. Choudhury

This report assesses the structure, background, and outlook for the world lube oils industry. Presents the historical and projected lube oils demand and trends in manufacturing technologies and production capacity and provides an indicative assessment of the economics of lube oil production with detailed market and economic data.

Energy Industries Report Series No. 1. 1982. 48 pages (including 13 annexes, references).

ISBN 0-8213-0054-7. Stock No. BK 0054. \$3.

Capital Utilization in Manufacturing: Colombia, Israel, Malaysia, and the Philippines

Romeo M. Bautista, Helen Hughes, David Lim, David Morawetz, and Francisco E. Thoumi

The authors surveyed 1,200 manufacturing firms in four developing countries to establish actual levels of capital utilization. The information collected was the first and remains the only data base available for the study of capital utilization. It was found that capital utilization is not as low as had been supposed. The study is concerned with factors that cause differences in levels of capital utilization and the policies that might be used to increase it.

Oxford University Press, 1982. 288 pages (including bibliography, index).

LC 81-9526. ISBN 0-19-520268-6, Stock No. OX 520268. \$22 hardcover.

The Construction Industry: Issues and Strategies in Developing Countries Ernesto E. Henriod, coordinating author

Presents a profile of the construction industry. Points out that construction work represents 3 to 8 percent of the gross domestic product of developing countries. Fostering a domestic capability in construction, therefore, is important. Discusses problems and constraints of the industry and formulates strategies for future actions. Draws heavily from the experience of the World Bank in supporting domestic construction industries over the past ten years. Useful to contractors, engineers, and administrators in construction industry.

1984. 120 pages.

ISBN 0-8213-0268-X. Stock No. BK 0268. \$5.

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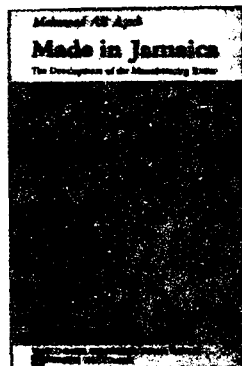
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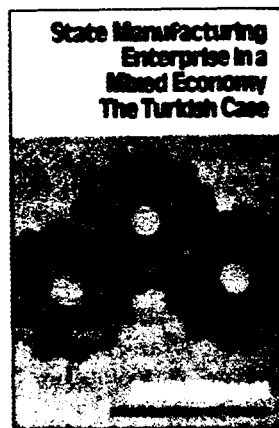
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