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THE U. S. STEEL INDUSTRY: AN ENERGY PERSPECTIVE

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MASTER

January 1988

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For
U. S. Department of Energy
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Washington, D.C.

By
Energetics, Incorporated
Columbia, Maryland

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ABSTRACT

This report investigates the state of the U.S. steel industry in terms of energy consumption and conservation. The specific objectives were:

- o To update and verify energy and materials consumption data at the various process levels in 1983;
- o To determine the potential energy savings attainable with current (1983), state-of-the-art, and future production practices and technologies (2000); and
- o To identify new areas of research and development opportunity that will enable these potential future savings to be achieved.

The results of this study concluded that in year 2000, there is a potential to save between 40% and 46% of the energy used in current production practices, dependent on the projected technology mix. R&D needs and opportunities were identified for the industry. Potential R&D candidates for DOE involvement with the private sector were assessed and selected from the identified list.

ACKNOWLEDGEMENTS

Energetics, Incorporated wishes to thank Dr. Donald Blickwede and Dr. James Fulton for their critical guidance and review throughout this study.

We express our thanks to Ms. Nancy Moore of Pacific Northwest Laboratory for her guidance throughout the study. In addition, we would like to acknowledge the contributions of Joseph S. Badin and Nancy G. Margolis of Energetics.

During the course of the study we contacted many individuals within industry and other associations. Where appropriate we have made reference to these contacts within the report. Frequently, however, because of the study's emphasis on future developments with comparative assessments of new technology, information given to us was of a confidential nature or was supplied to us with the understanding that it was not to be credited. Therefore, we extend a general thanks to all those participants for their interest in and contribution to this study.

SUMMARY

In July of 1985 Battelle Pacific Northwest Laboratories awarded Energetics, Inc. (EI) a contract to investigate the state of the U.S. iron and steel industry and the U.S. textile industry in terms of energy consumption and conservation. The specific objectives of this effort were:

- o To update and verify energy and materials consumption data at the various process levels within the two industries;
- o To determine the potential energy savings associated with current, state-of-the-art, and future production practices and technologies; and
- o To identify areas of research and development opportunity that will enable these potential savings to be achieved.

This report presents the results of the investigation of the iron and steel industry.

The U.S. steel industry (SICs 3312, 3315, 3316, and 3317) was ranked as the fourth largest industry in the U.S. as of 1983. The major growth period for this industry occurred when fuel prices were low and market demand was high; equipment and procedures were chosen on the basis of minimum capital cost. As a result, the U.S. steel industry has lost much of the competitive edge that it held in the 1950's and 1960's. Raw steel production dropped 38 percent between 1979 and 1983, from 136 million net tons to 84 million net tons. The impact of foreign competition has been severe for all steel products. The impact of this competition is reflected in Table 1, which shows recent production and import/export data for the industry.

TABLE 1
Selected Steel Industry Data

<u>Year</u>	<u>U.S. Production (10⁶ Net Tons)</u>	<u>U.S. Pro- duction as a Percent of World Production</u>	<u>U.S. Capability (10⁶ Net Tons)</u>	<u>Total U.S. Net Shipments (10⁶ Net Tons)</u>	<u>U.S. Import to Export Ratio</u>
1983	84.6	11.6	150.0	67.6	14.2
1982	74.6	10.5	154.0	61.6	9.0
1981	120.8	15.5	154.3	88.5	6.9
1980	111.8	14.2	153.7	83.9	3.8
1979	136.3	16.5	155.3	100.3	6.2
1978	137.0	17.3	157.9	97.9	8.7
1977	125.3	16.9	160.0	91.1	9.6
1976	128.0	17.2	158.3	89.4	5.4
1975	116.6	16.4	153.1	80.0	4.1

Source: 1983 Annual Statistical Report, AISI

The iron and steel industry is very energy-intensive, accounting for 6.8 percent of total U.S. industrial energy consumption and 2.5 percent of total U.S. energy consumption. Table 2 presents an energy consumption profile of the U.S. iron and steel industry for the five-year period 1979 to 1983.

TABLE 2.
Production and Energy Consumption Profile of the Steel Industry

<u>Year</u>	<u>Raw Steel Production (a) (10³ Net Tons)</u>	<u>Total Energy Consumed (b) in Production (10¹² Btu)</u>	<u>Average Specific Energy Consumption (10⁶ Btu/Net Ton)</u>
1983	84,615	1,854.02	21.91
1982	74,577	1,815.63	24.34
1981	120,828	2,872.45	23.77
1980	111,835	2,771.87	24.78

(a) 1983 Annual Statistical Report, AISI.

(b) Energetics, Inc. estimated data (a conversion factor of 10,500 Btu/kWh_e is used in the calculations).

Table 2 illustrates the recent downward trend in specific energy consumption for the industry. Much of this trend has been attributed to the fact that the industry has permanently shut down its least efficient mills

and some small plants in response to reductions in demand. Other factors contributing to the recent decrease in specific energy consumption are:

- o The closing of many inefficient integrated plants in favor of non-integrated plants;
- o Changes in product mixes;
- o Increased use of semi-finished materials;
- o Increased efficiencies resulting from the elimination of those products that are made least efficiently in a given plant;
- o Increased use of continuous casting over ingot casting; and
- o Overall improvements in production practices.

The energy consumed in production, as stated in Table 2, uses an energy intensity of 10,500 BTU/KWH-electric as opposed to the direct conversion factor of 3,412 BTU/KWH-thermal. This is a more realistic approach to the industry's actual energy consumption and is more consistent with the objective of the effort as well as the literature.

Industry experts have acknowledged the existence of a technological gap between current U.S. production practices and their counterparts in other industrialized nations such as Japan, West Germany, and Sweden. In the U.S., technological practices vary widely not only between companies but also within single companies. State-of-the-art technologies (e.g., continuous casting, continuous rolling, and scrap preheating) are often used little or not at all, in spite of their significant productivity and energy benefits. Some of these same technologies, however, are used extensively in other countries. Further benefits are expected from the development and utilization of advanced technologies such as direct strip casting, the energy optimization furnace, and the Korf reduction process.

This investigation of the U.S. iron and steel industry included a quantitative analysis of the potential energy impacts of both the state-of-the-art

and the advanced technologies, in the year 2000. A production of 100 thousand net tons of steel was assumed based on the industry experts' consented opinions. The analysis was performed for each of the following production-mix scenarios:

Scenario 1) -- 100 percent production by state-of-the-art technology alone.

Scenario 2) -- Production by a mix of state-of-the-art and advanced technologies as projected by the industry experts contacted for this study.

Scenario 3) -- Production technology mix of 90 percent state-of-the-art technology and 10 percent advanced technology.

Scenario 4) -- Production technology mix of 50 percent state-of-the-art technology and 50 percent advanced technology.

The results of the analysis, illustrated in Figure 1, indicate that significant reductions in the energy consumption requirements of the industry are possible.

The R&D needs and opportunities of the U.S. iron and steel industry were assessed based on perceived future steelmaking practices. The most significant areas that were identified, listed in order of importance, are:

- o thin strip casting;
- o sensor technology upgrades (for high-temperature and severe-environment operation);
- o computer control system advances (e.g., artificial intelligence);
- o programmed heating of coke ovens;
- o injection of carbonaceous fuels in the BOF; and
- o cokemaking process improvements.

FIGURE 1 : POTENTIAL ENERGY SAVINGS IN THE YEAR 2000

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SECTION 1. INTRODUCTION

1.1 INDUSTRY PERSPECTIVE

Despite recent recessions and increased foreign competition, the steel industry (SICs 3312, 3315, 3316, and 3317) was ranked as the fourth largest industry in the United States in 1983, with consolidated corporate sales of 48.4 billion dollars. Steel production accounts for more than 90 percent of all metals consumed in this country. There are approximately 300 domestic iron and steel companies; of these, roughly one-third produce raw steel. A geographical distribution of the iron and steel industry is presented in Figure 1.1. Table 1.1 presents a profile of raw steel production and production capability in the U.S. from 1975 to 1983.

TABLE 1.1 PROFILE OF RAW STEEL PRODUCTION AND PRODUCTION
CAPABILITY OF THE U.S. STEEL INDUSTRY (10^3 NET TONS)

Year	World Production	Production	Percent of World	Capability	Percent of Capability
1983	731,646	84,615	11.6	150,600	56.2
1982	710,738	74,577	10.5	154,000	48.4
1981	779,399	120,828	15.5	154,300	78.3
1980	790,419	111,835	14.2	153,700	72.8
1979	824,486	136,341	16.5	155,300	87.8
1978	790,607	137,031	17.3	157,900	86.8
1977	741,828	125,333	16.9	160,000	78.4
1976	745,592	128,000	17.2	158,300	80.9
1975	712,033	116,642	16.4	153,100	76.2

Source: 1983 Annual Statistical Report, AISI

Figure 1.1 Geographical Distribution of the U.S. Iron and Steel Industry

Recently, the steel industry has come under severe economic strains that have threatened the general health of the industry. These strains are primarily caused by factors such as increased foreign competition, increased production costs, and reduced demand. The impact of these factors are clearly seen in the recent production capability data published by the American Iron and Steel Institute (AISI). According to these data, national raw steel production capability, which peaked at 160 million net tons in 1977, was 135.3 million net tons in 1984. Much of the reduction in capability comes from the industry decision to rationalize operations through greater specialization or greater utilization of more efficient lines. Many experts believe this downward trend will continue for some time and U.S. steel production capability is projected to be reduced to 100 million tons by the year 2000.

The impact of the problems confronting the industry on production capability utilization, (i.e., the percentage of the total production capability that is actually used), has also been dramatic. Production capability utilization rose slowly during early 1981 to about 90 percent, but dropped almost 30 percentage points by the end of the year to finish with an average value of 78.3 percent.¹ This trend continued in 1982 when the capability utilization dropped to 48.4 percent, the lowest value since 1946.

Recent increases in foreign competition are partially due to the international glut of steel production and steelmaking capability. The glut has been fueled by recent worldwide recessions that have created imbalances in the world market. Fierce competition has resulted in sharp price reductions, reduced profitability, increased unemployment, and permanent plant closings around the world. The Japanese steel industry, for example, is currently only operating about 60 percent of its capability. In the U.S., foreign competition has had a significant impact on both steel imports and steel exports. The import share of the apparent steel supply (total net shipments plus imports less exports) rose steadily to 26.1 percent (19.8

¹"American Steel Industry to Remain a Dominant Force Despite Retrenchment," Industrial Heating, February, 1985.

million tons) in the first three quarters of 1984, compared with 19.6 percent in the same period of 1983, a 33 percent increase.¹ Exports, on the other hand, dropped from a high of 4.1 million tons in 1980 to approximately 1.2 million tons in 1983. Table 1.2 highlights recent steel import and export data.

TABLE 1.2 SELECTED STATISTICAL HIGHLIGHTS FOR
STEEL MILL PRODUCTS (10³ NET TONS)

Year	Total Net Shipments	Less Exports	Plus Imports	Apparent Steel Supply	Imports as % of Apparent Steel Supply
1983	67,584	1,199	17,070	83,455	20.5
1982	61,567	1,842	16,663	76,388	21.8
1981	88,450	2,904	19,898	105,444	18.9
1980	83,853	4,101	15,495	95,247	16.3
1979	100,262	2,818	17,518	114,962	15.2
1978	97,935	2,422	21,135	116,648	18.1
1977	91,147	2,003	19,307	108,451	17.8
1976	89,447	2,654	14,285	101,078	14.1
1975	79,957	2,953	12,012	89,016	13.5

Source: 1983 Annual Statistical Report, AISI.

The high inflation of the late 1970's and early 1980's had little impact on the price of steel products because of a worldwide soft market for these products. Iron Age reported that the annual average composite price for domestic finished steel was 26.19 cents per pound in 1983, a 3.6 percent increase over the 1982 price and the smallest annual increase since 1973. The composite price for pig iron remained unchanged from 1982 to 1983 at \$213

¹"American Steel Industry to Remain a Dominant Force Despite Retrenchment," Industrial Heating, February 1985.

per short ton. Prices at the end of 1984 were actually at the 1981-82 level and all indications are that no significant price changes are forthcoming in the near future. Many steel products have been sold at discounts of up to 40 percent from list prices in the last few years because of weak demand and the availability of low-priced imports.

On the other hand, production costs have increased dramatically during the 1970's and early 1980's. According to AISI, the two major contributors to this rise were labor costs and energy costs. The average total employment cost per hour worked by an hourly employee during 1983 was \$22.21, compared to \$14.30 in 1978 and \$9.08 in 1974. Similarly, the cost of energy has risen sharply since the era of cheap fuel. According to industry experts who were contacted for this study, in 1983 energy costs represented an average of 20 to 21 percent of the sale price of integrated-plant products, an average of 10 to 14 percent of the sale price of alloy steel products from non-integrated plants, and an average of 5 to 10 percent of the sale price of carbon steel products from non-integrated plants. These figures are double the cost of fuels as a percent of the sale price for the same products in 1972.

The impact of higher production costs on the U.S. steel industry has been dramatic. The industry, which was built for the most part when energy costs were low and foreign competition almost nonexistent, has been extremely susceptible to changes in these two factors and has suffered reduced profits as a result. In 1982 and 1983, the industry lost 3.2 and 3.5 billion dollars, respectively. These losses, along with average industry sales and employment costs for the years 1974 - 1983, are shown in Table 1.3.

Other problems facing the steel industry include the reduced steel demand of the past several years, a result of the weak capital goods sector, the increased use of substitute materials in several industries, and changes in the automobile industry. Increased use of composite materials in vehicle production, automobile downsizing, and recent reductions in domestic automobile manufacturing have led to reduced steel requirements for the automobile industry. Steel demand has also decreased in other traditional markets,

including housing and highway construction, because of increased use of concrete, plastics, and aluminum.

TABLE 1.3 SELECTED FINANCIAL HIGHLIGHTS

Year	Sales (\$000)	Total Employment Cost Per Hour (\$)	Net Income (\$000)
1983	48,448.6	22.21	(3,562.5)
1982	52,082.9	23.78	(3,206.4)
1981	60,172.7	20.16	2,600.8
1980	52,828.8	18.45	1,734.9
1979	55,140.4	15.92	1,154.5
1978	49,033.0	14.30	1,276.6
1977	39,399.8	13.04	22.3
1976	36,092.5	11.74	1,337.4
1975	33,143.8	10.59	1,594.9
1974	37,745.0	9.08	2,475.2

Source: 1983 Annual Statistical Report, AISI.

The recent losses have prompted many producers to permanently close down a number of old, inefficient plants. The industry has also been forced to make production policy changes. Many companies are promoting greater efficiency through specialization (i.e., by reducing the number of products made in a given mill). The U.S. steel industry appears to be reverting to the "one mill, one product" policy of the early 1900's instead of producing fifty or more products at a single mill.

Furthermore, recently published literature has indicated that the industry has also recognized the need for the adoption of new and more advanced

technologies in both current and future production practices. As a result, modernization through adoption of new and more efficient technologies has been occurring more and more frequently. (See Section 2.4.1 for a discussion of this in greater detail). The majority of these modernization activities employ technologies that use both energy and labor more efficiently.

1.2 OBJECTIVES

The goal of this study is to assess the potential energy savings in the iron and steel industry and to identify areas of opportunity for research and development in technologies that will enable these savings to be achieved. To do this, detailed profiles of state-of-the-art and advanced technology must be developed, as well as profiles of resource consumption in the various process steps that constitute iron and steelmaking. In addition, a common base of technical information must be established to ensure consistency within comparative analyses and to form a sound basis from which accurate and realistic judgements of energy conservation research and development opportunities can be made.

The specific objectives of this study are:

- o To update and verify energy and materials consumption data at the various process levels associated with the production of iron and steel;
- o To determine the potential energy savings associated with current, state-of-the-art, and future industry technology profiles; and
- o To identify areas of research and development opportunity that will make it possible for these savings to be achieved.

1.3 TECHNICAL APPROACH

An extensive literature search was performed to obtain the information required for this study. In addition to identifying related DOE and other government agency R&D publications, the Remote Console (RECON) data base system, (operated by the Office of Technical and Scientific Information), was searched for relevant articles and technical papers in technical journals and periodicals published both inside and outside the U.S. Information was also obtained from AISI, from the International Iron and Steel Institute (IISI), and from selected steel manufacturing company libraries.

Several industry experts were also individually interviewed for this study to verify information found in open literature as well as to obtain other data not available. Nine industry representatives from all types of plants provided recent energy consumption data by process level for their plants. These experts also described conservation measures used or considered by their companies and estimated the degree of use of specific advanced technologies in the year 2000, assuming no technical or economic constraints. Companies represented by the experts accounted for 20 percent of the total production by industry in 1983. In addition, Energetics' personnel made several field trips to mills operated by the participating companies.

The information acquired was used to develop updated flow diagrams of the three technological scenarios being considered (current, state-of-the-art, and advanced). These diagrams show the various technology alternatives that exist or most likely will exist in the future for each major process step.

Data gathered on the current state of the industry were used to establish trends in the state of technology development from the year that these data were reported to the year when improvements in energy use were realized. Using these trends as a base, the energy consumption profiles found in previous reports were updated to 1983. Other types of profiles that were developed for current steelmaking practices include: production, import/export, economic, technology mix (by process step), and materials consumption.

Recent conservation and modernization efforts within the industry were also identified. For the state-of-the-art and advanced steel industry scenarios, energy consumption profiles were developed based on technology mixes as conceptualized by the industry experts.

The potential energy savings associated with state-of-the-art and advanced practices as foreseen by the experts for the year 2000 were determined by comparing the energy consumption level for each process step with the corresponding level associated with current practices. In cases where the process technology mix estimated by the experts for the year 2000 was not the most energy efficient one, efforts were made to determine why use of the more efficient alternatives would not be more widespread. Additionally, the specific energy consumption of the process routes up to and including the steelmaking furnace for both state-of-the-art and advanced practices were compared to the theoretical minimum energy requirement. Based on these comparative analyses, areas of R&D opportunity with the highest potential energy savings were identified.

The findings of this study are reported in the sections that follow. In Section 2, current technological practices, production and energy consumption profiles, and recent conservation measures adopted by industry are discussed. Section 3 discusses future trends in steelmaking, including both state-of-the-art and advanced technologies. Section 4 presents an analysis of the potential energy savings associated with the steelmaking trends discussed. In the final section, areas of energy conservation R&D opportunities are identified.

The report contains the following appendices:

Appendix A - Glossary

Appendix B - Energy and Materials Use by Major Process: 1979, 1980, 1981, 1982

Appendix C - Conservation Technologies/Measures Adopted by the Industry Between 1980 and 1984

Appendix D - State-of-the-Art Steelmaking Technologies

Appendix E - Advanced Steelmaking Technologies

SECTION 2. ENERGY CONSUMPTION IN CURRENT STEELMAKING PRACTICES

This section describes the current technological status of the U.S. steel industry, presents energy consumption data for the overall steel-making process and for the individual processes involved, and discusses recent trends in energy conservation technology.

2.1 CURRENT PRODUCTION AND ENERGY CONSUMPTION IN THE INDUSTRY

The iron and steel industry is one of the most energy-intensive industries in the United States. Its 1983 consumption of 1.8 quads accounted for 6.8 percent of the total energy consumed by industry (26.45 quads) and approximately 2.5 percent of the total energy consumed in the nation. Figure 2.1 illustrates the percentages of the major fuel types used by the industry in 1983. The category "others" includes fuel oil, liquified petroleum gas and energy used in the production of oxygen and ferroalloys consumed by the industry.

FIGURE 2.1 MAJOR ENERGY SOURCES USED BY THE IRON
AND STEEL INDUSTRY IN 1983

* Includes utility losses

A large fraction of the U.S. steel industry was built in the decade after World War II, when fuel was cheap and market demand was high. Equipment and procedures were chosen on the basis of minimal capital cost. Compared to other industrialized nations like Japan and Germany, the U.S. steel industry uses relatively inefficient and obsolete technologies. For example, the last integrated plant built in the U.S. was completed in the mid 1960s. As a result, the U.S. steel industry has lost much of the competitive edge that it held in the 1950s and 1960s. Raw steel production dropped 38 percent between 1979 and 1983, from 136 million net tons to 84 million net tons. The impact of foreign competition has been severe across the board for all steel products. U.S. exports have become almost insignificant.

Table 2.1, a production and energy consumption profile for the U.S. steel industry, illustrates the impact of economic strains on the production levels from 1979 to 1983. Table 2.1 also presents gross energy consumption in the industry and specific energy requirements for a net ton of raw steel in the same period. This table shows a decline in energy consumption per net ton of raw steel from 25.35 million Btu in 1979 to 21.91 million Btu in 1983, an all-time low. In 1982 there was an increase in energy consumption per net ton of raw steel over that of 1981. Industry experts have agreed that this increase is directly attributable to the reduction in capability utilization in 1982, which dropped from 78.3 percent in 1981 to 48.4 percent.

Much of the reduction in energy consumption by the steel industry in the past several years was because the industry permanently shut down its least efficient mills and some small plants in response to reduced demand. Other factors contributing to this downward trend in energy consumption are:

- o The closing of many inefficient integrated plants in favor of non-integrated plants;
- o Changes in product mixes;
- o Increased use of semi-finished materials;

- o Increased efficiencies resulting from the elimination of those products that are made least efficiently in a given plant;
- o Increased use of continuous casting over ingot casting; and
- o Overall improvements in production practices.

TABLE 2.1 PRODUCTION AND ENERGY CONSUMPTION
PROFILE OF THE STEEL INDUSTRY

<u>Year</u>	<u>Raw Steel Production(a) (10³ Net Tons)</u>	<u>Total Energy Consumed in Production (b) (10¹² Btu)</u>	<u>Average Specific Energy Consumption (10⁶ Btu/Net Ton)</u>
1983	84,615	1,854.02	21.91
1982	74,577	1,815.63	24.34
1981	120,828	2,872.45	23.77
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1979	136,341	3,457.27	25.35

(a) 1983 Annual Statistical Report, AISI.

(b) Energetics, Inc. estimated data (a conversion factor of 10,500 Btu/kWh_e is used in the calculations).

The strategy of efficient production through increased specialization represents a return to the policies of the early 1900s when the motto was, "The greatest economy would result from having one mill make one product."¹ Steel companies are currently trying to rationalize operations by reducing the number of product types per plant.

¹"Steel Recasts Itself," Iron Age, January 4, 1985.

2.2 CURRENT PRODUCTION AND ENERGY CONSUMPTION BY PROCESS LEVEL

The six major post-beneficiation process steps in conventional steel-making technology are:

- o Agglomeration
- o Cokemaking
- o Ironmaking
- o Steelmaking
- o Steelcasting
- o Steelforming

Steel plants are classified as integrated or non-integrated on the basis of the number of process steps that they incorporate. Integrated plants incorporate all six process steps, while non-integrated plants use mostly the last three. There are also independent producers that utilize the steelforming step only; these producers purchase semi-finished steel for use in fabricating wire, bars, and pipe.

Figure 2.2 is a schematic of conventional steelmaking in an integrated plant illustrating the six major processes. Integrated steel producers operate on a scale of one to eight million tons per year and use iron ore and coal as the basic raw materials to produce molten pig iron in blast furnaces. The molten iron is then charged along with scrap into a steelmaking furnace to produce raw steel, which is cast and formed into various products. The majority of the steel produced in integrated plants is "carbon" steel. This grade represented approximately 93 percent of the 1983 integrated-mill output.

A flow diagram for a non-integrated plant (sometimes referred to as a mini-mill) is shown in Figure 2.3. These plants operate on a smaller scale than integrated plants, producing two hundred thousand to two million tons of steel annually. Non-integrated plants, which accounted for about 32 percent of the U.S. steelmaking capacity in 1983 are generally more modern than

FIGURE 2.2. CONVENTIONAL STEELMAKING PROCESS FLOW DIAGRAM FOR AN INTEGRATED MILL

FIGURE 2.3. CONVENTIONAL STEELMAKING PROCESS FLOW DIAGRAM FOR A NON-INTEGRATED MILL (MINI-MILL)

integrated plants but have more limited product lines. They account for a high percentage of the alloy steel and almost all of the stainless steel produced in the U.S. Recent industry trends towards non-integrated mills are due to a variety of factors, including lower construction costs and shorter lead times than integrated mills, the relatively high availability and low cost of scrap as compared to iron ore, and the constant demand for their products.

Current production and energy consumption by each of the six major steel-making processes are presented in the following subsections.

2.2.1 AGGLOMERATION

Iron ore concentrates produced from crude iron ore are agglomerated into coarse particles for processing in the blast furnace. Agglomeration processes enable the ore to provide uniform counter-current gas flow in the furnace. The two major agglomeration processes used in the steel industry are pelletizing and sintering.

Pelletizing

In the U.S., pellets are used in the ironmaking process more than all other agglomerated products combined. The American Iron and Steel Institute (AISI) reported a total agglomerated-products use of 53.6 million net tons in 1983, 35.5 million tons of which were pellets.

In pelletizing, an unbaked ball or "green" pellet is formed with iron ore concentrate combined with a binder. Such pellets are then hardened by heat treatment in an oxidizing furnace. The major pelletizing systems are the traveling grate, the shaft furnace, the grate kiln, and the circular grate. Pelletizing is almost always conducted at the mine site. From there, the pellets are transported by boat or railroad to the plant, where they are fed into the blast furnace along with coke, fluxes, and often sinter.

Recent data on pelletizing are not readily available from open literature. The specific energy consumption for the pelletizing process in 1979 was reported by Arthur D. Little, Inc. (ADL) as follows:

Magnetite:	300 - 450 x 10 ³ Btu/net ton of pellets
Hematite:	800 x 10 ³ Btu/net ton of pellets
Electricity:	25 kWh/net ton of pellets

Data obtained from an expert at the Bureau of Mines places the average total fuel requirement for pelletizing in 1984 at about 410 x 10³ Btu/net ton for hematite. However, this average included consumption levels as low as 245 x 10³ Btu/net ton. Almost all of the reduction in pelletizing process fuel consumption can be attributed to the use of waste heat recuperator systems or to improvements in these types of systems (e.g., better duct insulation). Energy saving of 20 to 40 percent have been realized through the use of waste heat recovery systems and another 20 percent is reported for improved duct insulation.

Sintering

In the sintering process, iron ore concentrates and other iron-bearing fines are mixed with coke breeze and limestone and placed on a traveling grate. The mix of coke and metal-bearing materials is ignited by gas burners and the flame is drawn downward through the bed by forced air suction. The high temperature thus produced fuses the metal oxide/limestone mix. After the resulting sinter product has cooled, it is crushed and screened before being fed into the blast furnace.

The specific energy consumption for sintering as reported by ADL in 1979 was between 1.3 and 1.9 x 10⁶ Btu/net ton. The average estimated specific energy consumption for a net ton of sintered product in 1983 was 1.5 x 10⁶ Btu. The industry experts who were contacted verified this figure; their estimates ranged from 1.5 to 1.6 x 10⁶ Btu/net ton. One energy conservation

measure reported as being used by the industry is steam power generation using sinter cooler exhaust.

2.2.2 COKEMAKING

Coke, which is a form of carbon, is used in the blast furnace for combustion to produce reducing gases and heat to reduce iron ore to metallic iron. Coke is produced from low sulfur, low ash content metallurgical coals. Different types of coals are blended together to get the desired size and strength of coke.

Coke production is comprised of the following steps:

- 1) The coking coal blend is prepared from the various metallurgical coals and is transported to the coke oven.
- 2) The coke oven is charged with the coal blend and is then sealed.
- 3) The oven is heated externally by a combination of injected and recycled gaseous fuels (including coke oven and blast furnace gases) to about 1000°C.
- 4) The coal is baked for 16 to 20 hours; devolatilization (carbonization) of the coal begins at the walls and proceeds inward.
- 5) The hot coke is removed from the oven by pusher machines and is placed into waiting cars.
- 6) The hot coke is quenched by overhead water sprays.
- 7) The cooled coke is crushed and screened for use in the blast furnace.

Approximately one fourth of the initial charge of coking coal (by weight) is transformed to gas during the coking process. These off-gases are cooled and processed to remove sulfur compounds and to recover tars, oils, naphthalene, and ammonia. The remaining coke oven gas is returned to the oven for use as a heating fuel, and is also used as a fuel in other steel plant operations.

According to the Energy Information Administration (EIA), 25.8 million tons of coke were produced in the United States in 1983.² Coke, which is primarily used in blast furnaces, is produced by furnace plants (i.e., steel producers) as well as merchant plants (i.e., independent producers). The 1983 production level was less than half the production level of 1979, 52.9 million tons. EIA reported that about 20 of 58 coke plants operating in January 1981 were closed down by December 1984. The decrease in the coke production rate was caused not only by recent decreases in the production of pig iron but also by increases in blast furnace efficiency and changes in operating practices. In 1983, an average of 0.55 net ton of coke was used to produce one net ton of iron compared with 0.57 in 1979. Table 2.2 shows coke production and associated energy consumption for furnace plants between 1979 and 1983.

Annual cokemaking energy consumption has been in the range of $6-7 \times 10^6$ Btu/net ton (see Table 2.2). This table also shows a downward trend in specific energy consumption in the past few years. This trend has been verified by industry experts, who indicated that 1983 energy consumption for coking operations in their companies has been an average of 5 to 10 percent lower than the 1983 value shown in Table 2.2 (i.e., 5.99×10^6 Btu/net ton). Furthermore, this trend is expected to continue as more plants adopt new practices or are retrofitted with new and more efficient equipment (See Section 3).

²"Quarterly Coal Report," Energy Information Administration, 1984.

TABLE 2.2 PRODUCTION AND ENERGY CONSUMPTION PROFILE
OF THE COKE MAKING PROCESS (FURNACE PLANTS)

Year	Production(a) (10 ³ Net Tons)	Total Energy Consumed in Production (b) (10 ¹² Btu)	Average Specific Energy Consumption (10 ⁶ Btu/Net Ton)
1983	22,710	136.0	5.99
1982	24,745	150.0	6.06
1981	38,117	265.5	6.97
1980	42,128	255.6	6.07
1979	48,221	348.8	7.23

(a) 1983 Annual Statistical Report, AISI.

(b) Energetics, Inc. estimated data (a conversion factor of 10,500 Btu/kWh_e is used in the calculations).

2.2.3 IRONMAKING

In ironmaking, iron is produced from iron oxide-bearing materials, coke, and limestone. The major ironmaking process in the steel industry is the blast furnace.

Blast Furnace

In the blast furnace, iron oxide is reduced to metallic or pig iron via the following steps:

- 1) Iron-bearing materials (agglomerated ores in the form of sinter or pellets, lump ores, steel scrap), limestone, and coke are fed into the top of the furnace shaft.

- 2) Heated air (and sometimes fuel) is blown into the bottom of the furnace shaft.
- 3) Carbon monoxide is produced from the reaction of the oxygen in the air and the coke.
- 4) The iron oxide is heated and partially reduced by the hot carbon and carbon monoxide to form lower oxides of iron.
- 5) As the charge descends through the furnace, further heating and reduction occurs and molten iron and gangue (slag) are produced.
- 6) The molten iron and slag are tapped from the furnace hearth.
- 7) The molten iron is transported in ladles or cars to the steel-making furnaces to be refined to steel.

In 1983, all iron produced by the U.S. steel industry came from the blast furnace. The Bureau of Mines reported as of 1983 one hundred (100) blast furnaces (both operating and non-operating) located in fourteen states. This number represents a decrease of almost 40 plants from the 1982 total. However, the number of blast furnaces that were operating rose from 42 in 1982 to 52 in 1983. Pig iron production in 1983 was up 12 percent from the 1982 production level of 43.3 million net tons, which was a record low for the past four decades. Table 2.3 presents production and energy consumption profiles of the ironmaking process. This table provides both gross energy consumption and specific energy consumption per net ton of iron produced for the ironmaking process from 1979 to 1983. The energy requirement for a ton of iron in 1983 was 13.86×10^6 Btu, a decrease of about 8 percent from the 1979 level.

The downward trend in energy consumption for ironmaking is expected to continue, although recent discussions with industry experts revealed that actual levels for individual producers vary widely in the industry. Specific

consumption data obtained from these discussions ranged from 25 percent lower than the 1983 figure shown in Table 2.3 to 55 percent higher than this figure. The lower consumption data came from those producers who have installed new blast furnace plants or have retrofitted their existing furnaces with energy-conserving technologies, or who have done both. Some of the more significant conservation measures that were taken include coal injection, hot blast main insulation, top gas pressure recovery, and Paul Wurth tops (for more uniform distribution of the charge).

TABLE 2.3 PRODUCTION AND ENERGY CONSUMPTION PROFILE
OF THE IRONMAKING PROCESS (BLAST FURNACE)

<u>Year</u>	<u>Production(a)</u> <u>(10³ Net Tons)</u>	<u>Total Energy</u> <u>Consumed in</u> <u>Production (b)</u> <u>(10¹² Btu)</u>	<u>Average</u> <u>Specific Energy</u> <u>Consumption</u> <u>(10⁶ Btu/Net Ton)</u>
1983	48,706	675.46	13.86
1982	43,309	590.98	13.64
1981	73,570	1,044.16	14.19
1980	68,721	1,012.33	14.73
1979	87,003	1,305.27	15.00

(a) 1983 Annual Statistical Report, AISI.

(b) Energetics, Inc. estimated data (a conversion factor of 10,500 Btu/kWh_e is used in the calculations).

Direct Reduction

Another method of producing iron is the direct reduction process, which replaces both the cokemaking process and the blast furnace. In this process, iron ore in the form of fines or agglomerated products is reduced in the solid condition (i.e., without melting) using gaseous reductants produced

from natural gas, oil, or coal. The reduction process is carried out at temperatures below the melting point of iron. The reduced product known as sponge iron, has low carbon content but still contains the impurities in the ore and is primarily used as a charge to electric arc furnaces. The process avoids the high capital costs of the cokemaking operation.

Uncertainties surrounding the availability of sufficient quantities and qualities of scrap and the very low cost of natural gas spawned the development of the direct reduction process. In addition to serving as a scrap supplement, the process can be used to replace Btu's from more critical metallurgical coke with Btu's from less critical fuels such as coal. Other benefits are lower amounts of tramp elements in Direct Reduced Iron (DRI) than in scrap, and the elimination of the pollution associated with coke-making. Although coal-based systems are considered to be the only economical alternative in the U.S., they use twice as much energy per ton as do gas-based systems.

Recent increases in natural gas or syngas prices and decreases in scrap demand and price have practically eliminated the production of DRI in this country because of the sensitivity of the process to fuel costs. The Bureau of Mines reported zero production of sponge iron in 1983 and 120,000 net tons in 1984. The existing DRI plants primarily use natural gas and electricity and therefore are not currently competitive with blast furnaces, nor are they expected to replace blast furnaces in the foreseeable future.

2.2.4 STEELMAKING

The pig iron produced in the blast furnace contains impurities such as carbon, silicon, manganese, phosphorus, and sulfur. In the steelmaking process, these impurities are partially or entirely oxidized and removed in the form of slag. Other elements, including nickel, chromium, and molybdenum, may be added to achieve certain mechanical or corrosion properties. Similarly, the sponge iron produced in the direct reduction process needs to be refined in steelmaking furnaces.

There are three types of steelmaking furnaces: the basic oxygen furnace (BOF), the open hearth furnace (OH), and the electric arc furnace (EF).

Basic Oxygen Furnace

In the basic oxygen steelmaking process, oxygen is blown into molten iron and scrap contained in a cylindrical, refractory-lined vessel. The vessel can be rotated about a fixed horizontal axis for charging and pouring. Slag-forming fluxes are added to the charge in controlled quantities. The heat required to melt the scrap iron is supplied by the oxidation of the carbon and other impurities (e.g., silicon and manganese) in the pig iron and by the sensible heat in the molten charge itself. Because of this, the scrap content of the charge does not exceed 30 percent in conventional practice.

The heat time for the BOF process is less than one hour. During the process, off-gases consisting primarily of carbon monoxide and carbon dioxide are released and collected in hoods over the vessel. In most cases in the U.S., these gases are cooled, cleaned, and released into the atmosphere, but it is possible to collect and use them if economical.

Open Hearth Furnace

The open hearth furnace is a long, shallow, refractory-lined bath in which the charge is heated by radiation from a flame that sweeps over the bath. Heat is also supplied by radiation from the refractory roof, which is heated along with the charge by the flame. The charge contains various proportions of molten pig iron, scrap, and flux (limestone).

In contrast to the BOF process, the energy required to heat the charge in an open hearth furnace comes almost entirely from externally supplied fuel, including natural gas, fuel oil, coke oven gas, coal, tar, or combinations of these. Therefore, there are few limitations on the amount of scrap allowed in the charge. However, the heat time for the OH process is four to twelve hours, considerably longer than for the BOF process, which makes the OH process more energy intensive.

Electric Arc Furnace

The electric arc furnace is a refractory-lined cylindrical shell with a removable roof. Three extendable graphite electrodes are suspended above the shell. The charge for the electric arc furnace consists of scrap and/or sponge iron. As the heat cycle begins, the electrodes are lowered into the furnace, forming an arc to the charge. The charge is melted by radiation from the arcs until the desired degree of refining is achieved, between two and six hours. Because conditions in this type of furnace can be controlled more easily than in the BOF or OH processes, it can be used to produce varieties of alloy steels, including specialty alloys and superalloys.

Table 2.4 shows the percentage of raw steel production by each type of furnace from 1974 to 1983. The basic oxygen furnace is the most widely used steelmaking process, accounting for 61.5 percent of all raw steel produced in the U.S. in 1983. Open hearth furnaces accounted for 7.0 percent of the production in the same year. Both of these furnaces can produce carbon and alloy steels, but the BOF can also be used to produce stainless steels. Electric arc furnaces, which produced 31.5 percent of the domestic raw steel in 1983, are used to produce carbon steels, stainless steels, and many types of alloy steels that cannot be produced in the OH furnace.

In the past several decades the percentage of annual U.S. raw steel production by furnace type has continually been shifting in favor of electric arc and basic oxygen furnaces. Much of this trend is attributable to changes in production factors such as lower capital costs, increased energy costs, more efficient technologies, and demands for higher quality. The data provided in Table 2.4 illustrates this shift from the less versatile open hearth furnace to the more flexible electric arc furnace; from 1974 to 1983, the percentage of raw steel produced in electric arc furnaces rose from 19.7 percent to 31.5 percent. Many OH furnaces were permanently closed down during recent reductions in production capacity. The increasing efficiency of the electric arc furnace and its ability to use 100 percent scrap as the

charge have made this furnace popular in the industry, especially for applications in non-integrated mills. The open hearth furnace is on the way out; industry experts believe that by the early 1990's it will no longer be in use.

TABLE 2.4 RAW STEEL PRODUCTION BY
FURNACE TYPE (PERCENTAGE)

<u>Year</u>	<u>Furnace Type</u>		
	<u>BOF</u>	<u>OH</u>	<u>EF</u>
1983	61.5	7.0	31.5
1982	60.7	8.2	31.1
1981	60.6	11.2	28.3
1980	60.4	11.7	27.9
1979	61.1	14.0	24.9
1978	60.9	15.6	23.5
1977	61.8	16.0	22.2
1976	62.5	18.3	19.2
1975	61.6	19.0	19.4
1974	56.0	24.3	19.7

Source: 1983 Annual Statistical Report, AISI.

Table 2.5 presents a production and energy consumption profile of the steelmaking step. The specific energy consumption of this process rose over the period 1979 to 1983 despite the fact that many older furnaces were closed down. There has been an upward trend for specific energy consumption over this five-year period. This trend has primarily been caused by the increased use (on a percentage basis) of electric arc furnaces, which are more energy intensive than both basic oxygen and open hearth furnaces.

TABLE 2.5 PRODUCTION AND ENERGY CONSUMPTION
PROFILE OF THE STEELMAKING STEP

Year	Production(a) (10 ³ Net Tons)	Total Energy Consumed in Production (b) (10 ¹² Btu)	Average Specific Energy Consumption (10 ⁶ Btu/Net Ton)
1983	84,615	236.5	2.79
1982	74,577	213.9	2.86
1981	120,828	328.5	2.71
1980	111,835	307.6	2.75
1979	136,341	363.3	2.66

(a) 1983 Annual Statistical Report, AISI.

(b) Energetics, Inc. estimated data (a conversion factor of 10,500 Btu/kWh_e is used in the calculations).

The average specific energy consumption levels for each of the three steelmaking furnaces was calculated by Argonne National Laboratory in their 1982 report entitled, "Energy and Materials Flows in the Iron and Steel Industry." These levels were: 1) open hearth furnace - 3.29×10^6 Btu/net ton of steel; 2) basic oxygen furnace - $.52 \times 10^6$ Btu/net ton of steel; and 3) electric arc furnace - 6.20×10^6 Btu/net ton of steel (assuming a conversion factor of 10,500 Btu/kWh to account for the efficiency in generating electricity).

Numerous developments have been reported in the literature that could result in reduced energy consumption and increased efficiency for both the electric arc and basic oxygen furnaces. Some of these new technologies are already in use by the industry. Data obtained from experts in several steel companies revealed that 1983 specific energy consumption levels for these companies averaged from 36 percent lower to 3 percent higher than the ANL

average. Similarly, BOF average energy requirements varied from 74 percent lower to the same value as reported for 1982.

2.2.5 STEELCASTING

Molten steel from the three types of steelmaking furnaces is either poured into a mold and cast as an ingot or it is continuously cast into semi-finished forms.

Ingot Casting

Ingot casting is the most widely used casting method in the U.S., accounting for two-thirds of all raw steel produced. Liquid steel from the steelmaking furnace is poured into a refractory-lined receiving vessel called a ladle, which is then positioned by an overhead crane above a pouring platform containing a series of molds. The steel is teemed into the molds and allowed to solidify to form ingots.

After the molds are stripped away, the ingots are heated to uniform temperatures in soaking pits to prepare them for rolling. The soaking pits are deep, refractory-lined chambers that hold up to sixteen ingots each. The fuels used to heat the pits are natural gas, blast furnace gas, and coke oven gas. The heated ingots are removed from the pits and rolled into one of three semi-finished forms -- slabs, blooms, or billets. Slabs and blooms result from hot rolling of ingots on the primary breakdown mill, and billets are produced from further hot rolling of blooms.

Continuous Casting

In the continuous casting process, molten steel is directly cast to semi-finished shapes (i.e., slabs, blooms, or billets), eliminating the need for the soaking pits and the primary breakdown mill. The ladle of molten steel is positioned over the casting machine, which can have up to eight strands or pathways (for billets). The metal is fed into water-cooled copper molds at the top of the casting machine, where solidification occurs at the

surface. The strand is further solidified throughout the cross-section as it proceeds downward through the machine and is completely solidified when it leaves the machine. At this time, the strand is cut with oxy-gas torches into the semi-finished forms.

The development of the continuous casting process is considered by many to be the most important achievement in modern steelmaking practices. The impact of continuous casting is quite extensive on those mills that adopt this technology. This process not only replaces three costly capital investment items (stripper, soaking pit, primary rolling mill) with one, but eliminates almost one full day of operations and increases yield by at least 10 percent. In addition, product quality is as high or higher than that achieved with conventional ingot casting.

Table 2.6 shows the percentage of raw steel cast by each of these two processes for the years 1975-1983.

TABLE 2.6 U.S. RAW STEEL PRODUCTION
BY CAST (PERCENTAGE)

<u>Year</u>	<u>Casting Process</u>	
	<u>Ingot</u>	<u>Continuous</u>
1983	67.9	32.1
1982	71.0	29.0
1981	78.3	21.7
1980	79.7	20.3
1979	83.1	16.9
1978	84.8	15.2
1977	87.4	12.6
1976	89.4	10.6
1975	90.9	9.1

Source: 1983 Annual Statistical
Report, AISI.

The U.S. steel industry has been steadily incorporating continuous casting technology. As shown in Table 2.6, this technology's share of the overall production more than tripled between 1975 and 1983. A number of continuous casters are currently under construction in the industry and even more are planned for operation by the year 2000. Several industry experts believe that the total share of continuous casting will be close to 90 percent of the total production by the end of the century.

The average specific energy consumption levels for ingot and continuous casting reported by Arthur D. Little in their 1978 report are as follows:

Ingot casting: 2.65×10^6 Btu/net ton of product

Continuous casting: 1.01×10^6 Btu/net ton of product

However, the data obtained from several steel producers (representing both integrated and non-integrated mills) were significantly lower than these values. The average specific energy consumption for continuous casting provided by the producers were approximately 90 percent lower than the ADL value, while the average energy requirements for ingot casting ranged from 2 to 55 percent lower than the corresponding ADL value.

2.2.6 STEELFORMING

In the steelforming process (also referred to as secondary processes), the semi-finished shapes produced in the steelcasting process or by primary rolling of ingots are reheated and rolled or forged into final products. The two main types of furnaces used in the reheating operation are the pusher type and the walking-beam type.

Pusher-type furnaces are used for almost all billet reheating applications and for about 90 percent of slab/bloom reheating applications. In this type of furnace, a mechanical pusher moves the semi-finished form through a series of narrow combustion zones that are fired by sets of burners. Slabs and blooms are heated to temperatures in the 2200-2400°F range, and billets are heated to temperatures in the 2100-2300°F range, depending on the carbon

content. Walking-beam furnaces, which are used in about 10 percent of slab and bloom reheating applications, use movable beams or "skids" instead of pushers to move the load through the furnace.

Depending on the desired product, the reheated forms are either hot rolled only or hot rolled and then cold rolled. Direct rolling, a relatively new practice in which the use of reheat furnaces is eliminated, can be used in those situations where a primary and secondary mill jointly constitute one production unit (e.g., some heavy section mills). If ingot casting is used, the hot semi-finished forms are taken directly from the primary breakdown mill to the hot rolling mill, where strip is produced in a continuous secondary finishing train. If continuous casting is used, the strands are heated, if necessary, to rolling temperature and transferred directly to the rolling operation.

Another aspect of the steelforming process is the heat treatment of cold-rolled steel for recrystallizing the deformation incurred by cold rolling, which improves the metal's ductility. The most common form of heat treatment is annealing, in which the steel product is heated to temperatures between 1200 and 1600°F. In box annealing, stacks of steel coils are placed on stands and covered by alloy steel covers. Inert gases within the sealed covers are kept circulating by fans in the stands. A large refractory-lined cover, either radiant-tube-fired or direct-fired, is placed over the set of stands. In a radiant-tube-fired furnace, heat transfer from the tubes to the alloy covers is in the form of radiation. In a direct-fired furnace, flame burners in the cover wall convect heat to the surrounding refractory, which then radiates heat to the alloy covers.

Fuels used in the slab/bloom/billet reheating furnaces are natural gas, coke oven gas, blast furnace gas, and residual fuel oil (in restricted applications). Annealing furnaces use natural gas, coke oven gas, and distillate fuel oil.

Because of the variety of process equipment and finished products associated with steelforming, average energy consumption data only exist for the

overall process rather than the individual process elements. Table 2.7 presents a recent production and energy consumption profile of the heating and annealing furnaces used in the steelforming process. Between 1979 and 1983, the energy required per net ton of product decreased from 4.20×10^6 Btu to 3.35×10^6 Btu. The 1983 figure also represents a 25 percent decrease from the 1976 average of 4.46×10^6 Btu/net ton that was reported by Arthur D. Little in 1978.

TABLE 2.7 PRODUCTION AND ENERGY CONSUMPTION PROFILE
OF HEATING AND ANNEALING FURNACES

<u>Year</u>	<u>Production(a)</u> <u>(10³ Net Tons)</u>	<u>Total Energy</u> <u>Consumed in</u> <u>Production (b)</u> <u>(10¹² Btu)</u>	<u>Average</u> <u>Specific Energy</u> <u>Consumption</u> <u>(10⁶ Btu/Net Ton)</u>
1983	84,615	283.4	3.35
1982	74,577	298.4	4.00
1981	120,828	462.5	3.83
1980	111,835	450.6	4.03
1979	136,341	572.6	4.20

(a) 1983 Annual Statistical Report, AISI.

(b) Energetics, Inc. estimated data (a conversion factor of 10,500 Btu/kWh_e is used in the calculations).

The industry experts who were contacted concurred that much of the energy savings gained in the past several years is attributable to the industry's efforts to improve heating operations. Furnaces have been "buttoned up" to prevent heat losses, and digital combustion controls and computer-assisted controls have been installed to increase efficiency. The growing use of hot charging has also had an impact on present operations; this practice is expected to be used widely by the industry in the future.

2.3 ENERGY CONSUMPTION IN 1983

Detailed information on the U.S. steel industry's total energy consumption in the year 1983 is necessary to establish a reference energy consumption level from which future energy savings can be estimated. The following have been developed using the historical data already discussed:

- o Estimated net¹ energy consumption for each major process step;
- o Material and energy flows for the major process steps; and
- o Energy requirements by fuel type for each step.

Table 2.8 shows the range of specific energy consumption reported for each of the various processes involved in iron and steelmaking. On the basis of interviews conducted with a representative sampling of plants in the industry, the best estimate of current practice is established. These estimates of process specific energy consumption are also shown in Table 2.8.

Table 2.9 shows detailed calculations of energy and materials use by major process in 1983. These data were used to develop Figure 2.4, an energy and materials flow diagram for the major steelmaking process steps. This figure shows the energy and materials (1983 levels) that are input for each step. It does not include data on the consumption of fluxes and refractories, electrodes for electric arc furnaces, or on the energy associated with the production of the imported raw materials used by the industry (e.g., imported ferroalloys). The gross energy inputs provided in Figure 2.4 are:

- o Purchased energy (such as coal, oil, natural gas, and electricity); and

¹Accounts for the fuels produced in the process and used in other processes or sold to the outside.

TABLE 2.8

1983 ENERGY CONSUMPTION BY MAJOR PROCESS IN
U.S. IRON AND STEEL INDUSTRY
(10⁶ Btu/Net Ton of Products)

<u>Process</u>	<u>Reported Range (1983 Consumption)</u>	<u>Current Practices Or Base Case Consumption</u>
AGGLOMERATION		
- Pelletizing	0.24 - 0.62	0.41(c)
- Sintering	1.50 - 1.60	1.50(c)
COKE MAKING		
	5.38 - 5.68	5.99(c)
IRON MAKING		
		13.86(c)
- Blast Furnace	10.46 - 21.48	13.86
- Direct Reduction	--	--
STEEL MAKING		
		2.79(c)
- Open Hearth	--	3.29(a)
- Basic Oxygen	0.13 - 0.52	0.52(a)
- Electric Arc	3.96 - 6.38	6.20(a)
STEEL CASTING		
- Ingot Casting	1.19 - 2.60	2.65
- Continuous Casting	0.05 - 0.10	1.01(b)
- Ladle Drying	0.80	0.80
STEEL FORMING		
- Reheating Furnace	1.31 - 2.40	1.85(d)
- Heavy Plate Mill	2.98 - 3.37	3.17(d)
- Hot Strip Mill	2.50	2.50(d)
- Billet Reduction Mill	2.55 - 3.60	3.10(d)
- Bloom Reduction Mill	3.10 - 5.70	4.40(d)
- Cold Rolling Mill	--	3.73(e)

(a) "Energy and Materials Flows in the Iron and Steel Industry," ANL April 1982.

(b) "Research, Development, and Demonstration for Energy Conservation: Preliminary Identification of Opportunities in Iron and Steelmaking, ADL, 1978.

(c) U.S. average calculated or reported (see Section 2).

(d) Average of the reported practices.

(e) "Technology Development of Thin Strip Casting," prepared by Westinghouse Electric Corporation for the U.S. Department of Energy, January 1984.

TABLE 2.9
ENERGY AND MATERIALS USE BY
MAJOR PROCESS - 1983

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit as Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Total Energy Use (10¹² Btu)</u>
<u>COKE PRODUCTION</u>			
Coal(a)	30,549 x 10 ³ tons	26.194 x 10 ⁶ (b)	800.20
Fuel Oil(c)	16,212 x 10 ³ gallons	150,000(b)	2.43
Natural Gas(c)	14,700 x 10 ⁶ ft ³	1,000(c)	14.70
Electricity(d)	749 x 10 ⁶ kWh	10,500	7.86
Steam(e)	22,710 x 10 ³ tons	1.15 x 10 ⁶ (f)	26.12
Blast Furnace Gas(c)	602,573 x 10 ⁶ ft ³	95(c)	<u>57.24</u>
Subtotal			908.55
Less:			
Heating Value of Coke(e) Produced	22,710 x 10 ³ tons	25.99 x 10 ⁶ (b)	-590.23
Coke Oven Gas(g)	188,413 x 10 ⁶ ft ³	500(c)	-94.21
Tar and Pitch(h)	24.13 x 10 ⁷ gallons	150,000(b)	-36.20
Light Oil(h)	78.05 x 10 ⁶ gallons	130,000(b)	-10.15
Coke Breeze(h)	2.09 x 10 ⁶ tons	20 x 10 ⁶ (b)	<u>-41.80</u>
Subtotal			-772.59
Net Total			<u>135.96</u>

TABLE 2.9
ENERGY AND MATERIALS USE BY
MAJOR PROCESS - 1983
(CONTINUED)

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit As Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Total Energy Use (10¹² Btu)</u>
<u>BLAST FURNACE & STOVES</u>			
Coke ⁽ⁱ⁾	26,415 x 10 ³ tons	25.99 x 10 ⁶ ^(b)	686.53
Fuel Oil (Including Tar and Pitch) ^(c)	131 x 10 ⁶ gallons	150,000 ^(b)	19.65
Natural Gas ^(c)	19,061 x 10 ⁶ ft ³	1,000 ^(c)	19.06
Electricity ^(j)	1,217 x 10 ⁶ kWh	10,500	12.78
Coke Oven Gas ^(c)	8,463 x 10 ⁶ ft ³	500 ^(c)	4.23
Oxygen ^(k)	16,223 x 10 ⁶ ft ³	183 ^(b)	2.97
Steam ^(l)	58,447 x 10 ⁶ lbs	1,000 ^(m)	<u>58.45</u>
Subtotal			803.67
Less:			
Blast Gas Furnace Used ^(c) Elsewhere in Mills	1,349.55 x 10 ⁹ ft ³	95 ^(c)	-128.21
Net Total			<u>675.46</u>
<u>STEEL FURNACES</u>			
Fuel Oil (Including Tar and Pitch) ^(c)	76 x 10 ⁶ gallons	150,000 ^(b)	11.40
Oxygen ^(k)	117,856 x 10 ⁶ ft ³	183 ^(b)	21.57
Natural Gas ^(c)	19,310 x 10 ⁶ ft ³	1,000 ^(c)	19.31
Coke Oven Gas ^(c)	28 x 10 ⁶ ft ³	500 ^(c)	.01
Electricity ⁽ⁿ⁾	175.35 x 10 ⁸ kWh	10,500	184.12
Blast Furnace Gas ^(c)	1,386 x 10 ⁶ ft ³	95 ^(c)	<u>0.93</u>
Net Total			<u>236.54</u>

TABLE 2.9
ENERGY AND MATERIALS USE BY
MAJOR PROCESS - 1983
(CONTINUED)

<u>Process, Materials Consumes</u>	<u>Total Amount (Unit As Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Total Energy Use (10¹² Btu)</u>
<u>HEATING/ANNEALING FURNACES</u>			
Fuel Oil ^(c)	84,436 x 10 ³ gallons	150,000 ^(b)	12.67
Natural Gas ^(c)	216,262 x 10 ⁶ ft ³	1,000 ^(c)	216.26
Liquid Petroleum Gas ^(c)	588 x 10 ³ gallons	95,000	.06
Coke Oven Gas ^(c)	103,950 x 10 ⁶ ft ³	500 ^(c)	51.98
Blast Furnace Gas ^(c)	25,139 x 10 ⁶ ft ³	95 ^(c)	<u>2.39</u>
Total			<u>283.36</u>
<u>OTHER PROCESSES AND UNALLOCATED ELECTRICITY</u>			
Light Oil ^(o)	26.01 x 10 ⁶ gallons	130,000 ^(b)	3.38
Fuel Oil (Including Tar and Pitch) ^(c)	143,606 x 10 ³ gallons	150,000 ^(b)	21.54
Liquid Petroleum Gas ^(c)	1,624 x 10 ³ gallons	95,000	.15
Natural Gas ^(c)	109,718 x 10 ⁶ ft ³	1,000 ^(c)	109.72
Coke Oven Gas ^(c)	75,972 x 10 ⁶ ft ³	500 ^(c)	37.99
Blast Furnace Gas ^(c)	720,452 x 10 ⁶ ft ³	95 ^(c)	68.44
Electricity ^(p)	22,893 x 10 ⁶ kWh	10,500	240.38
Steaming Coal ^(a)	2,280 x 10 ³ tons	26.194 x 10 ⁶ (b)	59.72
Coke Breeze ^(q)	885 x 10 ³ tons	20 x 10 ⁶ (b)	17.70
Oxygen ^(r)	23,661 x 10 ⁶ ft ³	183 ^(b)	4.33
Ferroalloys (Produced) ^(s)	785 x 10 ³ tons	56 x 10 ⁶ (b)	<u>43.96</u>
Subtotal			607.31
Less: Steam Used Elsewhere			-84.55
Net Total			<u>522.76</u>

TABLE 2.9

ENERGY AND MATERIALS USE BY
MAJOR PROCESS - 1983
(CONTINUED)

KEY

- a AISI, 1983 Annual Statistical Report, Table 36.
- b Table 3.5 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, 1982.
- c AISI, 1983 Annual Statistical Report, Table 48.
- d Calculated by multiplying 33 kWh/net ton of coke produced as stated in Table 6.6 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, 1982 to the total net ton of coke produced for the year (AISI, 1983 Annual Statistical Report, Table 38.)
- e AISI, 1983 Annual Statistical Report, Table 38.
- f Table 6.6 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, 1982 and Table 38 of "AISI 1983 Annual Statistical Report."
- g Calculated by subtracting coke oven gas used in coke ovens from the total production, Table 48, AISI, "1983 Annual Statistical Report."
- h Calculated by multiplying yields for each chemical product/ton of coal from "Coke and Coal Chemicals in 1980," DOE/EIA 0120/80, Table 2 and the total amount of coal used to produce coke for the year from AISI, "1983 Annual Statistical Report," Table 36.
- i AISI, 1983 Annual Statistical Report, Table 38.
- j Calculated by multiplying electricity intensity 25 kWh/net ton of metal to the total tonnage of metal produced for the year. The figure 25 kWh/net ton is taken from Table 7.1 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, April 1982.
- k AISI, 1983 Annual Statistical Report, Table 47.
- l Calculated by multiplying steam requirement of 1,200 lb/net ton from Table 7.1 of "Energy and Materials Flow in the Iron and Steel Industry," ANL, April 1982 to the total net tons of iron produced for the year (AISI, "1983 Annual Statistical Report," Table 30).
- m Table 7.1 of "Energy and Materials Flow in the Iron and Steel Industry," ANL, April 1982.

- n Represents the sum of all electric energy consumed by all types of steelmaking furnaces and is calculated by multiplying electricity intensities of 15, 30, and 596 kWh for open hearth, BOF, and electric arc, respectively, to the total tonnage for each product for the year. Data are taken from Table 10.2, 10.3, and 10.4 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, April 1982.
- o Estimated as 1/3 of the total light oil produced for the year in coke production. Estimated figure (1/3) comes from Table 3.5 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, 1982.
- p Unallocated electricity remaining from the total electric power purchased. Data for the purchased electricity is shown in AISI, 1983 Annual Statistical Report, Table 46.
- q AISI, 1983 Annual Statistical Report, Table 42.
- r Unallocated oxygen remaining from AISI Annual Statistical Report, Table 47.
- s AISI, 1983 Annual Statistical Report, Table 33.

FIGURE 2.4 ENERGY AND MATERIALS FLOWS IN STEELMAKING IN 1983

- o Recovered energy (such as by-product fuel gas, steam, and electricity).

Data on the sales of byproduct energy to outside markets are also presented.

Table 2.10 shows consumption of various fuels in the different processes. For example, of the total amount of coal used (859.92×10^{12} Btu), 93.1% was consumed in the coke oven while 6.9% was used in processes other than the major ones indicated.

Figure 2.5 compares the estimated net energy consumption in 1983 for ten major steelmaking process steps (including the three types of steelmaking furnaces and both casting processes) versus the corresponding 1976 estimated process energy consumption provided by ADL in their January 1978 report. This figure confirms the impacts of the developments that have occurred in steelmaking between 1976 and 1983. Results of this comparison and other observations include:

- o Blast furnaces are still the largest energy-consuming unit;
- o The significant reduction in total energy consumption shown for pelletizing is the direct result of the reduced market and increased import of pellets;
- o The total share of the open hearth furnace in steelmaking has decreased by a large percentage; and
- o The total energy consumption level for electric arc furnaces as compared to the combined consumption of the other two steelmaking furnaces illustrates the increased use of the electric arc furnace during the period.

TABLE 2.10 FUEL UTILIZATION (%) BY PROCESS FOR 1983

Fuel	Process					
	Total Use (10 ¹² Btu)	Coke Oven	Blast Furnace	Steel- making Furnace	Heating/ Annealing Furnaces	Other(a)
Coal	859.9	93.1				6.9
Fuel Oil	64.6	3.8	28.7	14.8	19.6	33.1
Nat. Gas	379.1	3.9	5.0	5.1	57.1	28.9
Electricity	445.1	1.7	2.9	41.4		54.0
Coke	686.5		100.0			
Steam	84.5	30.9	69.1			
LPG	0.2				25.0	75.0
Tar/Pitch	3.1		34.6	57.7		7.7
Coke Breeze	17.7					100.0
Coke Oven Gas	94.2		4.5	<0.1	55.2	40.3
Blast Furnace Gas	128.2	44.7		0.1	1.8	53.4
Light Oil	3.4					100.0
Process Total 10 ¹² Btu(b)	2766.5	908.5	800.7	215.0	283.3	559.0

(a) Sintering, casting, secondary finishing, balance of plant.

(b) Not including oxygen and ferroalloys.

FIGURE 2.5: COMPARISON OF ESTIMATED ENERGY CONSUMPTION BY MAJOR PROCESSES

2.4 RECENTLY ADOPTED CONSERVATION MEASURES

As a part of the recent modernization efforts by the steel industry, many companies have invested in more efficient technologies in order to reduce overall production costs through better energy efficiency, as well as better labor efficiency and product quality. Table 2.11 is a partial listing of recently adopted measures that have had major effects on energy consumption. The plant where each measure was adopted is also presented in this table.

Many U.S. steel companies have rebuilt, replaced, or upgraded cokemaking facilities in recent years. Modern coke ovens can increase productivity, conserve energy, and meet environmental standards for pollution control. Efforts have focused on coal and coke handling, coal chemical equipment, and the use of process control computers for control of coke quenching, pushing scheduling, conveyor operation, and monitoring of gas flows, temperatures, and pressures.

Conservation measures in ironmaking have centered on blast furnace modernization, such as the use of prepared burdens, higher blast temperatures and pressures, injected fuels, top gas turbine generators, and increased automation. Coal injection systems, including oil-coal slurry injection systems, have been implemented to replace oil in some plants.

The new Inland Steel blast furnace shown in Table 2.11 was part of a \$1 billion expansion program that also included energy efficiency improvements in the steelmaking operations.⁴ This furnace represents the state-of-the-art in blast furnace technology, including energy conservation and environmental control measures.

The installation of continuous casters in the early 1980's has led to increased energy efficiency and higher yields for many companies. The con-

⁴"Developments in the Iron and Steel Industry: U.S. and Canada - 1980," Iron and Steel Engineer, February 1981.

TABLE 2.11 EXAMPLES OF RECENTLY IMPLEMENTED CONSERVATION TECHNOLOGIES WITH MAJOR IMPACTS ON ENERGY CONSUMPTION

<u>Process Area</u>	<u>Technology</u>	<u>Year Implemented</u>	<u>Company/Plant</u>
Cokemaking	New coke oven battery and by-products desulfurization	1982	Republic Steel Corp. Chicago, IL
	Rehabilitation and replacement of several coke oven batteries	1980-1983	Several companies
Ironmaking	45-ft. hearth blast furnace with raw materials storage	1980	Inland Steel Company E. Chicago, IN
	Blast furnace rebuilt with Paul Wurth top	1981	Republic Steel Corp. Warren, OH
	Oil-coal slurry injection system	1982	Interlake, Inc. Chicago, IL
Steelmaking	Hot metal desulfurization station	1980	National Steel Corp. Granite City, IL
	Two 100-ton electric arc furnaces, lime injection system	1981	Cyclops Corp. Mansfield, OH
	Iron desulfurization furnace	1983	Republic Steel Corp. Warren, OH
Steelcasting	Addition of one strand to existing 2-strand continuous casting machine	1980	Cascade Steel Rolling Mills, Inc. McMinnville, OR
	Continuous slab casting strand	1982	Carpenter Tech. Corp., Reading, PA
	Improvements to slab casting machine	1982	U.S. Steel Corp. Gary, IN
	Rounds casting machine	1983	U.S. Steel Corp. Lorain, OH

tinuous casting process also reduces the emissions associated with ingot teeming and heating. New billet casters, slab casters, and round casters (for seamless tube and bar production) have been built and existing casters modified and improved. Caster modifications have included variable width modes, argon or electromagnetic stirring, throttling slide gates for constant level and speed control, and secondary cooling systems.

A more complete listing of modernization efforts that have been adopted by the steel industry between 1980 and 1984 is presented in Appendix C. Each measure is rated "high" ($> 10^{12}$ Btu) or "low" ($\leq 10^{12}$ Btu) according to its impact on energy consumption.

SECTION 3. STATE-OF-THE-ART AND ADVANCED IRON AND STEELMAKING TECHNOLOGIES

This section presents information on the most promising advanced steel-making technologies that are either under development or have recently completed development. This information is based on recent industry literature and on personal discussions with industry experts. The goal of each new technology or modification described in this section is to increase efficiency or productivity in the steel production process.

The results are presented in two parts. The first part (Section 3.1) discusses the state of the art in steelmaking, including the best available technologies. The second part (Section 3.2) discusses advanced technologies and presents a conceptualized steelmaking process that includes some of the more advanced ideas for each process step.

3.1 STATE-OF-THE-ART TECHNOLOGIES

State-of-the-art steelmaking technologies are those technologies that have demonstrated their technical feasibility in actual steelmaking environments, such as a commercial or pilot plant. Figure 3.1 is a simplified process flow diagram of steelmaking that incorporates various state-of-the-art process alternatives. The alternative technologies are either current technologies with numerous associated modification measures that increase process efficiency or totally new technologies. Water cooling of the shells and tops of electric arc furnaces and waste heat recovery in the BOF are both examples of modifications to existing technologies. Injection steelmaking, on the other hand, is considered to be a totally new steelmaking technology.

Table 3.1 summarizes some of the more significant conservation measures that have recently been adopted by the industry. These measures were chosen independently of their place of origin and current usage. Some were chosen

FIGURE 3.1 STATE-OF-THE-ART STEELMAKING

TABLE 3.1 HIGHLIGHTS OF STATE-OF-THE-ART TECHNOLOGIES

<u>Technology</u>	<u>Potential Impact</u>	<u>Reported Commercial Status</u>
<u>AGGLOMERATION</u>		
Pelletizing (Cold Bonding)		
- MTU (Michigan Technological University)	moderate	not commercialized
- COBO (Cold Bonding)	moderate	commercialized in Sweden
- Peridur	significant	not commercialized
Sintering		
- preheating combustion air in the sinter cooler	moderate	commercialized in the U.S.
- raw materials pre-heating	moderate	commercialized outside of the U.S.
- steam or power generation using sinter cooler exhaust	moderate	commercialized outside of the U.S.
<u>COKEMAKING</u>		
Dry Quenching	significant	commercialized outside of the U.S.
Coke Oven Gas Sensible Heat Recovery	significant	commercialized in the U.S.
<u>IRONMAKING</u>		
Blast Furnace Modifications		
- top gas pressure recovery	significant	commercialized outside of the U.S.
- hot stove waste heat recovery	moderate	commercialized outside of the U.S.
- Paul Wurth top	not reported	commercialized in the U.S.
External Desulfurization	significant	commercialized in the U.S.

TABLE 3.1 HIGHLIGHTS OF STATE-OF-THE-ART TECHNOLOGIES (Cont'd.)

<u>Technology</u>	<u>Potential Impact</u>	<u>Reported Commercial Status</u>
<u>STEELMAKING</u>		
Basic Oxygen Furnace Modifications		
- BOF gas recovery in combination with sensible heat recovery	moderate	commercialized in the U.S.
- combined top and bottom oxygen blowing	moderate	commercialized outside of the U.S.
- in-process control of temperature and carbon content	significant	Unknown
Electric Arc Furnace Modifications		
- ultra high power transformers	moderate	commercialized in the U.S.
- bottom tap vessels	moderate	commercialized outside of the U.S.
- water-cooled furnace panels and top	moderate	commercialized in the U.S.
Scrap Preheating	significant	commercialized outside of the U.S.
Ladle Drying and Pre-heating	significant	commercialized in the U.S.
Injection Steelmaking (Ladle Metallurgy)	significant	commercialized in the U.S.
Secondary Refining	significant	commercialized in the U.S.
- electroslag remelting	significant	commercialized in the U.S.
- vacuum arc remelting	significant	commercialized in the U.S.
<u>STEELCASTING</u>		
Modern Casters	significant	commercialized in the U.S.
Slab Heat Recovery	significant	commercialized in the U.S.
Soaking Pit Utilization and Pit Vacant Time	moderate	commercialized outside of the U.S.

TABLE 3.1 HIGHLIGHTS OF STATE-OF-THE-ART TECHNOLOGIES (Cont'd.)

<u>Technology</u>	<u>Potential Impact</u>	<u>Reported Commercial Status</u>
<u>STEELFORMING</u>		
Hot Charging	moderate	commercialized in the U.S.
Preheating Furnaces		
- improved insulation	moderate	commercialized in the U.S.
- waste heat recovery and fuel gas re-heating	significant	commercialized in the U.S.
Direct Rolling	significant	commercialized outside of the U.S.
Pickling		
- steam savings	moderate	commercialized outside of the U.S.
Annealing (Batch)		
- air preheating	moderate	commercialized in the U.S.
Continuous Annealing	significant	commercialized in the U.S.
Continuous Cold Rolling	significant	commercialized in the U.S.

KEY:

significant: energy savings impact on the total operation $> .2 \times 10^6$ Btu/net ton

moderate: energy savings impact on the total operation $< .2 \times 10^6$ Btu/net ton

because of their expected impact within the near future. Table 3.1 shows the potential impact of each measure on the energy consumption of its respective process and its current utilization by the steel industry.

A more comprehensive list of state-of-the-art steelmaking technologies is presented in Appendix D. These technologies include recent measures that have been developed for reducing energy consumption in the steelmaking processes. The list contains all breakthroughs reported as being in use by the steel industry, regardless of their economic viability in a specific application (e.g., dry quenching of coke in present U.S. coking plants). The information for each technology listed in Appendix D includes a brief description, impact on process energy consumption, and references in which the technology is described in more detail.

Several of the state-of-the-art measures shown in Table 3.1 have a high potential for significantly affecting energy consumption in the industry. These measures are described in more detail in the following paragraphs.

AGGLOMERATION

Peridur

Peridur is the trade name for a derivative of cellulose, a natural polymer. For the past several years, ENKA Industrial Colloids of Holland has been investigating the uses of this binder in the pelletizing process. Because it is an organic material, Peridur is eliminated for the most part during thermal treatment, which results in less chemical contamination in the blast furnace. This is a significant advantage over the presently used binder, bentonite, which contaminates the ore with silica and alumina and therefore decreases pellet iron content. For each one percent of bentonite added to the pellet concentrate, there is a two to three percent decrease in the iron

per ton of pellets charged to the blast furnace. Other advantages associated with the use of Peridur include:

- o higher pellet quality;
- o lower consumption requirements;
- o 10 to 30 percent improvement in reducibility;
- o increased drying rates;
- o lower pellet deformation during loading; and
- o Other improved metallurgical and mechanical properties for both green and fired pellets.

Peridur has already been used by ten pellet-producing plants in the U.S., South America, Europe, and Canada. It has also been tested for use in producing high-grade direct reduction pellets. Although Peridur pellets have been used successfully in several plants, further development is necessary for this process to become commercially acceptable.

COKEMAKING

Coke Dry Quenching

A new cokemaking process has recently been developed that eliminates the disadvantages associated with conventional coke wet quenching, in which sensible heat is lost to the atmosphere as steam. The dry quenching of coke has commercially been operated in Japan and the Soviet Union in the past several years. In this process, coke is quenched with an inert gas inside of a sealed chamber. When the coke is ready to leave the oven, a closed coke guide is attached between the oven and the chamber. The chamber cover is then closed and the coke remains inside until it is cooled by heat exchange surfaces that form the walls of the chamber. The thermal energy of the coke is recovered either directly as steam or indirectly as electric power.

The advantages of dry quenching over wet quenching are not limited to energy savings. Other coke quality and performance improvements, which are

attributable to slower and more uniform cooling than in wet quenching, include:

- o a reduction in environmental emissions;
- o a reduction in the level of coke breeze carried over to the blast furnace;
- o a reduction in moisture and volatile matter content;
- o an improvement in blast furnace coke rate and a corresponding increase in blast furnace productivity;
- o an increase in coke strength and greater uniformity of grain size blast; and
- o a lower reactivity than for wet quenched coke.

Reported disadvantages of the process include a slight decrease in coke yield and considerable added capital cost.

The dry quenching process is currently in use by a few plants outside of the U.S. but not in the U.S.

STEELMAKING

BOF Gas Recovery

The combination of BOF gas recovery and sensible heat recovery is a new energy conservation development in iron and steelmaking. The combination consists of a boiler and a suppressed combustion gas recovery system. Because of the relatively small gas volumes and low temperatures involved, the boiler section is smaller and cheaper than in a full boiler system and maintenance problems are reduced. Several variations of this type of system have been reported in the literature. One such variation employs a freon circuit that absorbs heat from the water in the hood cooling system. Another uses water cooling of the hood and skirt. The potential energy savings associated with this technology is estimated to be about 800,000 Btu/net ton of steel.

Scrap Preheating

Scrap preheating using the off-gas recycling route has proven to be a successful technique in preheating all types of scrap for electric arc furnaces without encountering the environmental problems associated with secondary gas emissions. Two preheaters, one for a 55 ton furnace and one for a 110 ton furnace, have been developed and used successfully in Japan.

In addition to the recovery of sensible heat from the off-gas, there are several advantages associated with the use of the scrap preheating system. These include:

- o a 15 percent reduction in meltdown energy use (100 kWh_e/net ton);
- o a 0.4 to 1.2 lb/net ton reduction in electrode consumption; and
- o an 8 minute time reduction in steelmaking.

Secondary Refining

Secondary refining, also known as injection steelmaking, refers to a number of newly developed methods in which refining and alloying are carried out in the ladles or processing chambers. Deoxidation and desulfurization are achieved by injection of solid materials such as calcium compounds into the molten steel. A carrier gas, usually argon or nitrogen, serves as a transportation and stirring medium. The use of ladle refining methods has reduced the role of electric arc and basic oxygen furnaces to merely that of melting and partial refining vessels.

The Japanese were the first to adopt ladle refining. Ladle refining systems are currently used in the U.S. to produce nearly all super alloys and high grade steels. Some of the more popular systems are shown in Table 3.2.

Ladle refining methods have a number of advantages over conventional methods, including:

- o increased quality;
- o increased yield;
- o shortened refining cycles (from hours to minutes); and
- o ability to use cheaper alloys in the charge.

TABLE 3.2 SECONDARY REFINING SYSTEMS

<u>Systems for Standard Steel Products</u>	<u>Systems for Alloy Products</u>
Vacuum arc decarburization	Electroslag remelting (ESR)
Argon stirring	Argon-oxygen decarburization (AOD)
Injection systems for desulfurization	Vacuum induction melting (VIM)
	Electron beam melting (EBM)
	Vacuum arc remelting (VAR)

STEELFORMING

Direct Rolling

The direct rolling process could prove to be the single largest energy-saving measure in steelmaking practices. Direct rolling eliminates the need for reheat furnaces, which are the biggest users of fluid fuels in any plant. An average slab reheat furnace, for example, consumes close to 3×10^6 Btu/net ton of steel produced. The present use of hot slab practices is a step towards the incorporation of direct rolling into the industry.

The following technologies have been developed for purposes of conserving energy and expediting the use of direct rolling:

Leveling furnace - Developed by the Japanese as a short, high intensity furnace ahead of the scalebreaker. This scheme allows

the operation of the main slab heating furnace at a temperature which is 100 to 200°F lower. This device would expand the use of direct rolling.

- o The coil box - Stelco has devised and built a coiler in the bar table between roughing and finishing stands. This eliminates skid marks and zoom rolling and permits lower slab furnace temperatures, as well as providing quality and energy advantages.
- o Covered delay table - An insulating cover over the delay table is being considered as an alternative to the coil box at Armco's Butler and Middletown works. This development should lower radiant heat losses and initial (slab furnace) temperatures.

3.2 ADVANCED TECHNOLOGIES

Some of the major costs associated with steelmaking operations are fuel and power, raw materials, and environmental control. These costs have risen dramatically over the past decade and no end is in sight. The advanced technologies discussed in this subsection have the potential to significantly lower these costs through reductions in energy and materials consumption and emissions.

Table 3.3 highlights some of the advanced steelmaking technologies shown in Appendix E. These measures are recognized by the industry experts as those with the highest potential for having major impacts on future steel-making operations. The table presents the state of development of each measure and its predicted impacts on such production parameters as:

- o process and overall efficiency;
- o yield;
- o environmental control;
- o process control; and
- o capital cost.

TABLE 3.3 HIGHLIGHTS OF ADVANCED TECHNOLOGIES

<u>Technology</u>	<u>Potential Production Impact</u>	<u>State of Development</u>
<u>COKEMAKING</u>		
Programmed Heating	1, 2, 3, 4	Under development; est. commercialization date within 3 years.
<u>IRONMAKING</u>		
Plasmared	1, 3, 5	Demonstration plant; est. commercialization date late 1980s.
KR Process (Korf Reduction Process)	1, 3, 4, 5	Pilot plant; est. commercialization date within 3 years.
Plasmasmelt	1, 5	Pilot plant; est. commercialization date late 1980s.
Inred	1, 4, 5	Commercial plant under construction; est. commercialization date within 2 years.
Elred	1, 4, 5	Pilot plant; est. commercialization date within 2 years.
<u>DIRECT STEELMAKING</u>		
Expanded Precessive Plasma (EPP)	Unknown	Pilot plant; est. commercialization date mid-1990s.
<u>STEELMAKING</u>		
Energy Optimization Furnace (EOF)	1, 3, 5	Demonstration plant in Brazil; est. commercialization date late 1980s.
Modern BOF (injection of carbonaceous fuels)	1, 5	Est. commercialization date early 1990s.
<u>STEELCASTING</u>		
Horizontal Continuous Casting	4, 5	Pilot plant; est. commercialization date late 1980s or early 1990s.
Direct Strip Casting	1, 2, 3, 5	Pilot plant in Japan; est. commercialization date in 3 to 6 years.
<u>KEY:</u> 1 - Increases process or total operation efficiency 2 - Increases yield 3 - Reduces environmental problems 4 - Enhances process control 5 - Reduces capital cost		

A more complete listing of the advanced technologies that are currently under development around the world is presented in Appendix E. This appendix provides a short description of each technology and information on its state of development, estimated date of commercialization, and references.

Several advanced steelmaking technologies have been incorporated into a conceptualized advanced steelmaking process flow diagram, Figure 3.2. This diagram depicts several technological alternatives that will be available to the industry by the year 2000 for each of the major process steps. The industry experts have agreed that these technologies will be in use to a certain extent at that time. However, the experts believe that the blast furnace will remain the dominant method of ironmaking in the near future because of its high efficiency.

The opinion of the industry experts is that the more advanced technologies, such as plasma arc and horizontal casting, are most likely to be utilized in small plants that produce high-quality alloy steels. The use of advanced technologies here would lead to the elimination of all transfer operations, a major source of contamination, by directly linking the various steelmaking processes. Furthermore, the experts believe that these technologies could be incorporated into an existing plant producing 80 to 100 thousand tons per year without necessitating new plant construction.

Detailed descriptions of some of the technologies identified in Table 3.3 are provided in the following pages.

IRONMAKING

Plasmared

Plasmared is a process that is being developed to produce high-quality direct reduced iron at low levels of energy consumption and low costs. This technology is based on the merger of one well established process and one

FIGURE 3.2 FUTURE STEELMAKING

advanced technology, the Wiberg-Soderfors process and plasma technology, respectively.

The Wiberg-Soderfors process has the lowest energy consumption of all reduction processes developed to date, achieving levels as low as 7.91×10^6 Btu/net ton of pellets (sponge iron) at 10,500 Btu/kWhe.¹ However, this process has a number of disadvantages such as limited possibilities for scaling-up the coke-charged, electrically heated gas reformer (carburator), unused carbon left in the waste coke, and problems with the hot fans. In developing the plasmared process, all of these disadvantages have been eliminated and the gasification of almost any carbon-or hydrogen-containing fuel has been made possible. The main difference between the two processes is that in the plasmared process, heat is supplied by a plasma arc heater instead of a resistance heater.

Since the late 1970's SKF Steel Engineering of Sweden has been involved in the development of the plasmared technology. During this period, a demonstration plant with a capacity of about 70,000 net tons a year has been built. Data obtained from the operation of this process has shown that metallization of up to 93 percent is possible.

KR Process

The Korf Reduction (KR) process, a new ironmaking technology based on the use of a wide variety of coals, is not dependent on metallurgical coal for coke production. In the KR process, the blast furnace is in effect split into two parts. In the first part, metallization of iron-bearing materials occurs in a shaft furnace in which these materials flow counter current to a stream of reducing gas enriched with carbon monoxide (CO). Pellets are typically more than 95 percent metallized in the shaft. In the second part of the process, reduced pellets are continuously fed, along with coal, oxygen

¹Calculated from data provided by "Plasmared - A New Technology for the Manufacture of Sponge Iron," Sven Santen, SKF Steel Engineering AB, May 13, 1980.

and flux materials, to a melter gasifier where the final reduction and melting occurs. The process produces liquid iron having pig iron qualities and fuel gas for export. In comparison to the blast furnace, the KR process substitutes coal for coke and oxygen for hot blast air. The energy requirement is estimated at 11.56×10^6 Btu/net ton of molten iron.²

The advantages of the KR process are:

- o production of hot metal using a wide variety of mine coals;
- o low investment cost;
- o economic production of hot metal even at a low rate of 100,000 tons/year;
- o generation of fuel gas or reducing gas as a by-product;
- o low infrastructural requirements;
- o high availability;
- o ease of operation and control; and
- o ecological benefits.

The KR process has not been commercialized to date. However, the developer of the process, Korf Engineering GmbH of West Germany, is currently marketing plants with 300,000 tons per year capacity (40 tons/hr) based on its experience with a pilot plant. In November of 1984, the process was successfully tested using raw materials shipped from the U.S.

Plasmasmelt

The plasmasmelt direct reduction process is being developed by SKF Steel Engineering of Sweden. The process is a modified blast furnace that uses plasma torches at each tuyere to raise the sensible heat input. The process is designed to take advantage of rapid reactions of fine ore concentrates, without agglomeration, to produce hot metal.

²Calculated from data; provided by KR-Process Test on Domestic Raw Materials Final Report, March, 1985, U.S. Department of Energy.

In the plasmasmelt process, prereduced iron ore is reduced to molten iron in a low-shaft reactor similar in some respects to a low-shaft blast furnace. The prereduced ore is injected along with coal and flux into the hearth of the reactor, where plasma torches supply energy. The shaft is filled with coke that is admitted into the top of the shaft through a charging mechanism. The principal reductant in the shaft is the coal, although a small amount of coke is consumed. The hot gases from the shaft pass through a two-stage fluid bed that produces the prereduced iron ore. The gas from the shaft (about 2000°F) is cleaned and cooled to about 1200°F before being admitted to the two-stage fluid bed. The exit gas from the fluid-bed reducers is available for drying and preheating the ore. The hot metal and slag are tapped intermittently as in the blast furnace. The liquid iron produced in the smelting operation is the equivalent of blast-furnace iron and, therefore, can be refined to liquid steel in conventional BOF operation.

A plasmasmelt process pilot plant has been built in Sweden. The reported energy requirement for a net ton of liquid steel for the process is estimated at 17.08×10^6 Btu.³

Inred

The inred process, another ironmaking process, has been under development by Boliden AB of Sweden since 1972. The process derives its name from intensive reduction, which describes the reaction that forms the basis of the process. Inred consists of a two-stage reaction that takes place in a single reactor. In the first stage, flash smelting of the concentrate by coal and oxygen is accomplished. The ore is prereduced to FeO and the charge is superheated. Coke is also formed at this time. In the second stage, the pre-reduced and heated material is collected with the coke from the first stage in the lower part of the reactor. Here, the remaining part of the energy is supplied by electricity. Submerged electrodes are used in the final stage.

³United States Steel Corporation, "Compilation of Reports on Direct Reduction Technology and Economics," June 1981.

The energy requirement for the production of a net ton of steel is estimated at 15.81 Btu.⁴

Some of the major characteristics of the inred process are:

- o ability to use fine grained iron oxides, such as ore concentrates, without agglomeration;
- o ability to use low-cost noncoking coal;
- o low production costs even for small scale units;
- o low investment costs; and
- o environmentally acceptable operation.

A pilot plant with a capacity of about 5.5 net ton/hr was built and operated in Sweden in 1978. Currently, a demonstration plant is also under construction in Sweden. This plant will have a capacity of about 600,000 net tons per year and is expected to be completed in the mid 1980's. The estimated commercialization date for the inred technology is in the early 1990's.

Elred

The elred process, developed by ASEA AB of Sweden, is a two-step smelting - reduction process that uses both coal and electricity. This process includes three major operations - prereduction, reduction and smelting, and combined-cycle generating. In the elred process, fine-grained iron ore concentrates and pulverized coal are prereduced to about 65 percent metallization in a fast fluidized bed. This is followed by final reduction and smelting of the prereduced concentrate in the plasma beneath the electrode in a direct-current (DC) arc furnace operating with an open bath. The liquid metal requires external desulfurization in preparation for charging to the BOF. The use of elred hot metal in the BOF permits only about half the scrap consumption that would be the case with the use of blast-furnace hot metal.

⁴United States Steel Corporation, "Compilation of Reports on Direct Reduction Technology and Economics," June 1981.

There are questions remaining on the operation and control of the pre-reduction unit and on the scale-up of the process. The energy requirement for elred is reported at 16.29 Btu/net ton of steel.⁽⁵⁾

DIRECT STEELMAKING

Foster Wheeler Tetronics Expanded Precessive Plasma Process

The Foster Wheeler Tetronics Expanded Precessive Plasma (EPP) Process produces hot metal using coal, metal oxide concentrates, and lime. In this process, a direct-current plasma gun is rotated to form a cone of very high temperature in which endothermic reactions can take place. The system operates in the transferred-arc mode with the plasma gun acting as the cathode and the furnace hearth acting as the anode return. The operation of the gun requires a small amount of plasma gas, typically argon. The injected feed materials are entrained in the plasma cone, where they are directly exposed to the electrical forces that exist within the plasma and are rapidly heated. The energy requirement is projected at 34.01 Btu/net ton of steel.⁵

Tests performed at a pilot plant built by Foster Wheeler in England produced a low-carbon, low-sulfur liquid steel in one step using bituminous coal as the reductant. The high sulfur content of the metal, however, necessitated the inclusion of a desulfurization step in the EPP process. Currently, there remains a number of unresolved problems regarding the operation and economics of this process. Experts estimate that its commercialization date will be around the mid 1990's.

⁵United States Steel Corporation "Compilation of Reports on Direct Reduction Technology And Economics," June 1981.

STEELMAKING

Energy Optimizing Furnace (EOF)

The Energy Optimizing Furnace (EOF) has applications in integrated mills, mini mills, micro mills, and mills based on the use of DRI, cupola furnaces, and KR furnaces. The EOF process can be used to produce up to 22 heats/day of a wide variety of steels. Current furnace capacities range from 200,000 to 600,000 tons/year. An EOF has been operating for several years by a Korf-affiliated mill in Brazil.

The energy optimizing furnace can use scrap, hot metal, scrap and hot metal, or DRI and requires no outside power for melting because the charge is preheated using hot EOF flue gas. This gas is also used to preheat combustion air up to 570°F. Refractory consumption is reduced by water cooling in the shell and roof of the furnace.

The advantages of the EOF process over the electric arc furnace include the following:

- o lower capital cost;
- o eliminates electric energy as a heating source.
- o shorter tap-to-tap time;
- o fewer environmental problems; and
- o less auxiliary equipment.
- o no penalty in building small furnaces (stable cost/size ratio).

STEELCASTING

Horizontal Continuous Casting

Although the horizontal continuous casting process was first developed around 1930, problems in developing suitable mold materials and methods of oscillating the mold have only recently been solved. The development of

copper molds and boron nitride break rings has eliminated many of the materials-related problems, while several different solutions have been found for the oscillation issue. There are currently several horizontal continuous casting systems that are capable of producing billets and blooms in low-alloy, high-alloy, and stainless steels of the same quality as conventional continuous casting machines.

The advantages associated with the use of horizontal continuous casting include:

- o lower capital cost;
- o smaller space requirements;
- o no requirements for new building construction;
- o less labor; and
- o higher heat transfer in the mold.

Direct Strip Casting

In the past twenty years, significant levels of effort went into the development of two separate casting processes - continuous casting and roller casting. Experts believe that a combination of these two technologies can now be further developed to directly produce strip products. Recent studies have recommended two basic direct strip casting technologies, the double-roller process and the single-roller process. Major technical challenges to be addressed in the development of these processes include: good surface finishing, dimensional control, uniform thickness control, and uniform width control.

The potential for savings in energy, capital, and labor costs are significant. A comparison of the energy consumption of the various methods for strip product shows that the direct strip casting route uses less than half of the energy required by the ingot and continuous casting routes (see Table

4.14). Another factor of significance is the amount of energy that is lost as a result of material losses during processing. The difference in the energy required "per ton reduced" and "per ton shipped" is estimated to be 2.2×10^6 Btu/ton in the ingot process, a 36 percent loss in energy usage.

As reported by Dr. Desai of General Electric Company in a testimony for the Energy Development and Application Subcommittee, Committee on Science and Technology, U.S. House of Representatives, several Japanese steel companies and one equipment manufacturer have been actively working on the development of direct strip casting for the last several years. A number of direct casting processes have been studied and several pilot plants are in place. Dr. Desai has also reported that commercialization of this technology in Japan will occur within the next 3 to 6 years.

SECTION 4. POTENTIAL ENERGY SAVINGS IN THE STEEL INDUSTRY

This section provides assessments of the potential energy savings associated with future U.S. iron and steelmaking processes. Savings are estimated for the following two cases:

- 1) Current (1983) industry practice as compared to state-of-the-art technology; and
- 2) Current (1983) industry practice as compared to advanced technology conceptualized for the year 2000.

The state-of-the-art and advanced technologies considered in these two analyses are those that were identified in Section 3.

The results presented in this section include:

- o Potential energy savings per net ton of product for each process step alternative technology;
- o Potential energy savings per net ton of steel by process step;
- o Overall potential energy savings per net ton of steel; and
- o Overall industry potential energy savings per year.

4.1 POTENTIAL ENERGY SAVINGS ASSOCIATED WITH STATE-OF-THE-ART TECHNOLOGIES

The assessment of the energy savings associated with state-of-the-art conservation measures has been divided into two parts. In the first part, energy savings per net ton of product are estimated for each process step or process step alternative technology. In the second part, these data are used

to calculate the potential energy savings associated with the production of a ton of steel for several steelmaking scenarios.

4.1.1 Potential Energy Savings by Major Process

The impact of state-of-the-art technologies on energy consumption in the steel industry is summarized in Table 4.1. This table presents the following types of energy consumption data for each process step technology:

- o The estimated current (1983) U.S. steel industry average; and
- o The value associated with the incorporation of the state-of-the-art technologies as reported by International Iron and Steel Institute (IISI).

Table 4.1 lists the major steelmaking process steps together with the estimated average energy consumption for the industry in 1983 as determined in Section 2, and energy requirements for each process step technology assuming incorporation of the various state-of-the-art conservation measures. State-of-the-art energy consumption estimates were obtained from the 1982 IISI report, "Energy and the Steel Industry," which analyzed a hypothetical one-million-ton-capacity plant using state-of-the-art technologies. The energy consumption data associated with these measures were derived from actual operating data.

Table 4.1 also shows the potential energy savings which represents the difference between estimated consumption for state-of-the-art technologies and current practices. These data are used as the basis for a comparison of the potential energy savings associated with the individual process levels.

4.1.2 Potential Energy Savings in Primary Processes

The potential energy savings associated with the production of a net ton of steel using state-of-the-art technology is defined as the difference

TABLE 4.1

POTENTIAL ENERGY SAVINGS BY MAJOR PROCESS LEVELS IN PRESENT U.S. STEEL PRACTICES AS COMPARED TO STATE-OF-THE-ART PRACTICES
(10⁶ Btu/Net Ton of Products)

Process	Current (1983) Practice Or Base Case Consumption	State-of- the-art(a) Consumption	Potential Savings
AGGLOMERATION			
- Pelletizing	0.41(d)	.24	0.17
- Sintering	1.50(d)	1.23	0.27
COKEMAKING	5.99(e)	3.03	2.95
IRONMAKING	13.86(e)		
- Blast Furnace	13.86	10.18	3.68
- Direct Reduction	--		--
STEELMAKING	2.79(e)		
- Open Hearth	3.29(b)	--	--
- Basic Oxygen	0.52(b)	(0.13)(f)	0.65
- Electric Arc	6.20(b)	4.98	1.40
STEELCASTING			
- Ingot Casting	2.65	0.73	1.92
- Continuous Casting	1.01(c)	0.23	0.78
- Ladle Drying	0.80	0.06	0.74
STEELFORMING			
- Reheating Furnace	1.85(e)	0.61	1.24
- Heavy Plate Mill	3.17(e)	2.35	0.82
- Hot Strip Mill	2.50(e)	1.45	1.05
- Billet Reduction Mill	3.10(e)	2.12	0.98
- Bloom Reduction Mill	4.40(e)	1.91	2.49
- Cold Rolling Mill	3.73(g)	2.32(a)	1.31

(a) "Energy and the Steel Industry," IISI, 1982.

(b) "Energy and Materials Flows in the Iron and Steel Industry," ANL, April 1982.

(c) "Research, Development, and Demonstration for Energy Conservation: Preliminary Identification of Opportunities in Iron and Steelmaking," ADL, 1978.

(d) U.S. average calculated or reported (see Section 2).

(e) Average of the reported practices (see Table 2.8).

(f) Energy recovered exceeds energy consumed.

(g) "Technology Development of Thin Strip Casting," prepared by Westinghouse Electric Corporation for the U.S. Department of Energy, January 1984.

between the energy requirements for state-of-the-art and current practices. To estimate these savings, it is essential to assume that the ratios of input materials such as pellets, sinter, coke, and iron used in the production of a net ton of raw steel are identical for current and state-of-the-art practices.

Tables 4.2 and 4.3 present 1983 industry averages for consumption ratios of the various major inputs to the steelmaking process. Table 4.2 shows data on the total consumption and consumption ratios (i.e., per net ton of iron) of sinter, pellets, and coke. Table 4.3 presents 1983 average data on the production levels of the three types of steelmaking furnaces and their consumption of scrap and pig iron per net ton of product.

TABLE 4.2 ANALYSIS OF IRONMAKING IN 1983 BY MAJOR PROCESS
(Based on the Production of 48,706 x 10³ Net Tons of Iron)

Process Level	Consumption (a) (10 ³ Net Tons)	Specific Consumption In Iron Production (Ton/Net Ton Iron)
Sinter	18,327(b)	0.38
Pellets	54,297(b)	1.11
Coke	26,415(c)	0.54

(a) 1983 Annual Statistical Report, AISI.

(b) Includes imports and/or inventory

(c) Includes imports and production by merchant plants.

Estimates of the energy requirements for each of the major process steps involved in the production of a net ton of pig iron are shown in Table 4.4. The potential savings shown for each step represents the difference between

TABLE 4.3

ANALYSIS OF 1983 STEELMAKING BY FURNACE TYPE

FURNACE TYPE	Production (10 ³ Net Tons)	Percent of (a) the Total Production	SCRAP		PIG IRON	
			Use(c) (10 ³ Net Tons)	Consumption Per Net Ton of Production (Tons)	Use(c) (10 ³ Net Tons)	Consumption Per Net Ton of Production (Tons)
BOF	52,038 ^(b)	61.5	16,219	0.31	44,330	0.85
OH	5,923 ^(b)	7.0	3,275	0.55	3,918	0.66
73 ELECTRIC ARC	26,654 ^(b)	31.5	25,786	0.97	52	0.002
TOTAL	84,615 ^(a)	100.0	45,280		48,300	

(a) 1983 Annual Statistical Report, AISI, actual reported data.

(b) 1983 Annual Statistical Report, AISI, estimated from percentages given.

(c) Bureau of Mines, reported by AISI.

the 1983 energy consumption and the projected state-of-the-art energy consumption for that step. The total potential savings associated with state-of-the-art ironmaking practices as compared to 1983 practices is 5.56×10^6 Btu/net ton of iron. Table 4.4 also shows the total energy requirement for the entire ironmaking process for both 1983 and the state of the art.

Table 4.5 shows estimated energy savings associated with upgrading each of the three major steelmaking furnaces from 1983 practices to state-of-the-art practices. The potential ironmaking energy savings, based on the 5.56×10^6 Btu/net ton of iron calculated in Table 4.4, are also shown for each of the three steelmaking routes. The total potential savings shown in Table 4.5 for each route is the sum of the potential ironmaking and steelmaking energy savings associated with that route.

Table 4.5 shows that the potential savings associated with the basic oxygen furnace route are larger than those for the open hearth furnace even though the BOF has smaller energy requirements in current practices. The larger BOF potential is due to two main factors:

- 1) The BOF uses a smaller ratio of scrap to pig iron than the OH; and
- 2) Little or no research is directed toward advancing the state of the art for the OH.

4.1.3 Potential Energy Savings in Secondary Processes

The potential energy savings associated with upgrading current steelcasting and steelforming operations to state-of-the-art were shown in Table 4.1. A detailed analysis of energy consumption and potential savings as a function of major steel product type and secondary mill type is presented in Section 4.3.

TABLE 4.4 POTENTIAL ENERGY SAVINGS ASSOCIATED WITH UPGRADING 1983 IRONMAKING PRACTICES TO STATE OF THE ART

Process	Energy Consumption (10 ⁶ Btu/Net Ton Product)		Materials Consumption In Ironmaking (Net Ton/Net Ton Iron)	Ironmaking Energy Consumption (10 ⁶ Btu/Net Ton Iron)		Potential Savings (10 ⁶ Btu/Net Ton Iron)
	1983	State-of-the-Art		1983	State-of-the-Art	
Sintering	1.50	1.23	0.38	0.57	0.47	0.10
Pelletizing	0.41	0.24	1.11	0.46	0.27	0.19
Cokemaking	5.99	3.03	0.54	3.23	1.64	1.59
Ironmaking	13.86	10.18	--	13.86	10.18	3.68
TOTAL				18.12	12.56	5.56

TABLE 4.5 POTENTIAL ENERGY SAVINGS ASSOCIATED WITH UPGRADING 1983 IRON AND STEELMAKING TO STATE OF THE ART

Steelmaking Furnace	Steelmaking Energy Consumption (10 ⁶ Btu/Net Ton Steel)		Ironmaking Energy Consumption (10 ⁶ Btu/Net Ton Steel)		Total Energy Consumption (10 ⁶ Btu/Net Ton Steel)		Total Potential Savings (10 ⁶ Btu/Net Ton Steel)
	1983	State-of-the-Art	1983	State-of-the-Art	1983	State-of-the-Art	
BOF (0.85 Ton Iron/Ton Steel)	0.52	(0.13)	15.40	10.68	15.92	10.55	5.37
Open Hearth (0.66 Ton Iron/Ton Steel)	3.29	3.29	11.96	8.29	15.25	11.58	3.67
Electric Arc (100% scrap use)	6.20	4.98	---	---	6.20	4.98	1.22

4.2 POTENTIAL ENERGY SAVINGS ASSOCIATED WITH ADVANCED TECHNOLOGIES

This section presents the results of an assessment of the potential energy savings associated with the advanced technologies described in Section 3.2. In performing this assessment, the six major process steps were divided into two groups - primary processes and secondary processes. The former group contains the first four major process steps (i.e., those used in the production of raw steel). The secondary processes group consists of steelcasting and steelforming.

4.2.1 Potential Energy Savings in Primary Processes

There are many benefits (e.g., reduced energy requirement, higher productivity, and others) associated with the implementation of advanced technologies that are not related to process energy consumption. In fact, when comparing advanced practices to state-of-the-art cokemaking/iron-making/steelmaking (BOF) practices, the results would show increased energy consumption for the advanced practices. It is therefore expected that advanced technologies will complement rather than replace the blast furnace, which is an extremely efficient process.

The plasmasmelt, inred, and elred processes are all based on the use of plasma arc furnaces. Each of these processes is capable of handling fine materials to produce iron and raw steel, which results in accelerated reaction rates, reduced reactor volume and residence time, lower capital investment, and enhanced ability to use mill waste. Despite the electric energy intensiveness of these technologies, many of the study's industry participants believe that they could be used in small-scale operations where very high quality steels are produced. Mill waste could be recycled to convert hazardous gangue components into a manageable form. Table 4.6 shows the energy consumption levels for several steelmaking routes that use the advanced technologies.

The three primary process advanced technologies most likely to have a significant impact on energy consumption in future steelmaking practices and

TABLE 4.6

**ENERGY CONSUMPTION IN VARIOUS STEELMAKING PROCESS
ROUTES IN 10⁶ BTU/NET TON OF STEEL**

Process Route	Current Technology	Advanced Technologies (10500 Btu/kWh)	Theoretical (3412 Btu/kWh)
Coke Oven/ BF/BOF	15.92		6.14(e)
Upgraded Coke Oven/BF/BOF	10.55		
Plasmasmelt/ BOF		17.08(f)	
Elred (a),(b)/ BOF		16.29(f)	
Inred(c)/BOF		15.81 (f)	
Foster Wheeler Tetronics Plasma Arc Furnace(d)		34.01(f)	
Plasmared(d)/Electric Arc		16.76(g)	
KR Process/BOF		10.97	

-
- (a) Higher charge of hot metal (.96 ton iron/net ton of steel) is required in BOF as a result of lower carbon content of the KR molten iron (i.e., less than 4 percent per net ton of iron).
- (b) Net electric producer.
- (c) Generates electricity necessary in the operation.
- (d) Direct steelmaking process.
- (e) "A Preliminary Overview of Innovative Industrial Materials Processes," Battelle, September 1983.
- (f) "Compilation of Reports on Direct Reduction Technology and Economics", United States Steel Corporation Research Laboratory for U.S. DOE, June 1981.
- (g) "Plasmared - A New Technology for the Manufacture of Sponge Iron," SKF Steel Engineering AB.

therefore considered in this analysis are the KR process, injection of carbonaceous fuels, and the energy optimization furnace (EOF).

KR Process

The KR process can utilize a wide variety of coals rather than being restricted to metallurgical coal. The KR process is believed to be applicable to integrated mills as well as mini mills. According to the technical literature, an electric arc furnace could use the product of the KR process with the addition of at least 50 percent scrap. In an integrated mill, this process can be used to compensate for fluctuations in production levels or to provide incremental ironmaking capability in cases where an additional blast furnace cannot be justified. The KR process can also be used to generate gas without producing hot metal in order to satisfy gas requirements.

The inputs required to produce one net ton of hot metal with the KR process are 1.5 tons of pellets, 0.42 tons of coal, and 9.54 kWh of electricity. This translates into an energy requirement of 11.56×10^6 Btu/net ton of hot metal, assuming the coal and electricity conversion factors from Table 2.9 and a pelletizing energy consumption of 0.41×10^6 Btu/net ton of pellets.

Injection of Carbonaceous Fuels

In conventional BOF steelmaking practices, the proportion of hot metal contained in the charge seldom falls below 70 percent because of limits imposed by the chemical and sensible heat content of the hot metal. The addition of solid carbonaceous fuels to the steel bath can increase the amount of scrap contained in the charge to 30 or 40 percent if adequate levels of post combustion are achieved.

The calculation of the energy consumption of the BOF steelmaking route with carbon injection is based on the assumption of a consumption fraction of 0.6 net ton of iron per net ton of steel instead of the 0.85 used in Table 4.5. Using the projected state-of-the-art ironmaking energy requirement of 12.56×10^6 Btu/net ton of iron and a projected BOF energy requirement of 1.30×10^6 Btu/net ton of steel,¹ the total energy requirement of the state-of-the-art BOF steelmaking route with carbon injection is calculated to be 8.84×10^6 Btu/net/ton of steel.

Energy Optimization Furnace

Using data supplied by the equipment producer, the estimated energy requirement for the production of a net ton of steel using a 100 percent scrap charge in an energy optimization furnace is 3.07×10^6 Btu. This yields a potential energy savings of 3.13×10^6 and 1.91×10^6 Btu/net ton of steel when compared with current and state-of-the-art electric arc furnace technologies, respectively.

4.2.2 Potential Energy Savings in Secondary Processes

The single secondary process advanced technology that is expected to have substantial energy savings potential is direct strip casting.

Direct Strip Casting

Direct strip casting will eliminate several energy-intensive steps from the overall steelmaking process. As discussed in Section 3, direct strip casting showed significant energy savings when compared to ingot and continuous casting - 68 and 61 percent savings, respectively. Another important factor is the amount of energy that is saved in direct strip casting because of the elimination of scrap generation.

¹"Energy and the Steel Industry," IISI, 1982.

In his Congressional testimony, Dr. Jay D. Desai estimated the benefits of direct strip casting as follows: energy savings - \$20 to \$60 per net ton of steel; capital cost savings - 40 to 70 percent of the capital cost for ingot and continuous casting equipment and subsequent rolling equipment; manufacturing cost savings - 40 to 50 percent of the cost for ingot casting and subsequent rolling.¹ In a 1984 study conducted by Westinghouse Electric Corporation for DOE, the potential energy savings of the direct strip casting process are estimated to be 5.9×10^6 Btu/net ton of finished product when compared with the continuous casting process.²

4.3 TOTAL POTENTIAL ENERGY SAVINGS IN THE YEAR 2000

4.3.1 Potential Energy Savings in Primary Processes

The specific energy consumption data associated with state-of-the-art and advanced steelmaking technologies are shown in Table 4.7. The total potential energy savings for the U.S. steel industry in the year 2000 can be made on the basis of various combinations of steel production routes leading to a total production of 100 million net tons per year. The four hypothetical production scenarios investigated are:

Scenario 1) -- 100 percent production by state-of-the-art technology alone.

Scenario 2) -- Production by a mix of state of-the-art and advanced technologies as projected by the industry experts contacted for this study.

¹"Direct Steel Sheet/Strip Casting", Testimony Prepared for Energy Development Application Committee on Science and Technology, U.S. House of Representatives, by Jay Desai of General Electric, February 29, 1984.

²"Technology Development of Thin Strip Metal Casting - Feasibility Study," U.S. Department of Energy, January 1984.

TABLE 4.7

**ENERGY CONSUMPTION DATA FOR STEELMAKING ROUTES
USED IN THE ANALYSIS OF POTENTIAL SAVINGS**

<u>Steel Production Route</u>	<u>Specific Energy Consumption (10⁶ Btu/Net Ton Steel)</u>
<u>Current Technology</u>	
- Coke Oven/Blast Furnace/ Basic Oxygen Furnace	15.92
- Electric Arc Furnace	6.20
<u>State-of-the-Art Technology</u>	
- Upgraded Coke Oven/Blast Furnace/Basic Oxygen Furnace	10.55
- Upgraded Electric Arc Furnace	4.98
<u>Advanced Technology</u>	
- KR/BOF	10.97(a), (b)
- Upgraded Coke Oven/Blast Furnace/BOF with Carbon Injection	8.84
- KR/BOF with Carbon Injection	8.60(c)
- Energy Optimization Furnace	3.07

(a) Assumes BOF energy requirement of (0.13×10^6) Btu/net ton of steel.

(b) Higher charge of hot metal (.96 ton iron/net ton of steel) is required in BOF as a result of lower carbon content of the KR molten iron (i.e., less than 4 percent per ton of iron).

(c) Includes additional 0.47×10^6 Btu/net ton of steel in the form of carbon to make up for the lower carbon content of the KR molten iron.

Scenario 3) -- Production technology mix of 90 percent state-of-the-art technology and 10 percent advanced technology.

Scenario 4) -- Production technology mix of 50 percent state-of-the-art technology and 50 percent advanced technology.

In performing the assessment, a number of assumptions have been made:

- o All operations in integrated plants using state-of-the-art BOFs are based on the use of 0.85 net ton of molten iron per net ton of steel produced; BOFs with injection of carbonaceous fuels use 0.60 net ton of molten iron per net ton of steel;
- o Process step efficiency is 100 percent and there is negligible or no waste generation;
- o The energy optimization furnace (EOF) has the potential for replacing the electric arc furnace;
- o Of the 100 million net tons of steel produced, integrated plants account for 60 million net tons and non-integrated plants for 40 million net tons;
- o The use of the KR process represents 10 percent of the total production attributed to integrated plants using advanced technology; and
- o Projected energy savings are based on present (1983) consumption profiles.

Table 4.8 presents the hypothetical case of 1983 energy consumption assuming a production level of 100 million net tons of steel. The

calculations in this table are based on the current technology specific energy consumption data from Table 4.7. The total energy consumption determined for this case, 1203.20×10^{12} Btu, will be compared to the projected energy consumption for the four hypothetical scenarios in order to assess the total potential energy savings in the year 2000.

TABLE 4.8 PROJECTED ENERGY CONSUMPTION LEVELS IN THE YEAR 2000
BASED ON 1983 CONSUMPTION LEVELS

Steel Production Route	Production (10^6 Net Tons)	Total Energy Consumption (10^{12} Btu)
<u>Integrated Plants</u>		
Coke Oven/Blast Furnace/ Basic Oxygen Furnace	60	955.20
<u>Non-Integrated Plants</u>		
Electric Arc Furnace	40	248.00
TOTAL	100	1203.20

Tables 4.9 through 4.12 show production levels and projected energy consumption levels for the various steelmaking routes considered in Scenarios 1, 2, 3, and 4, respectively. The energy consumption levels for each route represent the product of the specific energy consumption for that route (see Table 4.7) in Btu/ton and the production level in tons.

TABLE 4.9 PROJECTED ENERGY CONSUMPTION FOR A PRODUCTION LEVEL OF 100
MILLION NET TONS OF RAW STEEL IN THE YEAR 2000: SCENARIO 1

Steel Production Route	Production (10 ⁶ Net Tons)	Total Energy Consumption (10 ¹² Btu)
<u>Integrated Plants</u>		
Upgraded Coke Oven/ Blast Furnace/Basic Oxygen Furnace	60	633.00
<u>Non-Integrated Plants</u>		
Upgraded Electric Arc Furnace	40	199.20
TOTAL	100	832.20

TABLE 4.10 PROJECTED ENERGY CONSUMPTION FOR A PRODUCTION LEVEL OF 100
MILLION NET TONS OF RAW STEEL IN THE YEAR 2000: SCENARIO 2

Steel Production Route	Production (10 ⁶ Net Tons)	Total Energy Consumption (10 ¹² Btu)
<u>Integrated Plants</u>		
Upgraded Coke Oven/ Blast Furnace/Basic Oxygen Furnace	57	601.35
KR/BOF	3	32.73
<u>Non-Integrated Plants</u>		
Upgraded Electric Arc Furnace	38	189.24
Energy Optimization Furnace	2	6.14
TOTAL	100	829.46

TABLE 4.11 PROJECTED ENERGY CONSUMPTION FOR A PRODUCTION LEVEL OF 100
MILLION NET TONS OF RAW STEEL IN THE YEAR 2000: SCENARIO 3

Steel Production Route	Production (10 ⁶ Net Tons)	Total Energy Consumption (10 ¹² Btu)
<u>Integrated Plants</u>		
Upgraded Coke Oven/ Blast Furnace/Basic Oxygen Furnace	48.6	512.73
KR/BOF	5.4	58.91
Upgraded Coke Oven/BF/ BOF with carbon injection	5.4	47.74
KR/BOF with carbon injection	0.6	5.16
<u>Non-Integrated Plants</u>		
Upgraded Electric Arc Furnace	36.0	179.28
Energy Optimization Furnace	4.0	12.28
	<hr/>	<hr/>
TOTAL	100.0	816.10

TABLE 4.12 PROJECTED ENERGY CONSUMPTION FOR A PRODUCTION LEVEL OF 100
MILLION NET TONS OF RAW STEEL IN THE YEAR 2000: SCENARIO 4

Steel Production Route	Production (10 ⁶ Net Tons)	Total Energy Consumption (10 ¹² Btu)
<u>Integrated Plants</u>		
Upgraded Coke Oven/ Blast Furnace/Basic Oxygen Furnace	27	284.85
KR/BOF	3	32.73
Upgraded Coke Oven/BF/ BOF with carbon injection	27	238.68
KR/BOF with carbon injection	3	25.80
<u>Non-Integrated Plants</u>		
Upgraded Electric Arc Furnace	20	99.60
Energy Optimization Furnace	20	61.40
TOTAL	100	743.06

The total potential savings resulting from a comparison of each of the four scenarios with the base case (shown in Table 4.8) are summarized in Table 4.13.

TABLE 4.13 TOTAL POTENTIAL SAVINGS ASSOCIATED WITH THE FOUR STEELMAKING SCENARIOS

<u>Production Scenario</u>	<u>Savings When Compared to 1983 Consumption (10^{12} Btu)</u>
1 (100% state-of-the-art)	371.00
2 (production mix as projected by participating experts)	373.74
3 (90% state-of-the-art, 10% advanced)	387.10
4 (50% state-of-the-art, 50% advanced)	460.14

Of the total potential savings for Scenario 1, 87 percent is attributable to integrated plants and 13 percent to non-integrated plants. In addition, 50 percent of the total savings results from upgrades to the blast furnace, 22 percent from upgrades to cokemaking, 13 percent from upgrades to the electric arc furnace, and 10 percent from upgrades to the BOF.

In Scenario 4, almost 81 percent of the total potential savings is associated with integrated plants. Of the overall savings, 46 percent is attributable to the blast furnace, 17 percent to cokemaking, 14 percent to the energy optimization furnace, 8 percent to the KR process, 7 percent to the BOF, and 5 percent to the electric arc furnace. The remaining 3 percent of the total savings comes from the sintering and pelletizing steps.

4.3.2. Potential Energy Savings in Secondary Processes

Energy consumption data for the major steel products defined by AISI -- heavy plates, shapes and rails, wire rods, and sheets and strips -- are shown in Table 4.14. For each product, the corresponding mill or mills are listed; the specific energy consumption data for these mills were shown in Table 4.1. Table 4.14 projects energy requirements per net ton of product for both ingot and continuous casting routes assuming: 1) current practices as of 1983; 2) state-of-the-art practices; 3) advanced practices. As discussed in Section 3.2, direct strip casting is the only advanced technology that has the potential to be commercialized by the year 2000. Figure 4.1 illustrates the data presented in Table 4.14.

The total energy savings that will accrue as a result of adoption of state-of-the-art and advanced technologies can be estimated for various mixes of products finished from feedstock coming out of ingot casting or continuous casting. For both state-of-the-art and advanced technologies, the 1983 finished product mix is assumed. In Table 4.15, the shipment of steel mill products as a percent of 1983 U.S. total production is shown as function of the major product types (i.e., heavy plates, sheets/strips, shapes/rails, and wire rods/bars). This table is based on production data given in AISI's 1983 Annual Statistical Report.

A comparison of current and projected energy use for processing 98.4 million net tons of finished products and 1.6 million net tons of raw steel to be shipped is shown in Table 4.16. The specific energy consumption data from Table 4.14 were used in the calculation of the energy consumption by route for each of the major products. The ingot casting route is retained in all of the scenarios because there are certain products that cannot use the continuous casting route. The industry experts participating in this study agreed on an approximate production level of 10 percent for ingot casting in the year 2000.

TABLE 4.14 SPECIFIC ENERGY CONSUMPTION FOR STEELCASTING/STEELFORMING OF MAJOR STEEL PRODUCTS (10^6 BTU/NET TON OF PRODUCT)

Steel Product	Mills/ Processes	1983 Casting Route		State-of-the-Art Casting Route		Advanced Casting Route
		Ingot	Continuous	Ingot	Continuous	Thin Strip(a)
Heavy Plates	Heavy Plate Mill	5.82	4.18	3.08	2.58	---
Shapes/Rails	Bloom Reduction Mill	7.05	5.41	2.64	2.14	---
Wire Rods/ Bars	Reheating Furnace; Billet Reduction Mill	7.60	5.96	3.46	2.96	---
Sheets/ Strips (Hot Rolled)	Hot Strip Mill ^(b)	5.15	3.51	2.18	1.68	0.73
(Cold Rolled)	Hot Strip Mill ^(b) ; Cold Rolling Mill ^(c)	8.88	7.24	4.50	4.00	3.05

(a) "Technology Development of Thin Strip Casting," prepared by Westinghouse Electric Corporation for the U.S. Department of Energy, January 1984.

(b) Includes reheating furnace.

(c) Includes pickling.

FIGURE 4.1 ENERGY CONSUMPTION REQUIREMENTS IN
SECONDARY PROCESSES: BY ROUTES

TABLE 4.15

SHIPMENT OF STEEL MILL PRODUCTS AS A
PERCENT OF 1983 TOTAL PRODUCTION

<u>PRODUCT</u>	<u>% OF PRODUCTION</u>
<u>Sheets/Strips</u>	
o Cold Rolled	
- tin products	6.4
- cold rolled	20.4
- sheets and strip	<u>13.0</u>
- subtotal	39.8
o Hot Rolled	
- sheets	17.5
- strip	0.9
- pipe and tube (welded)	<u>3.5</u>
- subtotal	21.9
<u>Heavy Plates</u>	5.6
<u>Shapes/Rails</u>	
- structural shapes	5.0
- rails and accessories	<u>1.3</u>
- subtotal	6.3
<u>Wire Rods/Bars</u>	
- wire rods drawn	2.0
- bars	17.3
- wire rods	4.2
- pipes and tubes (seamless)	<u>1.3</u>
- subtotal	24.8
OTHER (Ingots, blooms, slabs, billets)	<u>1.6</u>
TOTAL	100.0

Source: 1983 Annual Statistical Report, AISI.

TABLE 4.16 COMPARISON OF CURRENT AND PROJECTED ENERGY REQUIREMENTS FOR
100 MILLION NET TONS OF RAW STEEL PRODUCTION IN
SECONDARY PROCESSES (a)

PRODUCT	1983 TECHNOLOGY PRODUCTION MIX		SCENARIO 1		SCENARIO 2			SCENARIO 3			SCENARIO 4		
	Ingot	Cont.	Ingot	Cont.	Ingot	Cont.	Direct	Ingot	Cont.	Direct	Ingot	Cont.	Direct
	Cast. (68%)	Cast. (32%)	Cast. (10%)	Cast. (90%)	Cast. (9%)	Cast. (90%)	Strip Cast. (1%)	Cast. (9%)	Cast. (31%)	Cast. (10%)	Cast. (9%)	Cast. (46%)	Strip Cast. (45%)
<u>SHEETS/STRIPS</u>													
<u>Cold Rolled</u> (39.8% of Total Production)													
- Production by Route (Net Tons)	27.06	12.74	3.98	35.82	3.58	35.82	0.40	3.58	32.24	3.98	3.58	18.31	17.91
- Energy Consumption By Route (10 ¹² Btu)	240.29	92.24	17.91	143.28	16.11	143.28	1.22	16.11	123.96	12.14	16.11	73.24	54.63
- Total Process Energy Consumption (10 ¹² Btu)	332.53		161.19		160.61			157.21			143.98		
<u>Hot Rolled</u> (21.9% of Total Production)													
- Production by Route (Net Tons)	14.89	7.01	2.19	19.71	1.97	19.71	0.22	1.97	17.74	2.19	1.97	10.08	9.85
- Energy Consumption By Route (10 ¹² Btu)	76.68	24.61	4.77	33.11	4.29	33.11	0.16	4.29	29.80	1.60	4.29	16.93	7.19
- Total Process Energy Consumption (10 ¹² Btu)	101.29		37.88		37.56			35.69			28.41		

(a) 98.4 million net tons of finished products and 1.6 million net tons of raw steel shipped.

TABLE 4.16 COMPARISON OF CURRENT AND PROJECTED ENERGY REQUIREMENTS FOR
100 MILLION NET TONS OF RAW STEEL PRODUCTION IN
SECONDARY PROCESSES^(a) (Continued)

PRODUCT	1983 TECHNOLOGY PRODUCTION MIX		SCENARIO 1		SCENARIO 2			SCENARIO 3			SCENARIO 4		
	Ingot	Cont.	Ingot	Cont.	Ingot	Cont.	Direct	Ingot	Cont.	Direct	Ingot	Cont.	Direct
	Cast. (68%)	Cast. (32%)	Cast. (10%)	Cast. (90%)	Cast. (9%)	Cast. (90%)	Strip (1%)	Cast. (9%)	Cast. (81%)	Cast. (10%)	Cast. (9%)	Cast. (46%)	Strip (45%)
<u>HEAVY PLATES</u> (5.6% of Total Prod.)													
- Production by Route (Net Tons)	3.80	1.80	0.56	5.04	0.56	5.04	-	0.56	5.04	-	0.56	5.04	-
- Energy Consumption By Route (10 ¹² Btu)	22.12	7.52	1.72	13.00	1.72	13.00	-	1.72	13.00	-	1.72	13.00	-
- Total Process Energy Consumption (10 ¹² Btu)	29.64		14.72		14.72			14.72			14.72		
<u>SHAPES/RAILS</u> (6.3% of Total Prod.)													
- Production by Route (Net Tons)	4.28	2.02	0.63	5.67	0.63	5.67	-	0.63	5.67	-	0.63	5.67	-
- Energy Consumption By Route (10 ¹² Btu)	30.17	10.93	1.66	12.13	1.66	12.13	-	1.66	12.13	-	1.66	12.13	-
- Total Process Energy Consumption (10 ¹² Btu)	41.10		13.79		13.79			13.79			13.79		
<u>WIRE RODS/BARS</u> (24.8% of Total Prod.)													
- Production by Route (Net Tons)	16.86	7.94	2.48	22.32	2.48	22.32	-	2.48	22.32	-	2.48	22.32	-
- Energy Consumption By Route (10 ¹² Btu)	128.14	47.32	8.58	66.07	8.58	66.07	-	8.58	66.07	-	8.58	66.07	-
- Total Process Energy Consumption (10 ¹² Btu)	175.46		74.65		74.65			74.65			74.65		
<u>TOTAL ENERGY CONSUMPTION FOR SECONDARY PROCESSES IN 10¹² BTU</u>													
	680.02		302.23		301.33			296.06			275.55		

(a) 98.4 million net tons of finished products and 1.6 million net tons of raw steel shipped.

A detailed analysis of Scenario 1 reveals the following contributions to the 377.79×10^{12} Btu total potential savings: continuous casting - 45 percent; hot rolling - 18 percent; cold rolling - 12 percent; bloom reheating - 7 percent; billet reduction - 6 percent; ingot casting - 6 percent; bloom reduction - 4 percent; and heavy plate mill - 2 percent. The energy savings attributable to continuous casting come from two sources -- increased use of this process (90 percent of production versus 32 percent in 1983) and state-of-the-art improvements that improve energy efficiency.

The impact of direct strip casting can be seen by examining Scenario 4, in which this route accounts for 45 percent of hot and cold rolled products. Of the total potential savings of 404.47×10^{12} Btu, 31 percent is attributable to the direct strip casting/hot rolling combination, 17 percent to the continuous casting/hot rolling combination, 16 percent to other continuous casting (i.e., plates, shapes/rails, and wire rods/bars), 11 percent to cold rolling, 7 percent to bloom reheating, 6 percent to billet reduction, 4 percent to the ingot casting/hot rolling combination, 4 percent to bloom reduction, 2 percent to other ingot casting, and 2 percent to the heavy plate mill.

4.3.3 Overall Potential Energy Savings

The results of the assessments of energy consumption and potential savings for primary and secondary processes are summarized in Table 4.17. This table shows projected energy requirements for the four future industry operating scenarios and the base case representing current practices at a production level of 100 million net tons (finished and raw steel products). These results do not include operations such as galvanizing, electrolytic tinning, fuel-fired boiler operations, power generation services, crude steel losses, and other miscellaneous services.

TABLE 4.17

SUMMARY OF TOTAL ENERGY REQUIREMENTS FOR
PRODUCTION OF 100 MILLION NET TONS (10^{12} BTU)

Process	Current Practices	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Primary Operations	1,203.2	832.2	829.5	816.1	743.1
Secondary Operations	680.0	302.2	301.3	296.1	275.6
Total	1,883.2	1,134.4	1,130.8	1,112.2	1,018.7

Figure 4.2 illustrates the energy requirements for each of the four industry operating scenarios for the year 2000 and compares them to the 1983 case. Figure 4.3 shows the potential savings associated with these scenarios when compared to the 1983 case. The largest savings, 0.86 quad, is achieved with Scenario 4 (i.e., a mix of 50 percent state-of-the-art and 50 percent advanced technology). The savings realized with Scenarios 1, 2, and 3 are 0.75, 0.75, and 0.77 quad, respectively. The difference between the energy requirements for Scenarios 1 and 4, 0.12 quad, represents the impact of advanced technologies. In each of the four scenarios, the total potential savings is almost evenly split between primary and secondary processes.

FIGURE 4.2: CURRENT ENERGY USE VS. FOUR OPERATING SCENARIOS FOR THE YEAR 2000

FIGURE 4.3: POTENTIAL ENERGY SAVINGS IN THE YEAR 2000

SECTION 5. U.S. STEEL INDUSTRY R&D NEEDS AND OPPORTUNITIES

Steel producers and R&D centers around the world have been performing ongoing research aimed at making the steelmaking process more energy efficient. Recent industry-related publications, such as IISI's, "Energy and the Steel Industry," have reported extensive lists of specific technologies that have recently been developed or are currently under development. However, these technologies are primarily process improvement or waste energy recovery techniques that are already being incorporated into present steelmaking practices. Examples of these technologies are blast main insulation, hot charging, and the use of high-temperature recuperators; many others were mentioned in Sections 2 and 3 of this report.

In this section, the identification of R&D needs and opportunities that is made does not consider currently available, state-of-the-art technologies such as those just described. Instead, needs and opportunities are assessed based on the future steelmaking practices projected in Section 4, keeping in mind the design and equipment of existing U.S. plants and how these factors relate to future decisions.

Steelmaking of the future has been envisioned by the experts as a process that will entail more continuous and higher speed operations with higher purity and more consistent quality and will promote response to demand. Figure 3.2 presented a flow chart of such a system, in which steelmaking is expected to be carried out as a continuous process on a stream that passes through closely coupled operations. Future steelmaking operations will therefore require fewer process steps than current practices. For example, the soaking pit, primary reduction, and the hot strip mill will virtually be eliminated by the thin strip casting process.

The potential impact of advanced steelmaking technologies on energy consumption and production efficiency is very large. Increased production efficiency will result from both the inherently higher efficiency of new process operations and from the elimination of certain process steps found in current practices.

The closely coupled operations of the future steelmaking process will require much closer control and more stringent limits than are needed in current practices. To achieve this, new and more advanced technologies are needed to continuously monitor such parameters as temperature, pressure, and steel composition and states either in real time or more quickly than is currently possible. Therefore, the development of more advanced sensors, measuring devices, and computer controls are essential to the successful implementation of advanced steelmaking technologies. For example, a recently published AISI report listed 18 control and instrumentation research opportunities, requiring various degrees of effort, that were identified by a task group of industry experts.¹

Projections for future steel operations discussed in Section 4 were based on a production level of 60 million net tons via the cokemaking/blast furnace/BOF route and a level of 40 million net tons via scrap and the electric arc furnace. Since the electric arc furnace is highly energy intensive, the increased use of scrap in the BOF and the use of other steelmaking furnaces such as the EOF should be investigated. For example, the injection of carbonaceous fuels in the BOF allows increased use of scrap, which could have a significant impact on industry electric energy consumption. Further development of the EOF and other steelmaking furnaces that combine scrap preheating (via waste heat) and melting in a single vessel is consistent with the future steelmaking goal of eliminating process steps.

¹AISI General Research Committee - Task Group on Steel Industry Research for Process Control and Sensor Development, Draft, 1981.

Industry experts interviewed for this study and others commenting in recent publications have agreed that ironmaking in the blast furnace is extremely efficient and that use of the cokemaking/blast furnace BOF route will not diminish in the near future. Therefore, R&D opportunities aimed at increasing cokemaking process efficiency, such as programmed heating and fuel gas preheating by CO gas sensible heat, should be investigated.

A qualitative assessment of the identified R&D areas of opportunity has been made based on two factors: 1) their perceived impact on production (e.g., increased productivity, reduced energy intensiveness, and industry acceptance); and 2) the views of the industry experts. Table 5.1 summarizes this assessment and provides a ranking of these opportunities by importance based on the above two factors.

Table 5.1
Identified R&D Areas of Opportunity
in Steelmaking

<u>Technology</u>	<u>Potential Impact</u>	<u>Perceived Priority</u>
o Thin strip casting	<ul style="list-style-type: none"> - eliminates process steps, - significant energy and labor savings, and - reduces production time 	high
o Sensor technology upgrades (to operate in high-temperatures and severe environments)	<ul style="list-style-type: none"> - promotes increased automation, - improves performance and steel characteristics - provides continuous real time measurement to be fed into on-line control systems 	high

Table 5.1
Identified R&D Areas of Opportunity
in Steelmaking
(Continued)

<u>Technology</u>	<u>Potential Impact</u>	<u>Perceived Priority</u>
Computer control system advances (e.g., artificial intelligence)	<ul style="list-style-type: none"> - promotes increased automation, - provides better process control, - promotes energy savings, - reduces production time and labor 	high
o Programmed heating of coke ovens	<ul style="list-style-type: none"> - increases process or total operation efficiency, - reduces environmental problems, - enhances process control 	high
o Injection of carbonaceous fuels in the BOF	<ul style="list-style-type: none"> - increased process or total operation efficiency, - reduced capital cost, - promotes increased scrap melting capability. 	medium
o Cokemaking process improvements	<ul style="list-style-type: none"> - promotes significant energy savings, - reduces environmental problems. 	medium

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APPENDIX A

GLOSSARY

- Agglomeration** - Process by which iron ore concentrates produced from crude iron ore are prepared for processing in the blast furnace. The two major agglomeration processes are pelletizing and sintering.
- Alloy steel** - Steel containing alloying elements intentionally added to impart desired physical, mechanical, or chemical properties not otherwise obtainable with iron and carbon alone.
- Annealing** - A process of heating and cooling metals to remove self-contained stresses, to refine the grain structure to alter ductility, toughness, electrical, or magnetic characteristics or other physical properties or to produce a definite microstructure.
- Annealing furnace** - Furnace intended for annealing metal products or parts. There are several types of annealing furnaces, such as gas-fired, electric-resistance, or induction furnaces.
- Apparent steel furnace** - Total net shipments plus imports less exports.
- Basic oxygen furnace (BOF)** - Refractory-lined steelmaking furnace containing molten iron and scrap. The heat required to melt the scrap is supplied by the oxidation of the carbon and other impurities in the pig iron and by the sensible heat in the molten charge itself.
- Billet** - A square or rectangular, semifinished rolled ingot with a cross section 4-36 in.² and with a width less than twice its thickness.
- Billet reduction mill** - Mill in which billets are rolled into wire rods, pipes, tubes, or bars.
- Blast furnace** - Furnace in which iron ore is reduced to pig iron using the following inputs: iron-bearing materials, fuel in the form of coke, and limestone. Hot air blown in at the bottom of the furnace burns the coke to heat, reduce, and melt the charge as it descends through the furnace. Pig iron and slag are tapped from the furnace hearth.
- Bloom** - A square or oblong, semifinished rolled ingot with a cross section 36-144 in.²; blooms are hot rolled to produce billets.
- Bloom reduction mill** - Mill in which blooms are rolled into structural shapes, rails, or accessories.
- Capability utilization** - The percentage of the total production capability that is actually used.
- Carbonaceous fuels** - Fuels containing carbon; injected into the BOF to increase its scrap melting capability.

- Carbon steel - Steel that owes its properties chiefly to various percentages of carbon and that does not have substantial amounts of alloying elements (as distinguished from alloy steel).
- Casting - Founding or the formation of an article or part by pouring or forcing molten or highly plastic metal into a mold or die and permitting the metal to solidify.
- Cast iron - Iron containing so much carbon that, as cast, it is not usefully malleable at any temperature. It usually contains 1.7-4.5% carbon and often contain 1.0-2.5% silicon.
- Charge - Inputs to the steelmaking furnace (i.e., scrap, molten pig iron, limestone).
- Coke - The form of carbon used to reduce iron ore to metallic iron in the blast furnace. Coke is produced in the coke oven from low sulfur, low ash content metallurgical coals.
- Cold rolling - A secondary finishing process in which cold steel is deformed.
- Continuous casting - A casting process designed to eliminate blooming, slabbing, and roughing operations by casting directly from the melting furnace, roll-squeezing, cooling, and cutting in a continuous cycle. In one process, molten metal is poured continuously into a thermoconducting, water-cooled mold and withdrawn from the opposite end by power rolls at a rate sufficient to permit solidification of an outer protective shell only. Subsequent cooling and cutting into desired lengths permits sending the slabs directly to the rolling mill, to other operations, or to storage.
- Direct reduction - Process in which iron ore is converted to sponge iron at temperatures far below the melting point of the ore. Reductants such as natural gas or coal substitute for metallurgical coke.
- Direct rolling - New rolling technology that eliminates the use of reheat furnaces; can be done using ingots or continuously cast slabs or billets.
- Direct strip casting - Combination of continuous casting and roller casting.
- Electric arc furnace - Electrothermic furnace in which heat energy is generated by the flow of an electric current through one or more internal arcs.
- Energy Optimization Furnace (EOF) - Advanced steelmaking furnace that can use scrap, hot metal, scrap and hot metal, or sponge iron; requires no outside power for melting.
- Finishing - Various operations performed on metal products to make them suitable for the purposes for which they are intended. Such operations may be final or they may be of an intermediate nature.

Galvanizing - Finishing process in which steel products (sheets and strips) are coated with zinc.

Heavy plate mill - Mill in which slabs are transformed into plates.

Hot metal ratio - The proportion of the total metallic charge that is in the form of hot metal.

Hot rolling - Process by which structural shapes, plates, and rails are produced from intermediate shapes (i.e., slabs and blooms).

Hot strip mill - Slab reduction mill in which hot rolling is carried out.

Ingot - A special kind of casting for subsequent rolling.

Integrated mill - Mill that incorporates both ironmaking and steelmaking.

Iron ore - Commercial ores of iron such as ferrous manganese ores.

KR process - Korf Reduction process, an ironmaking technology that uses a wide variety of coals to produce liquid iron having pig iron qualities.

kWh_e - Defined as kilowatt-hour electric and is equivalent to 10,500 Btu, per unit.

kWh_t - Defined as kilowatt-hour thermal and is equivalent to 3412 Btu, per unit.

Ladle - A refractory-lined metal receptacle used for transferring and pouring molten metal.

Ladle metallurgy - Methods by which refining and alloying are carried out in the ladles.

Mini-mill - A category of non-integrated plants having a capacity of less than 200,000 tons.

Non-integrated mill - A plant that incorporates steelmaking, steelcasting, and steelforming only; steelmaking is via electric arc furnaces.

Open-hearth furnace - Regenerative type of furnace for melting and refining iron in the open-hearth steelmaking process. The charge is processed in a shallow hearth beneath a flame and a mixture is recirculated through preheating sections of the furnace.

Paul Wurth top - Also known as bell-less top; blast furnace modification that results in reduced coke usage and better offgas efficiency.

Pellet - An unbaked ball formed from iron ore concentrate and a binder that is hardened by heat treatment in a furnace; used as an input to the blast furnace.

Pickling - (1) Removal of mill scale, and other foreign material from metal objects by immersing them in a pickling solution. (2) Removal of oxides or other compounds from metal surfaces by means of an acid or caustic soda solution, which reacts chemically with the compounds.

Pig iron - Cast iron usually produced by smelting iron ores in blast furnaces. Pig iron can be cast into pigs or held in the molten state for charging into a steelmaking furnace

Plate - A flat, usually rectangular, commercial product. In the metals industry, there is no universally accepted dividing line between plate and the thinner product, sheet.

Primary process - Those processes involved in the production of raw steel (i.e., agglomeration, cokemaking, ironmaking, and steelmaking).

Quad - 10^{15} Btu.

Raw steel - The first solid form of liquid steel.

Recuperator - Preheating equipment for recovering heat from hot, spent, furnace gases and using it for heating incoming air or fuel gases.

Refining - Process by which impurities are removed from steel and ferroalloys are added to bring it to its required composition.

Refractory - A heat-resistant ceramic material used to line furnaces.

Reheat furnace - Furnace used to heat steel shapes to 2300-2400°F prior to rolling.

Scrap - Refuse materials that are not usable in their existing form but that can be used as a raw material in reprocessing operations.

Section mill - Same as bloom reduction mill.

Sheet - Commercial metal product that is usually rectangular and flat but is sometimes rolled or coiled.

Sinter - Agglomeration product resulting from the mixture of iron ore concentrates with coke breeze and limestone. The mixture is ignited to form lumps of fine ore particles which are then crushed and screened before being fed into the blast furnace.

Slab - Rectangular piece of semifinished steel from the blooming mill. Usually rolled into plate.

Slab reduction mill - Mill in which slabs are transformed into sheets, strips, or plates.

Slag - Nonmetallic substance consisting mostly of silicates and formed by fusion during such operations as smelting. A flux (e.g., limestone) combines with the gangue, or waste portion of the ore.

Soaking pit - Pit furnace used for soaking metal products (usually newly cast ingots) immediately prior to rolling or forging operations.

Stainless steel - Alloy steel containing chromium and sometimes nickel or manganese that is practically immune to corrosion.

Steel - Primarily a refined alloy of iron and carbon that is malleable in the as-cast condition. Carbon content can vary from approximately 0.10-1.7%. There is no definite dividing line between the generic terms "steel" and "iron" and, in alloys containing less than 10% carbon, the terms are used interchangeably and somewhat loosely.

Strip - Commercial metal product that is flat but frequently rolled or coiled and that has widths somewhat narrower than products classified as bar.

Stripping - Process by which ingots are removed from the ingot molds; usually occurs while part of the inner ingot is still in a liquid state.

Thin strip casting - Same as direct strip casting.

Tuyere - a nozzle through which an air blast is delivered to a blast furnace.

Wire - Slender, rod-like product usually, but not necessarily, circular in cross section. Formed by cold drawing wire bar or rods through successively smaller dies.

APPENDIX B

ENERGY & MATERIALS USE BY MAJOR PROCESS 1979

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit as Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Total Energy Use (10^{12} Btu)</u>
<u>COKE PRODUCTION</u>			
Coal(a)	69,437 x 10^3 tons	26.194 x 10^6 (b)	1,818.83
Fuel Oil(c)	32,151 x 10^3 gallons	150,000(b)	4.82
Natural Gas(c)	35,018 x 10^6 ft ³	1,000(c)	35.02
Electricity(d)	1,601 x 10^6 kWh	10,500	16.81
Steam(e)	48,509 x 10^3 tons	1.15 x 10^6 (f)	55.79
Blast Furnace Gas(c)	882,764 x 10^6 ft ³	95(c)	<u>83.86</u>
Subtotal			2,015.13
Less:			
Heating Value of Coke(e) Produced	48,509 x 10^3 tons	25.99 x 10^6 (b)	-1,260.75
Coke Oven Gas(g)	473,373 x 10^6 ft ³	500(c)	-236.69
Tar and Pitch(h)	53.54 x 10^7 gallons	150,000(b)	-80.31
Light Oil(h)	172.2 x 10^6 gallons	130,000(b)	-22.39
Coke Breeze(h)	3.31 x 10^6 tons	20 x 10^6 (b)	<u>-66.20</u>
Subtotal			-1,666.34
Net Total			<u>348.79</u>

APPENDIX B
ENERGY & MATERIALS USE BY MAJOR PROCESS
1979
(Continued)

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit As Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Energy Use (10¹² Btu)</u>
<u>BLAST FURNACE & STOVES</u>			
Coke ⁽ⁱ⁾	50,239 x 10 ³ tons	25.99 x 10 ⁶ (b)	1,305.71
Fuel Oil (Including Tar and Pitch) ^(c)	633 x 10 ⁶ gallons	150,000 ^(b)	94.95
Natural Gas ^(c)	23,930 x 10 ⁶ ft ³	1,000 ^(c)	23.93
Electricity ^(j)	2,175 x 10 ⁶ kWh	10,500	22.84
Coke Oven Gas ^(c)	15,980 x 10 ⁶ ft ³	500 ^(c)	7.99
Oxygen ^(k)	35,058 x 10 ⁶ ft ³	183 ^(b)	6.42
Steam ^(l)	10,440 x 10 ⁷ lbs	1,000 ^(m)	<u>104.40</u>
Subtotal			1,566.24
Less:			
Blast Gas Furnace Used ^(c) Elsewhere in Mills	2,747 x 10 ⁹ ft ³	95 ^(c)	260.97
Net Total			<u>1,305.27</u>
<u>STEEL FURNACES</u>			
Fuel Oil (Including Tar and Pitch) ^(c)	289 x 10 ⁶ gallons	150,000 ^(b)	43.35
Oxygen ^(k)	202,411 x 10 ⁶ ft ³	183 ^(b)	37.04
Natural Gas ^(c)	38,720 x 10 ⁶ ft ³	1,000 ^(c)	38.72
Coke Oven Gas ^(c)	5,004 x 10 ⁶ ft ³	500 ^(c)	2.50
Electricity ⁽ⁿ⁾	230.19 x 10 ⁸ kWh	10,500	241.70
Blast Furnace Gas ^(c)	NA	95 ^(c)	<u>--</u>
Net Total			<u>363.31</u>

APPENDIX B

ENERGY & MATERIALS USE BY MAJOR PROCESS 1979 (Continued)

<u>Process, Materials Consumes</u>	<u>Total Amount (Unit As Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Energy Use (10¹² Btu)</u>
<u>HEATING/ANNEALING FURNACES</u>			
Fuel Oil ^(c)	383,839 x 10 ³ gallons	150,000 ^(b)	57.58
Natural Gas ^(c)	368,538 x 10 ⁶ ft ³	1,000 ^(c)	368.54
Liquid Petroleum Gas ^(c)	6,545 x 10 ³ gallons	95,000	.62
Coke Oven Gas ^(c)	254,963 x 10 ⁶ ft ³	500 ^(c)	127.48
Blast Furnace Gas ^(c)	193,518 x 10 ⁶ ft ³	95 ^(c)	<u>18.38</u>
Total			<u>572.60</u>
<u>OTHER PROCESSES AND UNALLOCATED ELECTRICITY</u>			
Light Oil ^(o)	57.4 x 10 ⁶ gallons	130,000 ^(b)	7.46
Fuel Oil (Including Tar and Pitch) ^(c)	229,850 x 10 ³ gallons	150,000 ^(b)	34.48
Liquid Petroleum Gas ^(c)	7,381 x 10 ³ gallons	95,000	.70
Natural Gas ^(c)	177,486 x 10 ⁶ ft ³	1,000 ^(c)	177.49
Coke Oven Gas ^(c)	197,426 x 10 ⁶ ft ³	500 ^(c)	98.71
Blast Furnace Gas ^(c)	1,670,939 x 10 ⁶ ft ³	95 ^(c)	158.74
Electricity ^(p)	33,180 x 10 ⁶ kWh	10,500	348.39
Steaming Coal ^(a)	2,006 x 10 ³ tons	26.194 x 10 ⁶ (b)	52.55
Coke Breeze ^(q)	1,892 x 10 ³ tons	20 x 10 ⁶ (b)	37.84
Oxygen ^(r)	33,566 x 10 ⁶ ft ³	183 ^(b)	6.14
Ferroalloys (Produced) ^(s)	1,875 x 10 ³ tons	56 x 10 ⁶ (b)	<u>105.00</u>
Subtotal			1,027.50
Less: Steam Used Elsewhere			-160.18
Net Total			<u>867.32</u>

APPENDIX B

ENERGY & MATERIALS USE BY MAJOR PROCESS 1980

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit as Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Total Energy Use (10¹² Btu)</u>
<u>COKE PRODUCTION</u>			
Coal(a)	58,446 x 10 ³ tons	26.194 x 10 ⁶ (b)	1,530.93
Fuel Oil(c)	10,768 x 10 ³ gallons	150,000(b)	1.62
Natural Gas(c)	30,697 x 10 ⁶ ft ³	1,000(c)	30.70
Electricity(d)	1,390 x 10 ⁶ kWh	10,500	14.60
Steam(e)	42,128 x 10 ³ tons	1.15 x 10 ⁶ (f)	48.45
Blast Furnace Gas(c)	727,414 x 10 ⁶ ft ³	95(c)	<u>69.10</u>
Subtotal			1,695.40
Less:			
Heating Value of Coke(e) Produced	42,128 x 10 ³ tons	25.99 x 10 ⁶ (b)	-1,094.91
Coke Oven Gas(g)	403,285 x 10 ⁶ ft ³	500(c)	-201.64
Tar and Pitch(h)	47.28 x 10 ⁷ gallons	150,000(b)	-70.92
Light Oil(h)	153.71 x 10 ⁶ gallons	130,000(b)	-19.98
Coke Breeze(h)	2.62 x 10 ⁶ tons	20 x 10 ⁶ (b)	<u>-52.40</u>
Subtotal			-1,439.85
Net Total			<u>255.55</u>

APPENDIX B

ENERGY & MATERIALS USE BY MAJOR PROCESS 1980 (Continued)

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit As Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Energy Use (10¹² Btu)</u>
<u>BLAST FURNACE & STOVES</u>			
Coke ⁽ⁱ⁾	39,276 x 10 ³ tons	25.99 x 10 ⁶ (b)	1,020.78
Fuel Oil (Including Tar and Pitch) ^(c)	340 x 10 ⁶ gallons	150,000 (b)	51.00
Natural Gas ^(c)	20,962 x 10 ⁶ ft ³	1,000 (c)	20.96
Electricity ^(j)	1,718 x 10 ⁶ kWh	10,500	18.04
Coke Oven Gas ^(c)	14,302 x 10 ⁶ ft ³	500 (c)	7.15
Oxygen ^(k)	23,007 x 10 ⁶ ft ³	183 (b)	4.21
Steam ^(l)	8,247 x 10 ⁷ lbs	1,000 (m)	<u>82.47</u>
Subtotal			1,204.61
Less:			
Blast Gas Furnace Used ^(c) Elsewhere in Mills	2,024 x 10 ⁹ ft ³	95 (c)	-192.28
Net Total			<u>1,012.33</u>
<u>STEEL FURNACES</u>			
Fuel Oil (Including Tar and Pitch) ^(c)	152 x 10 ⁶ gallons	150,000 (b)	22.80
Oxygen ^(k)	163,017 x 10 ⁶ ft ³	183 (b)	29.83
Natural Gas ^(c)	32,481 x 10 ⁶ ft ³	1,000 (c)	32.48
Coke Oven Gas ^(c)	5,885 x 10 ⁶ ft ³	500 (c)	2.94
Electricity ⁽ⁿ⁾	208.19 x 10 ⁸ kWh	10,500	218.60
Blast Furnace Gas ^(c)	10,051 x 10 ⁶ ft ³	95 (c)	<u>.95</u>
Net Total			<u>307.60</u>

APPENDIX B
ENERGY & MATERIALS USE BY MAJOR PROCESS
1980
(Continued)

<u>Process, Materials Consumes</u>	<u>Total Amount (Unit As Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Energy Use (10¹² Btu)</u>
<u>HEATING/ANNEALING FURNACES</u>			
Fuel Oil ^(c)	151,777 x 10 ³ gallons	150,000 ^(b)	22.77
Natural Gas ^(c)	317,432 x 10 ⁶ ft ³	1,000 ^(c)	317.43
Liquid Petroleum Gas ^(c)	2,506 x 10 ³ gallons	95,000	.24
Coke Oven Gas ^(c)	208,499 x 10 ⁶ ft ³	500 ^(c)	104.25
Blast Furnace Gas ^(c)	62,506 x 10 ⁶ ft ³	95 ^(c)	<u>5.94</u>
Total			<u>450.63</u>
<u>OTHER PROCESSES AND UNALLOCATED ELECTRICITY</u>			
Light Oil ^(a)	51.23 x 10 ⁶ gallons	130,000 ^(b)	6.66
Fuel Oil (Including Tar and Pitch) ^(c)	138,989 x 10 ³ gallons	150,000 ^(b)	20.85
Liquid Petroleum Gas ^(c)	3,388 x 10 ³ gallons	95,000	.32
Natural Gas ^(c)	158,740 x 10 ⁶ ft ³	1,000 ^(c)	158.74
Coke Oven Gas ^(c)	174,599 x 10 ⁶ ft ³	500 ^(c)	87.30
Blast Furnace Gas ^(c)	1,224,859 x 10 ⁶ ft ³	95 ^(c)	116.36
Electricity ^(p)	28,401 x 10 ⁶ kWh	10,500	298.21
Steaming Coal ^(a)	2,602 x 10 ³ tons	26.194 x 10 ⁶ (b)	68.16
Coke Breeze ^(q)	1,416 x 10 ³ tons	20 x 10 ⁶ (b)	28.32
Oxygen ^(r)	28,422 x 10 ⁶ ft ³	183 ^(b)	5.20
Ferroalloys (Produced) ^(s)	1,547 x 10 ³ tons	56 x 10 ⁶ (b)	<u>86.63</u>
Subtotal			876.75
Less: Steam Used Elsewhere			-130.90
Net Total			<u>745.85</u>

APPENDIX B

ENERGY & MATERIALS USE BY MAJOR PROCESS 1981

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit as Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Total Energy Use (10¹² Btu)</u>
<u>COKE PRODUCTION</u>			
Coal(a)	53,565 x 10 ³ tons	26.194 x 10 ⁶ (b)	1,403.08
Fuel Oil(c)	4,045 x 10 ³ gallons	150,000(b)	0.61
Natural Gas(c)	43,689 x 10 ⁶ ft ³	1,000(c)	43.69
Electricity(d)	1,258 x 10 ⁶ kWh	10,500	13.21
Steam(e)	38,117 x 10 ³ tons	1.15 x 10 ⁶ (f)	43.83
Blast Furnace Gas(c)	886,145 x 10 ⁶ ft ³	95(c)	<u>84.18</u>
Subtotal			1,588.60
Less:			
Heating Value of Coke(e) Produced	38,117 x 10 ³ tons	25.99 x 10 ⁶ (b)	-990.66
Coke Oven Gas(g)	374,019 x 10 ⁶ ft ³	500(c)	-187.01
Tar and Pitch(h)	42.316 x 10 ⁷ gallons	150,000(b)	-63.47
Light Oil(h)	136.85 x 10 ⁶ gallons	130,000(b)	-17.79
Coke Dreeze(h)	3.21 x 10 ⁶ tons	20 x 10 ⁶ (b)	<u>-64.20</u>
Subtotal			-1,323.13
Net Total			<u>265.47</u>

APPENDIX B

ENERGY & MATERIALS USE BY MAJOR PROCESS 1981 (Continued)

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit As Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Energy Use (10¹² Btu)</u>
<u>BLAST FURNACE & STOVES</u>			
Coke ⁽ⁱ⁾	40,546 x 10 ³ tons	25.99 x 10 ⁶ (b)	1,053.79
Fuel Oil (Including Tar and Pitch) ^(c)	305 x 10 ⁶ gallons	150,000 ^(b)	45.75
Natural Gas ^(c)	26,398 x 10 ⁶ ft ³	1,000 ^(c)	26.40
Electricity ^(j)	1,839 x 10 ⁶ kWh	10,500	19.31
Coke Oven Gas ^(c)	10,990 x 10 ⁶ ft ³	500 ^(c)	5.50
Oxygen ^(k)	24,278 x 10 ⁶ ft ³	183 ^(b)	4.44
Steam ^(l)	8,829 x 10 ⁷ lbs	1,000 ^(m)	<u>88.28</u>
Subtotal			1,243.47
Less:			
Blast Gas Furnace Used ^(c) Elsewhere in Mills	2,098 x 10 ⁹ ft ³	95 ^(c)	-199.31
Net Total			<u>1,044.16</u>
<u>STEEL FURNACES</u>			
Fuel Oil (Including Tar and Pitch) ^(c)	128 x 10 ⁶ gallons	150,000 ^(b)	19.20
Oxygen ^(k)	174,251 x 10 ⁶ ft ³	183 ^(b)	31.89
Natural Gas ^(c)	34,936 x 10 ⁶ ft ³	1,000 ^(c)	34.94
Coke Oven Gas ^(c)	4,725 x 10 ⁶ ft ³	500 ^(c)	2.36
Electricity ⁽ⁿ⁾	227.77 x 10 ⁸ kWh	10,500	239.16
Blast Furnace Gas ^(c)	10,200 x 10 ⁶ ft ³	95 ^(c)	<u>.97</u>
Net Total			<u>328.52</u>

APPENDIX B

ENERGY & MATERIALS USE BY MAJOR PROCESS 1981 (Continued)

Process, Materials Consumes	Total Amount (Unit As Specified)	Energy Use Per Unit (Btu/Unit)	Energy Use (10 ¹² Btu)
<u>HEATING/ANNEALING FURNACES</u>			
Fuel Oil ^(c)	125,295 x 10 ³ gallons	150,000 ^(b)	18.79
Natural Gas ^(c)	339,527 x 10 ⁶ ft ³	1,000 ^(c)	339.53
Liquid Petroleum Gas ^(c)	2,606 x 10 ³ gallons	95,000	.25
Coke Oven Gas ^(c)	195,210 x 10 ⁶ ft ³	500 ^(c)	97.61
Blast Furnace Gas ^(c)	66,265 x 10 ⁶ ft ³	95 ^(c)	<u>6.30</u>
Total			<u>462.48</u>
<u>OTHER PROCESSES AND UNALLOCATED ELECTRICITY</u>			
Light Oil ^(o)	45.61 x 10 ⁶ gallons	130,000 ^(b)	5.93
Fuel Oil (Including Tar and Pitch) ^(c)	130,857 x 10 ³ gallons	150,000 ^(b)	19.63
Liquid Petroleum Gas ^(c)	3,720 x 10 ³ gallons	95,000	.35
Natural Gas ^(c)	168,665 x 10 ⁶ ft ³	1,000 ^(c)	168.67
Coke Oven Gas ^(c)	163,094 x 10 ⁶ ft ³	500 ^(c)	81.55
Blast Furnace Gas ^(c)	1,135,731 x 10 ⁶ ft ³	95 ^(c)	107.89
Electricity ^(p)	31,639 x 10 ⁶ kWh	10,500	332.21
Steaming Coal ^(a)	2,675 x 10 ³ tons	26.194 x 10 ⁶ (b)	70.07
Coke Breeze ^(q)	1,434 x 10 ³ tons	20 x 10 ⁶ (b)	28.68
Oxygen ^(r)	29,167 x 10 ⁶ ft ³	183 ^(b)	5.34
Ferroalloys (Produced) ^(s)	1,493 x 10 ³ tons	56 x 10 ⁶ (b)	<u>83.61</u>
Subtotal			903.93
Less: Steam Used Elsewhere			-132.11
Net Total			<u>771.82</u>

APPENDIX B

ENERGY & MATERIALS USE BY MAJOR PROCESS 1982

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit as Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Total Energy Use (10¹² Btu)</u>
<u>COKE PRODUCTION</u>			
Coal ^(a)	34,130 x 10 ³ tons	26.194 x 10 ⁶ (b)	894.00
Fuel Oil ^(c)	9,509 x 10 ³ gallons	150,000 ^(b)	1.43
Natural Gas ^(c)	22,150 x 10 ⁶ ft ³	1,000 ^(a)	22.15
Electricity ^(d)	915.7 x 10 ⁶ kWh	10,500	9.61
Steam ^(e)	24,745 x 10 ³ tons	1.15 x 10 ⁶ (f)	28.45
Blast Furnace Gas ^(c)	576,485 x 10 ⁶ ft ³	95 ^(c)	<u>54.77</u>
Subtotal			1,010.41
Less:			
Heating Value of Coke ^(e) Produced	24,745 x 10 ³ tons	25.99 x 10 ⁶ (b)	-643.12
Coke Oven Gas ^(g)	241,872 x 10 ⁶ ft ³	500 ^(c)	-120.94
Tar and Pitch ^(h)	26.96 x 10 ⁷ gallons	150,000 ^(b)	-40.44
Light Oil ^(h)	87.20 x 10 ⁶ gallons	130,000 ^(b)	-11.34
Coke Breeze ^(h)	2.23 x 10 ⁶ tons	20 x 10 ⁶ (b)	<u>-44.60</u>
Subtotal			-860.44
Net Total			<u>149.97</u>

APPENDIX B
ENERGY & MATERIALS USE BY MAJOR PROCESS
1982
(Continued)

<u>Process, Materials Consumed</u>	<u>Total Amount (Unit As Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Energy Use (10¹² Btu)</u>
<u>BLAST FURNACE & STOVES</u>			
Coke ⁽ⁱ⁾	23,444 x 10 ³ tons	25.99 x 10 ⁶ (b)	609.31
Fuel Oil (Including Tar and Pitch) ^(c)	13,328 x 10 ³ gallons	150,000 ^(b)	19.99
Natural Gas ^(c)	19,160 x 10 ⁶ ft ³	1,000 ^(c)	19.16
Electricity ^(j)	1,082 x 10 ⁶ kWh	10,500	11.36
Coke Oven Gas ^(c)	7,106 x 10 ⁶ ft ³	500 ^(c)	3.55
Oxygen ^(k)	16,057 x 10 ⁶ ft ³	183 ^(b)	2.94
Steam ^(l)	5,197 x 10 ⁷ lbs	1,000 ^(m)	<u>51.97</u>
Subtotal			718.28
Less:			
Blast Gas Furnace Used ^(c) Elsewhere in Mills	1,340 x 10 ⁹ ft ³	95 ^(c)	-127.30
Net Total			<u>590.98</u>
<u>STEEL FURNACES</u>			
Fuel Oil (Including Tar and Pitch) ^(c)	79 x 10 ⁶ gallons	150,000 ^(b)	11.85
Oxygen ^(k)	107,740 x 10 ⁶ ft ³	183 ^(b)	19.72
Natural Gas ^(c)	20,530 x 10 ⁶ ft ³	1,000 ^(c)	20.53
Coke Oven Gas ^(c)	1,796 x 10 ⁶ ft ³	500 ^(c)	.90
Electricity ⁽ⁿ⁾	152.72 x 10 ⁸ kWh	10,500	160.36
Blast Furnace Gas ^(c)	6,173 x 10 ⁶ ft ³	95 ^(c)	<u>.59</u>
Net Total			<u>213.95</u>

APPENDIX B

ENERGY & MATERIALS USE BY MAJOR PROCESS 1982 (Continued)

<u>Process, Materials Consumes</u>	<u>Total Amount (Unit As Specified)</u>	<u>Energy Use Per Unit (Btu/Unit)</u>	<u>Energy Use (10¹² Btu)</u>
<u>HEATING/ANNEALING FURNACES</u>			
Fuel Oil(c)	94,393 x 10 ³ gallons	150,000(b)	14.16
Natural Gas(c)	219,371 x 10 ⁶ ft ³	1,000(c)	219.37
Liquid Petroleum Gas(c)	1,300 x 10 ³ gallons	95,000	.12
Coke Oven Gas(o)	123,357 x 10 ⁶ ft ³	500(c)	61.68
Blast Furnace Gas(c)	32,651 x 10 ⁶ ft ³	95(c)	<u>3.10</u>
Total			<u>298.43</u>
<u>OTHER PROCESSES AND UNALLOCATED ELECTRICITY</u>			
Light Oil(o)	29.06 x 10 ⁶ gallons	130,000(b)	3.78
Fuel Oil (Including Tar and Pitch)(c)	102,607 x 10 ³ gallons	150,000(b)	15.39
Liquid Petroleum Gas(c)	3,096 x 10 ³ gallons	95,000	.29
Natural Gas(c)	130,134 x 10 ⁶ ft ³	1,000(c)	130.13
Coke Oven Gas(c)	109,613 x 10 ⁶ ft ³	500(c)	54.81
Blast Furnace Gas(c)	724,956 x 10 ⁶ ft ³	95(c)	68.87
Electricity(p)	23,046 x 10 ⁶ kWh	10,500	241.98
Steaming Coal(a)	2,297 x 10 ³ tons	26.194 x 10 ⁶ (b)	60.17
Coke Breeze(q)	984 x 10 ³ tons	20 x 10 ⁶ (b)	19.68
Oxygen(r)	22,548 x 10 ⁶ ft ³	183(b)	4.13
Ferroalloys (Produced)(s)	838 x 10 ³ tons	56 x 10 ⁶ (b)	<u>46.93</u>
Subtotal			646.16
Less: Steam Used Elsewhere			-83.88
Net Total			<u>562.28</u>

APPENDIX B

ENERGY AND MATERIALS USE BY MAJOR PROCESS

KEY

- a AISI, 1983 Annual Statistical Report, Table 36.
- b Table 3.5 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, 1982.
- c AISI, 1983 Annual Statistical Report, Table 48.
- d Calculated by multiplying 33 kWh/net ton of coke produced as stated in Table 6.6 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, 1982 to the total net ton of coke produced for the year (AISI, 1983 Annual Statistical Report, Table 38.)
- e AISI, 1983 Annual Statistical Report, Table 38.
- f Table 6.6 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, 1982 and Table 38 of "AISI 1983 Annual Statistical Report."
- g Calculated by subtracting coke oven gas used in coke ovens from the total production, Table 48, AISI, "1983 Annual Statistical Report."
- h Calculated by multiplying yields for each chemical product/ton of coal from "Coke and Coal Chemicals in 1980," DOE/EIA 0120/80, Table 2 and the total amount of coal used to produce coke for the year from AISI, "1983 Annual Statistical Report," Table 36.
- i AISI, 1983 Annual Statistical Report, Table 38.
- j Calculated by multiplying electricity intensity 25 kWh/net ton of metal to the total tonnage of metal produced for the year. The figure 25 kWh/net ton is taken from Table 7.1 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, April 1982.
- k AISI, 1983 Annual Statistical Report, Table 47.
- l Calculated by multiplying steam requirement of 1,200 lb/net ton from Table 7.1 of "Energy and Materials Flow in the Iron and Steel Industry," ANL, April 1982 to the total net tons of iron produced for the year (AISI, "1983 Annual Statistical Report," Table 30).
- m Table 7.1 of "Energy and Materials Flow in the Iron and Steel Industry," ANL, April 1982.

APPENDIX B

- n Represents the sum of all electric energy consumed by all types of steelmaking furnaces and is calculated by multiplying electricity intensities of 15, 30, and 596 kWh for open hearth, BOF, and electric arc, respectively, to the total tonnage for each product for the year. Data are taken from Table 10.2, 10.3, and 10.4 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, April 1982.
- o Estimated as 1/3 of the total light oil produced for the year in coke production. Estimated figure (1/3) comes from Table 3.5 of "Energy and Materials Flows in the Iron and Steel Industry," ANL, 1982.
- p Unallocated electricity remaining from the total electric power purchased. Data for the purchased electricity is shown in AISI, 1983 Annual Statistical Report, Table 46.
- q AISI, 1983 Annual Statistical Report, Table 42.
- r Unallocated oxygen remaining from AISI Annual Statistical Report, Table 47.
- s AISI, 1983 Annual Statistical Report, Table 33.

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984)

<u>PROCESS AREA</u>	<u>TECHNOLOGY</u>	<u>IMPLEMENTATION</u>	<u>COMPANY AND PLANT</u>	<u>IMPACT ON ENERGY CONSUMPTION</u>
AGGLOMERATION AND COKING	One-spot quench car	1981	FORD MOTOR CO. Dearborn, MI	Low
	Desulfurization of coke-oven gas	1981, 1983	REPUBLIC STEEL CORPORATION Cleveland, OH	Low
		1982, 1983	REPUBLIC STEEL CORPORATION Warren, OH	
	One-spot quench car emission control	1981	REPUBLIC STEEL CORPORATION Cleveland, OH	Low
	New coke-oven battery, by-products desulfurization and environmental	1982	REPUBLIC STEEL CORPORATION Chicago, IL	High
	Rehabilitation, upgrading and replacement of several coke-oven batteries	1980-1983	Several Companies	High
IRONMAKING	45-ft. hearth blast furnace complete with raw materials storage and handling	1980	INLAND STEEL COMPANY E. Chicago, IN	High
	Elast furnace rebuilt with Paul Wurth top	1981	REPUBLIC STEEL CORPORATION Warren, OH	High

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984) (Continued)

PROCESS AREA	TECHNOLOGY	IMPLEMENTATION	COMPANY AND PLANT	IMPACT ON ENERGY CONSUMPTION
IRONMAKING (Continued)	Oil-Coal slurry injection system	1982	INTERLAKE, INC. Chicago, IL	High
	Iron desulfurization facilities	1982	ROUGE STEEL CO. Dearborn, MI	High
	Ingot bottom pour facilities		COPPERWELD CORP. Warren, OH	Low
	Complete the rehabilitation and relining of several blast furnaces	1980-1983	Various Manufacturers	High
STEELMAKING	50-ton electric arc furnace	1980	ARMCO, INC. Baltimore, MD	High
	Oxygen lance mechanism for electric arc furnace	1980	COLT INDUSTRIES, INCORPORATED	High
	VAR furnace	1980	CYCLOPS CORP. Titusville, PA	Low
	Melt shop improvements	1980	EDGEWATER CORP. Oakmont, PA	Low
	Water-cooled side wall panels installed in electric arc furnace	1980	JONES & LAUGHLIN STEEL CORP. Cleveland, OH	High
		1980	NORTHWESTERN STEEL AND WIRE COMPANY Sterling, IL	

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES
 INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY)
 (Between 1980 and 1984)
 (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY</u>	<u>IMPLEMENTATION</u>	<u>COMPANY AND PLANT</u>	<u>IMPACT ON ENERGY CONSUMPTION</u>
STEELMAKING (Continued)		1980	REPUBLIC STEEL CORPORATION Central Alloy District	
		1980	SOULE STEEL CO. Canton, OH	
		1981	CF&I STEEL CORP. Pueblo, CO	
		1981	MARATHON STEEL COMPANY Tempe, AZ	
		1983	NEW JERSEY STEEL CORPORATION Sayreville, NJ	
	Hot metal desulfurization station	1980	NORTHWESTERN CORPORATION Granite City, IL	High
	Three 40-ton electric arc furnaces	1980	NUCOR CORP. Jewett, TX	Low
	Electric furnace water-cooled shell and roof, on-line tap changer	1981	AMERON STEEL- TAMCO	High
	Vacuum melt and remelt furnaces	1981	CARPENTER TECH. CORPORATION	Low

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984) (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY</u>	<u>IMPLEMENTATION</u>	<u>COMPANY AND PLANT</u>	<u>IMPACT ON ENERGY CONSUMPTION</u>
STEELMAKING (Continued)	Two 100-ton electric arc furnaces, lime injection system	1981	CYCLOPS CORP. Mansfield, OH	High
	Alloy and lime handling system, oxygen-fuel burners, water- cooled roofs and static VAR controller installed	1981	GEORGETOWN STEEL CORP. Georgetown, SC	High
	Ladle preheat station	1981	KEYSTONE CONSOLIDATED INDUSTRIES Peoria, IL	High
	Two 60-ton electric arc furnaces	1981	NUCOR CORP. Plymouth, VT	Low
	40-ton electric arc furnace	1981	NUCOR CORP. Norfolk, NE	Low
	BOF electrostatic precipitator repaired and improved	1981	REPUBLIC STEEL CORPORATION Buffalo, NY	Low
	Hot metal desulfurization facilities	1981	REPUBLIC STEEL CORPORATION Gadsden, IL	High
	20-ton electric arc furnace	1982	CARPENTER TECH. CORPORATION Reading, PA	High

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984) (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY</u>	<u>IMPLEMENTATION</u>	<u>COMPANY AND PLANT</u>	<u>IMPACT ON ENERGY CONSUMPTION</u>
STEELMAKING (Continued)	Oxy-fuel burner system added to electric arc furnace	1982	FLORIDA STEEL CORPORATION Jacksonville, FL	High
	BOF combined top and bottom blowing	1982	JONES & LAUGHLIN STEEL CORP. E. Chicago, IN	High
	BOF computerized static process control	1982	NATIONAL STEEL CORPORATION Granite City, IL	High
			NATIONAL STEEL CORPORATION Weirton, WV	
	Hot metal desulfurization	1981	REPUBLIC STEEL CORPORATION Gadsden, AL	High
	Water-cooled shell panels for electric arc furnace; replaced ladle stopper rods with rotary nozzle system; and ladle preheat stations.	1982	THE TIMKEN CO. Canton, OH	High
	Two electroslog remelting furnaces vacuum induction melting	1983	CARPENTER TECH. CORPORATION Reading, PA	High
	Steel ladle desulfurization and BOF charge calculation	1983	INTERLAKE, INC. Chicago, IL	High

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984) (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY</u>	<u>IMPLEMENTATION</u>	<u>COMPANY AND PLANT</u>	<u>IMPACT ON ENERGY CONSUMPTION</u>
STEELMAKING (Continued)	Oxy-fuel burners	1983	NEW JERSEY STEEL Sayreville, NJ	High
	Iron desulfurization furnace control system	1983	REPUBLIC STEEL CORPORATION Warren, OH	High
	Ladle preheating stations	1983	THE TIMKEN CO. Canton, OH	High
CASTING, ROLLING & SHAPING	Added 1 strand to existing 2- strand continuous casting machine.	1980	CASCADE STEEL ROLLING MILLS, INC. McMinnville, OR	High
	Roll gap measuring, continuous casting machine	1980	LUKENS STEEL CO. Coatsville, PA	Low
	New starter and slab cut-off machine for continuous casting	1981	COLT INDUSTRIES INC. Midland, PA	Low
	16-stand continuous bar mill	1981	FLORIDA STEEL CORPORATION Charlotte, NC	Low
	New turnover-type cooling bed for casting machine	1981	GEORGETOWN STEEL CORPORATION Georgetown, SC	Low

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984) (Continued)

PROCESS AREA	TECHNOLOGY	IMPLEMENTATION	COMPANY AND PLANT	IMPACT ON ENERGY CONSUMPTION
CASTING, ROLLING & SHAPING (Continued)	Continuous slab casting machine	1980, 1981	NATIONAL STEEL CORPORATION Granite City, IL	High
		1980	NUCOR Corp. Jewett, TX	
		1981	WASHINGTON STEEL CORPORATION Houston, PA	
		1981	ARMCO, INC. Butler, PA	
		1982	CF&I STEEL CORP Pueblo, CO	
		1983	ARMCO, INC. Ashland, KY	
	Automatic guage control for tandem cold mill	1981	WHEELING- PITTSBURGH STEEL CORP. Allenport, PA	Low
	No. 14 forging press modernized	1982	BETHLEHEM STEEL CORPORATION Bethlehem, PA	Low
	Continuous caster second strand	1982	CARPENTER TECH. CORPORATION Reading, PA	High

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984) (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY</u>	<u>IMPLEMENTATION</u>	<u>COMPANY AND PLANT</u>	<u>IMPACT ON ENERGY CONSUMPTION</u>
CASTING, ROLLING & SHAPING (Continued)	Improvements to slab casting	1982	U.S. STEEL CORP. Gary, IN	High
	Rotary forge facility including	1983	CARPENTER TECHNOLOGY CORP. Reading, PA	High
	12-in. bar mill laser guage	1983	COPPERWELD CORP. Warren, OH	Low
	Continuous casting oscillators	1983	NEW JERSEY STEEL CORPORATION Sayerville, NJ	Low
	Rounds casting machine	1983	U.S. STEEL CORP Lorain, OH	High
FINISHING	Cold rolled continuous annealing line	1980	BETHLEHEM STEEL CORPORATION Bethlehem, PA	Low
	Continuous finishing line	1980	COPPERWELD CORP. Warren, OH	Low
	Continuous weld-pipe mill	1980	CYCLOPS CORP.	Low
	Closed loop coating control	1980	NATIONAL STEEL CORPORATION Granite City, IL	Low

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984) (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY</u>	<u>IMPLEMENTATION</u>	<u>COMPANY AND PLANT</u>	<u>IMPACT ON ENERGY CONSUMPTION</u>
FINISHING (Continued)	Cooling bed modifications, rolling mill	1980	SOULE STEEL CO. Carson, CA	Low
	Continuous coil annealing facility	1981, 1982	ARMCO, INC. Ashland, KY	Low
	Conversion of No. 1 galvanizing line to Galvalume line	1981	BETHLEHEM STEEL CORPORATION Sparrows Point, MD	Low
	Cold-rolled continuous annealing line	1983	BETHLEHEM STEEL CORPORATION Burns Harbor, IN	Low
	Shear, gage beam, automatic angle straightening equipment and automatic handling and tying equipment	1981	FLORIDA STEEL CORPORATION Jackson, TN	Low
	Galvalume Coating system	1981	NATIONAL STEEL CORPORATION Portage, IN	Low
	Continuous electrolytic galvanizing line	1982	ROUGE STEEL CO. Dearborn, MI	Low
	Continuous annealing line	1983	INLAND STEEL CO. E. Chicago, IN	Low
	New insulated roof for annealing furnace	1983	LUKENS, INC. Coatesville, PA	High

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984) (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY</u>	<u>IMPLEMENTATION</u>	<u>COMPANY AND PLANT</u>	<u>IMPACT ON ENERGY CONSUMPTION</u>
FINISHING (Continued)	Automatic in-line stacker for flats, squares, and angles	1983	NEW JERSEY STEEL CORPORATION Sayreville, NJ	Low
	Continuous galvanizing line	1983	ROUGE STEEL CO. Dearborn, MI	Low
	Continuous thermal treatment facilities: ID/OD quench, temper and straightener	1983	THE TIMKEN CO. Canton, OH	High
MISCELLANEOUS	Heat recovery in open hearth furnace	1980	COPPERWELD CORP. Shelby, OH	High
	Annealing furnace recuperators	1980	COPPERWELD CORP. Warren, OH	High
	Waste heat boiler	1980	EASTERN STAINLESS STEEL COMPANY Baltimore, MD	High
	Energy conservation for reheat furnace	1981	AMERON STEEL-TAMCO Etiwanda, CA	High
	Sulfuric Acid Recovery	1981	ARMCO, INC. Middletown, OH	Low
	Oxy-fuel burners added to soaking pits	1981	COLT INDUSTRIES, INCORPORATED Midland, PA	High

APPENDIX C

CONSERVATION TECHNOLOGIES/MEASURES INSTITUTED (OR IMPLEMENTED BY THE INDUSTRY) (Between 1980 and 1984) (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY</u>	<u>IMPLEMENTATION</u>	<u>COMPANY AND PLANT</u>	<u>IMPACT ON ENERGY CONSUMPTION</u>
MICELLANEOUS (Continued)	Ceramic fiber lining added to billet reheat furnace	1981	KEYSTONE CONSOLIDATED INDUSTRIES Peoria, IL	High
	Immersion ultrasonic inspection	1981	LATROBE STEEL CO. Latrobe, PA	Low
	Reheat furnace preheater	1982	AMERON Etiwanda, CA	High
	Modernization of soaking pits; computerization of controls; recuperator installation	1983	LUKENS, INC. Coatesville, PA	High
	Ladle preheaters (recuperative type)	1983	RARITAN RIVER STEEL COMPANY Perth Amboy, NJ	High
	Reheat furnace computerization	1983	RARITAN RIVER STEEL CO. Perth Amboy, NJ	High
	Soaking pit optimization	1983	REPUBLIC STEEL CORPORATION Chicago, IL	High

Source: Iron and Steel Engineer, Feb. 1981-1984 "Developments in the Iron and Steel Industry, U.S. and Canada.

APPENDIX D

STATE-OF-THE-ART STEELMAKING TECHNOLOGIES

<u>PROCESS AREA</u>	<u>ALTERNATIVE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT</u>	<u>REFERENCES</u>
<u>AGGLOMERATION</u>			
Pelletizing	<ul style="list-style-type: none"> - cold bonding processes: In most of these processes, pellets, briquettes, etc., are made at ambient temperatures. The two known processes, which are similar in concept, are MTU (Michigan Technological University) and COBO of Sweden. The first COBO commercial plant has been built in Sweden. - Peridur: An organic residue binder developed to substitute for bentonite in pelletizing. The advantage of this binder is that it is eliminated for the major part during thermal treatment, which in turn reduces chemical contamination. 	<p>Estimated energy savings are:</p> <ul style="list-style-type: none"> -COBO--446,000 Btu/net ton of pellets; and -MTU--346,000 Btu/net ton of pellets. <ul style="list-style-type: none"> -reduced contamination; -higher quality pellets; -extremely high rate of reduction; and -improved metallurgical properties. 	<p>ADL, Inc., "Research, Development and Demonstration for Energy Conservation: Preliminary Identification of Opportunities in Iron and Steelmaking," 1978.</p> <p>Harry R.G. Steeghs & Teije Kater, "Recent Experience with Organic Binders for Iron Ore Pelletizing," Skillings' Mining Review, December 15, 1984.</p>
Sintering	<ul style="list-style-type: none"> -preheating combustion air in the sinter cooler. -raw materials preheating. -steam or power generation using sinter cooler exhaust. -heat recovery from main exhaust gas. 	<ul style="list-style-type: none"> -5 to 10 Mcal/tonne (18,090 - 36,181 Btu/net ton). -up to 4.5 Kg of coke breeze/tonne of sinter (90,000 Btu/net ton). -30 to 40 Mcal/tonne (108,545 - 144,727 Btu/net ton). -20 Mcal/tonne (72,363 Btu/net ton). 	<p>International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.</p> <p>ANL, "Energy and Materials Flows in the Iron and Steel Industry," 1982.</p>

APPENDIX D

STATE-OF-THE-ART STEELMAKING TECHNOLOGIES (Continued)

<u>PROCESS AREA</u>	<u>ALTERNATIVE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT</u>	<u>REFERENCES</u>
<u>COKEMAKING</u>	<ul style="list-style-type: none"> -dry quenching of coke. -carbonization control (continuous measurement of the flue and CO gas temperatures by computer to determine the end point). -programmed heating (controlling underfiring). -wet quenching of coke with energy recovery. -coke oven gas sensible heat recovery. 	<ul style="list-style-type: none"> -energy savings up to 1.2 x 10⁶ Btu/net ton and reduced pollutants. -10 to 20 Mcal/tonne dry coke (36,180 to 72,360 Btu/net ton dry coke). -10% reduction in energy consumption. -60Kg steam/tonne of coke. -4.5 m³ hot water at 80 to 90°C (159 ft³ hot water at 176-194°F); -4.3 nm³ water gas of LCV 2600 Kcal/Nm³ (444,964 Btu); and -25 to 50 Mcal/tonne dry coke (99,250 - 198,500 Btu/net ton). 	<p>ADL, Inc., "Research, Development and Demonstration for Energy Conservation: Preliminary Identification Opportunities in Iron and Steelmaking," 1978.</p> <p>International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.</p>
<u>IRONMAKING</u>	<p><u>Modern Blast Furnace:</u></p> <ul style="list-style-type: none"> -coal injection. -movable throat armor for better burden distribution. -water-cooling. -hydro-electric power generation using circulation. -top gas pressure recovery. 	<ul style="list-style-type: none"> -savings not reported. -savings not reported. -savings not reported. -savings not reported. -25 to 40 kWh/tonne hm (209,100 to 334,500 Btu/net ton). 	<p>ANL, "Energy and Material Flows in Iron and Steel Industry," 1982.</p> <p>International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.</p>

APPENDIX D

STATE-OF-THE-ART STEELMAKING TECHNOLOGIES (Continued)

<u>PROCESS AREA</u>	<u>ALTERNATIVE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT</u>	<u>REFERENCES</u>
<u>IRONMAKING</u> (Cont'd.)	-hot stove waste heat recovery.	-20 Mcal/tonne hm (72,360 Btu/net ton hm).	
	-insulation of cold blast main.	-10 Mcal/tonne hm (36,180 Btu/net ton hm).	
	-recovery of BF gas released during charging.	-5 to 13 Mcal/tonne hm (19,900 to 47,760 Btu/net ton hm).	
	-slag waste heat recovery.	-16 kWh/tonne hm (133,810 Btu/net ton hm).	
	-Paul Wurth top.	-not reported.	Dr. Donald Blickwede.
	<u>External Desulfurization:</u> Is achieved by injecting calcium carbide or Mag-Coke as a desulfurizing reagent in torpedo cars between blast furnace and steelmaking shops.	-estimated energy savings of up to 0.9×10^6 Btu/net ton; -reduced slag volume; and -extension of the reserves of the coke coal.	ADL, Inc. "Research, Development and Demonstration for Energy Conservation: Preliminary Identification of Opportunities in Iron and Steelmaking," 1978.
<u>STEELMAKING</u>	<u>Modern Basic Oxygen Furnace:</u> -BOF gas recovery in combination with sensible heat recovery. -BOF slag sensible heat recovery.	-219 Mcal/tonne steel (790,000 Btu/net ton steel). -160 kg/tonne slag (320 lb/net ton slag). -higher productivity; -lower operating costs; -higher utilization of blowing stands; -uniform consumption of hot metal;	International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982. "New Technology In Action," Iron and Steel Engineer, July 1983.
	-two working vessels concept.		

APPENDIX D

STATE-OF-THE-ART STEELMAKING TECHNOLOGIES (Continued)

<u>PROCESS AREA</u>	<u>ALTERNATIVE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT</u>	<u>REFERENCES</u>
<u>STEELMAKING</u> (Cont'd.)		<ul style="list-style-type: none"> -flexibility in melting; -reduced downtime; and -minimization of the use of dolomite. 	
	-combined top and bottom oxygen blowing.	-5% increase in scrap use.	Dr. Donald Blickwede.
	-in-process control (dynamic) of temperature and carbon content.	<ul style="list-style-type: none"> -increased quality of product and efficiency; and -10 to 20% time savings tap to tap. 	
	<u>Modern Electric Arc Furnace:</u> A number of advances in electric furnace technology and operation have recently been reported. These advances include: <ul style="list-style-type: none"> -ultra high-power (UHP) transformers; -computerizations; -bottom tap vessels; -water-cooled furnace panels and top; -water-cooled electrode sections; -oxy-fuel burners; -foamy slag practice; and -material handling practices. 	<ul style="list-style-type: none"> -reduced production time by 5-10 minutes; -refractory savings; -savings in gunning materials up to 60%; -reduction in tap temperature up to 30°C; -electrode savings; -long bottom refractory materials; -heat time reductions of up to 3.5 min/heat; -increased ladle life up to 50%; and -alloy savings. 	<p>"New Technology in Action," Iron and Steel Engineer, July 1983.</p> <p>"A Review of New Electric Arc Furnace Technologies," Iron and Steel Engineer, October 1983.</p>

APPENDIX D

STATE-OF-THE-ART STEELMAKING TECHNOLOGIES (Continued)

<u>PROCESS AREA</u>	<u>ALTERNATIVE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT</u>	<u>REFERENCES</u>
<u>STEELMAKING</u> (Cont'd.)	<p><u>Scrap Preheating:</u> For electric arc furnaces, use of the off-gas recycling route has proven to be a successful technique in preheating all types of scrap without encountering the environmental problems associated with secondary gas emission.</p>	<ul style="list-style-type: none"> -15% reduction in meltdown or 100 kWh/net ton; -0.4 to 1.2 lb/net ton reduction in electrode consumption; and -8 minute time reduction in steelmaking. 	<p>"New Process Developments in Melting Scrap and Sponge Iron," Iron and Steel Engineering, February 1982.</p> <p>"Scrap Preheater for Electric Arc Furnace," Iron and Steel Engineer, April 1983.</p>
	<p><u>Ladle Drying and Preheating:</u></p> <ul style="list-style-type: none"> -high efficiency, bottom-fired ladle system. -heating ladles on a platform using carbon flue gas. 	<ul style="list-style-type: none"> -increase ladle heating efficiency from 3 or 4% to 60 or 65%. -reduce natural gas consumption by about half. 	<p>"Heat Recuperation in Ladle Preheating and Annealing Furnace Operations," Iron and Steel Engineer, April 1982.</p>
	<p><u>Injection Steelmaking:</u> (ladle metallurgy) is concerned with the actual refining and alloying which takes place outside the furnace, in ladles and vacuum chambers. These processes include:</p> <ul style="list-style-type: none"> -vacuum arc decarburization; and -argon-stirring. 	<ul style="list-style-type: none"> -increase yield up to 10%; and -shorten refining cycles from hours to minutes. 	<p>Dr. Donald Blickwede.</p>
	<p><u>Specialty Steelmaking Processes:</u></p> <ul style="list-style-type: none"> -electroslag remelting (ESR); -argon-oxygen decarburization (AOD); -vacuum induction melting (VIM); -electron beam melting (EBM); and -vacuum arc remelting (VAR). 	<ul style="list-style-type: none"> -increase yield; -shorten refining cycles; and -possibly allow use of cheapest grades of ferro-chrome in the charge. 	<p>"The Quest for Cleaner Steels," High Technology, September 1983.</p>

APPENDIX D

STATE-OF-THE-ART STEELMAKING TECHNOLOGIES (Continued)

<u>PROCESS AREA</u>	<u>ALTERNATIVE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT</u>	<u>REFERENCES</u>
<u>STEELCASTING</u>	<p><u>-Modern Casters.</u></p> <p><u>-Slab Heat Recovery.</u></p> <p><u>-Soaking Pit Utilization and Pit Vacant Time.</u></p>	<p>-increased quality; -continuous casting; -reduced cycling time; and -significant energy savings.</p> <p>-70 Mcal/tonne slab (252,600 Btu net ton slab).</p> <p>-significant energy savings.</p>	<p>International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.</p>
<u>STEELFORMING</u>	<p><u>Hot charging:</u> Charging of the hot products into rehear furnace.</p> <p><u>Preheating Furnaces:</u> -improved insulation. -waste heat recovery and air preheating. -waste heat recovery and fuel gas preheating. -increased length of the preheating furnace.</p> <p>-waste heat boilers.</p> <p>-evaporative cooling of furnace skids.</p>	<p>-appreciable savings.</p> <p>-10 to 15% energy savings. -30 to 50% energy savings. -savings not reported. -significant energy savings.</p> <p>-steam recovery levels equivalent to 40 Mcal/tonne slab (144,360 Btu/net ton slab). -steam recovery equivalent to 25 Mcal/tonne charged product (90,200 Btu/net ton).</p>	<p>Dr. Donald Blickwede.</p> <p>International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.</p> <p>Dr. Donald Blickwede.</p>

APPENDIX D

STATE-OF-THE-AFT STEELMAKING TECHNOLOGIES (Continued)

<u>PROCESS AREA</u>	<u>ALTERNATIVE/ADVANCED TECHNOLOGY</u>	<u>POTENTIAL IMPACT</u>	<u>REFERENCES</u>
<u>STEELFORMING</u> (Cont'd.)	<p><u>Direct Rolling:</u> A highly automated mill utilizing the latest technological innovations in computer and electronic controls. The new developments in strip mill configuration which can help to conserve energy and expedite direct rolling are:</p> <ul style="list-style-type: none"> -leveling furnace -the coil box; and -covered delay table. <p><u>Pickling:</u></p> <ul style="list-style-type: none"> -steam savings during pickling (insulating floats). <p><u>Annealing (batch):</u></p> <ul style="list-style-type: none"> -air preheating. -fuel gas preheating. -combustion control. <p><u>Continuous Annealing:</u></p> <p><u>Continuous Cold Rolling:</u> Is capable of reducing the length of a finishing processing sequence from 12 days to one day. The process includes such facilities as pickling, tandem rolling and annealing, temper rolling, and automatic inspection in sequence.</p>	<ul style="list-style-type: none"> -reduce labor requirements by as much as 70%; and -save energy (in some cases up to 3×10^6 Btu/net ton) by eliminating reheat furnaces. <p>-significant energy savings.</p> <p>-energy savings 10 to 20%.</p> <ul style="list-style-type: none"> -savings not reported. -significant savings. <p>-improved yield.</p> <ul style="list-style-type: none"> -reduced labor; -energy savings; -higher productivity; -better quality of products; and -low costs. 	<p>"Steelmaking in the Future," Iron and Steel Engineer, December 1981.</p> <p>"The Steel Industry: Present and Future," Metal Progress, October 1984.</p> <p>International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.</p> <p>International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.</p> <p>Dr. Donald Blickwede.</p> <p>"The Steel Industry: Present and Future," Metal Progress, October 1984.</p>

APPENDIX E

ADVANCED STEELMAKING TECHNOLOGIES

<u>PROCESS AREA</u>	<u>TECHNOLOGY DESCRIPTION</u>	<u>STATE OF DEVELOPMENT</u>	<u>REFERENCES</u>
<u>IRONMAKING</u>	<p><u>PLASMARED</u>: The development of this process involves one well-established technology (DRI) and one newly advanced technology (plasma arc) which have been merged into a practical tool for the production of high-quality direct reduced iron at low energy consumption and cost. The new process has made it possible to gasify any carbon or hydrogen-containing fuel to achieve metallization of up to 93%.</p> <p><u>KR PROCESS (KORF REDUCTION PROCESS)</u>: Designed to produce hot metal using a wide variety of coal. The process concept is based on separating the two process steps that are simultaneously occurring in the blast furnace - generation of a reduction gas and melting of a direct reduced iron and reduction of iron ore. In the new scheme of operation, the two process steps are carried out in separate reactors, the melter gasifier and reduction shaft.</p>	<p>-demonstration plant in Sweden with a production capacity of 70,000 tons/yr; -estimated commercialization date late 1980's.</p> <p>-a pilot plant with a capacity between 5 and 10 tons/hr has been in operation since mid-1981 in West Germany. Based on the experience with this pilot plant, a 300,000 ton capacity plant has also been engineered.</p>	<p>"PLASMARED - The Low-Energy Coal-Based Direct Reduction Process," Iron and Steel Engineer, May 1982.</p> <p>"The KR Process: A New Development in Ironmaking," Iron and Steel Engineer, August 1984.</p>
<u>DIRECT STEELMAKING</u>	<p><u>PLASMASMELT</u>: This technology is a modified blast furnace that uses plasma torches at each tuyere to raise the sensible heat input. The process is designed to take advantage of rapid reaction in fine ore concentrates, agglomeration, to produce hot metal.</p>	<p>-pilot plant operating in Sweden; -estimated commercialization date late 1980's.</p>	<p>"Steelmaking in the Future," Iron and Steel Engineer, December 1981.</p> <p>"Compilation of Reports on Direct Reduction Technology and Economics," U.S. Steel Corp., June 1981.</p>

APPENDIX E

ADVANCED STEELMAKING TECHNOLOGIES (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY DESCRIPTION</u>	<u>STATE OF DEVELOPMENT</u>	<u>REFERENCES</u>
<u>DIRECT STEELMAKING</u> (Cont'd.)	<p><u>INRED</u>: This technology involves an Intensive Reduction process reaction. It produces hot metal directly using fine-grained iron oxides, such as ore concentrates, without agglomeration, and non-coking coal. Production cost is competitive even in small-scale units, requires low investment costs, and environmentally acceptable.</p> <p><u>ELRED</u>: Powdered iron ore and coal are mixed in a fast fluidized bed reactor; the reactants are turbulently mixed with the reacting gas (air). The pre-reduced iron ore is then fed to an electric melting furnace to produce crude hot metal.</p> <p><u>FOSTER WHEELER - TETRONICS EXPANDED PROCESSIVE PLASMA PROCESS</u>: Developed to produce hot metal using coal and metal oxide concentrates. The reduction and melting processes are carried out in a single vessel which is equipped with a rotating plasma gun.</p>	<p>-demonstration plant with a production capacity of 600,000 tons/yr and a completion date in the mid-1980's is presently under construction in Sweden; -estimated commercialization date late 1980's.</p> <p>-pilot plant in Sweden; -estimated commercialization date late 1980's.</p> <p>-pilot plant in England by Foster Wheeler; -requires solutions to carbon and sulfur control, and using carbon as reductant, requires new refractory and economics; -estimated commercialization date mid-1990's.</p>	<p>"The Inred Process - A Revolutionary Method to Produce Hot Metal," Iron and Steel Engineer, April 1982.</p> <p>"Steelmaking in the Future," Iron and Steel Engineer, December 1981.</p> <p>"Compilation of Reports on Direct Reduction Technology and Economics," U.S. Steel Corp., June 1981.</p> <p>"Compilation of Reports on Direct Reduction Technology and Economics," U.S. Steel Corp., June 1981.</p>

APPENDIX E

ADVANCED STEELMAKING TECHNOLOGIES (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY DESCRIPTION</u>	<u>STATE OF DEVELOPMENT</u>	<u>REFERENCES</u>
<u>STEELMAKING</u>	<p><u>SCRAP PREHEATING:</u></p> <p>(See State-of-the-Art Steelmaking Processes)</p> <p><u>ENERGY OPTIMIZATION FURNACE (EOF):</u> Developed to produce molten steel using flexible metallic charge from a variety of sources such as scrap, hot metal, and cold or hot DRI. Fuel is supplied by carbon fires and requires no electricity for melting. The furnace is expected to have an industry-wide range of applications.</p> <p><u>MODERN ELECTRIC ARC FURNACE:</u></p> <p>(See State-of-the-Art Steelmaking Processes)</p> <p><u>MODERN BASIC OXYGEN FURNACE:</u></p> <p>The injection of carbonaceous fuels.</p> <p><u>LADLE DRYING AND PREHEATING</u></p> <p>(See State-of-the-Art Steelmaking Processes)</p> <p><u>INJECTION STEELMAKING</u></p> <p>(See State-of-the-Art Steelmaking Processes)</p>	<p>- pilot plant in operation since 1982 in Brazil; - estimated commercialization date late 1980's.</p> <p>-estimated commercialization date early 1990's.</p>	<p>Dr. D. Blickwede.</p> <p>International Iron and Steel Institute, "Energy and the Steel Industry," Brussels, 1982.</p>

APPENDIX E

ADVANCED STEELMAKING TECHNOLOGIES (Continued)

<u>PROCESS AREA</u>	<u>TECHNOLOGY DESCRIPTION</u>	<u>STATE OF DEVELOPMENT</u>	<u>REFERENCES</u>
<u>STEELCASTING</u>	<p><u>HORIZONTAL CONTINUOUS CASTER:</u> This mechanism has been used for the production of non-ferrous alloys and pig iron for a number of years. However, it has recently been reported that several companies have independently refined this system for casting steel as well.</p> <p><u>DIRECT STRIP CASTING:</u> A process where steel is continuously cast to yield a semifinished sheet or strip product. The process is expected to bring the following changes to the existing practices:</p> <ul style="list-style-type: none"> -shift from batch to continuous process; -manufacturing and capital cost reduction; -energy reduction; -down-sizing or decentralization without loss of economy of scale; and -increased product quality. 	<p>-estimated commercialization date late 1980's or early 1990's.</p> <p>-pilot plant in Japan, estimated commercialization date within 3 to 6 years.</p>	<p>"Horizontal Continuous Casting: A Technology for the Future," Iron and Steel Engineer, June 1984.</p> <p>"Direct Steel Sheet/Strip Casting," Jay D. Desai, testimony prepared for Energy Development and Applications Subcommittee, Committee on Science and Technology, U.S. House of Representatives, Feb. 1984.</p>
<u>STEELFORMING</u>	<p><u>DIRECT ROLLING:</u></p> <p>(See State-of-the-Art Steelmaking Processes)</p> <p><u>CONTINUOUS COLD ROLLING & FINISHING:</u></p> <p>(See State-of-the Art Steelmaking Processes)</p>		