ENERGY AND ENVIRONMENTAL PROFILE OF THE U.S. IRON AND STEEL INDUSTRY

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OVERVIEW

The U.S. iron and steel industry has undergone a major turnaround since its recession of the late 1980s and early 1990s. The United States has become one of the lowest-cost steel producers in the developed world. Shipments in 1995 were at their highest level in more than a decade, and total industry revenue was up approximately 25% in just three years.

The industry's current health is attributed to a variety of factors, including the weak U.S. dollar; strong demand from the automobile, appliance, and construction markets; consolidation of integrated steelmaking capacity, including the shutdown of less efficient mills; and the use of improved processes and process controls. After a period of relatively slow response to the rapidly evolving regulatory and competitive environment, the industry has also sharpened its competitive focus.

During the past decade, U.S. steel companies have invested nearly $30 billion in new process and product technologies, facilities, employee training, and product development. As a result, labor productivity has improved and the number of man hours required to produce a ton of steel has been cut in half. New process technologies have increased yields from around 70% in the early 1970s to more than 85% today. Yields may be pushed still higher as even newer technologies come on line.

Industry Focuses on Energy, Environmental Issues

The iron and steel industry, which accounts for between two and three percent of all energy consumed in this country, is also striving to improve its energy efficiency. The amount of energy required to produce a ton of steel has decreased by more than 40% since 1975. This reduction has been accomplished in part through adoption of more energy-efficient and productive processing steps. However, the capital to invest in new technologies is increasingly limited, especially as the costs of environmental control continue to rise.

Other than foreign competition, the biggest challenge facing the industry today is compliance with environmental regulations. The Clean Air Act and the Resource Conservation and Recovery Act have had significant impacts on the industry. Since 1970, the industry has invested approximately $6 billion in pollution control systems. The industry spent approximately $230 million in both 1993 and 1994 on capital expenditures for pollution abatement. In a typical year, 15% of the industry's capital investments go to environmental projects.[1] The industry faces even more challenges in the future as new, more stringent regulations are enacted.

Fewer Mills, Less Production Capability as Industry Consolidates

As a result of industry downsizing and consolidation over the last 15 years or so, the number of steelmaking facilities has decreased significantly. Large integrated mills have been the hardest hit, largely due to loss of market share to other materials, foreign competition, and the high cost of pension liabilities.[2] Many of these mills have closed, and those that are still operating have reduced their work forces while making process improvements to remain competitive.

Industry consolidation has also reduced U.S. raw steel production capability by about 30% since 1980. In the early 1980s, U.S. steelmakers were capable of producing raw steel at an annual rate of more than 150 million tons. By 1994 this capability had dropped to 108 million tons; in 1995 it rose for the first time in years to 112.5 million tons. During this same time period, the utilization of U.S. production capability rose from just over 50% to its current 93%.[3,4]

MARKET TRENDS AND STATISTICS

In 1995 total U.S. raw steel production was 104.9 million net tons. Of this, 62.5 million net tons were produced in Basic Oxygen Furnaces (BOFs) and 42.4 million net tons in Electric Arc Furnaces (EAFs) (see Figure 1). EAF raw steel production included 35.0 million net tons of carbon steel, 5.1 million net tons of alloy steel, and 2.3 million net tons of stainless steel.[3]

In 1995, net shipments of steel mill products reached their highest level in almost 15 years. Total net shipments were 97.5 million net tons, up nearly 25% from 1991. This upswing is attributed to strong demand from the steel industry's two largest customers, the automotive and construction sectors. Light vehicle production in the United States was up significantly in 1993, boosting steel demand in the automotive industry. Demand in the construction market also rose that year, as did demand in the oil and gas sector.

Recently, both imports and exports of iron and steel products have surged. In 1994, total imports of steel products were up by 50% over 1993 levels; in 1995 import levels dropped back a bit. In 1995, U.S. exports of iron and steel products were 8.6 million net tons, up 65% from 1994 levels and up more than 400% from export levels ten years earlier. The large increase between 1994 and 1995 was dominated by increases in sheet, strip, and plate.

ENERGY AND MATERIALS CONSUMPTION

Steel is an energy-intensive industry, consuming an estimated net total of more than 1.7 quads (10^{15} Btu) of energy (including electricity generating and transmission losses) in 1995. According to the most recent manufacturing energy consumption survey conducted by the Energy Information Administration, energy consumption by the U.S. iron and steel industry represents roughly 2.3% of all energy used in this country, and approximately 8% of all U.S. manufacturing energy use.

Energy costs account for up to 20% of the manufacturing cost of steel, typically $50 per ton or more, depending on location.[5,6] Nearly half of the industry's energy is derived from coal, most of which is used to produce coke for use in the blast furnace. Figure 2 illustrates the trends in fuel use by the U.S. steel industry between 1974 and 1994. Use of natural gas and electricity has increased over the period, while use of coal and petroleum has dropped slightly.

Table 1 shows the U.S. iron and steel industry's total energy consumption by fuel type for 1994 and 1995 according to data compiled by the American Iron and Steel Institute. The total energy consumption for 1994 was determined to be 1.82 quads with electricity losses included, or about 1.51 quads with energy losses excluded. For 1995, the total was 1.71 quads with electricity losses included.

Figure 1. U.S. Raw Steel Production (1980 - 1995)

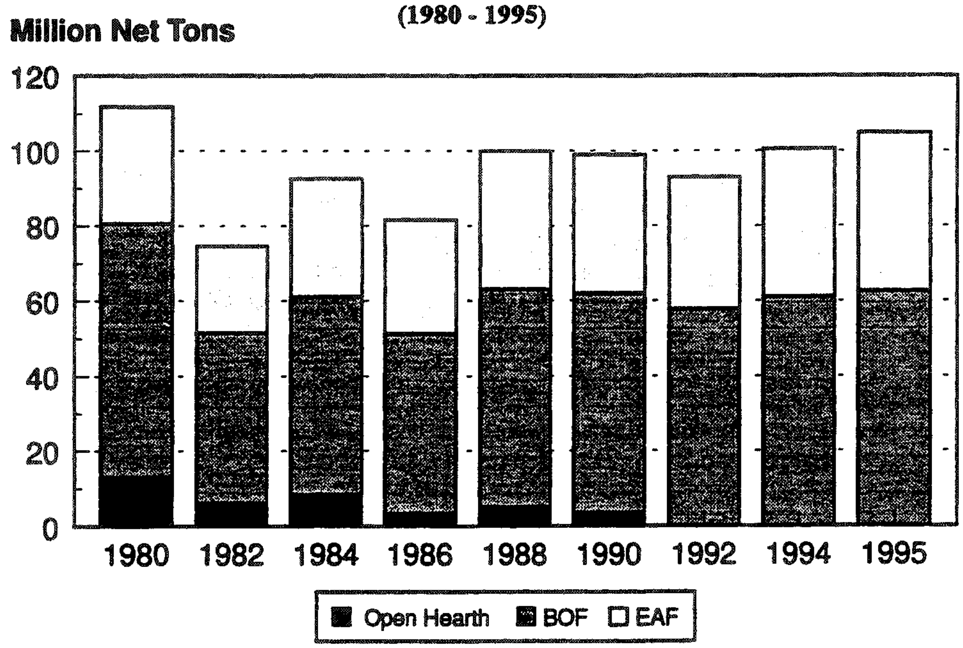
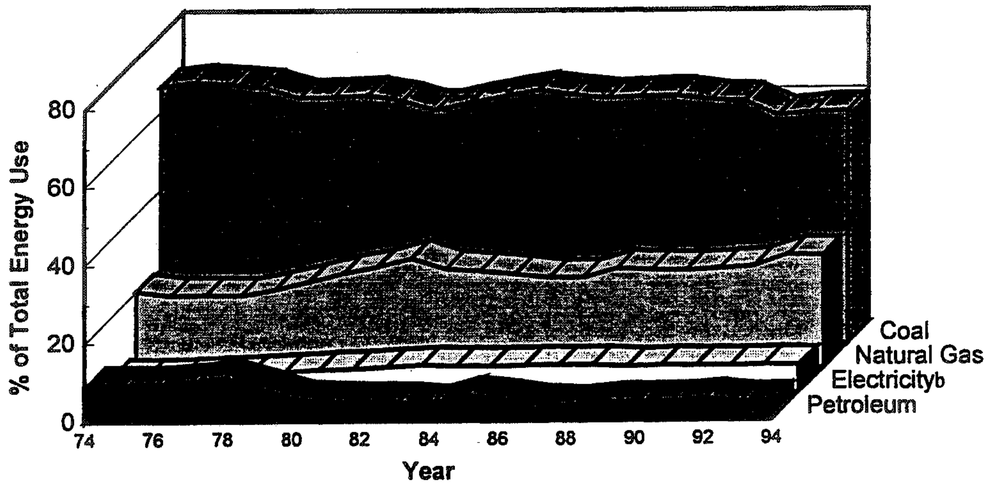


Figure 2. U.S. Steel Industry Energy Use by Fuel Type[a] (1974 - 1994)



Source: American Iron and Steel Institute

a Based on AISI survey companies
b Losses not included

Table 1 also shows usage levels for coke oven gas and blast furnace gas, the two major byproduct fuels associated with integrated steelmaking. These two fuels are recovered and used throughout the mill. Coke oven gas is typically used as a fuel for the coke ovens; blast furnace gas is used to generate steam and to preheat air coming into the blast furnace or to supply heat to other plant processes.

Table 2 shows total 1994 energy use (from Table 1) by major process within the iron and steel industry.

Energy Efficiency Continues to Improve

As shown in Figure 3, The U.S. iron and steel industry has reduced its process energy intensity by about 40% since 1974 through energy conservation measures, process improvements, and consolidation of the industry at the more productive and modern plants.[5] In 1994 the average energy intensity (excluding electricity losses) of producing semi-finished steel at integrated mills using BOF steelmaking was 20.76 million Btu/ton; for EAF steel producers it was 8.07 million Btu/ton.[7] The energy intensity of the EAF steelmaking step itself was approximately 5.5 million Btu/ton.

Twenty years earlier, in 1974, the average energy intensity for the industry as a whole was 31.71 million Btu per ton of shipped steel.[7] This reduction in energy intensity has occurred in spite of the industry's move toward higher value products, which has required additional processing (e.g., refining and finishing steps) that increases energy requirements.

Much of the reduction in energy intensity over the past 20 years has been achieved through the elimination of open hearth furnace steelmaking, the shutdown of older and less efficient mills, and the application of continuous casting, which has replaced the less energy-efficient and less productive process of ingot casting/soaking pits. Other process improvements that have increased steelmaking yields have also reduced energy requirements. In addition, the increased production of steel made in electric arc furnaces has reduced overall industry energy intensity.

Electric arc furnace steelmaking is less energy intensive (approximately 50% less) than basic oxygen furnace steelmaking because EAFs use 100% scrap as the charge versus about 25% by BOFs (although higher percentages of scrap charge can be achieved by preheating). Using scrap eliminates the most energy-intensive step of the steelmaking process – the conversion of iron ore to iron in the blast furnace. BOFs are limited in their use of scrap in the charge because of the inherent thermodynamics of the process.

Table 1. U.S. Iron and Steel Industry Energy Consumption - 1994 and 1995

Fuel	Total Industry Use (units as given)		Total Industry Use (10^{12} Btu)[a]	
	1994	1995	1994	1995
Coal	26.06 10^6 net tons	27.05 10^6 net tons	698.41	609.70
Coke (imported)	6.01 10^6 net tons	5.23 10^6 net tons	149.05	129.70
Electricity (with losses)	44.27 10^9 kWh	42.10 10^9 kWh	464.85	442.05
Natural Gas	403.45 10^9 ft^3	414.80 10^9 ft^3	403.45	414.80
Fuel Oil[b]	–	–	48.00	49.92
Petroleum Coke[b]	–	–	10.00	10.40
Oxygen	254.13 10^9 ft^3	288.10 10^9 ft^3	46.51	52.72
Purchased Steam[b]	–	–	4.00	4.20
Blast Furnace Gas	2,159.49 10^9 ft^3	2,348.11 10^9 ft^3	205.15	223.07
Coke Oven Gas	273.96 10^9 ft^3	277.71 10^9 ft^3	136.98	138.86
SUBTOTAL			**2,166.40**	**2,075.42**
LESS RECOVERED ENERGY				
Blast Furnace Gas	2,159.49 10^9 ft^3	2,348.11 10^9 ft^3	205.15	223.07
Coke Oven Gas	273.96 10^9 ft^3	277.71 10^9 ft^3	136.98	138.86
SUBTOTAL			**342.13**	**361.93**
EQUALS				
NET TOTAL			**1,824.27**	**1,713.49**

a Conversion factors are 26.8 10^6 Btu/ton of coal (EIA, 1995), 24.8 10^6 Btu/ton of coke (EIA 1995), 10,500 Btu/kWh, 1,000 Btu/ft^3 of natural gas (AISI 1995), 0.1387 10^6 Btu/gallon of fuel oil (EIA 1995), 183 Btu/ft^3 of oxygen (ANL 1982), 95 Btu/ft^3 of blast furnace gas (AISI 1995), and 500 Btu/ft^3 of coke oven gas (AISI 1995).

b Total industry use estimated based on survey results of AISI members, representing 59.4% of U.S. steelmaking capacity and approximately three-quarters of integrated steelmaking capacity.

Sources: *Annual Statistical Report 1995*, American Iron and Steel Institute, 1996.
Annual Statistical Report 1994, American Iron and Steel Institute, 1995.
Unpublished survey of energy consumption in the steel industry, compiled by the American Iron and Steel Institute, August 1995.

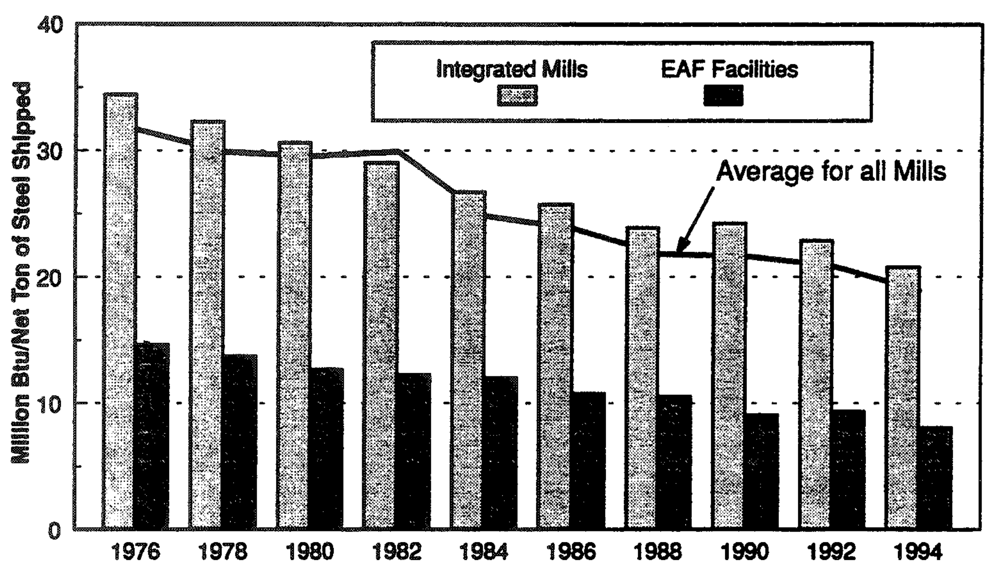
Table 2. U.S. Steel Industry Net Energy Use by Major Process - 1994

Process	Total Industry Use (10^{12} Btu)[a]	Percentage of Total
Cokemaking	109.17	6.0
Ironmaking	886.81	48.5
BOF Steelmaking	55.09	3.0
EAF Steelmaking	222.30	12.2
Casting	87.8	4.8
SUBTOTAL	**1,361.17**	**74.5**
All Other Processes (e.g., reheating, rolling, finishing)[b]	463.10	25.5
TOTAL	**1,824.27**	**100.0**

a Including electricity generating and transmission losses
b Taken as the difference between known total industry use and known subtotal use.

Source: *Annual Statistical Report 1994*, American Iron and Steel Institute, 1995.

Figure 3. U.S. Steel Industry Average Energy Intensity[a] (1972 - 1994)



Source: American Iron and Steel Institute a Electricity losses not included

EAF steelmaking currently accounts for 40% of all U.S. steel production. Some sources believe that this will increase to 50% over the next few years as additional EAF capacity comes on line. When using 100% scrap, EAF steelmaking cannot produce the highest quality sheet products because of the high level of residual elements in scrap. However, some EAF producers believe that alternative iron units from direct reduced iron and other sources can be used to upgrade a charge of lower grade scrap for higher grades of steelmaking.[8]

The late 1980s saw a relatively flat trend in the industry's average energy intensity. This trend is believed to be due in part to the industry's depressed operating levels during that period, which caused energy inefficiencies. Increased energy requirements associated with environmental controls were also a factor in this trend; another is the decline in growth of EAF capacity, which leveled off in about 1986.

Some additional improvements in energy efficiency are anticipated as the industry moves toward 100% continuous casting, improves yields, and produces stronger and lighter steels. The pace of these improvements, however, is dictated by the availability of capital to make the needed investments. Future reductions in energy intensity are not expected to be as dramatic as those already achieved.[7,9] Additional environmental requirements may offset some of the potential gains in industry energy efficiency.

In addition to the fuels shown in Table 1, the industry consumed iron ore in the form of pellets and other agglomerated products, fluxes, steel scrap, and direct reduced iron. Table 3 shows the amounts of these materials consumed in the U.S. iron and steel industry in 1994 and 1995. Total coke consumption includes imports plus coke produced domestically. Nearly two-thirds of 1994 U.S. steel production came from ferrous scrap, including home, purchased, and obsolete scrap.

ENVIRONMENTAL OVERVIEW

Over the past 25 years the U.S. iron and steel industry has invested approximately $6 billion in pollution control systems. In a typical year, 15 percent of the industry's capital investments go toward environmental projects. Costs for

Table 3. U.S. Iron and Steel Industry Materials Consumption - 1994 and 1995[a]

Material	Amount (1,000 net tons)	
	1994	1995
Iron Ore (total)	86,511	89,796
Natural ore	2,027	1,385
Pellets	71,085	74,564
Sinter, briquettes, nodules, and other	13,399	13,847
Fluxes (total)	5,918	5,632
Fluorspar	91	52
Limestone	1,350	1,241
Lime	3,949	3,898
Other fluxes	528	441
Scrap (total)	59,500	61,700
Carbon steel	55,000	57,200
Stainless steel	1,100	1,200
Alloy steel (excl. stainless)	900	870
Iron scrap	780	880
Other	1,700	1,600
Direct Reduced Iron	1,600	1,600

a Excludes alloys

Sources: *Annual Statistical Report 1994*, American Iron and Steel Institute, 1995.
Annual Statistical Report 1995, American Iron and Steel Institute, 1996.

operating and maintaining these facilities amount to $10 to $20 per ton of steel shipped.[1] In 1994 alone, the iron and steel industry (SIC 331) had capital expenditures of $231 million for pollution abatement, including $45 million on water pollution control, $20 million for solid/contained waste, and $166 million for air pollution control.[10] The figure for air pollution control (about 72% of total environmental expenditures) is primarily a result of operating coke ovens in compliance with the Clean Air Act.

Steelmakers Manage Large Quantities of Residues, Other Wastes

In 1993, the U.S. steel industry generated just over 30 million tons of solid wastes and residues such as slags, sludges, and dusts.[11] More than 80% of this total came from integrated mills.[12] The largest solid byproduct streams included blast furnace slag (about 40% of the total) and BOF slag (about 20%).

Although coke ovens are considered by many industry experts to be the biggest environmental problem of the iron and steel industry, environmental regulations affect the industry throughout all stages of the manufacturing and forming processes.[2] The following subsections briefly discuss air pollution, water pollution, and solid/hazardous waste in iron and steelmaking and describe the major environmental regulations that apply to the industry.

Industry's Emissions of Air Pollutants Must Comply with the Clean Air Act

In addition to air releases of chemicals reported in the EPA's Toxic Release Inventory (TRI) database, the iron and steel industry is a significant source of combustion-related particulate, carbon monoxide, nitrogen oxides, and sulfur compounds. Air pollutant emissions have dropped significantly since the 1970s as a result of increased pollution control as well as improved energy efficiency. A typical integrated steel mill in the U.S. currently emits about 4 million tons of CO_2 and about 10,000 tons of SOx annually, reductions of 28 and 95%, respectively, from their values 20 years ago.[12]

EPA has developed a list of sources that emit any of 189 hazardous air pollutants (HAPs). To date, EPA has listed the 174 categories of sources of these HAPs and has developed a schedule for the establishment of emission standards. These standards will be developed for both new and existing sources based on maximum achievable control technology (MACT). The MACT is defined as the control technology achieving the maximum degree of reduction in the emission of the HAPs, taking into account cost and other factors.[2]

Included on the list of 189 HAPS to be regulated are compounds of chromium, nickel, manganese, cadmium, and other heavy metals. Because many of these metals are routinely found in iron ore, scrap, and alloying materials, most steelmaking processes will be affected in some way. MACTs for air emissions of these metals are expected to be established in 2000.

As part of the clean Air Act, EPA has established National Air Emission Standards for Hazardous Air Pollutants (NESHAPS). NESHAPS currently in effect for the industry include standards for coke oven batteries, benzene emissions from coke byproduct recovery plants, halogenated solvent cleaning, and chromium from industrial process cooling towers.

The NESHAPs have already had a significant effect on the iron and steel industry's coke ovens. In late 1991, representatives of the iron and steel industry participated in formal regulatory negotiations with EPA, state and local regulatory agencies, and environmental groups to develop a mutually acceptable rule to implement the terms of the Act's coke oven provisions. In 2000, MACTs will be established for air toxic emissions from coke pushing, quenching, and battery stacks. In addition, coke oven operators will still face unknown but likely tighter technology-based standards in 2010 and risk-based standards in 2020.

The industry may also be affected by possible revisions to the National Ambient Air Quality Standard for PM-10 (particulate matter less than 10.0 microns in diameter). Under the CAAA, EPA reviewed the basis for the existing ambient air PM-10 standard and, in November 1996, proposed new standards for both particulate matter and ozone. A lower standard, or a restriction on the emissions of smaller-diameter particulate matter, may cause many more areas of the U.S. to be classified as non-attainment areas and would trigger requirements for states to impose much more stringent emission control standards for sources of particulate matter and precursors of fine particulate such as SOx and NOx.

Great Lakes Water Quality Initiative Affects Many Mills

A recent regulatory development that significantly affects iron and steel industry effluents has been the development of uniform water quality standards under the Great Lakes Water Quality Initiative. By March of 1997, the Great Lakes states (including Illinois, Indiana, Michigan, Minnesota, New York, Pennsylvania, Ohio, and Wisconsin) must adopt rules and procedures consistent with the Water Quality Guidance for the Great lakes System (40 CFR 132; also amendments 122, 123, and 131). The Guidance places particular emphasis on decreasing bioaccumulative toxics and also provides a process for addressing both point and non-point source pollution.

RCRA Establishes Regulations on Handling, Disposal of Solid and Hazardous Waste

In 1993, the U.S. steel industry generated just over 30 million tons of solid wastes and residues such as slags, sludges, and dusts.[11] Some of these materials are produced during an ironmaking or steelmaking process, such as the formation of blast furnace slag during ironmaking. Other of these materials result from pollution control measures, such as the air pollution control dusts captured during the cleaning of gaseous furnace waste streams. Applying 1993's rate of waste generation to 1994 would yield about 32 million tons of byproducts. In addition to these annual amounts, many additional tons of byproducts have been "stockpiled" at many mills for years.

The cost of disposing of these wastes is estimated to be as high as half a billion dollars each year. In addition, the value of the potentially recoverable iron units is believed to be in the $500-million range.[11] Table 4 lists the major solid wastes and, where available, an estimate of the amount of each produced annually.

There are specific RCRA-listed wastes associated with the iron and steel industry, including

Cokemaking

- Tar residues (K035, K087, K141, K142, and K147)
- Oil (K143 and K144)
- Naphthalene residues (K145)
- Lime sludge (K060)
- Wastewater sump residues containing benzene and polynuclear aromatic hydrocarbons (K144)

Iron and Steel Manufacturing

- EAF emission control dust and sludge (K061)

Finishing

- Wastewater sludge from cooling, descaling, and rinsing (D006, D007, D008, D009, D010, and D011)
- Spent pickle liquor (K062)

Byproducts Contain Valuable Iron

The byproducts or residues produced during ironmaking, steelmaking, and rolling operations – including slags, dusts, sludges, and mill scale – represent a valuable source of iron that can be recycled into the steelmaking process, saving energy by substituting for pig iron produced in the blast furnace. Table 4 lists these byproducts and the estimated amount of each produced in 1994. Table 5 summarizes the potential recoverable iron from each of the major byproducts streams.

According to Table 5, an estimated 3,700 thousand tons of iron contained in byproducts are currently recycled, with an additional 4,600 thousand tons remaining. Industry experts consider this iron nearly 100% recoverable with further research, development, and demonstration of the following:

- cold bonding (briquetting) technologies for dusts and sludges
- dewatering technologies for sludges
- dezincing technologies for dusts and sludges
- deoiling technologies for mill scale and rolling and finishing sludge

Table 4. Iron and Steel Industry Major Solid Wastes/Byproducts - 1994
(1,000 tons)

Solid Waste/Byproduct	Estimated Annual Production
Blast Furnace Slag	12,400
Blast Furnace Dust	410
Blast Furnace Sludge	690
Basic Oxygen Furnace Slag	6,000
Basic Oxygen Furnace Dust	270
Basic Oxygen Furnace Sludge	1,280
Electric Arc Furnace Slag	4,600
Electric Arc Furnace Dust	650
Mill Scale	3,670
Rolling Sludge	1,000
Spent Pickle Liquor	905
Other (including secondary slags, grinding wastes, fines, and fly ashes)	~1,000[a]
TOTAL SOLID WASTES	~ 32,000

a Estimated as the difference between documented total tonnage and documented tonnage of other wastes explicitly listed.

Sources: Personal communication with J. Hamling, US Steel Group, 1996.
Personal communication with B. Kolarik, Timken Steel, 1996.
Profile of the Iron and Steel Industry, U.S. Environmental Protection Agency, EPA 310-R-95-005, September 1995.
"A Research Program for the Minimization and Effective Utilization of Steel Plant Wastes," J. Szekely, *Iron and Steel Maker*, January 1995.
Microwave Separation of Oil-Water Sludges, Part 2: Application to Polymer-Treated Sludges, Electric Power Research Institute Center for Materials Production, CMP 95-4, October 1995.

Additionally, efforts to reduce the costs of some existing and emerging technologies are needed to make iron recovery economically viable.

In 1995, the industry consumed more than 56,000 net tons of pig iron and 1,600 thousand net tons of direct reduced iron (DRI). The recovery and reuse of the additional 4,600 thousand net tons of iron contained in byproducts could reduce the demand for pig iron and lessen the energy and environmental impacts of its production via the traditional cokemaking/blast furnace route.

Table 5. Potential Recoverable Iron from Steel Industry Byproducts - 1994

Byproduct	Average Iron Content (%)	Total Iron Content - 1994 (1,000 tons)	Iron Content Currently Recycled		Remaining Recyclable Iron (1,000 tons/yr)
			%	1,000 tons/yr	
Blast Furnace Slag	0 - 5	~0	0	0	0
Blast Furnace Dust	10 - 35 (avg. 32)	131	40	52	79
Blast Furnace Sludge	15 - 48 (avg. 44)	304	40	121	183
BOF Slag	20 - 25 (avg. 22)	1,320	50	660	660
BOF Dust	60 - 67 (avg. 62)	167	44	74	93
BOF Sludge	50 - 63 (avg. 62)	794	44	350	444
EAF Slag	20 - 25	1,000	50	500	500
EAF Dust	20 - 40 (avg. 24)	148	89[a]	132[a]	16
Mill Scale	60 - 74 (avg. 60)	2,220	75	1,670	550
Rolling Sludge	30 - 74 (avg. 40)	400	0	0	400
Spent Pickle Liquor	64 - 70[b]	680	19	126	554
TOTAL	--	**8,300**	--	**3,700**	**4,600**

a EAF dust is mainly processed for zinc, with residuals used in ways that are not actually recovering iron values.

b Iron content of iron oxide in hydrochloric acid spent pickle liquor and iron sulfate in sulfuric acid spent pickle liquor.

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