Kirk-Othmer Encyclopedia of Chemical Technology.

IRON AND STEEL, ECONOMIC ASPECTS

The economics of iron and all of its derivative materials is dominated by the fact that iron is the most widespread and ubiquitous metallic element found in the earth's crust. Iron ore deposits are present and mined on all the inhabited continents. From these ores, iron has been extracted for centuries, through the Iron Age and eventually the Industrial Revolution. The economics of iron production from ore is therefore the starting point, but then the preparation of steel from the base iron incurs further costs. And after centuries of iron products entering the world economies, iron in the metallic form, as iron and steel scrap, is now recycled in significant quantities, having a significant effect on the overall economics of steel. Therefore, in this article, the economics of iron and steel scrap will also be considered.

1. Iron Ores

1.1. Sources

Iron virtually never is found in nature in the metallic state; most ores are oxides, *hematite* Fe_2O_3, [1309-37-1] or *magnetite*, Fe_3O_4, [1309-38-2], a few are sulfide, *pyrite*, FeS_2, [1309-36-0] and fewer still carbonate, *siderite*, $FeCO_3$, [14476-16-5]. The grade of the ore is the percent iron in the ore. For example, if the ore is pure hematite, the grade is 70% Fe. This is the highest it can go. The ore mined in the Carajas region of Brazil is about 68% Fe. This means that only about 2% non-iron oxide minerals, known as gangue, are present in the ore as it is taken from the ground. This material, usually silica, SiO_2, and alumina, Al_2O_3, is not a problem in subsequent reduction processes unless it is present in exessive amounts. The economic cut-off for oxide ores to be sent directly to reduction processes is about 60% Fe. With less iron in the ore, the gangue costs too much to heat and melt in the reduction process, so the ore must be ground and the gangue separated, either by flotation of the silica, or magnetic separation of the ferrimagnetic Fe_3O_4.This adds significantly to the cost of the ore feed to a reduction process.

An example of the need for concentration of the ore is the ore found in northern Minnesota and Michigan in the United States. From the start of mining of the Mesabi Range ores in that region, late in the nineteenth century, until the Second World War, the ore was of a grade that allowed it to be shipped directly to the blast furnaces for reduction. However, the tremendous increase in shipments in conjuction with the war effort led to the depletion of the high grade ore deposits and a reduction in the average iron content to 50% by 1950. Yet there were millions of tons of low-grade magnetite ore with iron content around 35%, called taconite, in the same region and in Quebec and Labrador, Canada. The development of fine grinding and magnetic separation technology combined with the development of pelletizing processes forming pellets from the highly concentrated (64% Fe) fine material allowed this material to become economically viable as a source of iron for reduction processes in the Great Lakes region of the U.S. by the early 1960s prior to the development of the rich Venezuelan and Brazilian ore bodies. Subsequently, over 75×10^6 t of annual capacity to produce pellets in Minnesota and Michigan were constructed. Concentration and pelletizing plants were also built in other

Table 1. Operating Factors and Costs for Iron Ore Processing

Process	Units/sinter, t	Typical unit price, $	Typical cost, $/t
Sintering			
ore	1.1 t ore fines	26[a]	28.60
energy	0.05 t coke breeze	100	5.00
	1.8×10^6 Btu gas	2.50	4.50
	25 kwh electricity	0.05	1.25
labor	0.2 h	30	6.00
flux	0.125 t dolomite	25	3.12
maintenance			5.00
Total cost/t sinter			*53.47*
Pelletizing			
ore	1.0 t magnetite	16[b]	16.00
grinding energy	40 kwh	0.05	2.00
concentrating	20 kwh	0.05	1.00
balling	0.003 t binder	200	0.60
indurating	0.8×10^6 tu oil	2.50	2.00
	25 kwh	0.05	1.25
maintenance			5.00
labor	0.3 h	30	9.00
Total at mine site			31.85

[a]At blast furnace plant site.
[b]At mine site.

locations in the world where lower-grade ore bodies were present, including in Brazil, Philippines, Sweden, Canada, Russia, and Mexico.

Therefore, oxide for reduction to metal is available in three generic forms: high-grade lump ore (>2 cm), sinter fines (0.2–2 cm), and pellets (1–2 cm). The sinter fines are the most prevalent form, as the ore, when mined, is broken up by explosives and transported to crushers, which finish the breaking of the lumps to a maximum of about 2.5 cm. This results in a large amount of material that is too small to be charged into a reduction process based on upward flowing reducing gases, yet not fine enough to be pelletized, which requires 80% <27 microns. This sinter feed material is put through a sintering plant next to the blast furnace to produce sinter which is an agglomerate of larger irregular pieces that can be fed to the iron blast furnace for reduction.

1.2. Processing and Transportation Costs

All of these various treatments of the ore have costs for energy, labor, supplies, maintenance, and control. These costs depend on the unit consumption of each factor, and the unit cost of each. These obviously vary to some extent, particularly the unit costs, but Table 1 gives some reasonable values for each.

The capital costs to open ore mines, and construct concentrators, pellet plants or sinter plants vary widely. Pelletizing plants alone have been reported to cost about $100 per annual ton of capacity. Great care must be taken in using these numbers, however, because they are for the individual unit operation itself, and do not reflect the total cost of a project centered around the plant in question. This can often include rail lines, utilities, material storage and handling facilities, product shipping facilities, docks, dredging, etc., and environmental controls.

Iron ore bodies rarely occur where the reductants, water, and markets for iron and steel are located, and so the ore or pellets usually have to be transported to the iron and steelmaking plants. Transportation costs are not insignificant. Long-haul rail transportation in the United States can add $15–25/t to the cost of pellets made at the mine site by the time they reach the steel mill. A combination of rail and ship is also used for pellets going to mills on the Great Lakes, with typically a $10–15 /t transport cost.

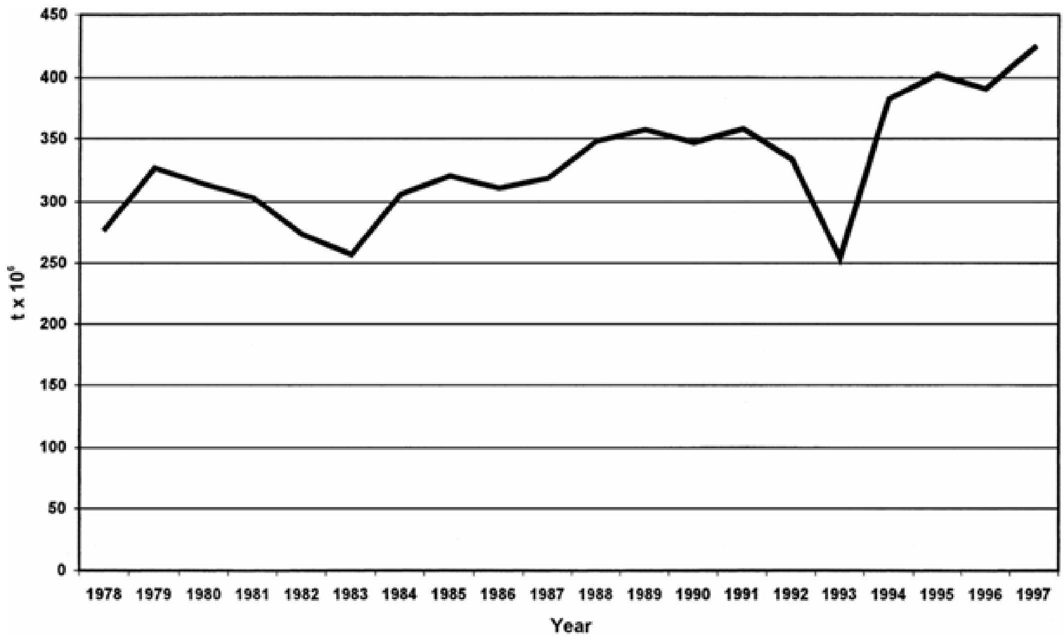

Fig. 1. Seaborne iron ore trade (1)

There has been a large increase in the international trade of iron ore in the latter half of the twentieth century, (Figure 1). The cost of water-born ore transportation has also been dramatically reduced by the advent of Cape-size super-ore carriers, capable of transporting up to 250,000 tons of ore in a single trip. Costs for long distance ship transportation, such as from Brazil to Rotterdam or Australia to Japan range between \$5 and \$8 per ton, depending on the level of business. To these costs have to be added stevedoring costs of typically \$4 /t.

1.3. Ore Prices

Figure 2 shows the fluctuations in prices paid for two of the most common iron ore commodities, whose prices influence all other contracts for iron ore. These contracts are negotiated annually in December-January for the following year.

2. Scrap Iron and Steel

Since the start of the Industrial Revolution in the Nineteenth Century, about 35×10^9 t of metallic iron has been produced and entered the economies of industrial countries. For example, about 2×10^9 tons of steel has been produced in the United States since 1900, and 200×10^6 tons of cast iron has been produced and put into iron products. Europe is the other location in the world where equivalent amounts of iron and steel have been consumed. Various studies have been made of the amount of steel that can eventually be recovered as scrap. Although not exact, in due course as much as 85% is eventually recoverable, and in fact is recovered by the scrap recycling industry. This industry is highly fragmented, in spite of recent attempts of aggregate. It is a highly competitive industry, involved in collecting, processing, and brokering scrap to the steel industry and to iron and steel foundries, worldwide.

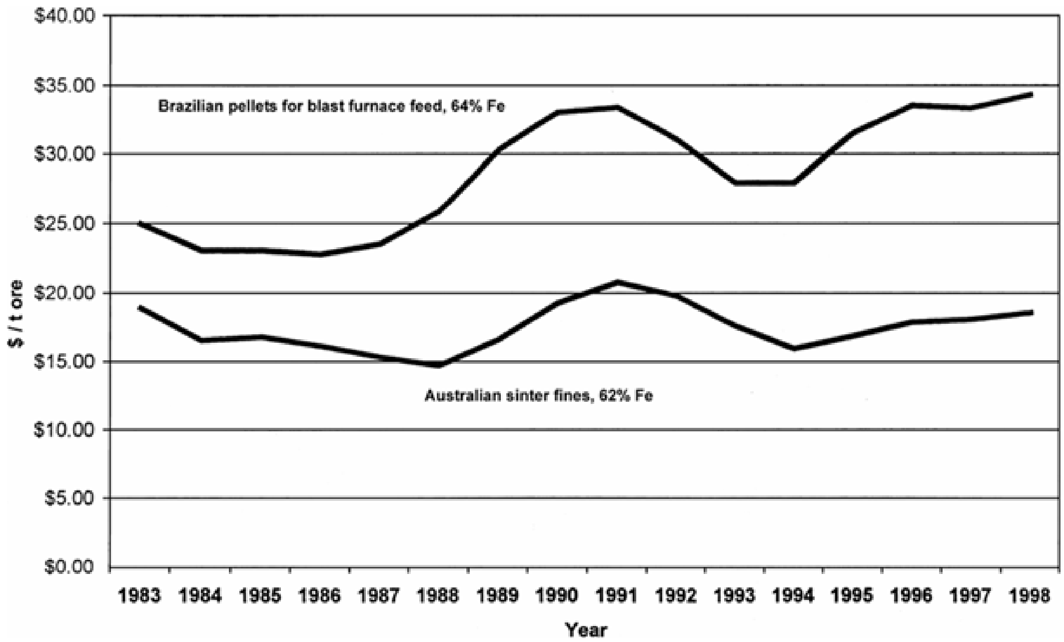

Fig. 2. Selected major iron ore product prices (1).

2.1. Scrap Types

There are many categories of scrap and they each have different end uses and markets. First, there is *prompt* industrial scrap. This is the scrap that results from manufacturing activities applied to recent mill products such as coils of hot and cold-rolled sheet steel, structurals, plate, etc. This material is collected by the fabricator, stamping plant operator, machine shop operator, etc, as they consume the mill product, and is sold to a scrap broker for resale to its customer, or is offered by the source firm directly to the market. Usually, this material is not accumulated, but flows on a monthly basis to scrap consumers. An example of this are the automotive (No. 1 factory) *bundles* that are auctioned off each month. Because they become available continuously and must be moved into the market regardless of demand for them, the price of such bundles fluctuates rather widely (see Fig 3).

Because this material is generally clean, segregated by grade, and kept separate from other scrap, it is worth more than most other types of scrap, include bushelling, which is the same material as in factory bundles, but in loose form, rather than formed into a bundle.

Scrap that is collected from previous use in the economy is obsolete scrap. It is collected in the first place by demolition firms or small scrap dealers, who bring it to scrap processing yards. Here it may be sheared to maximum lengths, and/or cleaned of tramp materials. In the case of junk automobiles, the radiator and wiring are removed, the tires removed, the cast iron or aluminium engine block is separated, and the remaining chassis, frame and body is fed to a massive shredder, which cuts it into pieces less than about four inches in diameter, and separates the cloth, glass, and plastics into a stream called “shredder fluff”, which is sent to landfills. A stream of nonferrous metals scrap, principally aluminium and copper, is separated from the metallic shred and sold to nonferrous scrap processors. Thus, the operation of an automobile shredding business is a typical process operation with raw material, energy, labor, and capital cost issues. The raw material cost is the price that the shredder is willing to pay the collector for an automobile hulk ready for shredding. That value is usually $25–50 /t, depending on the level of demand for shredded scrap at the moment. The net cost of operation

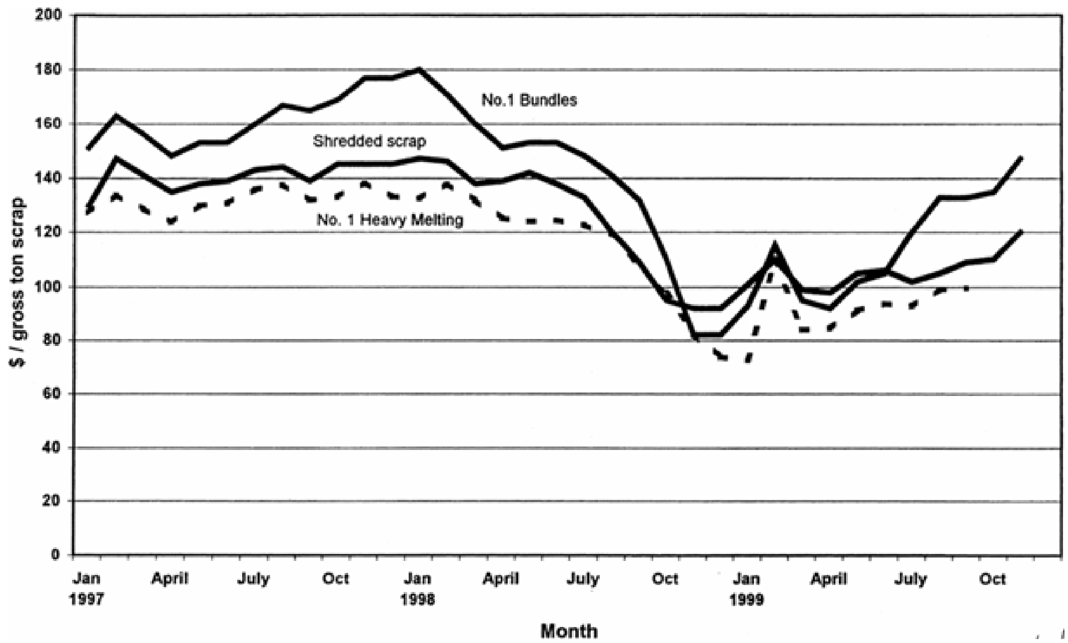

Fig. 3. Monthly prices of scrap in U. S. (2).

of the shredder is on the order of \$30–50 /t of fininshed shredded scrap. Since this product is relatively cleaned of nonferrous materials, usually containing 0.15–0.25%Cu, this material demands a premium among obsolete scrap products.

Other obsolete scrap types include No.1 Heavy melting scrap, No.2 Heavy melting scrap, plate and structural, rails, and turnings. Heavy melting scrap is a collection of old steel products, often processed through a large shear to reduce the length of pieces to a maximum of five feet. If it has been been some what segregated and obvious sources of copper and other contaminanats have been removed, it is known as No.1 HM scrap. If it has these potential contaminants still present, it is No.2 HM. The value of these two historically differed by \$10–20 /t but more recently most No.2 has been sent to megashredders that clean it up and the prices of No.1 and No.2 have merged. Plate and structural (P&S) is exactly what it says: cut up pieces of plate steel and steel structural shapes, cut to maximum of five feet lengths. Since the chemistry of plate and structurals is not highly variable, and P&S is relatively clean and free of contaminants, it commands a price near that of No.1HM. Cut up railroad rails are also predictable and command a good price. Turnings are the lowest quality scrap because of their elevated content of lead and sulfur, added to machining grades of steel to improve machinability, but both generally undesirable in most steel. Since they also are often alloy steels with valuable recoverable chromium, nickel and molybdenym in them, they are also used in steel furnaces, but usually in restricted amounts in each charge. Municipal incinerator scrap is sometimes sent to the steel industry for remelting. It is relatively low in metal content and purity. Also, tin cans are increasingly being recycled as such.

Finally, there is home scrap, which is scrap that occurs as steel is transformed from liquid into mill products. This occurs at every stage, from metal remaining in the ladle and tundish, and dumped out with the slag at the end of processing a batch (known as a heat) of liquid steel, to cropped ends of blooms and billets, to short pieces at the end of long product rolling, to scrap from incorrectly made material. This material is

Table 2. Types and Analyses of Steel Scrap

Scrap type		Typical residuals, % Cu+Ni+Cr+Mo	Range of residuals, % Cu+Ni+Cr+Mo
prompt industrial	factory bundles	0.10	0.07–0.20
	No 1 bundles	0.10	0.07–0.25
	busheling clips	0.10	0.07–0.25
	cut structurals	0.50	0.40–0.65
	turnings		0.30–1.50
obsolete scrap	No.1 heavy melting	0.50	0.30–0.65
	No. 2 heavy melting	0.70	0.45–1.00
	plate and structural	0.35	0.20–0.50
	shredded	0.45	0.35–0.60
	broken cast iron	3.5% C, 1.5% Si	
	RR rails/wheels	0.70	0.60–0.80

Table 3. Residuals Limits for Steel Products

Steel product	Maximum residuals, % Cu+%Ni+%Cr+%Mo
tin-plate steel	0.12
deep drawing sheet steel	0.14
drawing quality sheet	0.16
enameling sheet steel	0.14
commercial quality sheet	0.22
rod of fine wire drawing	0.25
special quality bar	0.30

collected and returned to the furnace for remelting, It may be a credit to a given charge of metal, but in the long run it is an expense because it reduces the yield of finished product from the liquid made up front.

Table 2 is a summary of the various types of scrap and an estimate of the content and range of contaminants in each.

Table 3 gives typical residual limits for various types of steel products.

2.2. Scrap Consumption and Prices

A steady decrease in home scrap is the result of the implementation of continuous casting in place of ingot casting. The rise in obsolete scrap consumption is a reflection of the increase in electric-furnace based steelmaking by mini-mills. Figure 4 gives the prices of various types of scrap. Note the volatility of these prices. They reflect the close relationship between demand and price. Prompt scrap is sold regardless of demand, and a lack of demand drives prices for it down. On the other hand, obsolete scrap is only demanded, and a decrease in demand reduces the price, but also reduces the price paid by brokers to collectors. As that price drops, the collection of scrap slows, and the margin for the dealer stays about the same.

Obsolete scrap is one of the purest forms of elastic supply–demand commodities there is, reflecting the fact that in the United States there is no shortage of scrap. Figure 5 illustrates the relationship between prices paid for obsolete scrap, No.1 Heavy Melting scrap, in dollars deflated by the Urban CPI, and the quantity of obsolete scrap collected by the scrap industry. There is clearly an inverse relationship, which can only happen if the quantity of scrap is increasing faster than the demand. The sharp price peak in 1974 occurred because the United States government imposed a limit on the total export of scrap but not on the number of export licenses, and so a bidding war to maximize the ownership of scrap for export purposes broke out, and lasted

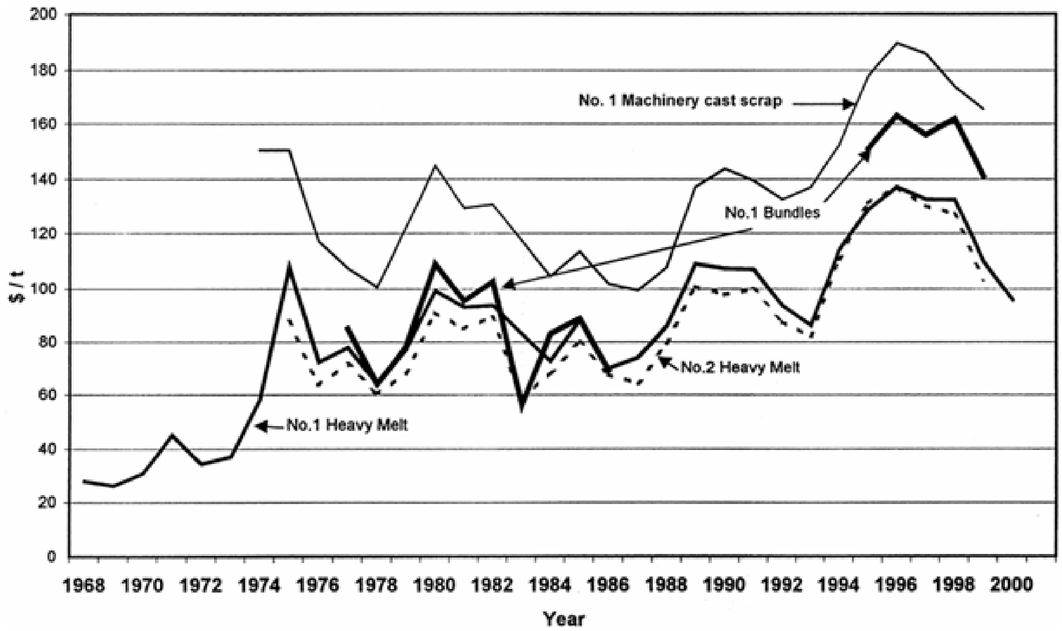

Fig. 4. Prices of various types of scrap in the U.S.

until this action was rescinded. This is a confirmation of the predictions of how much iron is present in the economy, and the ultimate recoverability of that material. Figure 6 illustrates how much scrap is added to the U.S. economy in the form of 85% of the steel products that enter the economy that year, (which will be recoverable over the next several decades as products wear out and are recycled), and the net increase in scrap inventory by subtracting the amount of scrap recovered in the same year. For all years in the past, there has been a net increase in the scrap inventory in the economy.

Given the estimates made by various organizations in the 1970s of the inventory existing at the time, which ranged from 500 to 750 $\times$ 10^6 tons of iron, the existing inventory in the U.S. has continued to grow over the last three decades to over 1 $\times$ 10^9 tons.

There is a large worldwide trade in scrap. Table 4 shows which countries are exporters and which are importers of scrap in 1997.

Figure 7 shows the history of scrap exports from the United States, which has been the major exporter of scrap for a long time. During the years since the end of the cold war, scrap has been increasingly exported by the Ukraine and Russia, which has changed the trading pattern. Turkey is now less of an importer from the United States than it used to be. In 1998–1999, the United States began to import scrap from Europe and the former Soviet states, and its exports dropped precipitously. Because the world steel economy contracted in response to the Asian financial crisis, demand for scrap in Asia fell, and scrap prices fell. Since the supply in Russia and others is essentially unlimited, the price can become very low.

In additon to scrap that enters the steel industry, the iron foundry industry also consumes significant quantities of iron and steel scrap, approximately 12 $\times$ 10^6 t/yr in the United states. This is true across the globe. All foundries have to have a metallic charge for their melting devices, whether they be cupolas, electric arc furnaces, or induction furnaces. The industry utilizes pig iron, and scrap steel, to which carbon raisers are added, since cast iron contains about 3.5% carbon. The recycled cast iron engine blocks from scrapped automobiles and trucks are used in charges to cast iron furnaces.

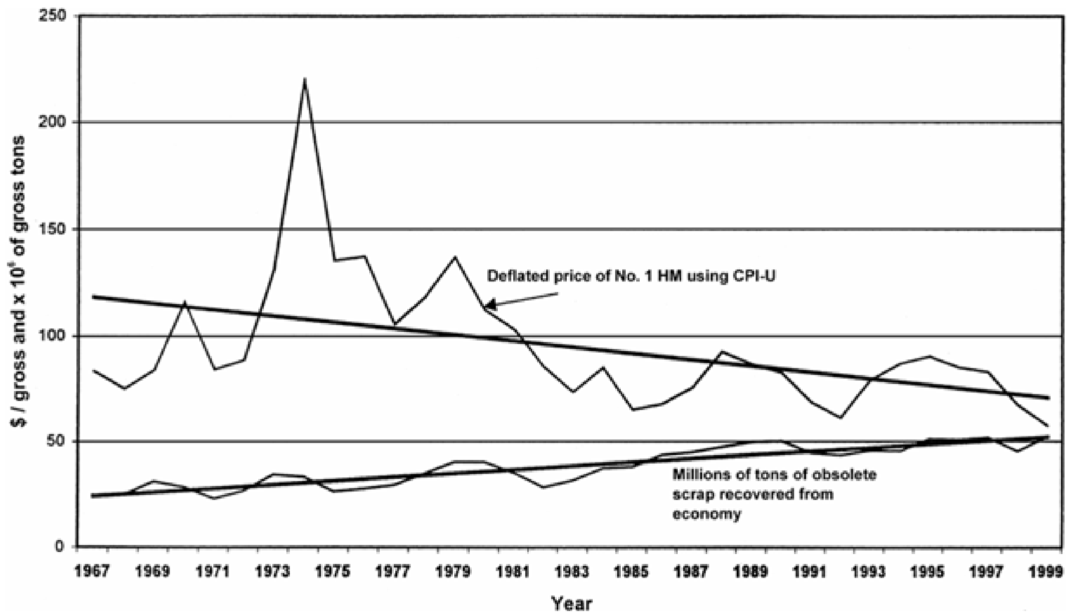

Fig. 5. Deflated price of No. 1 Heavy melt scrap and tonnage of obsolete scrap recovered each year.

Table 4. Major Scrap Importing and Exporting Countries, 1997

Country	Imports, $\times 10^6$ t	Exports, $\times 10^6$ t
United States	2.9	8.9
Japan	0.4	2.3
Korea	6.5	0.0
Turkey	7.2	0.0
France	2.3	3.5
England	0.2	3.6
Taiwan	2.0	0.1
Italy	4.3	0.0
France	2.3	3.5
Spain	5.2	0.0
Germany	1.9	6.9
World Total	*52.1*	*49.5*

3. Iron Reduction

Regardless of the chemistry and form of iron ore, it has to be reduced to the metal to be useful. The reductant is ultimately a gas, either CO or H_2, which comes from coal, coke, oil, or natural gas. The process used most widely to reduce ore to metal is the iron blast furnace process, which annually produces about 600×10^6 t of molten pig iron around the world. This process (see Iron by direct reduction) utilizes coke, made from coal, as the principal reductant and source of CO reducing gas. Lump ore, sinter, or oxide pellets are charged into the top of the furnace, along with limestone to flux the silica and alumina, and the coke. Air injected into the bottom of the shaft of the furnace reacts with the carbon in the coke to form CO, which in turn reduces the oxide ore progressively from Fe_2O_3 to Fe_3O_4 to FeO and finally to Fe. Since there is a solid column of coke from

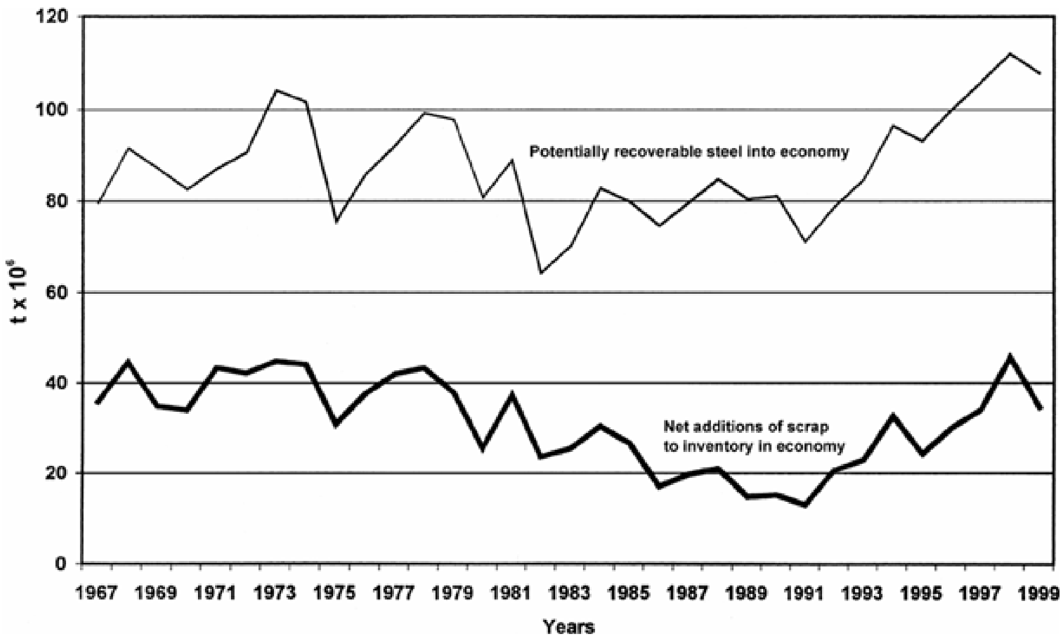

Fig. 6. Net scrap additions to the scrap inventory.

the bottom of the furnace, the iron runs over the coke and absorbs carbon, up to about 4.5%, which is collected in the bottom of the furnace and periodically tapped out in to ladles. This material is known as pig iron, in the solid form, or hot metal, in the liquid form.

Other supplemental fuels/reductants may be injected into the furnace along with the air blast to improve the production rate or cost structure of the pig iron. They include fuel oil, natural gas, oxygen, and finely ground coal. They each reduce the amount of coke needed per ton of pig iron, but cannot replace it entirely because the coke, with its high-temperature strength, is needed to keep the porosity of the bed of solids in the shaft open for the passage of the reducing gases necessary for the gas–solid reduction reactions.

The gases leaving the top of the furnace contain CO, CO_2, H_2, H_2O, and N_2, as well as minor amounts of NH_3 and $(CN)_2$. This gas has a low heating value, about 10% of that of natural gas, but it can be burned. After cleaning, it is burned to provide heat to preheat the air blast to the furnace, thus recouping its energy content. The hotter the air blast, the less coke is needed to provide the thermal energy required for the blast furnace process. This temperature is typically on the order of 1000°C. If the temperature is lower, more coke is needed; if higher, less is needed. Thus, the efficiency of preheating the air blast is an important factor in the economics of the blast furnace, and much work was done in the 1960s, 1970s, and 1980s to improve this process.

Of course, the air blast must be propelled into the furnace in order to overcome the resistance of the bed of solids, and this is done by large compressors, which require electrical energy, another cost of production.

The size of blast furnaces has increased over the decades until it has reached monumental proportions, up to 15 meters in hearth diameter, producing upwards of 10,000 t/d of pig iron. Productivity of blast furnaces is usually expressed as ton of pig iron per day per cubic meters of internal furnace, volume, and ranges from 1 to 3.5. Of course, many smaller furnaces still remain in active use, but their production cost is relatively higher, since it takes about the same labor to run a smaller furnace as it does a larger one. On the other hand, if the hourly pay rate is lower, the labor cost may be equivalent, or lower, and in any case the labor cost is usually a small fraction of the total operating cost.

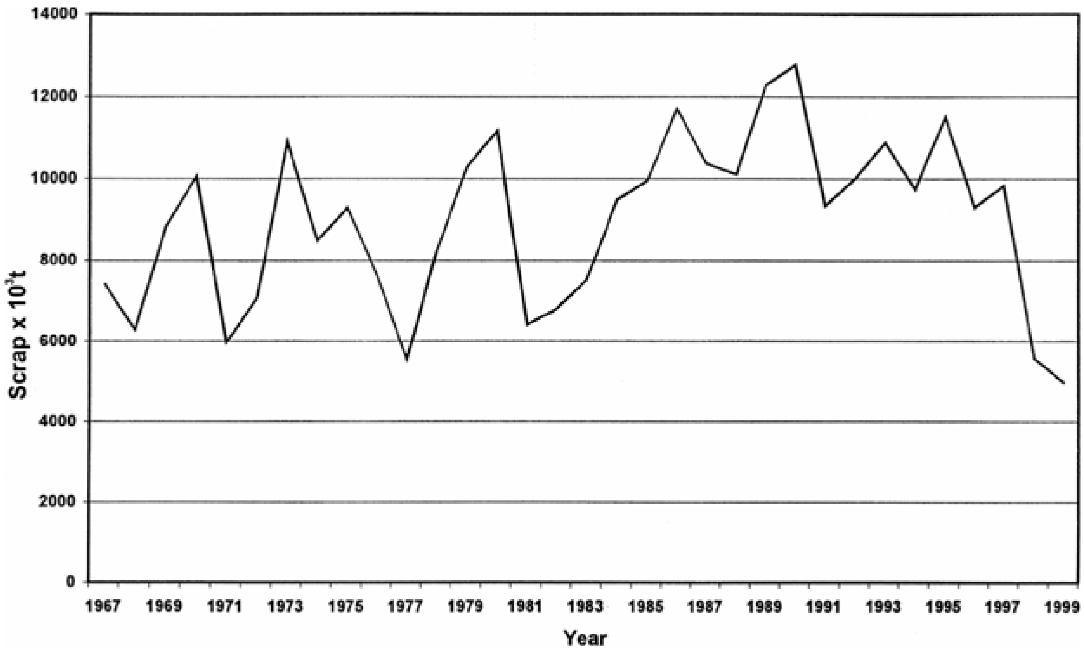

Fig. 7. Steel scrap exports from the United States (3, 4)

Table 5. Operating Factors and Typical Costs for Blast Furnace Production of Pig Iron

Item	Factor, units	Unit cost, $	Cost, $ /t
pellets	1.5 t	40	60
coke	0.5 t	120	60
flux	0.1t	20	2
energy	20 kwh	0.05	1
gas	2×10^6 tu	2.50	5
maintenance			6
labor	0.3 h	30	9
Total /t of liquid pig iron			143

Once hot metal is tapped from the furnace, it is either sent directly to an adjacent basic oxygen furnace plant or open hearth shop to be charged into those furnaces for refining into steel, or it is cast into solid 50 kg “pigs” via pigging machine. These pigs are are sold to foundries or to electric funace steelmakers for remelting.

There are environmental costs associated with the blast furnace process, principally tied to the operaation and disposal of wastewater from the dust scrubbers cleaning the top gas before its reuse.

Because of the variety of combinations of ores, reductants, preheat temperatures, and furnace productivities, it is not possible to give a single final cost to produce pig iron. Table 5 give the essential component factors of this cost and some reasonable values of the amounts of each consitituent and their costs.

Needless to say, there is a range of cost across the world’s iron industry, estimated to be from a low of $100 /t of pig iron to a high of $190 /t.

There is a variation on the blast furnace that uses coke as the solid support for the charge and the reductant, and that is the charcoal blast furnace, found principally in Brazil. In this furnace, which is much

Table 6. Operating Factors and Typical Costs for Direct Reduction Process

Item	Factor	Unit cost, $	Cost, $ /t
pellets	1.50	50	75
natural gas	10×10^6 tu	2.50	25
electricity	200 kwh	0.05	10
labor	0.1 h	30	3
briquetting			5
maintenance/supply			10
Total cost / t DRI			*128*

smaller in both height and diameter than the coke blast furnace, charcoal made from eucalyptus tree wood is charged into the furnace instead of coke. It has enough strength to support a moderate weight of iron ore charge and has become quite efficient, particularly when using a high temperature air blast. Its typical production rate is, however, only on the order of 800–1000 tons per day. The supply of charcoal is critical, of course, and so the company using eucalytus trees for this purpose must provide for reforestation, with an average of seven years from planting until harvesting a tree. The cost of the investment in this operation must be reflected in any calculation of the cost of producing pig iron in this process.

The capital cost of constructing a blast furnace and its associated material handling facilities (ore piles, limestone piles, coke piles), coke batteries, sinter plants or pellet plants, shipping docks, etc. is enormous. The last large blast furnace built in the United States cost about $\$800 \times 10^6$ dollars in 1980, for a 7,000 t/d blast furnace, a coke battery, a pellet plant and an ore carrier, or about $315 per annual ton of capacity. Current estimates for the construction of a blast furnace alone have been $300 per ton annual capacity. This does not take into account the ancillary facilities costs, such as described above in regards to iron ore facilities.

Very few new furnaces have been built in recent years. On the other hand, many furnaces have been rebuilt or relined to extend their lives. A reline of a major sized furnace takes at last three months, often longer, and costs on the order of $\$100 \times 10^6$. A lining lasts about seven years. Of course as a furnace ages, all of its auxiliary equipment wears out and needs to be repaired or replaced, adding to maintenance costs over time. It will be interesting to see how many blast furnaces are replaced in kind or allowed to close in the next decade, given the overall economics of the industry to be discussed later.

There has always been a possibility that a more economical method to reduce iron oxide to metal could be found, and over the past centuary, dozens of such processes have been developed and a few commercialized. However, as each has been developed, threatening the continued existence of the blast furnace, the operators of the blast furnaces have responded with continued improvement in productivity and efficiency, making the target more difficult to beat.

Some new technologies to reduce oxide ore to iron in the solid state, called direct reduced iron or DRI, have been built and operated. The total amount of capacity of these tecnologies is about 50×10^6 t/yr. Production has seldom equaled capacity, as indicated by Figure 8.

The majority of this capacity, based on the Midrex and HyL processes, uses reformed natural gas as its reductant and fuel. In both cases the raw material is either lump ore or pellets. Table 6 gives representative cost factors for this type of operation.

The product is typically solid iron with some residual iron oxide and gangue material, in briquette form, (called HBI, or hot-briquetted iron) to avoid reoxidation. This material is used principally as a feed material to electric arc furnaces, in place of scrap.

The capital cost of DRI plants ranges from $200 to $300 per annual ton of capacity, *not* including storage, shipping, utilities, etc.

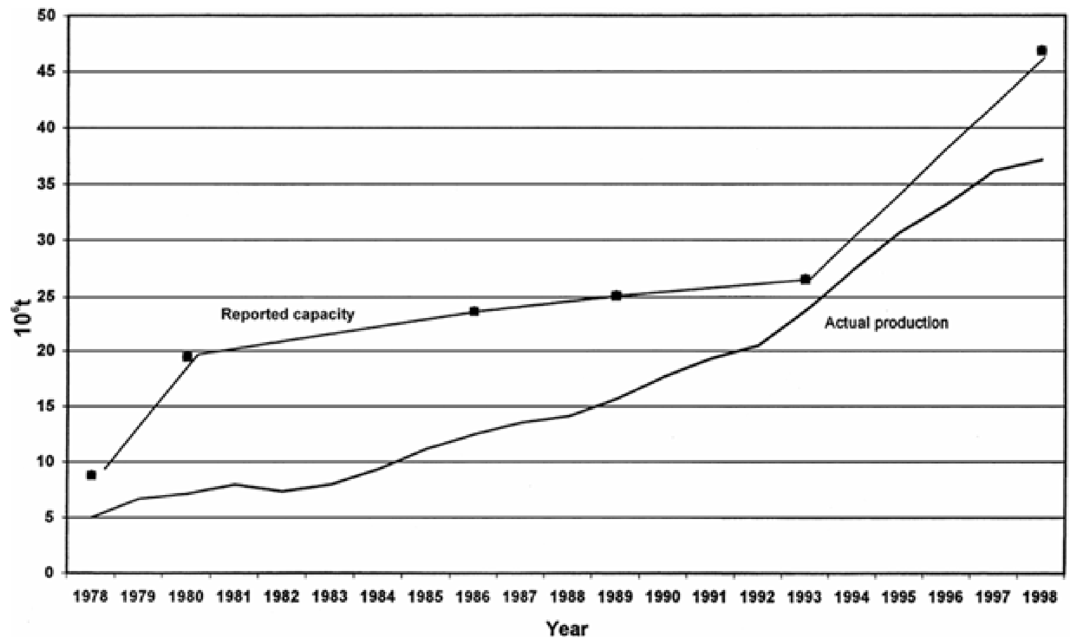

Fig. 8. Capacity and production of direct reduced iron products.

Table 7. Chemistry Ranges for Plain Carbon Steel Products

Product	C, %	Mn, %
tin plate	0.01–.08	0.20–0.60
enameling quality sheet	0.005	<0.10
deep-drawing quality sheet	0.01–0.06	0.20–0.60
commercial drawing quality sheet	0.03–0.12	0.20–0.60
structural shapes	0.15–0.30	0.40–0.80
rod for fine wire	0.06–0.70	0.40–0.80
engineered bar steel	0.18–0.90	0.40–1.20
railroad rails	0.65–0.80	0.60–1.00
rebar	0.15–0.30	0.40–0.70

4. Steel Production

Once the ore has been reduced to metal, it must be refined to produce steel. In simplest terms, steel is an alloy of iron and carbon. Most steel is low carbon, between 0.02 and 0.20% but may contain up to about 1% C. It also contains small amounts of sulfur, which comes from the coke used to make pig iron, and phosphorus, which comes from the ore used. To make the sulfur behave and not cause problems in the steel, about 0.5% to 1% manganese is added. These are the basic constituents of plain carbon steel, found principally in the form of thin sheets and plates of steel. Table 7 gives the levels of elements that are acceptable for plain carbon steels destined for various products.

Table 8. Operating Factors and Typical Costs to Produce Liquid Steel via BOF Process

Item	Factor, units	Unit Cost, $	Cost, $/t
scrap	0.35 t	100	35
liquid pig iron	0.75 t	143	107
oxygen	0.08 t	100	8
lime	0.1 t	50	5
ferroalloys			10
labor	0.2 h	30	6
refractories			5
dust disposal			3
maintenance/suppl.			6
Cost of stage			*48*
Total cost/t of liquid steel			*190*

In order to produce steel from the hot metal produced in the blast furnace, the excess carbon in the hot metal must be removed. This is accomplished by introducing pure oxygen into the liquid pig iron in a basic oxygen furnace, or BOF. This vessel is essentially an upright, tiltable cylinder. It starts its production cycle by charging scrap steel, a fixed amount at about 25% of the total charge, followed by liquid pig iron, or hot metal, and lime to flux the silica formed in the process from the silicon contained in the hot metal. Oxygen is then introduced through a supersonic lance into the metal, reacting with the silicon and carbon in the hot metal, and generating enough heat in the process to melt the scrap. At a predetermined time, the vessel is sampled for carbon content and temperature and the process is stopped when the correct carbon content is reached. The metal is then tapped out of the furnace into a waiting ladle, where the manganese is added. In many plants the ladle is then moved to a treatment station where the final temperature adjustments are made via an electric arc and final chemistry adjustments are made, and for extra-low carbon steel (for deep-drawing applications) the steel is subjected to a vacuum recirculation process. During the oxygen blow, about 1.5% of the iron in the charge is lost as fine dust, which has to be captured in gas scrubbers and disposed of as sludge. The slag is tapped separately and cleaned of entrained metal, which is recycled back to the furnace later.

The vessels used have capacities of between 100 and 300 tons, more typically 200 tons of steel, and the cycle time is typically 40 minutes, giving productivity of about 300 t/h. The process cost factors are given in Table 8.

The BOF is the predominant steelmaking process in the world today (6), producing 59% of the steel in the world, haveing replaced the Bessemer converter and most open hearth furnaces. However, particularly in Russia and East European countries, some open hearth plants still remain in operation, producing 33% of the steel made in that area. Open hearths have more flexibility in the ratio of scrap to hot metal in their charge than the BOF, being able to melt 100% scrap if necessary, because they are heated by combustion of fuel oil above the charge on the hearth below. The capacity of such furnaces can be up to 400t of steel, more typically 250 tons, and the cycle time is typically five hours, for a productivity of 50 t/h.

If an abundant supply of scrap of the proper quality, or DRI, or solid pig iron is available, a charge of solid metallics can be melted down in an electric arc furnace, (EAF). This type of furnace uses the energy from an electric arc to create the thermal energy to melt the charge. Supplemental amounts of natural gas can be combusted to assist the melting process. Oxygen is injected to remove carbon and unwanted nitrogen and hydrogen absorbed fro mthe air under the arc. Lime is added to flux the silica from the charge and lining. Furnace sizes range from 15 tons (in steel foundries) to 200 tons, more typically 125 tons, and cycle times are typically 60 minutes, for productivity of about 60 tons per hour. Table 9 gives the typical cost factors and costs factors and costs for EAF operations.

Table 9. Operating Factors and Typical Costs for Electric Furnaces Melting Scrap

Item	Factor, units	Unit cost, $	Cost, $/t
scrap	1.1 t	100	110
electricity	400 kwh	0.05	20
electrodes	3 kg	3.33	10
natural gas	0.2×10^6 Btu	2.50	5
oxygen	20 CCF	0.15	3
refractories			5
labor	0.3 h	30	9
alloys			10
dust disposal			5
maintenance/suppl.			10
Total cost/t liquid steel			*187*

Table 10. Operating Factors and Typical Costs for Ladle Furnaces

Item	Factor, units	Unit cost, $	Cost, $/t
electricity	40 kwh	0.05	2
electrodes	0.33 kg	3.33	1
argon	1 CCF	2	2
sampling, etc.			2
additives			8
Total cost of ladle treatment			*15*

In most electric arc steel plants today, the steel tapped from the furnace into a ladle is next taken to a ladle metallurgy station. There it is cleaned by bubbling argon, the temperature is adjuxted via a set of electrodes, the chemistry is adjusted by alloy additions, and in some cases for high quality steel, it is subjected to a vacuum treatment. The cost factors for this treatment are given in Table 10.

4.1. Casting

Once the liquid steel has the correct temperature, on the order of 1600°C, and chemistry, it must be cooled and solidified into the first solid form of steel, referred to as raw steel or crude steel. In the past, and still in some places, the metal is poured into tall cast iron molds, one after the other. The liquid metal solidifies into ingots, each weighing several tons, up to about 15 tons maximum. These ingots, considered raw steel, take many hours to solidify, after which the molds are stripped off them and recycled for use again. The hot ingots are then usually charged into soaking pits and held for many more hours, while they are brought to a uniform temperature of about 1100°C before rolling into semi-finished shapes. All of these operations require energy (to heat the soaking pit) and labor (to move the ingots and molds, and to prepare the molds and teem the metal into them). The molds themselves wear out and must be replaced. The movement of ingots and molds is often done using in-plant railroads, an additional operating expense. Furthermore, each ingot is a relatively small portion of a heat of steel, ultimately resulting in large yield losses from liquid to finished mill product.

Because of the obvious high costs of the ingot route, steelmakers long wished for a method to cast the liquid steel continuously into the semifinished shape that is obtained by rolling the ingots into billets, blooms, and slabs. A billet has a cross section of 24,000 square millimeters or less, a bloom is a square or rectangular near square with larger than 24,000 square millimeter cross section, and a slab is a rectangle of any cross

Table 11. Operating Factors and Typical Costs for Slab Casting Using BOF Steel

Item	Factor, units	Unit cost, $	Cost, $/t
liquid steel	1.03	202	208
electricity	20 kwh	0.05	1
molds			2
refractories			3
gases	0.2×10^6 tu	2.50	1
tundishes			2
labor	0.2 h	30	6
maintenance/suppl.			6
Total casting stage cost			*21*
Cumulative cost of slab			*229*

section that has a width to height ratio of over about 5 to 1. A typical slab is anywhere from 75 to 250 mm thick and anywhere from 750 to 2500 mm wide. The length can be whatever is needed to meet the weight of the order, limited only by the maximum that can fit into a reheating furnace ahead of the rolling mill, usually 10 to 15 meters. When cast from the liquid directly into one of these shapes, the solid material that emerges from the continuous casting machine is considered *raw steel*.

The development of commercially viable continuous casting technology emerged in the 1960s and 1970s, first for billets, and later for slabs. The technology spread in the Western World during the next two decades, until in 2000, 95% of the steel made in the Western World is continuously cast, the only exceptions being for a few specific grades and quantities of steel for which the technology is not yet suited.

The operation requires a refractory-lined tundish to distribute the metal from the ladle into the mold and control the flow of metal. The water-cooled molds are very carefully machined out of copper, and occasionally replaced after too much wear has occured. Electromagnetic stirring of the metal is often applied in the mold area. Below the mold, where the solid skin as steel containing the still liquid core is continuously being withdrawn from the mold, water sprays continue the solidification process until the entire cross-section is solid. At that point the piece can be cut to the desired length. Although there are costs incurred in all these steps, they are less than in the production of ingots, the rolling of ingots to these semi-finished shapes is avoided, and the yield from liquid steel to semi-finished shape is significantly improved. Yield from liquid to semifinished shape is about 65% via the ingot route, and as high as 95% via the continuous casting route. Cost factors for a slab caster are given in Table 11.

At this point we have added up the stage costs, taking into account the yield losses at each stage and obtain the approximate cost of the cast slab.

Stage	Cost of Stage	Cumulative Cost, $/t
Steelmaking	187	187
Ladle furnace	15	202
Casting	21	229

5. Steel Processing

5.1. Hot Rolling

Once the steel is solid, it has to be rolled into a usable shape. Ingots are first rolled into slabs, blooms, or billets on slabbing, blooming, or billet mills. These are usually reversing mills, that roll the metal back and forth between very large rolls until the desired cross section has been reached. Then the resulting material is either cooled for transporting elsewhere, inventoried, surface conditioned, or it is transported by roller conveyors to be charged into another reheat furnace, ahead of the finishing mill.

Rolling takes fuel energy to fire the reheat furnace, electrical energy to run the mill motors and provide the energy to deform the steel. It takes labor to operate and maintain this complex equipment which receives great abuse from the radiant heat in the steel and the mechanical shocks as the steel enters and leaves the equipment. It takes occasional replacement or regrinding of the rolls to ensure the proper shape and surface quality of the product.

Once the semifinished form is available, it must be hot-rolled to finished size and shape. Rolling temperatures are typically 1100°C to start with and 900°C at the end of rolling. Long products are made from billets rolled into reinforcing bar, round bars, squares, flats, channels, angles up to 75 mm on a side, and wire rod. Blooms are rolled into other long products such as structural shapes, large flats, and special shapes like elevator guides and railroad rails, or pierced and rolled into seamless tubing or casing for the oil and gas industry. In some cases of large structural shapes the cast product looks like a dogbone and is rolled into I-beams and H-beams from that cast shape. Most modern finishing mills are continuous mills, that is, the bar of steel never changes direction once it enters the mill, progressing from stand to stand until it emerges from the last stand with the desired shape and size. This requires a long sequence of stands, as many as 16, each with its own set of motors and rolls, and sophisticated controls to match the speed of each stand to the next as the workpiece speeds up in response to its decrease in cross-section at each stand. At the end of the rolling mill are large cooling beds where the products are cooled to a temperature where they can be cut to customer length or standard length, then trimmed if need be, inspected, aud bundled for shipment or moved to storage. In the United States, all long products are now made by combination of such rolling mills with scrapbased electric arc furnaces, because of the abundance of scrap, and the match between rolling mill capacity and an are furnace. These rolling mills can typically roll between 0.5×10^6 and 1×10^6 tons per year.

In the case of flat products there are two different cases to be considered. The large integrated (blast furnace based) plants usually continuously cast large slabs, on the order of 250 mm × 2000 mm cross-section and cut them into 6m long slabs weighing about 20 tons. These slabs are then rolled , after reheating, on a hot-strip mill to produce a coil of hot-rolled sheet with sheet thickness on the order of 3 to 10 mm. This product is useful in its own right or is subjected to further cold processing. Modern hot-strip mills of this type have an annual capacity of about 4×10^6 t/yr. Operating cost factors for this process are given in Table 12.

Table 12. Operating Factors and Typical Costs for a Hot Strip Mill to Produce Hot-rolled Coils

Item	Factor, units	Unit cost, $	Cost, $/t
slab	1.02	229	234
labor	0.2 h/t	30	6
electricity	80 kwh/t	0.05	4
rolls and guides			4
maintenance			6
supplies			4
gas	$1\ 5 \times 10^6$ tu	2.67	4
Operating cost for hot rolling stage			*28*
Cost of hot-rolled coil from BOF slab			*262*

On the other hand, during the 1990s, a new technology, known as thin-slab casting has come into its own as a competitor to the older technology. In this case, the liquid steel is cast through a much thinner mold, forming a slab only on the order of 50 to 100 mm thick by 1500 mm wide, withdrawn from the mold much faster, and charged straight into a long temperature-equalizing furnace, never allowed to cool down, and thence straight into a hot strip mill. Because the slab is much thinner to start with, several fewer stands are needed in the hot strip mill to achieve the reduction to the same final thickness. With the addition of one or two stands, further reduction to thickness on the order of 1 mm can be achieved. For some products this alleviates the need for further rolling operations altogether. Many such plants have now been combined with electric arc furnaces to produce flat products. Such cast/roll mills have an annual production capacity of between 1×10^6 and 1.5×10^6 t/yr. If two casters are set side-by side, and a second parallel temperature-equalizing furnace is used to feed the hot-strip mill, capacity can be increased to over 2×10^6 t/yr. Operating costs for these plants are similar to those for the thick slab process route, with the exception of operating labor, which is slightly less and fuel energy, which is also less, since complete reheating of the steel is not needed Capital costs for thin slab hot-strip mills are on the order of $400 per annual ton, including the melt shop, caster, and 5-stand hot strip mill. Again, they are for the plant itself and not necessarily for infrastructure.

Plate, defined as flat product that is thicker than about 10 mm, is also made by casting a thick slab, cut to length, and hot rolled on a plate mill. A plate mill usually has two stands, in which one may be a Steckel mill in which the material is reversed in direction between passes and coiled up in a heated coilbox on either side of the mill. This requires less length of runout table on either side of the mill to contain the ever increasing length of the steel piece as its cross section is reduced, which is the case in a normal plate mill. When the desired plate thickness is reached, the long thin piece is cooled on a cooling bed, and cut to the desired length or shape for use in plate products for shipbuilding, storage vessel construction or large diameter pipe production. Some plate is coiled and sent to smaller diameter pipe plants where it is welded into pipe, or is shipped to plate processors who uncoil it and cut it to length and shape at that location.. Plate mill operating costs are similar to hot-strip mill costs. Capital costs for a reversing Steckel mill for plate are on the order of $300 per annual ton of capacity.

5.2. Cold Rolling and Pickling

Hot rolled sheet coils can be used directly for some products, such as pipe or tubing, but are usually pickled in an acid bath, either HCI or H_2SO_4, to remove the iron oxide scale that forms on the surface during the hot rolling operation. This can either be a continuous operation, in which one coil after another is welded onto the preceding one and pulled through the acid and subsequent washing continuously, being recut and recoiled at the exit to the process, or it can be batch processed in a push-pull type process, one coil at a time. In either case, the pickled material is then coated with oil, to prevent rust. A waste pickle liquor containing either $FeCl_2$ or $FeSO_4$ is also generated. This is the principal source of these two iron compounds, which are crystallized out of the liquor by downstream processors. Pickling costs on the order of $15–20/t.

In a cold-rolling operation, the hot-rolled and pickled coil is fed into a cold-rolling mill where it is rolled at room temperature to a thinner gauge, down to thickness from 1 to 3 mm or less, and recoiled at the outlet. This takes electrical energy, labor, rolls and maintenance to run a cold-rolling operation, with operating cost of $15–30/t

The product of this operation has increased strength and reduced ductility compared to hot rolled product, because of the low temperature working of the metal, eliminating the chance for the metal grains to recrystallize and relieve the stresses put into the metal. For some applications, this is desirable. For others, involving significant deformation into shapes, i.e., deep-drawing, it is not. Thus, the relief of the stresses must be provided by a subsequent anneal at elevated temperature. The annealing must be done under a reducing atmosphere, provided by cracked ammonia or pure hydrogen, in order to preventive reoxidation of the surface. Again, the added cost of this operation includes the cost of the gas consumed and the labor and energy associated with it, and is about $10/t.

5.3. Coated Products

Some sheet steel is coated with zinc, (galvanized), or aluminum, (aluminized), or painted, to protect it from corrosion in its ultimate use. Some is coated with tin, to produce tinplate, which is used almost exclusively in food industry tin cans because it protects foodstuffs from reacting with the steel. Sheet for automobile fuel tanks is coated with terne-plate, a tin–lead–zinc alloy. Most of these coating operations are done on continuous lines, and the costs are electricity for the line, labor, and consumable materials; $50–100 t.

5.4. Total Costs

All of the preceding cost numbers lead to micro-economic cash operating costs for the production of steel. Beyond these costs there are the costs of executive, sales, accounting, engineering, scheduling, shipping, personnel, purchasing, and quality assurance departments. Such costs are known as sales, general and accounting (SG&A) costs. These add about an additional 0.3 person hours/t. Total SG&A costs vary from $15 to $50/t, depending on the company and the operating rate. To this must be added the cost of any debt service payments, which clearly depend on the way in which the company is financed. Obviously the total cost at a specific plant and company depends on the factor costs in any location in the world as well as how the plant has been financed.

The cost-capacity curve for a *specific product* is a curve that starts with the capacity of the lowest cost producer of *a particular product* and plots its cost up to its capacity. Then the capacity of the next higher cost firm is added to the first capacity, at its cost, and so on. The cumulative capacities to produce the product and the cost of the highest cost producer finish the curve at the upper right-hand side, In general, the price of the product will come from the curve where the actual cumulative demand for the product intersects the curve, unless demand exceeds supply, which in the steel business does not happen. And the profit for all but the supplier with cost at the demand intersection point is the difference between price and the cost capacity curve at their location on the curve. Such a curve indicates a good opportunity to make profit if there is a significant portion of the demand satisfied by high cost producers but where a new producer can enter the market for the product at the low cost end of the curve. Such a situation existed until 1980 for reinforcing bar in the U.S. At that point, however, low cost capacity added to the curve at the right end was enough such that all of the demand could be satisfied by low cost producers. The price then fell as the high cost integrated producers exited the market until the average profit was only about $15 per ton because the cost-capacity curve was very flat, with very little difference between the costs of the highest and lowest cost producer.

A graph of the estimated cash operating cost versus capacity curve for hot-rolled carbon steel sheet steelplants, worldwide (5), given in Figure 9 illustrating the effects of varying productivity, factor cost, and currency valuations at the time of the graph, which is in U.S. dollars. On top of these costs, one must add the SG&A to get the total cash cost to produce the product.

6. Stainless Steel

A class of steels known as stainless steels are made virtually entirely via the electric arc furnace, ladle furnace, and continuous casting route, except for some long products which are still ingot cast and rolled. However, in the case of stainless steels, another unit refining operation is usually added, the argon–oxygen converter step, after the arc furnace melts the charge, and before the ladle furnace adjusts the final temperature and chemistry for casting.

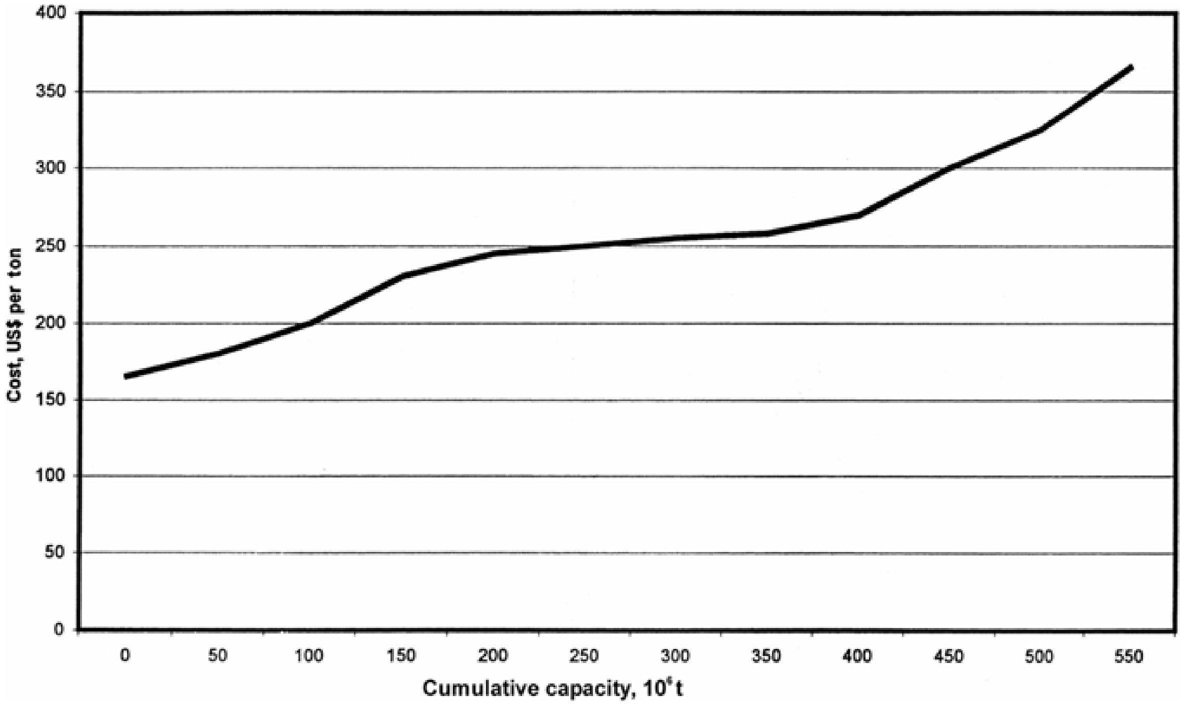

Fig. 9. World-wide operating cost-capacity curve for production of hot-rolled coils.

All stainless steels contain significant amounts of chromium, rarely less than 10%, and usually 18%. Most stainless steel is of the 300-series, which means that it contains both chromium and nickel, usually about 18% Cr and about 9% Ni. Other alloying elements may be present, such as niobium, titanium, and molybdenum, in much smaller amounts, but all add to the cost to produce. The operating cost to melt stainless steel is similar to that for carbon steel, except for the cost of the chromium and nickel. The nickel is added as either ferro-nickel, or nickel oxide, or electrolytic nickel. Nickel recovery is essentially 100%, with little loss to the slag. Chromium is added as ferrochromium, either high carbon, low carbon, or as ferro–silicon–chromium alloy. With good practices, the recovery of chromium in the metal is 90%, with poor practices it can go as low as 70%. Major world-wide sources of chromium include Russia, South Africa, Turkey, and Finland. Stainless steels make up about 1% of the total steel made in the world.

7. World-Wide Trade in Steel

The macro-economics of steel depend on the micro-economics above, the movement of currencies relative to one another, and local economic conditions. Local markets will predominate for locally produced steel mill products, unless there is a need to earn foreign currency by exporting. The latter has been the case in recent years for mills in the former Iron-curtain countries and Asian plants. With the end of the Cold War, the steel industries of the Iron curtain countries and China have entered the world trade in steel, which has increased dramatically. Figure 10 shows the increase in world trade in steel products, with a distinct change in slope at 1991. Note the very gradual increase in trade from 125×10^6 t per year to 175×10^6 t per year over the period 1975 to 1991.

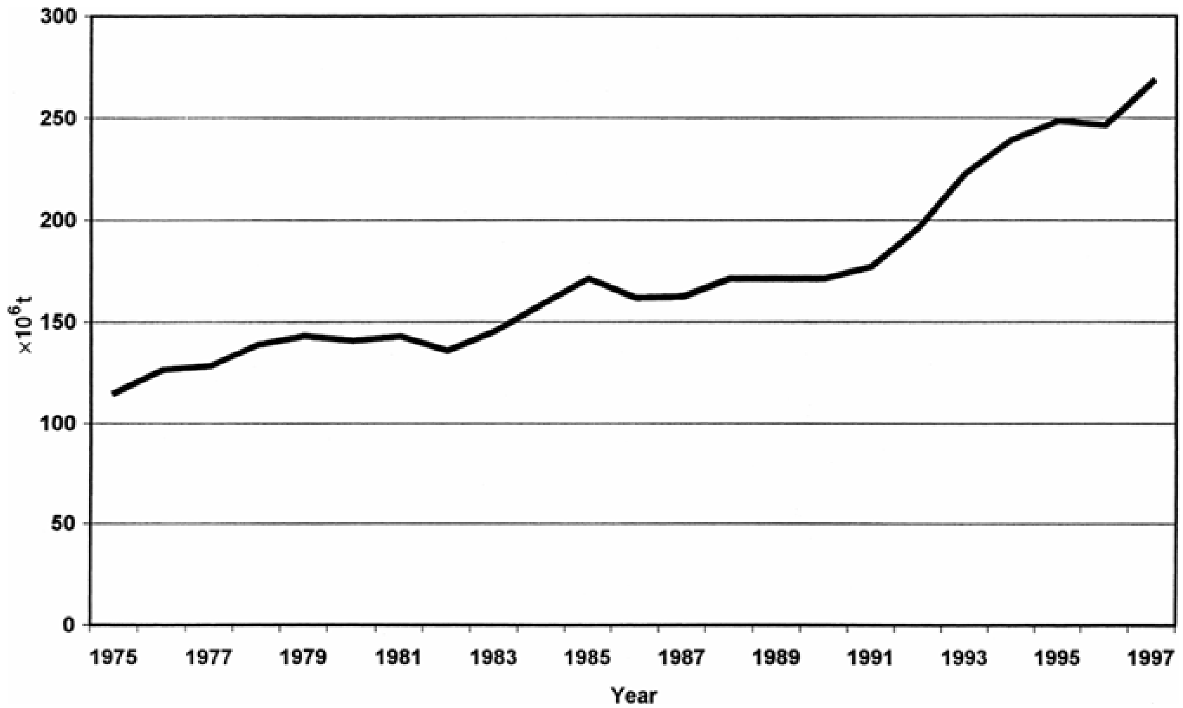

Fig. 10. World volume of trade in steel mill products (6)

After World War II there was plenty of demand for steel to rebuild war-torn Europe and Asia. The industries in those regions had plenty of domestic demand and did not export significant amounts. There was pent-up demand for consumer products in the United States, and the U.S. industry also did not export significantly. This situation prevailed until the late 1960s, when significant amounts of steel began being imported into the U.S. principally from Europe and Japan. Figure 11 shows that steel imports into the U.S. have been significant ever since, but have become overwhelming in 1998–99. The big change has occurred because of (1) the end of the Cold War, meaning that the ex-Communist countries could enter world markets, and (2) the financing excesses in the developing world which have increased steel capacity without a commensurate increase in local demand.

The major problem of the industry, that which overshadows all of the cost-cutting and technology development the industry can do, and comes back to what a firm can earn for producing iron and steel is supply and demand. Figure 12 is a graph showing the reported capacity to produce steel in the world, and the actual production of steel.

It is clear that capacity exceeds demand by a significant amount, about 200×10^6t/yr. Depending on whose argument you want to use, the effective capacity is less than or greater than the nameplate capacity. It certainly has proved to be greater in the mini-mill industry. In any case, there is absolutely no doubt that there is a gross excess capacity to produce steel that has never really been tested. It is true that when operating rates are high *all over the world*, and the *global* industry approaches an operating rate of 90%, prices rise and the industry actually makes money! But that happens all too rarely.

Figure 13 shows the capacity and production of both the former Communist bloc including China, and of China alone. The total capacity has dropped only slightly, because the decreases in the European ex-Communist countries has been just about countered by the increase in Chinese capacity. It is interesting to

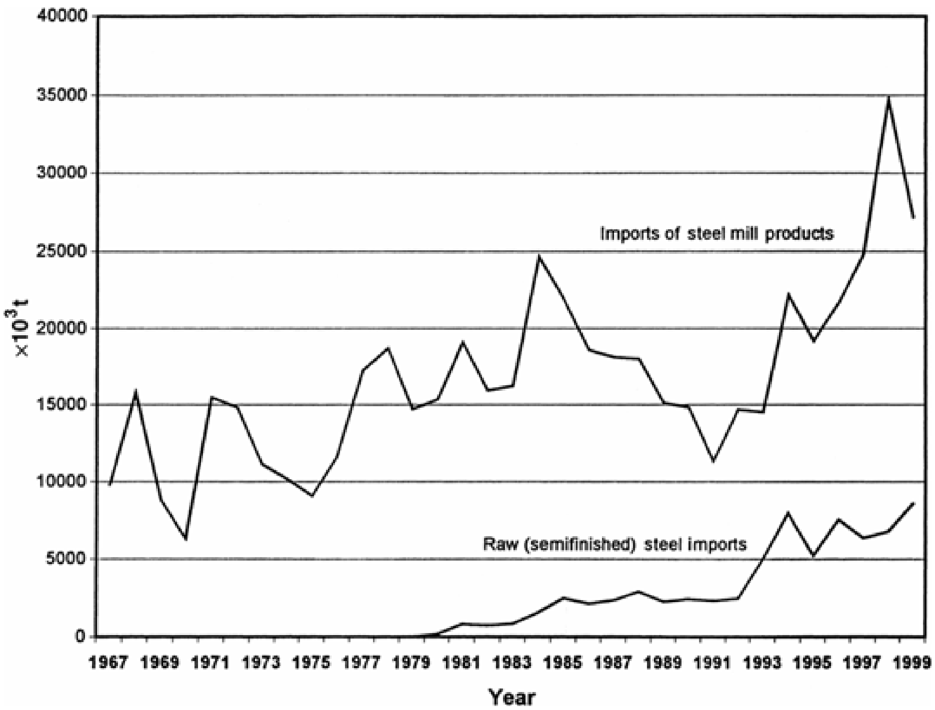

Fig. 11. U. S. imports of raw steel and steel mill products (7).

note that Chinese production tracks very close to capacity, meaning that they operate fully most of the time. But overall, the former Iron Curtain countries are still in considerable excess

Beyond that, the Developing world, Figure 14 has continued to add capacity, thanks to huge inflows of capital, even though many of the companies in these regions have lost money or broken even for years, with a significant fraction of the total built, owned and operated by govermnents. Table 13 lists the countries producing over 10×10^6 tons of steel and their raw steel production since 1993.

In addition there are 18 countries that have steel industries producing between 2 and 10×10^6 t/yr.

Look at the world situation and compare various aspects of financial results, not between individual companies, but by regions. Figure 15 is a comparison over the past two decades, of the rate of return on assets (ROA) of the majority of steel producers in the U.S., Japan, the European Community, and the Rest of the Industrialized World (RIW). The data are from the studies compiled by World Steel Dynamics (5). The average return over this period was 0.16% for the U.S., 0.96% for Japan, −2.17% for EC, and 1.90% for RIW. Most of the companies in the RIW category had near monopoly positions in their countries, and were better able to control pricing in their markets. ROA is a measure of how much money a firm makes regardless of the financing used to support the company. At zero, this means that the firm just manages to pay interest on any debt in the asset structure.

For those who want returns on stock, Figure.16 shows the return on equity for the same regions. For the U.S. the average is −0.14%, for Japan 1.78%, for EC −2.17%, and for RIW, 1.90%.

These results are indicative of a world-wide industry in serious trouble, the result, at least in part, of globalization. Paul Krugman, in his recent book *The Return of Depression Economics* (8), states that “globalization (is) the transfer of technology and capital from high-wage to low-wage countries.... But in the mid-1970s cheap labor was not enough to allow a developing country to compete in world markets for manufactured goods. The

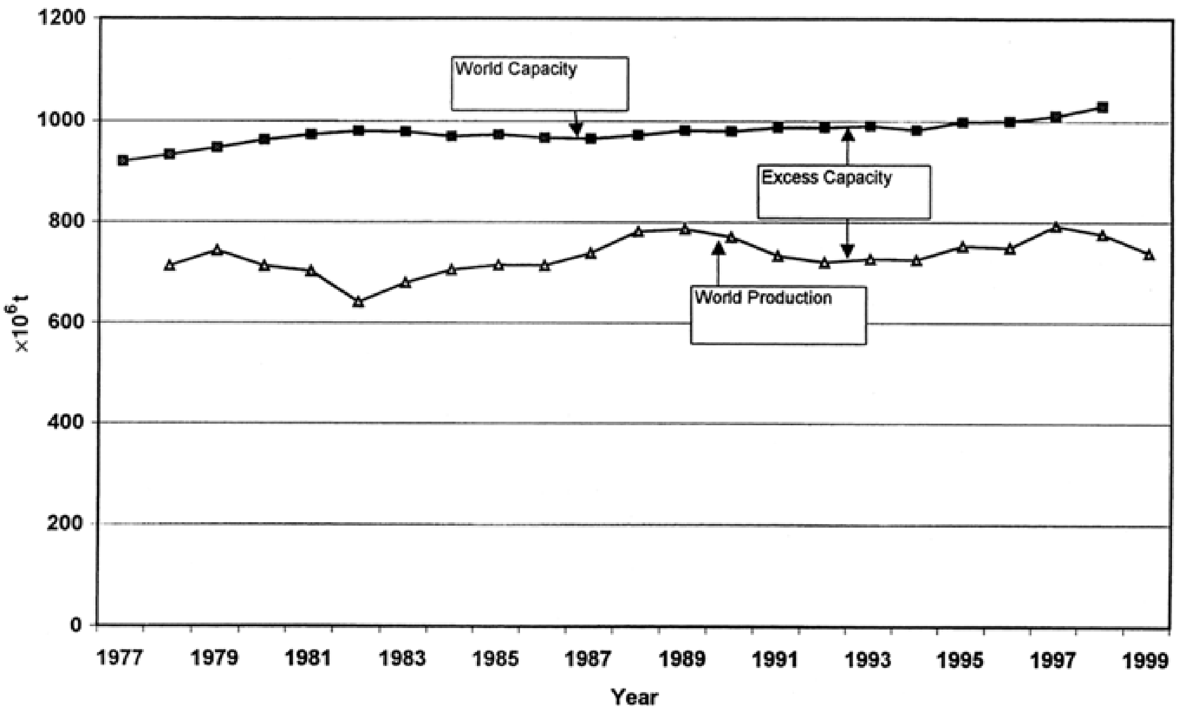

Fig. 12. Comparison of world-wide capacity and production of raw steel (5)

entrenched advantages of advanced nations – their infrastructure and technical know-how, the vastly larger size of their markets and their proximity to suppliers of key components, their political stability and the subtle but crucial social adaptations that are necessary to operate an efficient economy—seemed to outweigh even a ten- or twentyfold disparity in wage rates.... And then something changed. Some combination of factors that we still don't fully understand–lower tariff barriers, improved telecommunications, the advent of cheap air (and sea) transport–reduced the disadvantages of producing in developing countries." One of the things that changed was the cost of ocean transport and the reduction of tariff barriers. The cost of ocean transport has decreased to the point where it only costs about \$15 to ship a ton of steel from Japan to the West Coast of the United States and about \$20 to the East Coast. Stevedoring at the port typically adds about \$4 /t.

Until the overcapacity of the world steel industry, which is now quite globalized, is reduced, there can never be price stability that will allow for reasonable profits for the majority of the industry the majority of the time. Many small companies are fighting for a piece of the market, with cutthroat competition. In 1901, a gigantic merger created United States Steel Corporation, with control of 60% of the U.S. market. This resulted in price stability in the U.S. market for a considerable length of time. If the four largest steel companies in the world in 2000 were combined, one would have a combined capacity of only about 10% of the world sheet steel market, nowhere near the influence of Morgan and Gary's U.S. Steel in 1902. If one combined all of the North American flat-rolled producers, again this would have been only about 10% of the world capacity.

The point of this history lesson is that there is a benefit to having a player in the industry that is large enough to have a steadying influence on ruinous price competition. This all took place at a time when there was little world trade in steel, and imports were not a major factor, so that the influence on competition was primarily by and on the domestic industry alone. The situation has obviously changed, as the industry is now global, with significant worldwide flows of iron ore, coal, scrap, semifinished and finished steel mill products.

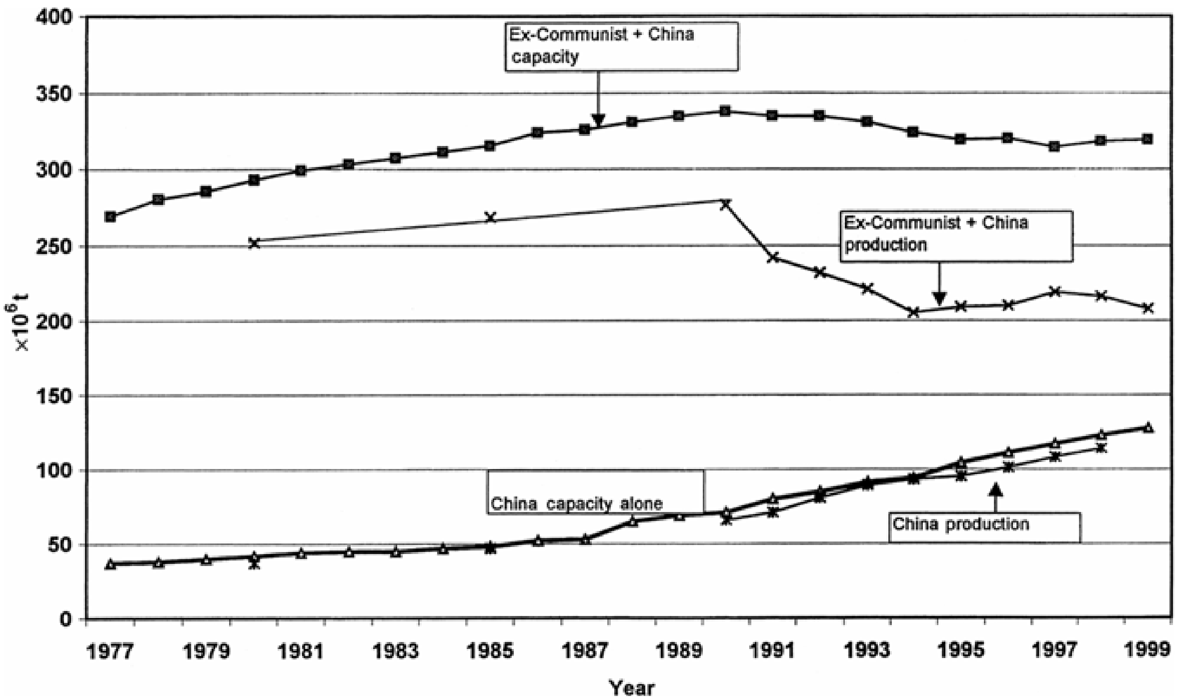

Fig. 13. Ex-Communist and China capacity and production of raw steel (5)

One has to look at the whole world industry and ask whether anything close to the influence created by the formation of United States Steel in 1901 is possible with the structure of the industry today While it is becoming clearer that U.S. anti-trust laws are becoming obsolete in the case of commodity metals, putting together such a large single entity in the steel industry seems extremely unlikely.

Figure 17 illustrates the fluctuations in prices of steel commodities. The U.S. prices are list prices for the early part of the graph and market prices later (3). The World price for hot rolled band illustrates the much larger fluctuations in price in the world market, which is in greater turmoil. Until old obsolete capacity being run in a last ditch effort to make a few more dollars is permanently closed and at least 100 million tons of excess capacity is eliminated,, the current situation is destined to continue. The financial community and governments that support the continuation of operation of "*obsolete*"facilities through such actions as loan guarantees or the support for the construction of new facilities without a commensurate removal of old facilities must be taken to task for the damage they do to the majority of the industry. It is interesting to read about the willingness of Brazilian banks to assist in financing consolidation of that countries' steel industry, but it does not appear that any significant capacity will be removed in the process (9). However, the reorganization of the Russian and Ukrainian steel industries may actually result in closure of some obsolete facilitiesi (10).

Paul Krugman has pointed out that what is meant by "depression economics" is the economic condition that exists when there are too many goods chasing too little demand; a demand shortage. This is clearly the case in most basic commodities today: steel, copper, aluminum, gold, pork, beef, grain, apples, oil, etc. Figure 18 is a graph showing the relative price indexes (11) for U.S. domestic steel mill products and for imported steel mill products.

The parallels between the import prices and domestic prices are obvious, indicating the lack of pricing power of either one.

Table 13. Countries Producing over 10 × 10^6 t of Raw Steel[a]

Country	1993	1995	1997	1999
China	89.5	95.4	108.9	123.3
United States	88.8	95.2	98.5	97.2
Japan	99.6	101.6	104.5	94.2
Russia	58.3	51.6	48.5	49.8
Germany	37.6	42.1	45	42.1
Rep. of Korea	33	36.8	42.6	41
Ukraine	32.6	22.3	25.6	27
Brazil	25.2	25.1	26.2	25
Italy	25.7	27.8	25.8	25
India	18.2	22	24.4	24.3
France	17.1	18.1	19.8	20.2
U.K.	16.6	17.6	18.5	16.3
Canada	14.4	14.4	15.6	16.3
Taiwan	12	116	16	15.4
Mexico	9.2	12.1	14.2	15.3
Spain	13	13.8	13.7	114.6
Turkey	11.5	13.2	14.5	14.4
Belgium	10.2	11.6	10.7	11

[a]Ref. 6.

Although there is obviously plenty of demand for steel in the United States, with record economic growth and expansion, the rest of the world does not enjoy the same situation. What is needed is an increase in demand *on a world-wide basis*. Table 14 shows that the per capita consumption of steel is widely divergent between areas of the world.

Table 14. Apparent Steel Consumption, kg Finished Steel Products Per Capita[a]

Region	1992	1994	1996	1998
NAFTA	272	329	326	366
European Union	315	313	310	364
Australia/N.Z.	238	287	297	290
other Europe	135	134	158	177
former USSR	265	132	106	1101
Asia	79	91	92	88
Middle East	78	74	87	73
Central/South America	52	60	64	71
Africa	20	19	19	20
World	112	115	114	118

[a]Ref. 3.

It is clear that there is a large unsatisfied need for steel for infrastructure, housing, utilities, household goods, and transportation in the most populated regions of the world. The world steel industry could supply this need and become profitable in the bargain if more money was spent in those regions on projects that consume steel and not on steel production facilities. The problem is the lack of understanding by financiers, economists and government officials of the economics of a depressionary environment. Assuming that this understanding is not likely to occur soon, then until the overcapacity of the world steel industry, which is now quite globalized, is reduced, there will not be price stability that will allow for reasonable profits for the majority of the industry the majority of the time.

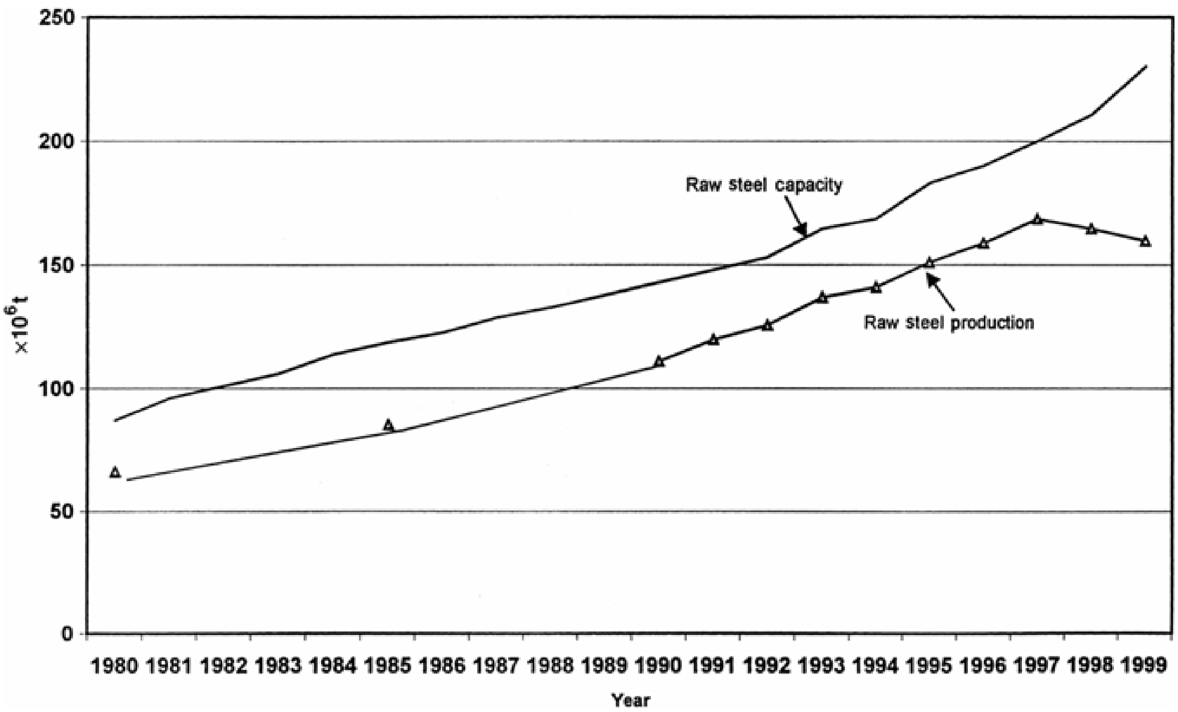

Fig. 14. Developing world capacity and production (5).

8. Environmental Concerns

The Western world iron and steel industry has made major strides in facing up to environmental problems involving air and water pollution. The most difficult problem has been the pollution from recovery coke oven batteries, which emit particulates and hydrocarbon compounds from doors during coking and when the coke is pushed from the oven on the way to the quench tower. Although most of the current batteries in operation are operating under agreements with the various pollution control agencies, there have been no new batteries built for a long time and it would be difficult to get permission to build a new one, although rebuilding existing ones is possible. One new non-recovery coke battery has been built in the United States, but it loses the economic advantage of recovering the coal chemicals and coke oven gas fuel, which is used elsewhere in the steelmaking complex. However, it does meet the air standards for a New Source, which are quite stringent.

As mentioned above, blast furnace gas is scrubbed and used as fuel. The waste stream from the scrubbing process contains iron oxide and carbon particulates, which must be collected and filtered out of the water before it is recirculated. This waste can be sent to a sinter plant for recycling, or disposed of in a landfill. The water must be treated to neutralize or remove the ammonia and cyanide absorbed from the gases.

The BOF process generates significant quantities of fine dust particles, containing principally iron and iron oxide, with small amounts of manganese and silicon oxides. This dust is collected and either recycled via a sinter plant or landfilled, as it is not hazardous.

The EAF process, on the other hand, also generates dust, but because it is scrapbased, the dust can contain significant quantities of zinc, cadmium and lead. These elements come from the coated steel scrap in the scrap mix, and since they are considered hazardous, EAF dust must be handled and disposed of as a hazardous waste, with all the attendant costs associated with that category. Baghouses are used to capture

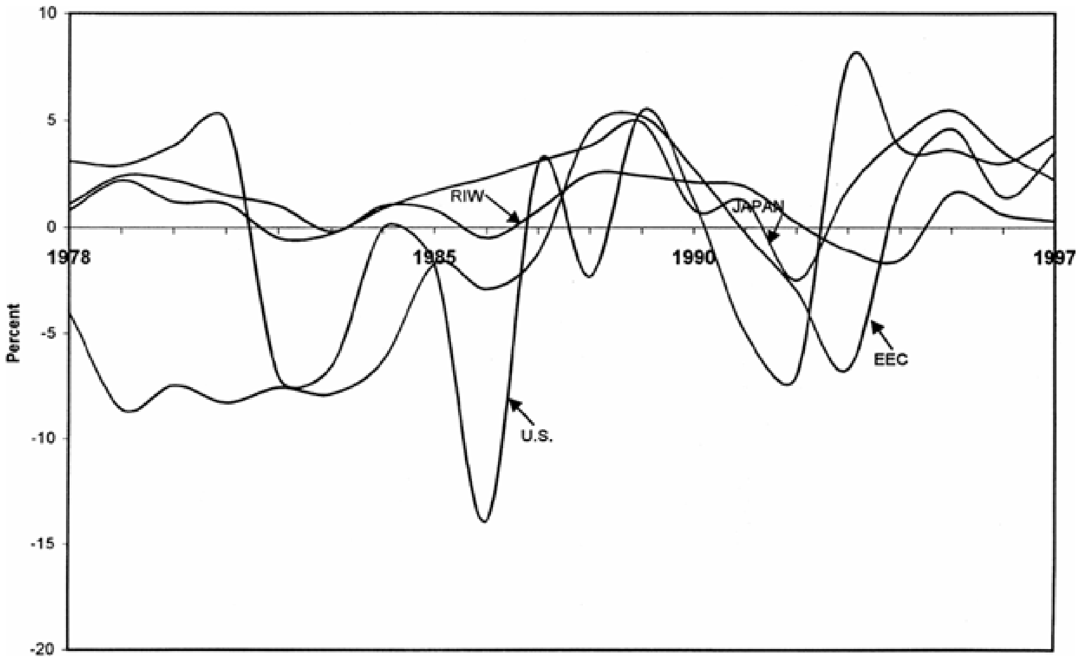

Fig. 15. Return on assets employed for steelmaking (5).

the dust, and no dust can be spilled in the subsequent handling until it reaches a licensed hazardous waste landfill or processor. Many processes have been proposed and attempted to recover the zinc, lead and cadmium and convert the remainder to a non-hazardous status. The Flame-reactor process and the rotary kiln process are the most successful of these. Many others have failed.

Several European countries have imposed severe limits on dioxin emissions from EAF waste gas stacks. Dioxins can be formed from waste plastics in the scrap charge. Dioxin removal to the levels required in Germany is very difficult and would cause severe economic problems if the same standards were to be implemented in the United States.

The water systems of all steel plants continuously lose water due to evaporation in cooling towers, since a major function of the water is equipment cooling. However, since much of the water comes in contact with the rolling and casting equipment, which use lubricants, and is also treated with corrosion inhibiting chemicals, the build-up of these oils and chemicals requires an amount of water be continuously removed from the system. This "blow down" has to be treated before being discarded to the sewer. This is an expensive process. Also, since the hardness of the water has to be kept low in order to avoid scaling the inside of cooling channels (thus decreasing the effectiveness of cooling) the incoming make-up water to replace the evaporation and blow down losses has to be softened, leading to a waste stream of concentrated salt, which has to be disposed of. In general, water system management is a complex and expensive subsystem operation that has a very direct effect on the cost and quality of steel made.

Unfortunately, many of the older plants in the former Communist bloc and in China have little to no environmental control systems and continue to pollute. They, of course, therefore do not have the costs associated with these controls, which gives them an unfair cost advantage in the global economy.

The largest *future* environmental problem facing the world's steel industry is that of greenhouse gas emission, specifically carbon dioxide. The preparation of sinter fines or pellets uses a large amount of electricity, in addition to hydrocarbon fuel. The production of electricity is primarily based on coal and oil, which ends

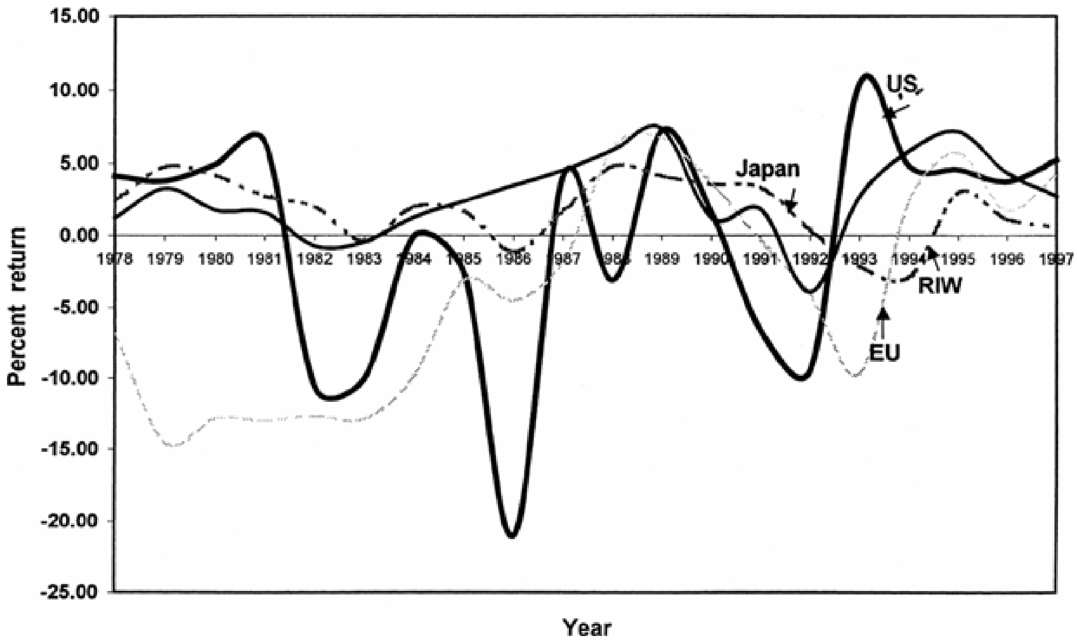

Fig. 16. Average return on steelmaking equity (5).

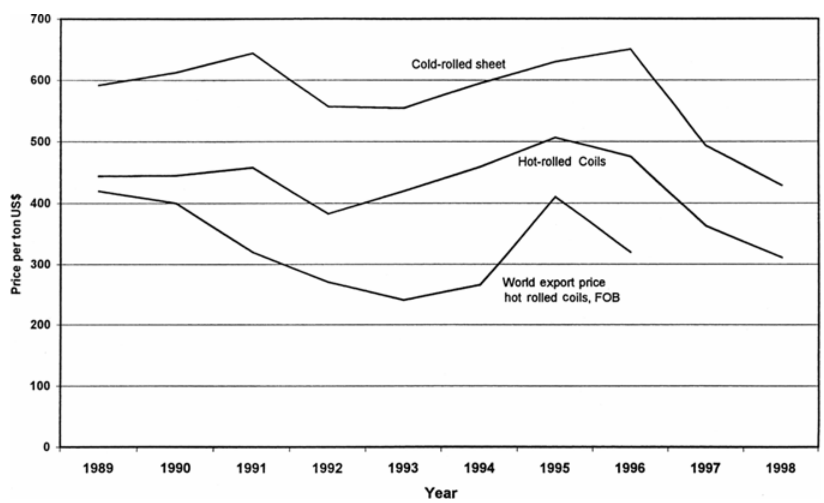

Fig. 17. Prices of commodity steel products in U.S.

up as CO_2 and water. The reduction of iron ore is largely based on the use of carbon, which ultimately ends up as CO_2. The oxygen used is in steelmaking is produced from air using electricity, and the limestone used ultimately dissociates into CaO and CO_2. Thus, the industry produces a tremendous amount of carbon dioxide. Table 15 gives the total emissions of carbon dioxide per liquid ton of steel from different process routes. The most common route, ore-pelletcoke-blast furnace-BOF, results in emission of about one tone of CO_2 per ton of steel.

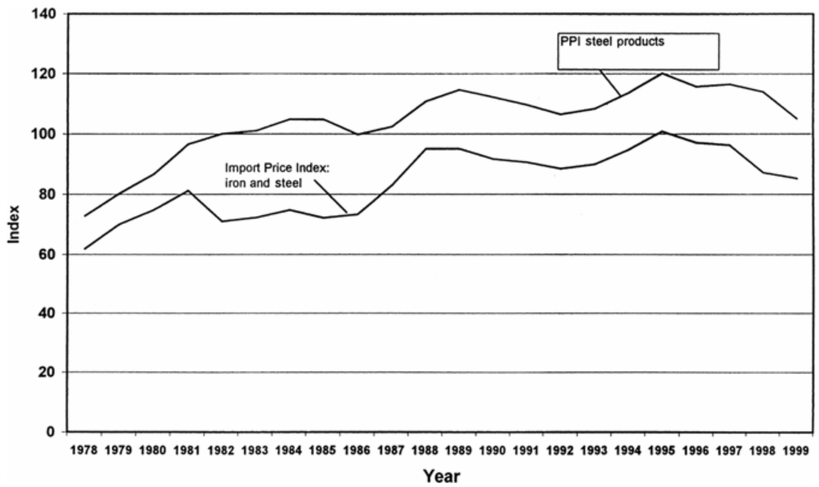

Fig. 18. Comparison of domestic and import price indexes (11).

Table 15. Carbon Dioxide Emissions by Process Route[a]

Process Route	kg CO_2 /t liquid steel
Ore–Pellet–Coke–Blast furnace–BOF	2010
Ore–Pellet–Corex furnace–BOF	3089
Ore–Pellet–Midrex–EAF	1874
Scrap–EAF	641

[a]Ref. 12.

The result is that the industry is one of the largest contributors to greenhouse gas emissions. Unfortunately, there is no economic substitute for the reductant and energy requirements of the industry at this point in history, and so the only choice to reduce these emissions is to incrementally improve the energy efficiency of the existing plants and processes. Should this become mandated, this will require increased capital investment with little or no return on the investment, which, in light of the economic situation of the industry described above, will only further decrease the overall return on capital and the incentive to modernize.

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GORDON H. GEIGER
Consultant