Mineral Commodity Profiles—Iron and Steel

By Michael D. Fenton

Open-File Report 2005–1254

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey
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U.S. Geological Survey, Reston, Virginia 2005

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Suggested citation:
Fenton, M.D., 2005, Mineral commodity profiles—Iron and steel: U.S. Geological Survey Open-File Report 2005-1254, 34 p.

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
pound per square inch (lb/in2)	6.895	kilopascal (kPa)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

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Overview

Iron and steel, which are the basic metals of any industrial society, are vital to the United States for national security and economic well-being. No practical substitutes exist on a large scale for iron and steel because of the relatively high cost of' alternative materials.

An iron and steel industry comprises steel mills, iron and steel foundries, and the suppliers of ferrous scrap and iron ore. Iron ore mines provide the major raw material from which iron and steel products are made. Iron and steel scrap raw materials are collected and distributed by brokers, collectors, and dealers in the ferrous scrap industry to steel mills and foundries. Steel mills can be divided into integrated mills, which produce pig iron from iron ore and refine the pig iron to steel, and nonintegrated mills, which use scrap as their primary raw material. Steel mills produce relatively simple steel shapes that adjoining finishing mills roll or hammer into finished products, such as bar, sheet, or structural shapes. Foundries pour molten cast iron or steel into molds to produce castings with the approximate shapes of the final products.

The U.S. iron and steel industry and ferrous foundries produced goods valued at about $57 billion in 2002. About 90 companies produced raw steel at about 139 locations with a combined raw steel production capability of about 114 million metric tons (Mt). The foundry industry included about 650 gray and ductile iron casters, 150 steel casters, 100 investment casters, and 15 malleable iron casters that produced more than one type of casting. Domestic steel mills and iron and steel foundries employed about 256,000 workers.

Crude steel was produced in 83 countries during 2001 (International Iron and Steel Institute, 2001). China, Japan, and the United States produced about 40 percent of world crude steel. Much of the remainder was produced in Europe, Russia, and the Republic of Korea. Between 1983 and 2001, the Chinese share of world steel production increased from 6 to 18 percent, the U. S. share declined to 12 percent from 15 percent, and the Japanese share remained the same. The steel industries and their histories in China, Europe, and Japan are similar to those of the United States. Early large integrated plants produced most of the steel, but as minimills increased in numbers and size, integrated production declined to about 63 percent in China, 56 percent in Europe, 71 percent in Japan, and 53 percent in the United States. One major difference between many foreign steelmaking industries and that of the United States is the high degree of State control, influence, and financing in many foreign countries.

Worldwide growth of demand for iron and steel products increased steadily throughout the 20th century as did demand in lesser developed countries (LDC). An historical high in global crude steel production was attained in 2002 when more than 900 Mt of steel was produced. Demand for steel is expected to increase over the long term as LDCs industrialize, make more steel, and consume manufactured steel products. Demand is expected to decrease in industrialized economies where service and manufacturing industries that use little iron and steel are expanding, where efficiency of use of materials in manufacturing and construction and substitution of other materials for iron and steel are increasing, and where imports of manufactured products from LDCs are increasing.

By the turn of the 21st century, agreement was widespread that world steelmaking capacity far exceeded steel demand, which caused an excess of available steel in the world market. The result was a 30 percent plunge in steel prices to a 20-year low in 2001. During a Paris steel summit in December 2001, 40 countries agreed that overall current steel production capacity was about 1,000 Mt, and that actual production was about 840 Mt (in 2000) with a demand level of about 770 Mt. Therefore, these countries agreed to cut world steel capacity by nearly 98 Mt through 2010. The agreement does not guarantee reduced production, which is necessary to stop price decline.

History

The first making and use of iron is lost in antiquity. The first iron to be used may have been meteoric in origin because pieces of iron meteorites can be hammered into useful shapes without the necessity of smelting. Mesopotamians smelted nonmeteoric iron as early as 5000 B.C. and the remains of iron ornaments that date back to about 4000 B.C. have been found in Egypt. Smelted iron objects have been found in increasing numbers in Anatolian, Egyptian, and Mesopotamian archaeological sites dated between 3000 and 2000 B.C. Although iron has been found in the Great Pyramid at Giza dated at 2900 B.C., iron was not commonly used in Egypt for utilitarian purposes until 600 B.C. Written references to iron and artifacts have been found at the archeological sites of most ancient civilizations in China, India, and the Middle East. Until about 1600 B.C., iron was used as a ceremonial or ornamental metal. An ancient Assyrian text records that iron was eight times more valuable than gold. After about 1600 B.C., iron became a utilitarian metal in some regions, although bronze remained the dominant metal for tools and weapons.

Several theories have been offered to explain the beginning of iron production. One theory is that iron ore may have been mistaken for copper ore in a smelting operation being conducted for bronze production (Fisher, 1963, p. 9). This theory is the most plausible because these people had the facilities to produce the required heat needed to smelt iron ore. Alternatively, early iron production may have been related to the ancient practice of using iron ore as a flux in copper smelting.

The Iron Age is usually dated as beginning about 1200 B.C. when iron usage commonly exceeded that of bronze as a working metal. At this time, the process of carburization, which is the heating of iron in contact with carbon, was discovered. This process results in an iron alloy called steel that has a definite hardness advantage over bronze. Steel may have been discovered in the Hittite kingdom, which was centered in modern Turkey, and the knowledge of ironmaking then spread throughout the Middle East and to Greece after the collapse of the kingdom. Implements of iron were mentioned in Homeric poems (880 B.C.); Herodotus referred to iron in his "History" (446 B.C.), and Aristotle named mines on Elba as sources of iron (350 B.C.). The Romans, who learned ironmaking technology from the Greeks, spread it throughout Europe. By the time of the European discovery of America, iron was in widespread use in most of the rest of the world, but it was unknown in the Western Hemisphere. The Romans also likely knew something of the technology of steelmaking, specifically the process of tempering (reheating and slowly cooling the steel), despite the poor and inconsistent quality of their steels. Although they did not understand why, they realized that the introduction of carbon to iron was necessary for the process to case harden steel tools and weapons (Ginzel, 1995).

Ironmaking in North America began during colonial times (Lankford, 1985, p. 8). Iron was produced in bloomery forges for local consumption beginning in the early 17th century. The first blast furnace works was built at Falling Creek on the James River in Virginia and destroyed in an Indian raid in 1622 before production began. The earliest blast furnace to produce iron in America was built in 1644 near Braintree, MA, and abandoned in 1647. The first furnace to operate successfully for a period of time was Hammersmith, which was built at what is now Saugus, MA, in 1646 and operated until 1675 (Fisher, 1963, p. 6). Later, ironworks were built in Maryland, Virginia, Massachusetts, Connecticut, and New Jersey. Most of the iron was consumed locally, but some was exported to England. By 1732, 19 hammer mills, 16 blast furnaces, and numerous forges were operating in the American Colonies. During the late 18th and early 19th centuries, ironmaking spread westward into Indiana, Illinois, Ohio, Pennsylvania, and West Virginia. Larger blast furnaces were developed, and as supplies of wood-generated charcoal became scarce, coal and later coke were substituted for charcoal. The introduction of pressurized hot air to iron furnaces around 1840 caused them to become true "blast" furnaces and greatly improved furnace productivity. Production of pig iron in anthracite blast furnaces increased rapidly in the United States from approximately 20,000 metric tons (t) in 1856.

Through the 19th and 20th centuries, the blast furnace increased in size and design, and operational techniques improved. In the 20th century, higher productivity was achieved by the use of beneficiated and sized raw materials, better refractory linings, higher blast temperatures, humidity control, high top pressure, and fuel and oxygen injection.

Low-carbon wrought iron that was used for pipe and structural purposes was made by refining high-carbon pig iron in puddling furnaces in batches of about 227 kilograms (kg). Steel was made by the cementation process in which wrought iron bars were packed in charcoal and heated to red heat in closed pots for 10 days or longer, which causes diffusion of carbon into the solid wrought iron, or by the crucible process, in which wrought iron was melted together with wood in clay or graphite crucibles holding about 45 kg each. The medium- to high-carbon steel produced was used for tools, implements, and machinery parts where greater hardness and strength were required than could be obtained from wrought iron.

The introduction of the Bessemer converter in the mid-19th century made the modern age of steel possible. Batches of up to 25 t or more of molten pig iron could be converted into steel by blowing air through the metal to remove the excess carbon and other elements. The heat of combustion of these elements prevented the iron from cooling and solidifying. Bessemer steel could be made with any desired carbon content and was used in large quantities for construction, railroad rails, and shipbuilding. Although the pneumatic process for making steel was discovered independently in the United States by William Kelly in 1850 and in England by Henry Bessemer in 1856, the process was developed commercially by Bessemer and is now known by his name. An important part of the process, deoxidation by manganese, was developed in England by Robert Mushet in 1856. The Thomas converter, which is lined with basic refractories, was later developed to use the high phosphorus iron ores of Europe.

The Bessemer process was the dominant method of making steel in the United States from its inception up to the early 20th century. The Siemens-Martin, or open-hearth, process was invented in England by William and Friedrich Siemens in the 1864 and improved by Pierre and Emile Martin, but did not become important until the late 19th and early 20th centuries. This process had the advantage of producing higher quality steel, such as the grades used for deep drawn automobile body parts, and was also able to utilize a large proportion of scrap in its charge. Open-hearth production surpassed that of the Bessemer converter by 1908, and by 1968, the Bessemer process had virtually disappeared. Open hearth production, however, began to decline in the 1960s, and in 1983, only 7 percent of U.S. raw steel was produced by this process, which became obsolete by January 1992 (American Iron and Steel Institute, unpub. data, 2003).

The Linz-Donawitz (L-D) process for oxygen steelmaking was developed in Austria in 1952 and first brought to the United States in 1954. By 1965, this process, which is known in the United States as the basic oxygen process (BOP), accounted for 17 percent of U.S. raw steel production; in 1970, BOP production, at 63 Mt, exceeded open-hearth production for the first time. In 1983, the BOP accounted for 62 percent of total U.S. raw steel production. Since then, the BOP contribution to steel production declined to 50 percent by 2002.

The first A.C. direct electric-arc furnace (EAF) was developed and patented by Paul Heroult in the late 1800s, and the first Heroult furnace used to produce steel in the United States began operations in 1906 in Syracuse, New York. The EAF was first used for the production of alloy, stainless, and tool steels. During and after World War II, ordinary grades of steel were made in furnaces of larger capacity than those used for specialty steels. EAFs that exceed 1 million metric tons per year (Mt/yr) capacity are now operating. By 2003, 51 percent of U.S. raw steel was made in EAFs.

Description

Alloys, Types, and Shapes

Iron and steel products or alloys are commonly specified by a large number of characteristics. These include chemical composition, dimensions, mechanical properties, surface condition, size and number of allowable defects, grain size, hardenability, and production process. U.S. organizations that publish widely used standard specifications include the Alloy Castings Institute, the American Foundry Society (AFS), American Iron and Steel Institute (AISI), the American Society of Mechanical Engineers (ASME), the American Society for Testing and Materials, and the Society of Automotive Engineers. The American Petroleum Institute and the Metal Powders

Industries Federation have specifications for many tubular products and for iron and steel powders, respectively. ASM International has published reference sources related to specifications. Grades of ferrous scrap have been defined by the Institute of Scrap Recycling Industries (ISRI).

Pig iron is a high-carbon alloy made by smelting iron ore in the blast furnace with carbonaceous material as a reducing agent, usually coke in current practice. “Hot metal” generally refers to molten pig iron. Direct-casting pig iron is hot metal that is cast directly into useful shapes, such as ingot molds. DRI generally refers to iron produced from ore by reduction with a hydrocarbon gas without melting. If the product is highly porous, then it is sometimes called sponge iron or prereduced iron. The term “DRI” is sometimes used broadly to include the product of any of several new processes that produce molten iron similar to pig iron. Iron and steel scrap consists of all alloyed or unalloyed ferrous materials that contains iron or steel as a principal component, which are the waste of industrial production or are objects discarded because of failure, obsolescence, or other reasons.

Iron and steel scrap is classified as home scrap, obsolete or old scrap, or prompt industrial scrap. Purchased scrap consists of obsolete scrap or prompt industrial scrap. Home scrap, also known as revert scrap or runaround scrap, consists of scrap that is produced in steel mills and foundries as a byproduct of their operations. It is recirculated to the furnace for remelting. Prompt industrial scrap is the waste material that results from fabrication of iron and steel products. Obsolete scrap, or old scrap, consists of iron or steel products that have been discarded because they are broken, obsolete, worn out, or rejected for other reasons.

“Cast iron” is a generic term for the family of high-carbon casting alloys, which includes the following types of iron: ductile or nodular, gray, malleable, vermicular, and white. Gray iron, which is the most common type of cast iron, is brittle cast iron that has a gray fracture surface and contains a relatively large percentage of carbon in the form of flake graphite. Ductile or nodular (cast) iron is gray iron that has been treated with an oxidizing agent while in the liquid state; when the metal solidifies, the graphite is in nodular rather than flake form. Ductile iron is also called spherulitic graphite, or S.G., iron. Magnesium or a magnesium alloy is the most frequently used oxidizing agent. Nodular iron is far more ductile than gray iron and competes for applications with steel.

Vermicular (cast) iron or compacted graphite iron is an intermediate product between gray iron and nodular iron, in its graphite form and its mechanical properties. It is produced with alloy additions to the molten iron. White iron, which is very hard and brittle, is cast iron that has a white fracture because all or most of the carbon is in the iron carbide form. It is used to make malleable iron by heat treatment to convert the structure into a ferritic-iron matrix that contains nodules of temper carbon or graphite. The properties and applications of malleable iron are like those of nodular iron. Various grades of alloy cast iron are also made for special purposes, such as heat and corrosion resistance.

Steel is an iron-base alloy that contains up to 2 percent carbon. In practice, it usually contains manganese and residual amounts of phosphorus, silicon, and sulfur and has a carbon content of between 0.05 percent and 1.25 percent. Crude (raw) steel is the first solid state after melting and is suitable for further processing or sale. It includs ingots, steel castings, and strand or pressure cast steel. Steels that derive their properties mainly from carbon with no specified minimum alloy content (other than manganese) are classified as carbon steels. Carbon steels are sometimes classified according to carbon content as follows: high carbon, more than 0.55 percent; medium carbon, 0.25 percent to 0.55 percent; and low carbon, or mild steel, less than 0.25 percent. They have also sometimes been classified by method of manufacture, such as basic open hearth, basic oxygen, Bessemer, or EAF.

Carbon steels are also often classified by degree of deoxidation. Rimmed steel contains sufficient oxygen to give a continuous evolution of carbon monoxide while the ingot is solidifying. This results in blowholes in the body of the ingot, which are subsequently closed during working, surrounded by a case or rim of metal virtually free of voids. Killed steel is steel deoxidized with aluminum or silicon to reduce the oxygen content to a level such that no reaction between carbon and oxygen occurs during solidification. In semikilled steel, smaller quantities of oxidizer are added so that some oxygen reacts with carbon to form carbon monoxide, which offsets solidification shrinkage. Capped steel is semikilled steel cast in a bottle-top mold and covered with a cap that fits into the neck of the mold, which causes the top metal to solidify. Pressure is built up in the sealed-in molten metal and results in a surface condition much like that of rimmed steel.

Medium- and high-carbon steels may be hardened and strengthened by heat treatment, which consists of heating to a certain temperature, quenching in a cooling medium, such as water or oil, and tempering by heating to a lower temperature that partially softens the steel and restores ductility. Hardened steel can be softened by annealing, which generally consists of heating to the proper temperature and slow cooling. Low-carbon steels are case hardened or case carburized by heating in a carbonaceous medium to raise the carbon content of the surface layers of the steel followed by an appropriate heat treatment to develop the desired properties. The surface may also be hardened, by nitriding by heating in a nitrogenous medium, or by cyaniding, which is a combination of carburizing and nitriding.

An alloy steel is any steel to which alloying elements (other than carbon and the usual amounts of silicon and manganese) have been added to develop specific properties. High-strength low-alloy steels are steels to which small quantities of alloying elements have been added to improve their properties. Tool steels are characterized by high hardness and resistance to abrasion, which are generally attained by high-carbon content, by high-alloy content in many types, and by heat treatment. The high-speed steels are tool steels that contain tungsten and/or chromium, molybdenum, and vanadium, which resist softening at elevated temperatures and, hence, can be used for machining at high speeds where considerable frictional heat is developed. Many other grades of tool steel have been developed for specific purposes.

Heat-resisting steels, which contain alloying elements to improve their properties at high temperatures, include stainless steels. Stainless steels usually contain between 12 percent and 50 percent chromium, which imparts resistance to atmospheric rusting and chemical corrosion of the material. The three classifications are ferritic or straight chromium, austenitic or chromium-nickel, and martensitic or heat-treatable stainless steels.

After steel has been made in the EAF or basic oxygen furnace, it is transferred to a ladle in which refining operations, such as deoxidization, desulfurization, and the addition of alloying elements, are performed. From the ladle, steel is passed to the continuous-caster machine from which strands of steel emerge to be cut into billets, blooms, or slabs or into molds in which ingots are made that will be formed later in pressure-rolling machines into billets, blooms, or slabs. These products, whether rolled from ingots or continuously cast, are known as semifinished steel. A billet has a square cross section that ranges from 50 by 50 mm to 125 by 125 mm. A bloom, which is larger than a billet, has a square or rectangular cross section that ranges from 150 mm to 300 mm on a side. A slab is oblong in cross section, and is mostly 50 to 230 mm thick and mostly 610 to 1,520 mm wide.

Uses

Steel Products

Steel is not a single product, but more than 3,500 different products that have many different physical and chemical properties, 75 percent of which have been developed in the last 20 years. In the late 19th century, steel became an important construction material for skyscrapers and bridges because of its strength. It was the foundation of the new railroad industry that encouraged the westward expansion of the United States. Since then, steel has remained the material of choice for a wide variety of applications in which no other material is suitable. Steel has many applications, which include bridges; buildings and houses; construction equipment; electricity powerline towers; farm implements; highways; household appliances; machine tools; military weapons; natural-gas pipelines; subways, trains, and other vehicles. Every person uses products that contain steel.

As the 21st century begins, steel is stronger and more durable than earlier steel, and it is extremely versatile. It continues to be used in new ways, such as in eyeglass frames, jet aircraft, the space shuttle, and surgical instruments,. High-strength and ultra-high-strength steels are used to make the safest automobile bodies for occupants. Steel is indispensable in our modern society, and it is now less expensive relative to the per capita gross national product than it was 50 years ago. Steel is the most recycled material by weight. The distribution of steel shipments by market in early 2003 was steel service centers and distributors, 22 percent; construction, 15 percent;

transportation (predominantly for automotive production), 14 percent; machinery and equipment, 3.7 percent; cans and containers, 2.9 percent; appliances, 1.7 percent; oil, gas, and petrochemical industries, 1.7 percent; and others, 39 percent.

Properties That Determine Usage

Hot-finished carbon plates and sheet, structural shapes, bars, wire rods and wire, rails, and reinforcing bars, and cold-rolled carbon sheet and strip comprised about 94 percent of total shipments of steel products in early 2003. Hot-finished carbon steel has the lowest unit cost of all forms of steel and has good formability, machinability, and weldability in certain grades. The largest amounts of hot-finished steel are in the form of angles, channels, I-beams, plates, and other structural shapes used in bridges, buildings, pressure vessels, railroad cars, ships, storage tanks, and where carbon contents of less than 0.25 percent predominate. Cold-rolled, cold-rolled low-carbon steel sheets and strip, and hot-rolled incorporate, in various degrees and combinations, attractive appearance, ductility, ease of fabrication, predetermined strength after fabrication, and before and after fabrication, as well as compatibility with other materials and various coatings and processes. These products, which are used in consumer goods, and require steels that are serviceable under a wide variety of conditions. They are also adaptable to low-cost techniques of mass production and to consideration of sales appeal in the finished article. The bulk of these steels are low-carbon (0.15 percent maximum) steels.

The mechanical properties of yield strength, fatigue strength, low-temperature impact strength, and directional properties of hot finished steel are influenced by several variables, the primary one being chemical composition, and more specifically the carbon content. Lower carbon grades are most easily formed. Other factors include deoxidation practice, finishing temperature, section size, and the presence of residual elements, such as chromium, molybdenum, and nickel. Cold formability is directly related to the yield strength and ductility of the material. A small load is required to produce permanent deformation when the yield strength is low. Large deformation without fracture is easier when ductility is high.

When the carbon content is below about 0.50 percent, most hot-finished carbon steels are easily machined. Steels with low carbon and manganese content may be too soft for good machining. Higher carbon steels may need to be annealed for softening prior to machining.

The ease with which a material can be welded with sound welds possessing good mechanical properties is influenced primarily by composition, heat input, and rate of cooling. For carbon steels, the carbon and manganese contents are the primary elements of the composition factor that determine the effect on the steel of given heating and cooling conditions. Most steel used for welded applications is low-carbon steel. Higher-carbon and higher manganese grades often can be welded satisfactorily if preheating, special welding techniques, and postheating are used.

Low-carbon hot-rolled and cold-rolled sheet typically contains from 0.05 to 0. 10 percent carbon, 0.25 to 0.50 percent manganese, 0.04 percent maximum phosphorus, and 0.05 percent maximum sulfur. Where only mild forming is involved, a certain latitude is permissible, especially for carbon, phosphorus, and sulfur. For deep drawing, phosphorus and sulfur are held as low as possible. Where nonaging characteristics are desired, aluminum, boron, titanium, or vanadium may be added.

Substitutions

Potential substitutes are available for most applications of iron and steel, but practical substitution is limited by the usually higher cost of other materials. Other metals are generally used only where they possess some clear advantage over iron. For example, iron can be alloyed, heat treated, and otherwise processed to obtain a wide variety of characteristics, such as strength, hardness, or corrosion resistance needed for particular applications. The specialty steel industry produces relatively small quantities of high-quality steel with special properties needed for critical applications. In many of these applications, performance rather than price is the deciding factor for choosing steel over other materials.

Despite its higher material price, aluminum is sometimes substituted for applications of iron and steel, especially where light weight is desired. Aluminum's main advantage over steel in vehicles is its higher strength-to-weight ratio, which reduces fuel cost. Aluminum also has a higher thermal efficiency that may result in better engine performance. Aluminum can be drawn into thin-walled, two-piece containers; this minimizes forming costs and material use per can. Aluminum cans are lighter than steel cans and cost less to transport per unit volume of beverage. Other materials, such as glass and paper, also replace steel in various containers. Aluminum's high strength-to-weight ratio allows architects to design to specifications while minimizing the load on the building's support structure. In the kitchen, cooking utensils once made exclusively of iron are increasingly made of aluminum.

High-performance plastic composites with various fibers are increasingly being used in critical mechanical parts where steel was used. Substitution for steel by composites is increasing as improved materials and techniques reduce the cost of producing composite components.

Plastics are often used instead of steel materials in consumer products, such as toys, because of their relatively high formability and light weight. They are readily molded or shaped into complex configurations, which is more important than their relatively high material cost. For high-temperature conditions or corrosive conditions, nickel or titanium alloys are sometimes substituted. In construction, concrete, plastics, and wood compete with steel and cast iron in various applications.

During the 20 years after 1977, the weight of a typical family vehicle, in which iron and steel is about two-thirds of the total weight, decreased by 11 percent, from 1,670 kg to 1,490 kg. Part of the reason was the substitution of aluminum, copper and brass, magnesium, and plastic for iron and steel components. Between 1977 and 1997, the weight of iron and steel materials declined by 20 percent while that of aluminum, copper and brass, magnesium, and plastic increased by 143 percent, 18 percent, 600 percent, and 45 percent, respectively (New Steel, 2002).

Processing

Ironmaking

Iron is produced from ore either by blast furnaces or by one of several direct reduction processes (figure 1). Although direct reduction has been used successfully in certain locations, blast furnace operations continue to produce the bulk of the world's iron.

The modern blast furnace resembles its forerunners in its essentials. It consists of a refractory-lined steel shaft in which the charge is continuously added to the top through a gas seal, and preheated air is blown through tuyeres at the bosh near the bottom to be emitted as combustible top gas. Iron and slag are intermittently tapped from the hearth at the bottom. The furnace has high thermal efficiency because of the countercurrent flow of solids descending and hot gases rising from the combustion zone and transferring their heat to the charge. The charge consists principally of iron ore, sinter or pellets, coke, and limestone or dolomite; iron and steel scrap may be added in small amounts. The chemical reactions are complex; the main reactions are combustion of coke to produce carbon monoxide, reduction of the iron ore to iron by the carbon monoxide, and fluxing of the silica and alumina in the ore and coke ash with limestone to form a slag that absorbs much of the sulfur from the charge.

Preheated air up to 2,000°F for the furnace is supplied by refractory-lined checker-brick stoves heated by burning cleaned top gas. The molten pig iron, which has dissolved some carbon and silicon, is generally tapped into a transfer ladle, which delivers the hot metal to the steelmaking plant. The metal may also be cast into pigs for subsequent sale or use. Slag is tapped into ladle cars for hauling to the slag dump, allowed to solidify in a slag pit, or granulated with water. Blast furnace slag is used for concrete aggregate, railroad ballast, soil conditioner, or landfill.

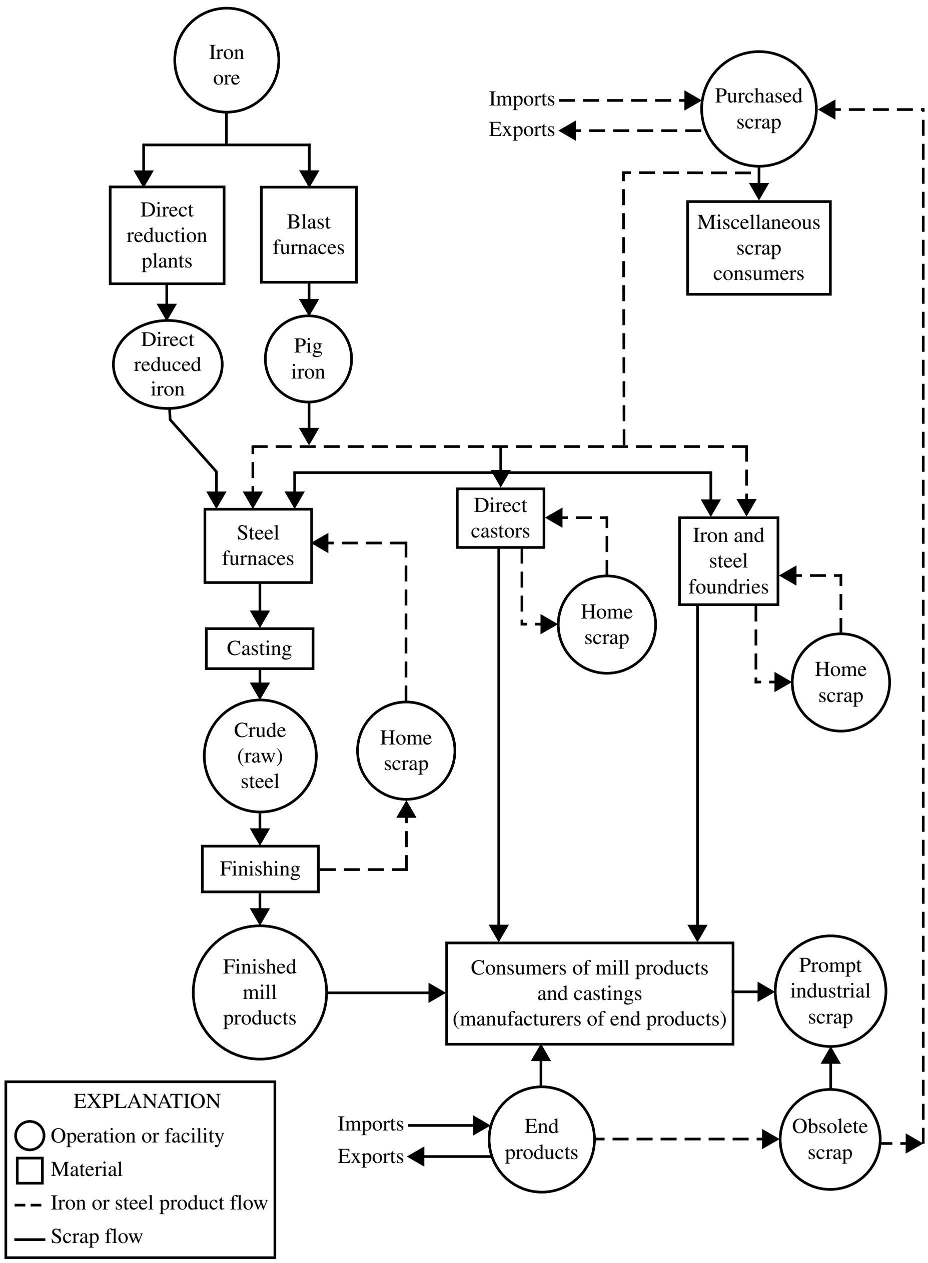

Figure 1. Iron and steel material flow diagram. Source: Schottman, 1985.

In recent years, the efficiency, productivity, and size of blast furnaces have greatly increased. The largest modern blast furnaces have working volumes 2.5 times that of furnaces constructed in the 1940s, and productivity per unit of working volume has increased by improved charge quality and preparation, which includes the use of sized ore, pellets and sinter, better fuel and refractories, higher blast temperatures and volumes, humidity control, fuel and oxygen injection, and high top pressure.

DRI is produced by several processes in which iron ore or pellets are reduced to solid iron by reductants produced from solid, liquid, or gaseous fuels. For steelmaking, DRI should not contain more than a small percentage of the slag-forming materials silica and alumina (the less the better and preferably no more than 4 percent). DRI may be in the form of sized lump, briquets, pellets, or unconsolidated fines depending on the original raw material and the process used to produce it. Normally, it is less than 1 inch in maximum dimension, except for briquetted fines, which may reach 3 inches.

DRI can be used to replace all or part of the purchased pig iron or scrap in cold-melt steelmaking and foundry operations. It is most efficiently used by continuous charging through the EAF roof during melting rather than charging in large batches as is done with scrap. DRI is especially valuable for feed to EAFs that make high-grade steel because the unwanted elements are lower than those normally found in most scrap. Therefore, DRI additions can reduce the concentrations of these elements that accumulated in the melt from previous scrap charges. Only a relatively small quantity of DRI is used in the United States because steel scrap is usually plentiful at relatively low cost.

Scrap

The scrap industry consists of collectors and small dealers, large dealers and processors, and brokers. Collectors and small dealers generally handle all types of recyclable scrap, and the large dealers and processors specialize in iron and steel scrap, nonferrous metals, waste paper, and so forth. Processors of scrap use a large variety of equipment. Shears of various types are used for cutting bulk scrap and flattened automobile bodies to manageable size. Balers are hydraulic presses capable of compressing an automobile body or other light scrap into a dense cube. One modern development is the shredder or fragmentizer, which is capable of reducing an automobile to fist-size pieces of scrap in less than 1 minute. The iron and steel fraction is magnetically separated from the other materials to produce high-quality scrap. Depending on their size, shredders can process from 25,000 to 250,000 cars per year. Another development is the mobile car crusher, which flattens cars prior to shipment to the scrap yard and makes the more economic transportation of scrapped automobiles over greater distances possible. Other processing equipment includes the cutting torch, the drop ball for breaking cast iron scrap, the rail breaker, and the briquetter and turnings crusher for compacting turnings and borings. Materials-handling equipment includes belt conveyors and overhead and crawler cranes equipped with electromagnets or grapples.

Steelmaking

All contemporary steelmaking processes convert pig iron, scrap, DRI, or mixtures of these into steel by a refining process that lowers the carbon and silicon content and removes impurities, mainly phosphorus and sulfur. The excess oxygen that remains in the molten steel is then neutralized by adding deoxidizing elements, such as aluminum, manganese, or silicon. The first commercially developed process for producing steel in tonnage quantities was the Bessemer process in which air is blown through a bath of molten pig iron in a pear-shaped converter. Because the Bessemer process produced steel with high contents of nitrogen and phosphorus and was unable to utilize much scrap, it was gradually replaced by the open-hearth process in the United States.

The basic open-hearth process was the dominant steelmaking method in the United States between 1908 and 1969. In this process, a relatively shallow bath of metal is heated by a flame that passes over the bath from burners at one end of the furnace, and the hot gases that result from combustion are used to heat checker-brick regenerators at the other end of the furnace. Periodically, the direction of the flame is reversed—the hot checker-bricks preheat the air for combustion and the exhaust gases reheating the checkers at the other end of the furnace. Gas, oil, or tar can be used as fuel.

The EAF has been used since its inception at the beginning of the century for the production of stainless and alloy steels, which include tool steels. Since about the end of World War II, this furnace has been increasingly used for the tonnage production of plain carbon steels. In almost all cases, EAFs operate with a cold charge in which the ferrous content is close to 100 percent scrap. DRI is a potential substitute for scrap and it is used as the major iron input in some EAF plants.

Close control of quality can be obtained in the basic EAF, and sulfur can be removed by using special slags. One advantage of the EAF process is its relatively low capital cost per t of steel produced. Plants can be located to take advantage of local supplies of scrap and local markets for steel. Small EAF plants have been built in locations where large integrated steel mills would be uneconomical in the United States, Europe, and Japan, and in the developing countries.

In making stainless steel in the EAF, oxygen lancing has long been used to reduce the carbon to the required low level. Processes have been developed in which the metal is first melted in the EAF and refined in a second vessel, by using combinations of oxygen with argon, vacuum, or steam for decarburization. Almost all stainless steel is now produced in the United States by the argon-oxygen-decarburization (AOD) process. The AOD process is able to remove carbon from molten steel without oxidizing large amounts of valuable alloying elements, especially chromium. The process economically produces stainless steel by using lower grade, lower cost, high-carbon ferrochromium instead of refined low-carbon ferrochromium.

Other developments in EAF melting include the use of ultrahigh power; that is, operation at about twice the power rating formerly used for a given size furnace, which reduces the melting time by about one-half. These high-power levels have stimulated development of high-conductivity graphite electrodes, coatings of electrodes to reduce oxidation losses, water-cooled power cables, water-cooled furnace panels and roofs, and improved refractories.

The electric induction furnace differs from the electric arc furnace in that the metal is heated by induced electric current within the charge rather than by an arc. Induction furnaces are generally smaller than electric arc

Table 1. Effects of alloy elements in steel.
[Hale, 2000]

Element	Effects
Boron	Improves hardenability without loss of or even with some improvement in machinability and formability.
Calcium	Improves hardenability, strength, hardness, and wear resistance; reduces ductility, weldability, and toughness.
Cerium	Controls the shape of inclusions and improves toughness in high-strength low-alloy steels; deoxidizes steels.
Chromium	Improves toughness, hardenability, wear and corrosiion resistance, and high-temperature strength; increases depth of hardness penetration in heat treatment by promoting carburization.
Cobalt	Improves strength and hardness at elevated temperatures.
Columbium (niobium)	Imparts fine-grain size, improves strength and impact toughness; lowers transition temperature; may decrease hardenability.
Copper	Improves resistance to atmospheric corrosion and to a lesser extent strength with little loss in ductility; adversely affects hot-working characteristics and surface quality.
Lead	Improves machinability; causes liquid metal embrittlement.
Magnesium	Has the same effects as cerium.
Manganese	Improves hardenability, strength, abrasion resistance, and machinability; deoxidizes the molten steel and reduces hot shortness; decreases weldability.
Molybdenum	Improves hardenability, wear resistance, toughness, elevated temperature strength, creep resistance, and hardness; minimizes temper embrittlement.
Nickel	Improves strength, toughness, and corrosion resistance; improves hardenability.
Phosphorus	Improves strength, hardenability, corrosion resistance, and machinability; severely reduces ductility and toughness.
Selenium	Improves machinability.
Silicon	Improves strength, hardness, corrosion resistance, and electrical conductivity; decreases magnetic hysteresis loss, machinability, and cold formability.
Sulfur	Improves machinability when combined with manganese; lowers impact strenth and ductility; impairs surface quality and weldability.
Tantalum	Has effects similar to those of columbium.
Tellurium	Improves machinability, forability, and toughness.
Titanium	Improves hardenability; deoxidizes steels.
Tungsten	Has the same effects as cobalt.
Vanadium	Improves strength, toughness, abrasion resistance, and hardness at elevated temperatures; inhibits grain growth during heat treatment.
Zirconium	Has the same effects as cerium.

furnaces, and often they are used in iron and steel foundries and for special purposes such as melting under vacuum or in an inert atmosphere, and melting of relatively high-purity charge materials.

The latest entry into the steelmaking process is the BOP, which is the L-D process, which was developed in Austria about 1952. Beginning in the early 1950s in the United States, the BOP is now the dominant steelmaking process in this country. In this process, a jet of pure oxygen is injected into the molten metal by a lance of regulated height in a basic refractory-lined converter. Excess carbon, silicon, and other reactive elements are oxidized during the controlled blows, and fluxes are added to form a slag. A production cycle can be completed in approximately 45 minutes. Under present practice, the charge consists of about 28 percent scrap with the balance molten pig iron. Several variations on the standard BOP have been developed. In various processes, oxygen, fuels, lime, or inert gases may be injected through tuyeres in the sides or bottom of the furnace vessel with or without the use of the top lance.

Several elements may be added to molten steel to remove dissolved oxygen (deoxidation), to control the embrittling effects of sulfur, or to change the properties of the finished steel. The main functions of the more common additive elements are listed in table 1. Hardenability is a measure of the depth of hardening of a steel and is useful in steels that are to be heat treated. High-temperature hardness and strength are useful in cutting tools and in high-temperature applications.

Casting

Steel may be poured from a refractory-lined ladle into a continuous-casting machine from which strands of steel emerge to be cut into billets, blooms, or slabs, which are then passed through a series of hot and cold rollers in the rolling mill for additional processing. Continuous casting has the advantage of producing a higher yield than ingot casting and eliminating the primary hot-rolling process. Continuous casting of steel on a commercial scale originated in Europe in the early 1950s and was introduced in the United States, generally as large-scale units, during the 1960s. Continuous-casting machines consist basically of a relatively short water-cooled copper mold; a cooling chamber that contains water sprays below the mold; pinch rolls; and rollers for supporting the casting beyond the cooling chamber. The mold generally oscillates vertically to prevent the casting from sticking. When the molten steel comes into contact with the mold, a thin skin of solid metal forms. The center of the casting remains molten until some distance below the bottom of the mold, where it is finally solidified by the water sprays in the cooling chamber. The steel from the ladle is poured into a refractory-lined container known as a tundish, from which it flows into the mold through a nozzle in the bottom. The tundish may have two or more nozzles for simultaneous pouring into a multiple-strands machine.

The four basic continuous-casting machines in contemporary use are vertical casting in which the vertical steel strand is torch-cut into slabs or billets, which are then lowered into the horizontal position; the vertical-plus-bending machine, in which the casting is bent into the horizontal position; the semihorizontal, or curved-mold machine in which a specialty designed mold and a curved cooling chamber are used, which permit the height of the machine to be about one-third that of vertical types; and horizontal casting. Another process, which is used to a limited extent, is bottom-pressure pouring of blooms, billets, or slabs in which the molten steel is forced by air pressure into graphite molds where it solidifies.

Conventional slab casting has evolved to the new thin slab casting technology. Molten steel is initially cast as a thin slab in a mold that ranges from 60 to 100 millimeters (mm) in thickness. The slab is reduced to about 50 mm in thickness on withdrawal from the caster compared with 200 to 300 mm in thickness in the conventional caster and further reduced through a tandem hot strip mill. Roughers are not needed in the rolling mill and fewer finisher rollers are required. Casting speed is increased from 1 to 2 meters per minute (m/min) to 4 to 6 m/min. A facility comprising an advanced EAF and thin-slab caster has a much lower investment cost, and less energy is consumed to reheat the slab.

In 2001, a revolutionary casting plant was built in Crawfordsville, IN, called a strip caster. The strip-casting process takes molten steel and casts it between rotating copper rolls directly into its final thickness and shape with minimal additional hot or cold rolling. Final strip thickness is 2 mm; casting speed ranges from 15 to 120 m/min. Advantages are that no roughers, no finishers, and no reheat furnace are needed. Energy usage and pollution are significantly reduced compared with slab-casting processes. Smaller, less expensive plants (micromills) can be built to use this new technology.

Rolling and Forging

Steel that is not processed through a continuous-casting machine may be poured into ingot molds, which are tall cast iron containers that weigh from 1 to 1.5 times as much as the ingots cast in them. The molds are usually tapered to facilitate removal of the ingots, which may range in size from a few hundred kilograms for specialty steels to 270 t or more for large forging ingots; most ingots, however, are in the 2- to 36-t range. The exact shape of the ingot is determined by the products to be made from it.

After ingots have been stripped from their molds, they are reheated in soaking pits to bring them to a uniform temperature of between 2,150° and 2,450° F prior to rolling in a primary mill. Soaking pits are large furnaces that are heated by oil, gas, or electricity and are usually below ground level. A primary mill reduces ingots to billets, blooms, or slabs by a process of gradual compression between two rotating rolls driven by a powerful electric motor. Several passes through one or more sets of rolls (stands) are required to reduce an ingot to final size.

Ends of the still-hot products from primary rolling or continuous casting are cropped to remove defective material. Billets, blooms, or slabs may be continuously rolled further in one operation to intermediate or finished products; they, however, are usually cooled and stored. Before the next processing step, most material is surface conditioned to remove defects by grinding or by scarfing with an oxygen torch.

Reheated semifinished steel is processed either into flat-rolled products or into rails, structural or other shapes, bars, wire rods, pipe, or tubing. Flat-rolled products are produced on smooth-faced rolls in contrast to grooved rolls used to make the other products. Flat-rolled products include black plate, plate, sheet, strip, and tin plate. A term that remains from blacksmithing days, “black plate” is thin, cold-rolled sheet steel used mainly to make tin plate. About one-half of all steel rolled in the United States is flat rolled. Black plate, sheet, strip, and tin plate, compose about three-fourths of all flat-rolled material.

Plate is a flat-rolled product more than 3 mm thick which is used for fabricated structures such as bridges, storage tanks, pressure vessels, railway cars, and ships. Hot-rolled band is obtained by hot rolling a billet, ingot, or slab, until its thickness has been reduced to 3 to 7 mm and is further processed by cold rolling. Sheet and strip are less than 3 mm thick, differ in width and thickness, and are both produced on continuous hot strip mills. Hot-rolled carbon steel strip ranges up to 305 mm wide and may be thinner than sheet, whereas sheet is over 305 mm wide.

A continuous hot-strip mill consists of one or more sets, or stands, of roughing mills and a final series of finishing rolls. Finishing rolls comprise four rolls arranged vertically—one pair of smaller work rolls that deform the steel, and one pair of larger backup rolls that prevent excess deflection of the work rolls. Hot rolling usually begins at 2,200°F and finishes well above 1,300°F. The product of the hot-strip mill may either be used without further rolling or further processed by cold rolling.

If sheet or strip is to be processed further, then oxide coating, or mill scale, must be removed from the surface. In most cases, this is done by pickling; that is, chemically removing the scale with a solution of hydrochloric or sulfuric acid. In some cases, shot or grit blasting is used to remove the scale. After descaling, the steel is coated lightly with oil to prevent rusting. Most hot-rolled material is given a light cold pass through temper rolls, to improve flatness, surface quality, and mechanical properties. The product is usually coiled, but if it is cut into sheets, it is usually flattened or leveled. Coiled material may be slit into narrower widths on a slitting line and recoiled.

Plate is a flat-rolled product heavier than sheet. Plates up to 48 inches wide have a minimum thickness of 0.23 inch; with plates over 48 inches wide, the minimum thickness is 0.18 inch. Plate is used for fabricated structures such as bridges, storage tanks, pressure vessels, railway cars, and ships.

Railroad rails, structural and other shapes, bars, and rods are rolled on grooved rolls in several passes, the final pass being through grooves having the dimensions of the finished product. Structural shapes include I-beams, angles, channels, and wide-flange beams; other shapes include miscellaneous sections for special purpose. Bars may be round, square, or hexagonal in cross section. Wire rod, which is also hot rolled on grooved rolls, is the starting material for wire drawing. Seamless tubing is rolled on special mills equipped with piercing mandrels for forming the inside bore.

Forging is a form of hot working that may be done by hammering or pressing usually with a die for controlling shape. Hammers are operated by steam, compressed air, or electromechanical devices; presses are either hydraulic or mechanical. Extrusion is a related hot-working process. A machine-driven ram shapes metal confined within a tubular container by pushing the metal out through a die opening at the opposite end of the container.

Cold Rolling

In cold rolling, the only heating the metal receives is a small amount from frictional effects during deformation. Cold-rolled steel is stronger and has better surface and dimensional characteristics than hot-rolled steel. Most cold rolling is done continuously with semifinished steel (hot-rolled bands) being fed through rolls from a coil.

Steel is most frequently cold rolled in four-high mills in which each work roll is backed by a larger roll; all rolls are vertically aligned. In a continuous-tandem mill, three to six four-high roll stands are arranged in a line. Material from a coil is reduced progressively as it advances through each stand. Some steel is rolled using by single-stand, four-high reversing mills; the steel is rolled first in one direction and then in the reverse direction until the final gage is reached. Another type of mill used for special applications is the Sendzimir mill, which has a clustered arrangement of backup rolls for transmitting force to the work rolls. In addition to roll stands, a typical cold mill may also have other equipment or lines for intermediate annealing and cleaning of steel. Some form of heat-treatment is applied to most cold-rolled sheet or strip to restore the ductility lost in cold reduction, except when the improved strength developed in cold rolling is required..

Coatings for Steel

Protective coatings have been developed for steel to prevent it from rusting and corroding and to expand its use. These coatings include, singly or in combination, other metals, such as aluminum, chromium, nickel, lead, tin, and zinc; enamels; lacquers; organic paints; plastics; varnishes; and vitreous enamel. Most important of the metallic coatings for flat-rolled steel are zinc, tin, and chromium. In 2002, 15.1 percent of all steel shipped was galvanized, and 2.2 percent was tinplated.

In the continuous hot-dip galvanizing method, a prepared coil of either hot- or cold-rolled steel is passed through a molten zinc bath. Relatively thick coatings of about 0.025 mm are produced. An increasing amount of galvanized steel is being produced by the electrolytic deposition of zinc. Electrolytic galvanizing can produce thinner coatings and better surface finishes and can coat types of steel that would be harmed by the heat of hot-dip galvanizing. Galvanized steel is used in the automotive and construction industries and in a wide range of other applications. Recently developed zinc-aluminum alloy coatings compete with conventional galvanized steel. An operation similar to galvanizing is used to manufacture long terne sheet, which is steel coated with a lead-tin alloy. Long terne sheet is a small-tonnage item especially suited for gasoline tanks.

Tin cans are made from tinplate, which is produced by a continuous process of electrolytic deposition of a thin tin layer onto cold-rolled sheet steel. Subsequent heating of the coated steel fuses the coating and gives it a metallic luster. Production of tinplate has declined somewhat in recent years partly because of competition from aluminum cans and partly because of the development of tin-free steel, which is made from the same steel as tinplate but coated instead with chromium. The coating is thinner than tin coatings, is put on electrolytically, and is lacquered to make it suitable for certain food and beverage containers.

Foundry

Iron and steel foundries produce castings, which are ready for use after a minimum of processing by pouring molten metal into molds. Among the advantages of the casting process are that complex parts can be produced in one piece, it is the most direct method of converting raw materials to finished products, products in a wide range of sizes and shapes can be cast, and castings can be designed with the metal distributed for maximum efficiency for strength, wear resistance, or other properties.

Molds for iron and steel castings are made from special sand mixtures or other materials. First, a pattern of the object to be cast is made, usually of wood; then the sand mixture is compacted around the pattern in a boxlike container known as a "flask", which is divided into a bottom part (the drag) and a top part (the cope). Opening the divided mold permits the pattern to be removed so that reassembly leaves a cavity of the required shape for the casting. To produce hollow or other special shapes, cores, which are made of hardened sand mixtures, are placed in the molds. Molten metal is poured into the mold through passages known as "sprues" and "gates", and special cavities known as risers are sometimes included to allow for shrinkage of the metal as it solidifies.

The predominant means of melting the charge in iron foundries is in a refractory-lined shaft furnace called a cupola. In recent years, however, EAF melting and induction melting have become increasingly important. The induction furnace is also used in combination with the cupola or EAF for increasing the metal temperature and as a holding furnace. The air furnace, which is a type of reverberatory furnace, accounts for a small proportion of the total production. Cupolas that have water-cooled walls, hot blast, and other design improvements have been introduced in recent years. In Europe and to some extent in the United States, a rotating variant of the air furnace has been used. The iron foundry industry historically has consisted of many small operations and only a few large plants. The trend, however, is toward larger foundries with increasing use of automation in the operations of sand and mold preparation, pouring of castings, and subsequent handling.

Steel foundries differ from iron foundries mainly in the higher temperatures and lower carbon contents required to produce steel rather than cast iron. Melting is done mostly in EAFs. Induction furnaces are used to a limited extent for melting special grades of steel. Steel castings also are made by some producers of steel ingots.

Research and Process Modifications

The blast furnace with an accompanying basic oxygen furnace is the primary means of converting iron ore to metallic iron and then steel. Efforts continue to improve these processes. Major modifications of the blast furnace and its operation by one U.S. company illustrate how the process is expected to be competitive for many years by increasing the pressure of the hot air blown into the furnace to 40 pounds per square inch (psi) at the bottom and 12 psi at the top, raising the temperature of the hot blast of air from the stoves of the furnace from 1,650° F to 2,000° F, incorporating computer control of the stoves, installing high-density cooling coils around the refractory brick, installing a closed-loop cooling system, increasing the troughs of the furnace and incorporating a tilt system to facilitate the filling of the hot metal cars with pig iron, automating the stock house, installing a computer control room to automate the running of the blast furnace and to perform computer modeling, and installing a new scrubber system to improve boiler operations (Best Manufacturing Practices, 2003b). This $79 million capital investment to the blast furnace was expected to decrease fuel consumption rates from to 420 kg from 444 kg of fuel per t of iron produced and increase production within a payback period of less than 2 years.

The torpedo bottle is an insulated railroad car that has a capacity of about 200 tons and is used to transport molten iron from the blast furnace to the basic oxygen furnace. Because the refractory lining in the torpedo bottle needs to be replaced periodically, the process flow is interrupted. The frequency of the replacement process is constantly reviewed and improved to extend the life of the refractory bricks. Special gunning material has been developed to coat and protect the bricks.

The basic oxygen furnace is modified so that gases and other materials can be injected at different locations. Many vessels can now inject fuels, nitrogen, oxygen, or other gases through the bottom of the vessel with or without top blowing. In all cases, the gas improves the stirring of the melt. Most such processes claim better metallic yield and better alloy recovery. Pulverized coal injected into the melt supplies extra heat and allows the furnace to accept a larger charge of scrap. New refractory material compositions and lining designs are reducing furnace down-time for maintenance.

Melting and decarburization are performed in the furnace; refining, such as deoxidation, desulfurization, modifying the nature of inclusions, and addition of alloying elements, are performed in the ladle to which molten steel is transferred from the furnace. Several processes are used in ladle metallurgy—argon-oxygen decarburization, electron beam melting, electroslag melting, vacuum induction melting, vacuum ladle degassing, vacuum oxygen decarburization, and vacuum stream degassing. Research continues to satisfy the increasing demand for cleaner, higher quality steels. A significant problem in ladle metallurgy is achieving successful addition into liquid steel of many elements that are light, reactive, or easily oxidized. An injection technique that uses a refractory lance with inert carrier gas was developed in the 1970s, and a decade later, wire injection began to replace lance injection. Wire injection causes less agitation of the steel, which minimizes pick-up of oxygen, hydrogen, and nitrogen, splashing, and temperature losses; requires smaller investment and operation costs; and improves yield, especially for calcium alloys and other reactive additions.

The use of continuous casting has been expanding rapidly in the United States. By 1975, 9 percent of steel production was continuously cast, and by 2001, 97 percent of steel production was continuously cast. Research has developed several improvements to the process. Blockage of small-diameter nozzles in the continuous caster by solid inclusions of alumina, silica, calcium sulfide, and other materials causes a break in the process flow. Steelmakers found that the problem of nozzle clogging is solved by the introduction of pure calcium or calcium alloys into the liquid steel, which modifies the inclusions and prevents clogging. Slag inclusion can also block the sliding gates and plug the holes. Steelmakers reported implementing a slag detection system to monitor the steel level in the tundish and to cut off drainage before the slag can carry over into the mold. A submerged pour method allows the pouring shrouds to be extended from the bottom of the ladle into the molten pool so that the pour emerges below the surface and is protected from exposure to the atmosphere. These changes have improved the process by keeping the openings free 97 percent of the time (Best Manufacturing Practices, 2003a).

The technology of continuous casting has been evolving steadily. Early conventional slab casters produced slab that had thicknesses from 200 to 300 mm and strip that had thickness from 1 to10 mm. Newer thin-slab casters produce slab that have thicknesses from 50 to 60 mm and strip having thickness from 1 to10 mm. Thin-slab casting requires no roughers, uses less energy to reheat slab, and has a faster casting speed. More recently, the revolutionary strip caster takes molten steel and casts it between rotating copper rolls directly into its final thickness and shape with minimal further hot or cold rolling. Strip thickness is 2 mm, and casting speed is faster than for thin-slab casting. Energy usage is reduced significantly. Operating and capital costs are reduced because roughers, finishers, or reheat furnaces are not needed.

Recycling

The recycling of iron and steel scrap (ferrous scrap) is an important activity worldwide, especially in the United States, where 73 Mt of new, old, and home scrap was consumed in the making of new steel during 2002. Obsolete iron and steel products and the ferrous scrap generated in steel mills and steel-product manufacturing plants are collected because it is economically advantageous to recycle iron and steel products by melting and recasting them into semifinished forms for use in the manufacture of new steel products. The steel scrap market is mature and highly efficient. The recycling rate for steel scrap, which has been defined by the Steel Recycling Institute (2003a) as total scrap recovered versus total raw steel produced, has exceeded 50 percent every year since World War II , has been more than 60 percent for about two decades, and reached almost 71 percent in 2002.

Iron and steel scrap is more than just economically beneficial to steel makers; ferrous scrap recycling is part of wise management of iron resources. Recovery of 1 t of steel from scrap conserves an estimated 1,134 kg of iron ore, 635 kg of coal, and 54 kg of limestone. Each year, steel recycling saves the energy equivalent required to power electrically about one-fifth of the households in the United States (about 18 million homes) for 1 year.

In the production of steel, 99.9 percent of scrap melted is consumed in the new steel while producing negligible environmentally undesirable waste (Steel Recycling Institute, 2003a).

Steel mills and foundries require ferrous scrap provided by brokers and scrap collectors and processors. Brokers bring scrap buyers and sellers together on a scrap transaction and receive a fee for this service. Consumers use brokers to procure scrap; processors use their services to market their scrap. Without having storage or processing facilities, brokers purchase scrap for a particular client buyer or with the hope of finding a future buyer offering a favorable price and profit. Thousands of automotive dismantlers and scrap-processing facilities in the United States play an integral role in the steel industry by collecting and preparing scrap for transport to steel mills that need raw materials. The greatest concentration of these facilities is in the northeast, north-central, and middle Atlantic regions because the large population uses more steel products and generates more scrap than the rest of the United States. The scrap recycling infrastructure causes the recycling rate of steel in the United States to be equal to and in most cases exceed that of other industrialized countries. The rate is much higher than that of lesser developed countries.

By using a variety of equipment, scrap dealers collect and process scrap into a physical form and chemical composition that steel mill furnaces can consume. The type and size of equipment they use depends on the types and volume of scrap available in the area and the requirements of their customers. The largest and most expensive piece of equipment is the shredder. The shredder can fragment vehicles and other discarded steel objects into fist-size pieces of various metals, glass, rubber, and plastic. These materials are segregated before shipment by using fans, magnets, air ducts, hand pickers, and flotation equipment. Hydraulic shears, which have cutting knives of chromium-nickel-molybdenum alloy steel for hardness, slice heavy pieces of ship plate, railroad car sides, and structural steel into chargeable pieces. Baling presses are used to compact scrap into manageable bundles, thereby reducing scrap volume and shipping costs. Total scrap-processing capability in the United States is an estimated 1.8 Mt (Robert Garino, Director of Commodities, Institute of Scrap Recycling Industries, Inc., written commun., January 2, 2001).

Ferrous scrap available for recycling comprises home, new, and old scrap. Home, mill, revert, or old plant scrap is generated within the steel mills and foundries as a byproduct of their operations. Trimmings of mill products and defective products are collected and quickly recycled back into the steel furnace because their chemical compositions are known. The availability of home scrap has been declining as new and more efficient methods of casting have been adopted by the industry. Old scrap includes metal articles that have been discarded after serving a useful purpose. The largest source of obsolete, old, or postconsumer scrap is junked automobiles followed by demolished steel structures, worn out railroad cars and tracks, appliances, machinery, and other products. Manufactured steel products have a wide range of chemical and physical characteristics according to relative contents of the trace elements carbon, chromium, cobalt, manganese, molybdenum, nickel, silicon, tungsten, and vanadium. Also, some steel products are coated with aluminum, chromium, lead-tin alloy, tin, or zinc. For these reasons, scrap dealers must carefully sort the scrap they sell, and steelmakers must be careful to purchase scrap that does not contain undesirable elements, or residuals, that exceed acceptable levels, which vary according to the product being produced. New, prompt, or industrial scrap is generated from manufacturing plants that make steel products. Scrap accumulates when steel is cut, machined, extruded, or drawn. The casting process also produces scrap as excess metal. Fabrication of new steel products produces new steel scrap that is relatively chemically and physically clean, and of known chemical composition. For this reason, most scrap consumers prefer this new scrap to old scrap. Preparation of new scrap is usually limited to cutting, cleaning, and baling prior to rapid transport back to the steelmaker for recycling. The supply of new scrap is a function of industrial activity. When activity is high, more industrial scrap is generated. The amount of new scrap is an estimated 15 percent of apparent consumption of steel mill products.

In the United States, the primary source of obsolete steel is the automobile (Steel Recycling Institute, 2003b). Of the ferrous metals used to make a typical 2002 U.S. family vehicle, 45 percent was recycled metal. The steel industry recovered and recycled about 12.8 Mt of iron and steel scrap for recycling in 2002—enough steel to produce about 14 million new cars. The recycling rate of automobile scrap steel was 101 percent in 2002 compared with 95 percent in 2000. A recycling rate of more than 100 percent is a result of the steel industry recycling more steel from automobiles than was used in the production of new vehicles. Appliances and other steel products are also shredded for recycling. The recycling rate of obsolete appliance scrap increased from 20 percent in 1988 to 81 percent in 1997, decreased to 72 percent in 1998, and rebounded to 87 percent in 2002 (American Iron and Steel Institute, 2003a).

During 2001, more than 1.9 Mt of steel was recovered from recycled appliances (Steel Recycling Institute, unpub. data, July 2003). The typical appliance consists of about 75 percent steel, and from 25 percent to 100 percent of the steel used in appliances is recycled. The recycling rate of steel cans increased from 15 percent in 1988 to 61 percent in 1997, decreased to 56 percent in 1998, and rebounded to more than 58 percent in 2000 through 2002 (American Iron and Steel Institute, 2003). The estimated rates of recycling of structural beams and plates in 2002 was 95 percent, and those of reinforcement bar and other materials were 58 percent. By 2002, an estimated 25 percent of all new homes built in the United States will be framed in recycled steel.

In a free market economy, scrap prices react quickly to changes in supply and, especially, demand. When demand for steel mill and foundry products is low, demand for scrap is low, and prices fall. Dealers cannot influence sales of scrap if mills and foundries do not need it to charge their furnaces. Although prices of scrap depend upon the market conditions for new products, the scrap industry uses inventory to absorb price differentials; that is, inventories increase as scrap prices decrease. Prices also are influenced by technological changes in mills, processing of scrap, use of scrap substitutes, environmental controls and other Government regulations, and export demand. During the decade prior to 1998, the average annual composite price of No. 1 Heavy Melting Steel scrap, an industry standard, fluctuated between $135.03 and $584.67 per t (Fenton, M.D., 1999). Ferrous scrap prices declined significantly during 1991 and 1992 as domestic and world demand for scrap decreased. The period from 1993 to 1995 was one of strengthening demand, and prices rose to a peak average price of $135.03 in 1995. Prices then declined to an average of $74.90 in 2001 and then rebounded slightly in 2002 to $91.58.

Because scrap comes from such sources as old buildings, industrial machinery, discarded cars, consumer durables, and manufacturing operations, the mature industrialized economies are the main exporters of scrap. The main trade flows of scrap are from the heavily industrialized and developed countries of Europe and North America to lesser developed steelmaking countries. In less developed countries, articles of iron or steel that would be recycled as obsolete scrap in an industrialized country, are likely to be used directly by crafts persons to produce other useful products and, thus, would not be available as scrap to the iron and steel industry. Also, these countries have not yet built up a reservoir of scrap in the form of steel structures and machines that are nearing the end of their useful lives. Germany was the leading exporting country of iron and steel scrap in 2000, followed by Russia, the United States, Ukraine, France, the United Kingdom, the Netherlands, and Japan. The most significant importing nations were, in decreasing order of importance, Turkey, the Republic of Korea, Spain, Belgium-Luxembourg, China, and Italy (International Iron and Steel Institute, 2001, p. 102, 104).

The U.S. trade surplus for all classes of ferrous scrap was 4.7 Mt in 2001 (U.S. Census Bureau, unpub. data, 2000). Total U.S. exports of carbon steel and cast-iron scrap went to 65 countries and totaled 6.4 Mt. The largest tonnages went to China, the Republic of Korea, Canada, Mexico, and Malaysia. Total U.S. exports of stainless steel scrap went to 43 countries and consisted of 443,000 t. The largest tonnages went to Taiwan, the Republic of Korea, Canada, China, and Japan. U.S. exports of alloy steel scrap (excluding stainless steel) were shipped to 47 countries and consisted of 611,000 t. The largest tonnages went to China, Canada, and Mexico.

Environmental Impact

The steelmaking and foundry industry is subject to Federal, State, and local regulations that deal with water- and air-polluting emissions and solid-waste disposal. Governmental policies on pollution control continue to evolve by balancing the benefits of reduced pollution against the costs of controls, but the trend is for stricter required control of emissions and waste disposal. In response to Governmental policies, industry promotes responsible corporate and public policies that conserve energy and natural resources and environmental laws and regulations that emphasize the need for effective and realistic risk assessment and cost-benefit analysis.

Scientific Certification Systems, which is an independent certification organization, conducted a life cycle study to determine the environmental savings associated with annual steel production from a single North American steel mill (American Iron and Steel Institute, 2002b). Some of the savings during 1 year are as follows: Enough energy is saved to light 3.6 million homes; reductions in sulfur dioxide releases are equal to the emissions associated with heating 12 million northeast U.S. homes; and solid-waste reductions are equal to the amount of garbage generated by 4 million Americans.

Environmental Costs

The American Iron and Steel Institute (2002a) reviewed the cost to mitigate environmental impacts by the U.S. steel industry. Environmental expenditures have amounted to more than $8 billion during 25 years. In a typical year, more than 15 percent of capital spending is for environmental facilities. Costs to operate and maintain environmental facilities amount to between $10 and $20 per t of steel produced, which exceeds industry profits even in prosperous years. These and other expenditures are beneficial to the environment. Since 1975, the amount of energy required to produce a ton of steel decreased by almost 45 percent, and the discharge of air and water pollutants was reduced by more than 90 percent. More than 95 percent of the water used for steel production and processing is recycled. Most hazardous wastes once generated by the steel industry are now being recycled for recovery for beneficial reuse.

Environmental Issues

In 1997, the U.S. Environmental Protection Agency (EPA) reduced the standard for airborne particulate matter (PM) from 10 microns (PM10) to 2.5 microns (PM2.5) because of epidemiological evidence of a link between increased hospital admissions, respiratory illness, and increased mortality and ambient particulate levels which were below the previous standard (Pennsylvania Department of Environmental Protection, 2004). According to the EPA, the PM10 standard does not protect against fine particles produced by fossil fuel combustion that lodge deep in the lungs and that research indicates pose the greatest health hazard. The biological mechanism, or mechanisms by which PM could cause health problems are uncertain. The Steel Manufacturer's Association's (SMA) response was that the new PM2.5 standard could eliminate thousands of high-paying, highly skilled manufacturing jobs in the steel and supporting industries and produce no quantifiable benefits to public health (Fenton, 1998). Imports of steel products to satisfy domestic demand would come from countries that have few or no environmental regulations comparable to those of the United States. According to the SMA, the result would be an increase in worldwide environmental degradation. The new standard will not be effective until a national PM monitoring network is established at the time of the next review of the National Ambient Air Quality Standards. The EPA announced that it would develop a rule to require industrial facilities, which include steel plants built between 1962 and 1977, to install technology to limit the release of pollutants, such as sulfur dioxide, nitrogen oxide, and particulate matter (Bourge, 2001). Plants to be covered under this Clean Air Act rule would be those emitting more than 227 Mt/yr of smog-causing agents that affect visibility in 156 national parks and wilderness areas. Although generally supportive of air-quality standards, the industry has stated that particulate and ozone ambient air standards and atmospheric visibility standards should be based on sound science and with consideration of the costs and social consequences of complying with a new standard (American Iron and Steel Institute, 2003b).

The Office of Solid Waste in the EPA has been preparing a list of persistent, bioaccumulative, and toxic substances that will be branded among "the worst chemicals in the world" and become the focus of significant regulatory attention during the next several years (Green, 2000). Of immediate importance to the steel industry are lead, mercury, and cadmium, although other metals are expected to be added to the list. The SMA and the Specialty Steel Industry of North America are working with the EPA to identify appropriate scientific ways to assess the hazards and risks posed by metals. According to the AISI, the Clean Water Act has been effective in improving water quality in the United States, but its focus has been on point source discharges. The AISI also states that as the United States turns future efforts toward remaining water quality challenges, the focus should shift to nonpoint sources of water pollution. As greater attention is given to nonpoint source contributions to water-quality problems, basin-wide approaches need to be pursued to deal with agricultural, forest, and urban runoff, as well as traditional point sources (American Iron and Steel Institute, 2003c). The Great Lakes Water Quality Initiative represents such a basinwide program that should be considered as guidance.

Brownfields are abandoned, idled, or underused industrial and commercial sites where expansion or redevelopment is complicated by real or perceived environmental contamination that can add cost, time, or uncertainty to a redevelopment project. From about 130,000 to 450,000 contaminated or abandoned commercial and industrial sites are in the United States, and the cost of cleaning U.S. brownfields may be as high as $650 billion (Envirotools, 2001). Legislation designed to encourage development of brownfield sites and reform related Federal and State programs, which is supported by the steel and scrap industries, ISRI, and numerous other groups, passed both houses of Congress during 2001. Industry's position is that voluntary cleanups for the redevelopment of underused industrial properties should have incentives. According to the industry, Federal legislation should address this problem to facilitate the transfer and productive use of these properties with specific attention to the liabilities of purchaser and seller (American Iron and Steel Institute, 2003d).

Concern over climate change has prompted proposals to mandate reductions in industrial emissions of greenhouse gases, principally carbon dioxide, which is closely associated with the combustion of the fossil fuels coal, oil, and natural gas. Although concentrations of carbon dioxide in the atmosphere and global atmospheric temperatures appear to be increasing, a cause-and-effect relationship has yet to be established. The American steel industry uses fossil fuels as its primary energy source. About two-thirds of the energy required to produce steel is derived from coal, and most of that is needed to produce coke, which is an essential material for the conversion of iron ore to iron. Because energy costs represent about 20 percent of the manufacturing cost of steel, efficient energy use has been of paramount importance to the industry, and increasing energy costs place even more importance on conservation and efficiency. The industry, largely through investments in new technology, has already reduced energy use significantly, but additional reductions that depend on continued investment in new technology cannot continue without limit because of the inherent requirements for carbon in making iron and steel. Mandated use of alternative fuels, forced reductions in carbon or energy consumption, or energy taxes designed to reduce consumption will increase production costs and reduce output. Such mandates, however, may encourage the development of new technologies. The industry supports governmental policies that encourage improved manufacturing cost efficiencies through energy alternatives or technology (American Iron and Steel Institute, 1997a). Credible science, however, must provide the foundation for policy decisions and the corresponding economic and social impacts of alternative policy choices related to greenhouse gases (American Iron and Steel Institute, 1997b). Any program that reduces emissions to address global concerns calls for a global approach that is verifiable and enforceable, particularly with respect to impacts on international trade.

The Industry

Types of Steel Mills

The companies that produce mill products are in one of two major groups: integrated and minimill. About 53 percent of raw steel production was from the large integrated steel companies, those that have blast furnaces and are able to produce steel from ore using the basic oxygen furnace. The beginnings of most of these companies and many of their plants can be traced to the late 19th century or the early decades of the 20th century. These integrated companies produce much of the coal, iron ore, and limestone needed in its plants. Most of the integrated companies own more than one plant and produce a wide range of products. The seven largest integrated U.S. steel companies in 2001 produced about 48 percent of U.S. steel. This was down from 66 percent in 1983 (International Iron and Steel Institute, 2002).

The fastest growing and youngest sector of the domestic steelmaking industry is made up of the so-called minimills, or market mills. These mills typically use electric furnaces and continuous casting to produce products from mostly scrap with some pig iron and direct reduced iron. The production capacity of each minimill is relatively small (maximum about 1.1 Mt/yr) compared with that of a modern integrated steel plant (maximum about 6.7 Mt/yr). Compared with the integrated mills, the minimills have a number of advantages, such as generally lower non-union labor costs, locations near markets and scrap supplies, lower capital cost, and lower environmental impact. A new integrated mill in a new location would require a capital investment of billions of dollars, but a 1-Mt capacity minimill would cost only about $255 million (Industry Canada, 2003). For those products for which their technology is appropriate, the minimills dominate the market because of their lower costs; many of these products have been discontinued by the integrated producers. These products include steels for the food container industry and deep-drawing steels for the automotive and appliance industries. Although the minimill industry began as producers of lower quality types of steel, which include bars, wire rod, and light structural shapes, minimills now produce higher value special-quality bars, medium-weight structural shapes and pipe, and sheet as a result of new technology, such as ladle refining technology and the use of alternate iron feed material. Some products, however, are still more economically made only on the large scale of the integrated plants using the basic oxygen furnace and argon-oxygen degassing equipment.

Specialty steel companies produce relatively small quantities of high-quality, high-value products that include stainless, tool, and electrical steels. They also produce other alloy steels to very high-quality standards for such applications as aerospace where exceptionally high reliability is required. Some of the companies also produce other specialty metals such as superalloys and magnetic alloys. Specialty steel companies range from small independent companies that produce highly specialized tool steels to specialty steel divisions of major integrated producers.

Steel Service Centers

Situated between the steel mills that make the finished steel and the manufacturers of steel products are the steel service centers. Service centers buy steel and process it by using burning units, cut-to-length lines, edgers, grinders, levelers, plasma tables, saws, shears, and slitters before reselling it to manufacturers, or they distribute it without additional processing. Centers offer a valuable service to manufacturers that operate just-in-time operations, which hold little inventory to reduce costs and rely on the distributor to supply the steel products when needed. About one-fourth of steel produced is sold to more than 5,000 steel service centers in the United States, the largest U.S. steel customer group. This $50 billion per year industry employs more than 88,000 people and ships about 24.5 Mt of steel each year (Metals Service Center Institute, 2003).

Steel Mill Locations

The steel industry is concentrated in an area that extends from the Mid-Atlantic States to Illinois. Integrated mills are located near the Great Lakes, along river systems, or near the coal beds of West Virginia and western Pennsylvania. Minimills are widely distributed across the United States because they are less reliant on water transport and do not need coal for fuel. In 2002, the leading steel-producing States were Indiana (18.4 Mt), Ohio (12.1 Mt), Michigan (5.6 Mt), Pennsylvania (5.4 Mt), and Illinois (3.4 Mt). Other States with large steel industries include Alabama, Kentucky, Maryland, New York, Texas, and West Virginia.

In Ohio and Pennsylvania, many of the older plants that were built to use local raw materials are not well situated now that iron ore is brought from a distance and are at a disadvantage to the newer integrated mills built on the Great Lakes. Until 1982, Pennsylvania had been the leading producing State. In 1982, however, production in Pennsylvania was 55 percent lower than that of 1981, and it decreased an additional 50 percent by 2002. Employees engaged in the production and sale of iron and steel products, as reported by the U.S. Bureau of Labor Statistics, declined by 30 percent to 124,000 in 2002 from 176,000 in 1993 (American Iron and Steel Institute, 2002c, p. 4).

Foreign Ownership

Historically, foreign ownership of the U.S. steel industry has been negligible, but by 1997 about 18 U.S. steel companies had foreign owners and 12 other companies were joint ventures with at least one U.S. company partner. One significant example is the acquisition of Inland Steel Co. by Ispat International NV of London. Inland

Steel is the sixth largest steel company in the United States and produces 5 percent of U.S. steel. Ispat Inland Inc. also partners with Nippon Steel Corp. of Japan at two Indiana finishing plants. National Steel Corp. of the United States is a subsidiary of Japan's NKK Corp. The largest steelmaker in the United States, the integrated producer U.S. Steel Corp.(USS), has a joint venture with Kobe Steel Ltd. of Japan and Pohang Iron & Steel Co. Ltd. of South Korea. Also, Companhia Siderúrgica Nacional of Brazil agreed to buy the cold-rolling plant Heartland Steel Inc. of Terre Haute, In., in 2001, which had been operating in Chapter 11 bankruptcy since January 2001. The Duferco-Farrell Corp. bought the Sharon Steel Co. in Sharon, Pa, in 1998 to convert imported steel slabs. About 42 percent of steel shipments in the United States during 1999 was estimated to be from American mills owned or partly controlled by foreign companies. The U.S. steelmaking industry traditionally has made few investments in foreign countries, but in 2000, the largest steel maker in the United States, U.S. Steel Corp. acquired the Slovakian steel company VSZ Holding, a.s. (formerly Vychodoslovenske zelezarny) for about $1.2 billion paid over 10 years. The new company is known as U.S. Steel Kosice (USSK).

Steel Mill Capacity

The U.S. steel industry has been reducing its capacity in recent years. Between 1983 and 2002, capacity was reduced by about 33 percent to about 103 Mt. Furthermore, the corporate structure of these companies is being reorganized through the sale of steel operations and mergers. U.S. steel companies have invested more than $50 billion in steel plant modernization since 1980. More than 50 percent of the types of steels made today did not exist 10 years ago (Fair Trade Watch, 2003).

Steel Mill Capitalization

The determination of the capital value of the U.S. steel industry is difficult because analysts define capitalization differently. Many companies do not publish financial data, and, to compound the problem, about 32 steel companies have filed for Chapter 7 or 11 bankruptcy during the past 4 to 5 years. Pre-1997 capitalization has been estimated to be about $60 billion (54.4 Mt at about $1100 per ton for integrated mills and about $16.5 billion (49.9 Mt at about $330per ton) for minimills (Thomas Danjczek, Steel Manufacturers Association, written comm., April 22, 2003). The U.S. Census Bureau (1999, p. 8) reported that the gross book value of total assets of U.S. iron and steel mills (NAICS 331111) at the end of 1997 was about $37.2 billion. This value includes capital expenditures for new and used buildings and other structures and new and used machinery and equipment, less retirements.

At the end of 2001, total capitalization was estimated to be nearly $13 billion, which included $7.3 billion in long-term debt and $5.5 billion in total equity (American Iron and Steel Institute, 2001, table 3). The AISI's reported data represents only 69 percent of domestic steelmaking capacity and estimated capitalization for the remainder. An unknown number of steel processors are included with steelmakers. Also, long-term liabilities of $16 billion are not included in this calculation, although some would claim that such long-term liabilities are equivalent to long-term debt (C. Bradford, Bradford Research, oral comm., April 22, 2003).

Recent sales of integrated steel mills illustrate the precipitous decline of capitalization of mill capacity from a pre-1997 average value of about $1,100 per ton (Thomas Danjczek, Steel Manufacturers Association, written comm., April 22, 2003). The integrated mill LTV Steel Corp., which has 7.3 Mt of capacity, sold for $1.5 billion ($205 per ton capacity). Bethlehem Steel Corp. sold 9.1 Mt of capacity for $1.5 billion ($165 per ton capacity). National Steel Corp. sold about 5.4 Mt of capacity for $1.0 billion ($185 per ton capacity). Sales of minimills illustrate the similar decline of capitalization of mill capacity from the pre-1997 average value of about $330 per ton. Qualitech Steel Corp., which has a 453,500-t capacity, sold for $35 million ($77 per ton capacity). Birmingham Steel Corp. sold 2.7 Mt of capacity for $600 million ($220 per ton capacity). Trico Steel Corp. sold 0.9 Mt of capacity for $110 million ($122 per ton capacity).

According to the annual Capital Spending Survey by New Steel (2001), capital spending by the North American steel industry was expected to decline by 33 percent, to $2.1 billion in 2001 from $3.3 billion in 2000. The industry spent $4.9 billion on capital projects in 1998. Capital spending by minimills was expected to decrease by 40 percent to $0.9 billion in 2001 from $1.4 billion in 2000. Integrated steel producers spent $1.6 billion in 2000 and were expected to spend only 1.0 billion in 2001; this would be a 38 percent decrease. The U.S. Census Bureau (2003) reported that total capital expenditures by iron and steel mills (NAICS331111) was $2.60 billion during 1997 and declined steadily to $1.32 billion in 2001.

Supply and Demand

Components of Supply

Production

The principal products of the iron and steel industry consist of steel mill products, steel castings, and iron castings. Details of shipments of steel mill products by type and form and of iron castings are given in figures 2 and 3, respectively. From 1997 to 2001, steel mill shipments, foundry shipments-iron, and foundry shipments-steel made up about 90 percent, 9 percent, and 1 percent, respectively, of total U.S. shipments (table 2).

The level of production and shipments of steel and cast iron is primarily determined by the level of activity in manufacturing. U.S. steel production reached a peak of 137 Mt in 1973 and then declined dramatically to a low of 67.7 Mt. in 1982 Production then increased gradually to a high of 102 Mt in 2000 and dropped the following year to 90.1 Mt.

Imports

The United States had been largely self-sufficient in iron and steel production until 1968 when, for the first time, import dependency (imports as a percentage of apparent consumption) exceeded 10 percent. From that year,

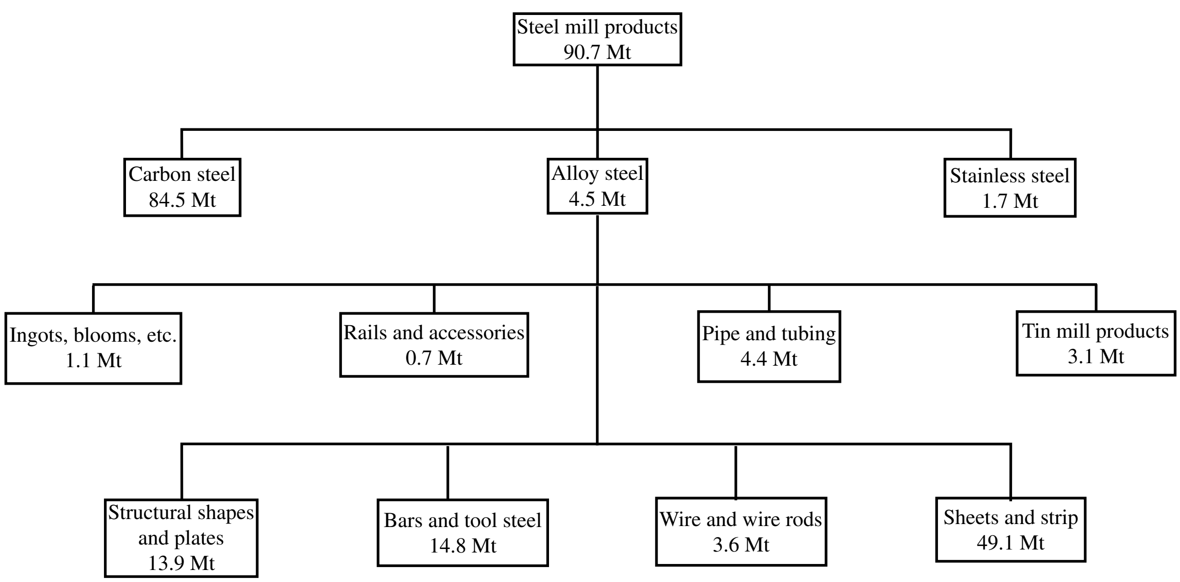

Figure 2. Shipments of steel mill products in 2001, by type and form. Mt, million metric tons. Source: American Iron and Steel Institute, 2002.

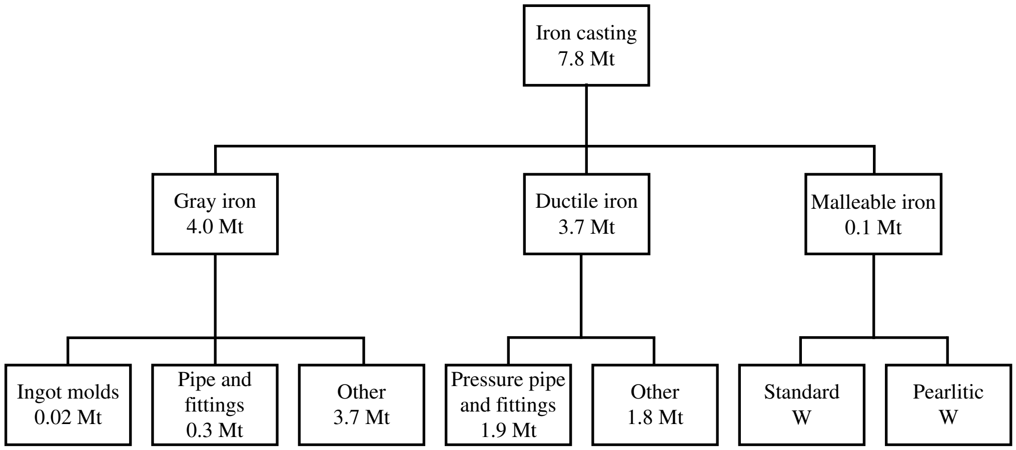

Figure 3. Foundry shipments of iron castings in 2001, by type and form. Mt, million metric tons; W, withheld to avoid disclosing company proprietary data. Source: U.S. Census Bureau, 2003.

Table 2. Iron and steel supply-demand relationships, 1992-2001.
[In million metric tons]

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
WORLD PRODUCTION										
Raw steel production:										
United States	84.3	88.8	91.2	95.2	95.5	98.5	98.6	97.4	102.0	90.1
Rest of world	639.7	641.2	638.8	656.8	655.5	698.5	671.4	686.6	743.0	756.9
Total of world	724.0	730.0	730.0	752.0	751.0	797.0	770.0	784.0	845.0	847.0
COMPONENTS AND DISTRIBUTION OF U.S.SUPPLY										
Finished iron and steel:										
Steel mill shipments	74.6	80.7	86.2	88.4	91.5	96.0	92.9	96.3	98.9	89.7
Foundry shipments:										
Iron	7.9	11.9	13.3	13.0	9.8	9.8	9.8	9.8	9.4	8.3
Steel	1.0	1.4	1.0	0.9	1.2	1.2	1.3	1.2	1.0	0.7
Imports of iron and steel	15.5	17.7	27.3	22.1	26.5	28.3	37.7	32.4	34.4	27.3
Exports of iron and steel	3.9	3.6	3.5	6.4	4.6	5.5	5.0	4.9	5.9	5.6
Adjustments[1]	2.1	2.9	5.9	1.8	5.4	5.3	7.2	7.7	7.9	4.9
Total U.S. supply	93.0	105.2	118.4	116.3	119.0	124.5	129.4	127.1	129.9	115.5
U.S. DEMAND PATTERN										
Service centers and distributors	19.3	21.5	21.9	21.5	24.6	25.2	25.2	25.5	27.3	24.6
Construction	11.1	12.2	13.0	13.5	14.1	14.4	13.9	16.7	18.4	19.5
Automotive	10.1	11.5	13.4	13.3	13.3	13.8	14.4	15.2	14.6	12.8
Machinery	5.8	6.3	6.7	6.5	6.9	6.7	2.0	1.6	1.6	1.3
Containers	3.6	4.0	4.1	3.8	3.7	3.8	3.5	3.5	3.4	2.9
Others	24.7	25.3	27.2	29.8	28.9	32.1	34.1	33.9	33.6	28.6
Total U.S. primary demand	74.6	80.8	86.3	88.4	91.5	96.0	92.9	96.3	98.9	89.7

[1]Adjustments for semifinished imports and annual steel mill inventory changes.

import dependency gradually increased to a peak of 25 percent in 1984, declined to 18 percent during the following 8 years, and then increased to 29 percent in 2000 before decreasing to 25 percent in 2001. The United States and Canada are now the only two major steel-producing nations without self-sufficiency in steelmaking.

Imports of steel mill products by type and form in 2001 are shown in figure 4. The import share of apparent supply for several forms, which are listed for the decade 1992 to 2001 in table 3, has varied with time. Wire rods and hot-rolled bars increased gradually and steadily to 18 percent from 13 percent and to 48 percent from 20 percent. Trends for structural shapes, plates, and hot-rolled sheets correlated over time with each form's import share peaking

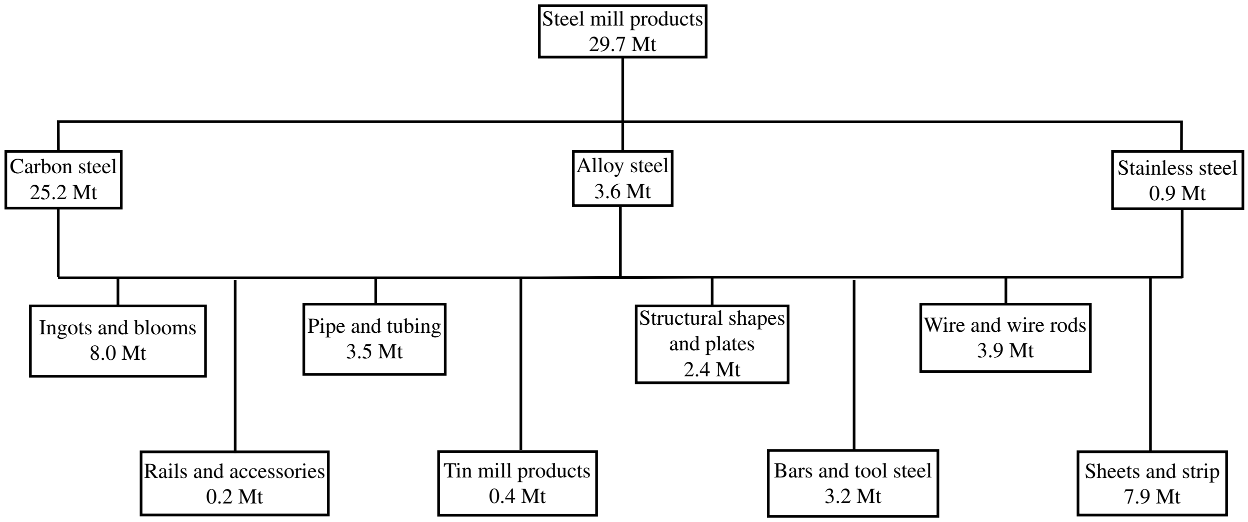

Figure 4. Steel mill product imports in 2001, by type and form. Mt, million metric tons. Source: American Steel Institute, 2002.

Table 3. U.S. imports as percentages of apparent consumption of selected products.[1]
[Data from the American Iron and Steel Institute and the U.S.Census Bureau]

Items	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Wire rods	20.1	22.1	26	27.9	28.1	30	31.9	34.8	38.2	47.9
Structural shapes (more than 3 inches)	8.8	10.6	12.4	11.3	16.1	16.5	36.1	21	23.6	14
Plates	19.4	15.9	22.9	21.9	28	26.7	38.6	24.8	24.2	17.1
Bars, hot-rolled	12.9	15.1	14.3	14.8	15.1	14.3	16.7	16.6	19.3	18.4
Sheets:										
Hot-rolled	20	15.3	22.2	17.5	19.6	22.2	35.6	21.3	23.5	11.9
Cold-rolled	16.8	16.6	24.9	20.9	17.8	22.4	24.4	20.3	17	20.7

[1]Apparent consumption = shipments + imports - exports.

at between 36 percent and 39 percent during 1998 before declining to 12 percent to 17 percent in 2001. The import share of cold-rolled sheet fluctuated cyclically in the range of from 17 percent to 25 percent. Between 1992 and 2001, net imports of iron and steel (imports minus exports) increased their share of total U.S. supply from 7 percent in 1974 to 33 percent in 1998 before declining to 22 percent in 2001.

The U.S. steel industry is an important source of steel for weapons, ships, planes, tanks, and other vehicles needed in conflicts abroad and for repair and replacement of infrastructure, which includes power plants, bridges, highways and roads, and oil and gas pipelines. An emergency need for steel could place a serious demand on the domestic steel supply unless a healthy steel industry that has adequate capacity and trained steelmakers is in operation and ready to satisfy any unexpected emergency.

Old Scrap

Total reported scrap consumption by steel mills and ferrous foundries in 2001 was 57.0 Mt (Fenton, 2002). The reported supply of scrap to these consumers included 13.1 Mt of home scrap and net receipts of 43.0 Mt from sources outside the plants. Home scrap consisted of 13.0 Mt of recirculating scrap and 140.000 t of obsolete scrap generated in steel mills and molds and old equipment in foundries. The quantity of scrap, exclusive of recirculating scrap, consumed was equal to about 50 percent of total steel mill and foundry shipments. The balance of the iron units needed by the iron and steel industry was obtained from ore. The percentage of iron units supplied by scrap has been increasing steadily primarily because of the increased fraction of steel made in electric furnaces and because of the increased use of continuous casting by integrated steel plants.

U.S. and World Production

Production of iron and steel in the industrialized countries and LDCs in Asia increased steadily to satisfy increasing demand after World War II. Between 1950 and 1974, world steel production grew at a steadily increasing rate; during this time, the average annual rate of production growth was about 16.2 Mt. The world steel industry operated at capacity in 1973 and 1974, and capacity was being expanded to meet the expected growing demand. The sharp rise in petroleum prices and the following economic disturbances, however, resulted in much slower growth in steel demand. After 1974, the world steel industry operated below capacity in most countries, and many steel companies suffered financial losses because of low production and low prices. The steel industries of the European Economic Community and Japan, which export a significant part of their steel production, lost part of their markets in the LDCs as those countries built their own steel capacity. In the United States, steel production was limited by weak markets and higher imports. Production was particularly depressed in 1982 when U.S. production of raw steel was less than one-half of that in 1973 (American Iron and Steel Institute, 1982, p. 77). From 1974 to 2000, the annual growth rate of steel production was 5.5 Mt, which was considerably less than that of the previous 24 years. World steel production in 2001 and capacities from 1999 through 2001 are listed in table 4.

Table 4. World raw steel production, 2001, and capacity, 1999, 2000, and 2001.
[In million metric tons. [e], estimate.]

Area	Production, 2001[1]	Capacity[2] 1999	2000	2001[e]
North America:				
United States	90.1	114	116	116
Canada	16.3	17	17	17
Mexico	13.3	17	18	18
South America, Brazil	28	31[e]	34	34
Europe, European Economic Union	161	198	198	198
Africa		23	23	23
Asia:				
Japan	103	150[e]	150[e]	150
China	149	131	132	136
Korea, Republic of	45	43	43	43
World total	847	1,070[e]	1,101[e]	1,115

[1]Source: American Iron and Steel Institute.
[2]Source: Organisation for Economic Co-operaton and Development.

The Economics of Steel

Production Costs

The U.S. steel industry faces stiff competition by foreign producers, and within the United States, integrated mills compete with minimills. Profitability is difficult to achieve when production costs cannot be reduced below those of the competition. World Steel Dynamics compiled after-tax total-operational costs of 12 major steel-producing countries during 2001 (Tavares, 2002). Total average operating cost was highest in the United States at $441 per ton. Canada, Japan, Germany, and France, in declining order, had lower costs. The lowest average operational costs were in the Republic of Korea, $308 per ton; China, $296 per ton; and Brazil, $295 per ton.

USS produced hot-rolled coils for about $265 per ton plus an additional $40 per ton to pay for retirement and health benefits for former workers, known as legacy costs. USS reported a loss of $218 million in 2001 (Duvall, 2003). In addition to the legacy cost burden, iron ore is a major factor in the integrated steelmakers' costs. In 2000, iron ore was about 12 percent of the pretax cost of $480 for a typical integrated producer.

Prices

Prices of steel mill products, as represented by the Producer Price Index (PPI), generally increased from January 1980 (PPI=84.0) to a peak in July 1995 (PPI=121.9) as demand and production increased (table 5). This trend was interrupted occasionally for periods of between 6 months to 4 years.

Table 5. Producer price index for steel mill products, 1980-2002.
[Base year, 1982. U.S. Bureau of Labor Statistics, 2003]

Year	Price index	Year	Price index
1980	86.6	1991	109.5
1981	96.6	1992	106.4
1982	100	1993	108.2
1983	100.9	1994	113.4
1984	104.7	1995	120.1
1985	104.7	1996	115.6
1986	99.8	1997	116.4
1987	102.3	1998	113.8
1988	110.7	1999	105.3
1989	114.5	2000	108.4
1990	112.1	2001	101.3
		2002	104.8

Production and shipments of steel in 1982 dropped to the lowest levels since 1946, and the rate of capacity utilization fell to 34 percent in December. Prices declined during the year as minimills and integrated mills competed for customers. Oil drilling activity declined and prices for tubular goods and line pipe were discounted by as much as 50 percent.

In 1985, production of raw steel and shipments of finished products declined slightly to continue the historically low levels. Despite cost-cutting efforts, most major steel producers continued to be unprofitable. Only two of the six leading integrated steel companies reported profits. As employment in the steel industry declined, Wheeling-Pittsburgh Steel Corp. went into bankruptcy and other companies restructured and closed unneeded or high-cost capacity. Transaction prices generally declined during the year as minimills put competitive pressure on integrated mills by producing higher quality steel products.

The beginning of 1989 was marked by strong demand and firm prices, but by yearend, demand was low, especially from the automakers, and discounting was severe—up to 20 percent from list price and even more in stainless steels. Demand and prices continued to decline as the economy went into recession in late 1990. The combination of lower volume and lower selling prices resulted in continued financial losses for the U.S. steel industry. Numerous efforts by steel companies to increase their prices were reported, but vigorous competition prevented prices from being increased through 1992. The PPI reached a low of 105.1 near the end of 1992 and increased steadily to a high of 121.9 in 1995.

During an 81-month period beginning in 1991, the United States experienced remarkable economic growth and prosperity. Nevertheless, steel prices began to decline in mid-1995, and the Asian financial crisis of 1997 caused a declining Asian demand for steel, excess steel-producing capacity, unusually low steel prices, and major export activity from Asia to the United States where low-priced steel was welcomed by consumers. U.S. steelmakers were forced to compete against low-priced imports. The PPI dropped to a low of 98.3 in January 2002 and rebounded to 110.4 in October 2002 as a result of new tariffs imposed to combat alleged steel dumping.

Taxes

The AISI compiled financial statistics from a group of its member companies that accounted for about 69 percent of U.S. steel production during 2000 and 2001 (American Iron and Steel Institute, 2001, p. 8). These data are for the steel operations of the businesses. According to these data, total taxes between 1992 and 2001 were equal to 1.9 percent of sales, but down from 4.7 percent between 1972 and 1981. Nonincome taxes decreased from 5.6 percent of payroll and 1.8 percent of sales in 1981 to 3.4 percent of payroll and 0.8 percent of sales in 2001. Income taxes increased from 1.6 percent of sales in 1981 to 2.5 percent in 2001.

The Federal income tax code provides indirect subsidies to the steel industry by not taxing the interest paid on bonds issued by States or local governments. Steel companies have sometimes benefitted from low-interest financing for certain projects through tax-free bonds issued as part of environmental quality or economic development programs.

Labor Productivity

During the past two decades, the domestic steel industry responded to domestic demand and foreign imports of low-cost steel mill products by adopting new steelmaking technology and eliminating less-efficient plant and equipment. Industry success can be measured using labor productivity as reported by the U.S. Bureau of Labor Statistics (2003). The U.S. Bureau of Labor Statistics labor productivity index (output per hour) for U.S. Standard Industrial Classification (SIC) 331—blast furnace and basic steel products—increased by 144.8 percent from 65.4 in 1980 to 160.1 in 2000. The same index for SIC 3312—blast furnace and steel mills—increased by 71.7 percent from 100 in 1987 to 171.7 in 2000. The greatest annual increase for both indexes was in 1993 when SIC 331 increased by 14.2 percent and SIC 3312 increased 17.3 percent. That worker productivity has been improving during the past 26 years is indicated by the decreasing worker-hours per ton of raw steel produced listed in table 6.

Table 6. Worker-hours per metric ton of raw steel production in the U.S. steel industry.

[American Iron and Steel Institute, 1982, p. 14; 1992, p. 15; 2001, p. 15]

Year	Wage workers	Salaried workers	Production (metric tons)	Workers per metric ton		
				Wage	Salaried	Total
1975	453,385	163,273	106,000,000	4.28	1.54	5.82
1980	390,359	163,189	101,000,000	3.87	1.62	5.48
1985	150,906	57,262	80,100,000	1.88	0.71	2.60
1990	119,683	44,280	89,700,000	1.33	0.49	1.83
1991	105,045	41,095	79,700,000	1.32	0.52	1.83
1992	101,220	38,444	84,300,000	1.20	0.46	1.66
1993	93,225	33,967	88,800,000	1.05	0.38	1.43
1994	92,587	33,031	91,200,000	1.02	0.36	1.38
1995	91,125	31,488	95,230,000	0.96	0.33	1.29
1996	88,191	30,612	95,500,000	0.92	0.32	1.24
1997	83,466	28,359	98,500,000	0.85	0.29	1.14
1998	81,572	28,062	98,600,000	0.83	0.28	1.11
1999	75,826	26,392	97,400,000	0.78	0.27	1.05
2000	74,028	25,508	102,000,000	0.73	0.25	0.98
2001	65,374	22,676	90,084,000	0.73	0.25	0.98

The integrated producer USS made steel at the rate of 3.3 hours/t produced (Duvall, 2003). The non-integrated steelmaker IPSCO Inc. reported a productivity increase—about 4 hours/t to 1 hour/t—between 1982 and 2002 after a $1 billion capital investment and expansion into the United States from Canada (Sutherland, 2003).

Energy Requirements

All U.S. iron and steel producers combined used about 19 million British thermal units per metric ton (Mbtu/t), or more than 3 percent of total U.S. energy consumption and more than 10 percent of that used by the whole manufacturing sector (American Iron and Steel Institute, 1997c). Energy is the largest single component of operating cost for many producers (15 to 20 percent). Since 1975, the industry has reduced energy consumption per t of steel shipped by about 45 percent (Washington Times, 2001). The U.S. Department of Energy reported energy consumption in 2000 of U.S. integrated and minimill steel producers (Wilson, 2001). Total energy used in integrated mills was about 25 Mbtu/t. Ironmaking, hot rolling, and pelletizing and sintering consumed about 53 percent (13.3 Mbtu/t), 11 percent (2.6 Mbtu/t), and 9 percent (2.2 Mbtu/t), respectively, of total energy consumed. Cokemaking, steelmaking, ladle metallurgy, pickling, and coating each used about 4 percent (5.0 Mbtu/t) of total energy consumed. Coal pulverization, continuous casting, cold rolling, and tempering and finishing accounted for the rest. For minimills, total energy used was about 10 Mbtu/t, or only 44 percent of the total energy consumed by integrated mills. Steelmaking and hot rolling consumed about 58 percent (6.4 Mbtu/t) and 18 percent (2.0 Mbtu/t), respectively, of total energy consumed. Pickling and ladle metallurgy used 7 percent (700,000 Mbtu/t) and 6 percent (500,000 Mbtu/t), respectively, and continuous casting, tempering and finishing, and cold rolling accounted for the rest. Average energy requirements per ton of raw steel in the U.S. steel industry in 1983, 1998, and 2001 are listed in table 7. Energy needed from all sources—coal, electricity, natural gas, and fuel oil—decreased during nearly 2 decades of steelmaking, probably as a result of declining blast furnace production relative to EAF production.

Table 7. Average energy requirements per metric ton of raw steel in the U.S. steel industry, 1983, 1998, and 2001.

[In million British thermal units per metric ton unless otherwise specified. Data from the American Iron and Steel Institute]

Type	Quantity	British thermal unit equivalent
1983:		
Coal	33 million net tons	9.4
Electricity	42,400 million kilowatthours	4.8
Natural gas	379 billion cubic feet	4.1
Fuel oil	431 million gallons	0.6
1998:		
Coal	22 million net tons	5
Electricity	42,900 million kilowatthours	3.8
Natural gas	395 billion cubic feet	3.3
Fuel oil	172 million gallons	0.2
2001:		
Coal	19 million net tons	4.3
Electricity	43,500 million kilowatthours	3.8
Natural gas	320 billion cubic feet	2.7
Fuel oil	107 million gallons	0.1

Coal and natural gas provide 60 percent and 30 percent, respectively, of the energy consumed by the steel industry (American Iron and Steel Institute, 2001). The steel industry has formed a partnership with the U.S. Department of Energy's Office of Industrial Technologies to accelerate development of technologies and processes that will improve the industry's energy efficiency (Chan and Margolis, 2002). Projected energy reductions possible through technological changes between 2000 and 2010 for integrated mills, minimills that produce long products, and minimills that produce flat products are 2.0 Mbtu/t, 1.5 Mbtu/t, and 500,000 Mbtu/t, respectively.

Infrastructure

The U.S. steel industry relies on dependable low-cost rail, water, and truck transportation for raw materials and finished steel products. In June 1999, the acquisition of Conrail, Inc. by CSX Transportation, Inc. (CSXT) (42 percent) and Norfolk Southern Corp. (58 percent) reduced the number of large rail carriers from three to two in the eastern part of the United States. The routes of both carriers are in 23 States east of the Mississippi River, the District of Columbia, Quebec, and Ontario. The steel and scrap industry has been described as captive to the rail companies because the railroad system is the main form of transportation of ferrous scrap in the United States (Scrap Price Bulletin, 2000). Because profitability is based on receiving reliable, affordable transportation, steel producers and scrap suppliers expressed concern prior to the restructuring that it might adversely affect them. A significant part of the industry experienced considerable deterioration of service, such as significantly increased turnaround times of rail cars, lost cars and billing, erroneous information given to shippers, car unavailability, and mistakenly routed shipments, that are based for the most part, on the railroads' computer problems. All this resulted in canceled contracts, increased costs, and smaller orders (American Metal Market, 1999a, 2000). To alleviate the problems, greater reliance was placed on truck transportation, which can be twice as expensive and was even more so because of the increased demand on a limited number of trucks and because the fuel surcharge for trucks was about 10 percent (American Metal Market, 1999b). By April 2001, CSXT reported that the company's performance was better than at any time since the company was formed in 1980, as measured by average train velocity and on-time destination arrival (Bagsarian, 2001).

New and expanding minimills with electric furnaces that need ferrous scrap and scrap substitutes use the well-developed barge system that operates on the navigable waterway system of the Central United States. Barges are an integral part of the total shipping system of ocean vessels, trains, and trucks that serve the mills, thus giving them flexibility in their transportation planning. Shipping in large barges is the most economical way of handling ferrous scrap and scrap substitutes because of its efficiency. Although slow, one barge can hold from 1,400 to 1,800 t of scrap, which is comparable to more than 15 rail cars or 58 tractor-trailers. One standard 15-barge tow equals more than 225 rail cars or 870 tractor-trailers. Because construction of new barges was nearly nonexistent during the past decade, the barge industry has been left with an aging fleet of thousands of older barges that will need to be replaced during the next few years at a cost of $275,000 per barge (Alley, 1999). A capital expenditure of more than $1 billion was estimated as required to meet the ever-increasing demand for barge freight.

Capital Costs

No company has built a greenfield integrated steelmaking facility in the United States since Bethlehem Steel Corp. completed its Burns Harbor, IN, plant in 1963. Since then, more than 80 minimills have been established because it costs as much as seven times more, per t of capacity, to build a new greenfield integrated plant than to establish a new EAF-steelmaking minimill (Fruehan, 1998, p. 525).

Projecting costs of building new mills is difficult and controversial. In 1981, capital cost estimates of a new integrated mill were reported as between $117 and $146 per ton of capacity, in 1978 dollars (National Academy of Sciences, 1985). A more recent estimate of capital cost per t of annual installed capacity was between $154 and $200 for a minimill compared with about $1,100 for an integrated mill (Fruehan, 1998, p. 525). At the same time, another estimate indicated that it would cost at least four times more per ton of capacity to build a new integrated plant than to build a minimill (Stundza, 1998).

In 1996, Steel Dynamics, Inc. built a 2-Mt flat-rolled minimill in Butler, IN, for a total capital cost of $630 million, or $315 per ton of capacity (Financials.com, 2000). More recently, this company built a structural steel and rail minimill in Columbia City, IN, that had an annual production capacity of 900,000 t to 1.2 Mt, depending on product mix. Capital cost was approximately $315 million total, or from $263 to $346 per ton of capacity depending on product mix (Steel Dynamics, 2002).

In 2001, World Steel Dynamics, Inc., estimated capital costs for greenfield integrated mills and minimills (Noboru Uchida, Director, World Steel Dynamics, written commun., 2003). The EAF/thin-slab mill capital costs for the EAF, ladle furnace, thin slab caster, tunnel furnace, hot strip mill, and infrastructure were estimated as $235 per ton of capacity and $541 million total. The blast furnace/BOF mill capital costs for coke ovens, pulverized coke injection, blast furnace, BOF, ladle furnace, conventional continuous caster, hot strip mill, and infrastructure were estimated to be $614 per ton of capacity and $2,457 million total (World Steel Dynamics, 2003, written commun., June 6, 2003).

Besides the relatively low capital cost per t, the possibility of adding capacity in relatively small increments has been an additional reason for the trend toward increased electric-furnace capacity. The minimill cost advantage is also a result of, in part, the use of modern electric furnaces, new thin-slab casting technology, and more efficient operating practices. World Steel Dynamics estimated that the minimill production cost for sheet products in 1998 was $394 per ton compared with $483 per ton for integrated mills; this was an 18 percent production cost advantage for the minimills. By 2000, the cost advantage had increased to 22 percent—$376 per ton for minimills compared with $481 per ton for integrated mills.

U.S. and World Consumption

According to statistics compiled by the International Iron and Steel Institute (2001, p. 87), per capita annual consumption of raw steel in 2000 ranged from 624 kg in Canada and 472 kg in the United States to 89 kg in South America and 29 kg in Africa. From 1991 to 2000, consumption increased steadily for an overall increase of 64 percent in Canada and 33 percent in the United States. In the European Union and other European countries, the Middle East, and Asia, consumption also increased between 10 percent and 30 percent during this decade, although less steadily. During that same decade, steel consumption decreased steadily in Africa by 20 percent. South America experienced a 47 percent increase from 1991 to 1997 and then decreased 18 percent for an overall increase of 29 percent by 2000. The Commonwealth of Independent States (CIS) experienced a precipitous 79 percent consumption decrease from 455 kg in 1991 to 97 kg in 1998 before consumption of the CIS increased to 115 kg in 2000 for an overall decrease of 71 percent during the decade. World steel consumption decreased by 6 percent from 145 kg in 1991 to 136 kg in 1996 and rebounded to an overall increase of 5 percent during the decade that ended 2000.

Trade

From 1998 through 2002, a flood of allegedly unfairly traded imports entered U.S. markets as a result of steelmaking overcapacity worldwide, declining foreign steel demand, the collapse of the Russian and Asian economies, and the appreciation of the U.S. dollar by 37 percent. When the United States became the most important market for the world's excess steel production, domestic mills could not compete because import prices reached record lows in real dollar terms in 2001, and few U.S. steel companies were able to make a profit. Since 2000, 15 steel plants with 22 Mt of capacity, or 17 percent of the country's total capacity, have been closed or idled. U.S. steelmaking employment declined by 15 percent since January 1998. Nearly 21,000 of the 34,300 total steel jobs lost were lost during 2001.

The economic cost of the large number of former workers on company-funded pensions and healthcare programs contributed to the lack of profits experienced by most companies. The allegedly dumped iron and steel by foreign producers caused domestic producers to make numerous requests to the U.S. Government for relief. The Government responded in early 2002 by implementing tariffs of up to 30 percent against certain imported steel goods and creating an import licensing system to facilitate the monitoring of these imports. U.S. import duties for steel mill products in 2002 are listed in table 8.

By 2002, industry and Government recognized that steelmaking capacity in the United States needed to be reduced and that this would probably be accomplished by industry consolidation. New steel capacity will continue to be built in LDCs, which have such advantages as low employment cost or inexpensive raw materials. In some cases, these new steel industries will export most of their production. Exports of steel mill products by selected exporting countries in 2001 and destinations of exports are listed in table 9.

Table 8. U.S. import duties, 2002.

[In percentage ad valorem. Source: U.S. Geological Survey, 2003, p. 88]

Item	Number[1]	Normal trade relations[2]	Mexico
Pig iron	7201.10.0000	Free	Free
Carbon steel:			
Semifinished	7207.12.0050	0.008	0.004
Structural shapes	7216.33.0090	0.002	Free
Bars, hot-rolled	7213.20.0000	0.004	0.001
Sheets, hot-rolled	7208.39.0030	0.01	0.004
Hot-rolled, pickled	7208.27.0060	0.01	0.005
Cold-rolled	7209.18.2550	0.006	0.003
Galvanized	7210.49.0090	0.013	0.006
Stainless steel:			
Semifinished	7218.91.0015 and 7218.99.0015	0.01	0.005
Bars, cold-finished	7222.20.0075	0.021	0.01
Pipe and tube	7304.41.3045	0.015	Free.
Cold-rolled sheets	7219.33.0035	0.02	0.01

[1]Harmonized Tariff Schedule of the United States code.

[2]No tariff for Canada, Israel, and certain Andean and Caribbean nations.

Table 9. Exports of steel mill products, by selected exporting countries 2001.

[In million metric tons. Data from International Iron and Steel Institute, 2003, p. 10. XX, not applicable]

	Destination								
	Europe						Asia		
Exporting country	European Union	Other	Commonwealth of Independent States	North America	South America	Africa and Middle East	China	Japan	Other
European Union	XX	13.7	7.7	0.2	1.7	1.6	0.4	1.8	1.5
Other Europe	13	XX	7.1	0	0.1	0	0.1	0.3	0.4
Commonwealth of Independent States	2.4	2.3	XX	0	0	0	0	0.1	0
North America	6.3	1.9	2.4	XX	7.1	0.7	1	2.4	4.2
South America	1.6	0.8	3.1	1.8	XX	0.3	0.1	1.3	0.7
Africa and Middle East	4.5	1.7	13.1	0.2	4.7	XX	0.3	1.9	1.3
China	0.7	0.5	9	0	0.3	0.5	XX	4.4	10.1
Japan	0.1	0	0.1	0	0	0	0.3	XX	3.6
Other Asia	2.6	1.1	10	0.3	2.4	3.3	5	17.8	XX

Outlook

Although during the past 35 years, tens of millions of tons of steelmaking capacity has been eliminated in the United States, which has made U.S. operations much more efficient, a majority of observers believed that by the end of 2001, global overcapacity remained the basic cause of the depression of the world and U.S. steelmaking industries. Overcapacity in the world was estimated to be between 116 and 272 Mt (American Metal Market, 2002). That the health of the domestic steel industry could be improved by consolidating mills, especially the integrated mills and perhaps the minimills, rather than by continuing to rely on antidumping trade laws was becoming increasingly apparent (Robertson, 2000). Large companies formed by the consolidation of small companies, provided that the latter are efficient, should be able to reduce overhead, to achieve purchasing scale, to eliminate unnecessary product duplication, and to control pricing better while attracting investors to finance modernization. Only by closing inefficient operations, reducing costs, adopting the latest steelmaking technology, and improving return on invested capital will these new companies become competitive with foreign mills. The industry would also need to decide if it wants to produce less raw steel than domestic demand requires and to continue to import supplementary quantities of semifinished steel to emphasize downstream product lines (Berry, 2001). To some observers, relinquishing significant raw steelmaking capacity to foreign countries by closing down coke ovens and blast furnaces raises national security concerns.

Minimills continued to improve efficiency and competitive capability, which supports the commonly held view that the EAF will eventually be the primary steel production method in the United States and the world. At least in the United States, blast furnaces will continue to face closure because of environmental restrictions, U.S. steelmakers' increasing reluctance to make long-term maintenance expenditures on blast furnaces, and because the EAF is more energy efficient and pollution free. Minimills cost less to build and operate, are more flexible in satisfying customer requirements, and satisfy the growing demand for recycling. Minimills will increase their efforts to conserve energy, which is less than for integrated mills. The minimills will increase usage of some form of iron (DRI, pig iron, hot metal) with the scrap charge to improve the quality of the steel they produce to serve broader markets. Thin slab casting in minimills eliminated the need for traditional hot-rolling facilities to reduce slab to hot-rolled sheet. Similarly, newly developing thin-strip casting may produce light-gauge sheet steel without several hot and cold reduction steps. This new technology will reduce the need for capital investment and will enable minimills to enter new markets.

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