STEEL IN THE MAKING

How the world's most useful metal is made, and some of the ways it serves us all

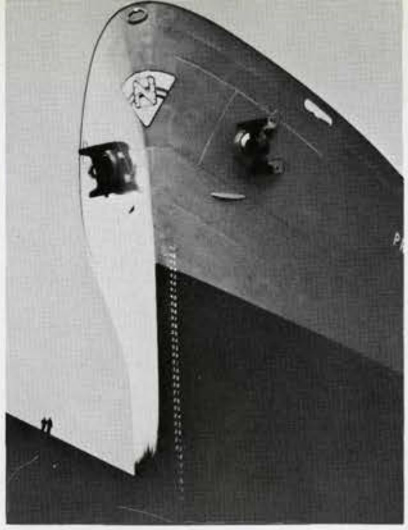
STEEL IN THE MAKING

How the world's most useful metal is made, and some of the ways it serves us all

BETHLEHEM STEEL CORPORATION
Bethlehem, Pa.

FRONT COVER: Molten steel is poured into molds where it cools and solidifies into ingots.

INSIDE FRONT COVER: This ladle of hot steel has just been tapped from the open-hearth furnace.



STEEL

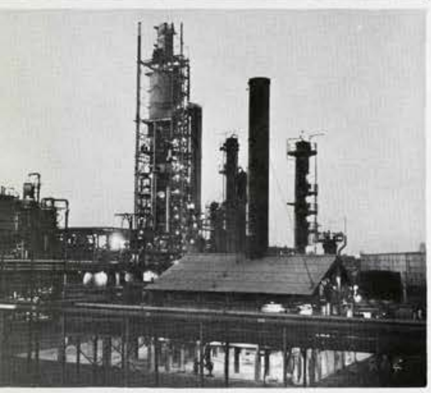
...our most useful metal

Steel is the most important metal we use in everyday living. Automobiles are made largely of steel; houses are built with many steel products. As for the food we eat, steel implements plant the seeds, cultivate and harvest the crops, prepare the food and pack it in steel "tin" cans. Trains and trucks transport it to our grocery stores. There is hardly anything we use that does not depend on steel in some way. And steel is finding new roles every day.

Of all metals steel is the most abundant and the least expensive, because of the modern, efficient production equipment and methods used by the steel industry.

Steel has a combination of strength, hardness, and toughness that is unequalled by any other material. Even more important is the fact that we can make steel with endless varieties of these qualities.

Then, too, steel can be processed into so many different forms. It can be made into wire as fine as a hair, yet amazingly strong. It can be rolled into thin, flat sheets for forming into the curving contours of an automobile fender. It can be forged into objects large or small, from hammer heads to propeller shafts for huge ocean liners.



The Beginnings of Ironmaking

It was probably during the New Stone Age that primitive man learned to make iron by heating rocks and earth containing *iron oxide* in an open fire. Gradually he added improvements. He built stone hearths, used crude bellows to make hotter fires, and substituted charcoal for wood. Such simple furnaces provided man's supply of iron for many years.

The earliest writing to mention ironmaking is the Book of Genesis, where it is recorded that Tubal-Cain, seven generations after Adam, forged cutting instruments of iron. The oldest objects made of iron that are still in existence are the remains of iron beads found in an Egyptian cemetery dating back to 4000 B. C. There is also evidence that the Egyptians used iron tools when they built the pyramids as early as 3100 B. C.

Ancient writings indicate that the Chinese made iron around 2200 B. C. Skilled artisans in India, Korea, and Japan made and used iron and steel many centuries ago. From India came a fine grade of steel which the Syrians used in forging the famous swords of Damascus.

In the Middle East the Persians, Medes, Hittites, and Phoenicians carried on a trade in iron long before the Christian era. It was probably the Phoenicians who introduced iron to all the Western World.

Homer's writings, which date back to about 850 B. C., tell us that the prizes awarded winners of Olympic contests were sometimes made of iron. Iron was also made and used by the ancient people of Britain, France, and Spain. However, the military use of *ferrous* metals (that is, metals composed chiefly of iron), was most highly developed by the Romans, whose legions were equipped with excellent iron and steel armor and weapons.

This suit of steel armor is a striking example of the amazing ability of medieval smiths.

Early Progress in Ironmaking

One of the first important advances in ironmaking is credited to the Spaniards. The Catalan forge, developed in Catalonia in northern Spain, probably before the eighth century, produced considerable quantities of wrought bar iron. Another early ironmaking furnace was the *stuckofen*, a crude version of the present day blast furnace, first used in Germany and Austria.

As these and other furnaces made an increased supply of iron available during the late Middle Ages, European artisans became remarkably skillful in the art of forging iron and, sometimes, steel bars. They produced numerous metal tools, weapons, cooking utensils, locks and—their supreme achievement—richly ornamented suits of armor.

In earlier times steel was thought to be simply a superior grade of iron. By the seventeenth century, however, European ironmasters understood the basic difference between iron and steel (steel is a refined form of iron) and were producing steel in small quantities. One early use of this steel was the fine cutlery for which the town of Sheffield, England, is famous to the present day.

How early ironmasters lived and worked can be seen at the restored ironworks in Saugus, Massachusetts.

This simple cast iron cooking pot was made at the Saugus works in mid-17th century.

Steelmaking in America

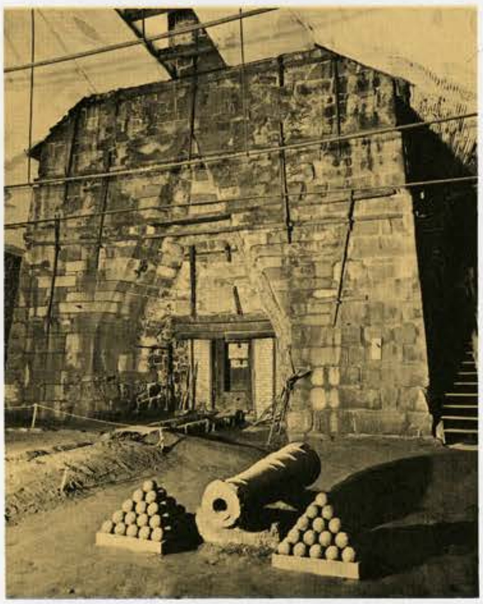
Early in the seventeenth century the London Company built the first ironworks in the New World at Falling Creek in Virginia. But in March, 1622, just as operations were starting, Indians suddenly attacked the settlement. They destroyed the works, killing 347 colonists. Only one young boy survived.

Another Colonial ironworks, recently rebuilt according to its original design, was completed in Saugus, Massachusetts, in about 1650. One of the first iron articles made there, a simple cooking pot, is still in existence.

It was not until the latter half of the nineteenth century that any significant progress was made in producing steel in large quantities. Then two men, Sir Henry Bessemer, an English engineer, and William Kelly, an American ironmaster, independently developed the method of converting pig iron into steel now known by Bessemer's name.

For some years nearly all the steel produced was made by the bessemer process. However, late in the nineteenth century the more efficient open-hearth process was developed. By 1909 more steel was being made in open-hearth furnaces than in bessemers. A later development was the electric-furnace process, followed by the various oxygen processes.

The growth of our steel industry has been nothing short of phenomenal. In 1900 America's steel furnaces poured 11 million tons of steel; in 1920, 36 million tons; in 1960, nearly 100 million tons, or 26 per cent of the entire world output. This tremendous increase in steel production has been closely interwoven with the industrial advances of the twentieth century that have given the people of the United States the highest standard of living the world has ever known. Today, while American furnaces are capable of pouring nearly 150 million tons of steel, the emphasis is on developing new and improved steel and steel products, and efficient ways of making them.



Cornwall furnace, near Pottstown, Pa., made cannon for the War of the Revolution. This ironworks was in operation for 134 years.

Engineer

Draftsman

Melter

Steel Erector

Steelmaking requires a wide variety of

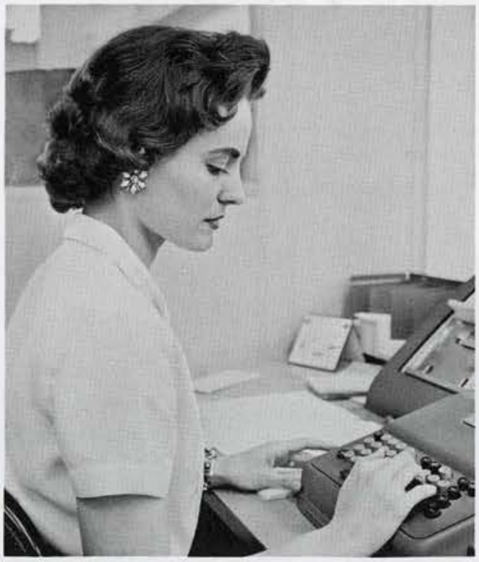
Human Skills

So complex is the making of steel that many thousands of separate job classifications and skills are required to produce the nation's steel.

From the developing and production of raw materials, through the manufacture of steel products, and the study of new and improved ways of making steel, many different skills and crafts are needed. Besides the regular steel plant jobs such as open-hearth furnace melters, machinists, welders, bricklayers, draftsmen, and many others, there must also be geologists, engineers, clerks, metallurgists, plumbers, electricians, construction and repair men, and experts in materials handling, safety, and maintenance.

But the majority of the employees of the steel industry are engaged in the actual production of steel. Many of these jobs call for highly skilled men, such as mill operators or machine shop technicians. Many steel plants have training programs to assure that these employees have all possible help in learning their skills.

While there is no substitute for the part human beings play in steelmaking, today it is their skills that are important rather than the muscular strength that once was the main factor. Everywhere you turn in a steel plant you see modern and complex machinery making short work of tasks that once meant hard labor. The steel industry ranks near the top among all basic industries in respect to rates of pay, working conditions, and average length of service of employees.

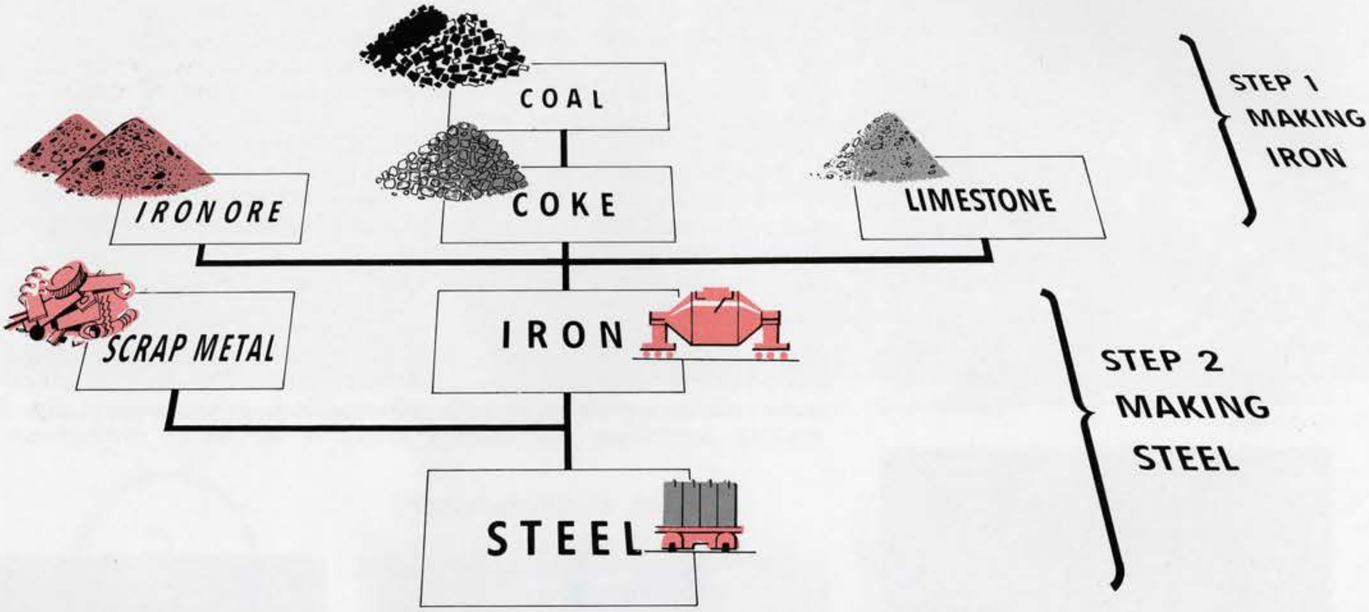


Stenographer

Welder

Wire Drawer

THE RAW MATERIALS OF STEELMAKING



Four basic raw materials—iron ore, coal, limestone, and iron and steel scrap—are used to make steel. The first step of steelmaking, the making of iron, requires iron ore, coal (after it has been converted into coke), and limestone.

The second step is converting the iron, to which iron and steel scrap are added, into steel.

At Bethlehem's Grace Mine, near Reading, Pa., iron ore deposits, 1,500 to 3,000 feet underground, are reached by shafts and tunnels.

Iron Ore

The basic source of all iron and steel is *iron ore*, an oxide of iron combined with alumina, silica, phosphorus, manganese, and sulphur. Small amounts of iron are found almost everywhere, but the areas in which iron ore is mined are relatively few. It costs so much to provide facilities to mine and prepare the ore, and to transport it to the steel mills, that the expense can be justified only when the ore is present in large quantities, and is either of high grade or can be upgraded by processing it.

Most of the iron ore mined in this country has been "direct-shipping" ore of two types: *hematite* and *magnetite*. As shipped, these ores normally contain about 52 per cent iron. Hematite has a brick-red color. Magnetite is black.

Taconite—A Vital Source of Iron

Another vitally important source of iron is *taconite*. This extremely hard rock, containing particles of iron oxide, is found in vast quantities surrounding high-grade ore deposits. However, taconite is too low in iron content in its natural state to be used in the iron-making blast furnaces. In order to solve this problem, several groups of steel companies have worked out a way to extract the iron oxide from taconite and concentrate it in marble-sized pellets with iron content of about 65 per cent. Taconite is one of the important sources of ore today.

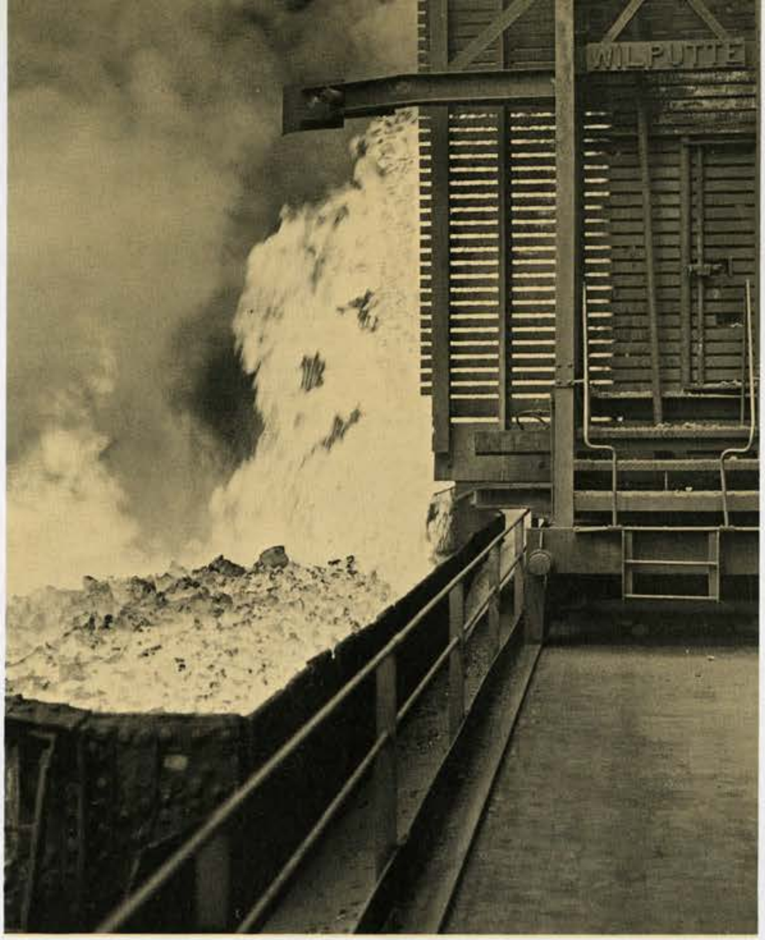
Both Domestic and Foreign Ores Used

The leading iron-ore-producing region in the United States is the Lake Superior district of Minnesota, Michigan, and Wisconsin, which includes the famous Mesabi Range. Other important ore-producing areas are in Pennsylvania, New York, New Jersey, and Alabama, and in a number of the Rocky Mountain states. Steel mills in the United States also import ore from Canada, South America, Europe, and Africa.

Bethlehem Steel uses ore from several of these sources. Large tonnages come from the Lake Superior district, from the historic Cornwall Mine in eastern Pennsylvania, from our Grace Mine near Reading, Pa., and from Bethlehem mines in Venezuela, Chile, and Canada. Supplementing these sources, we are participants in large ventures in Labrador and Africa.

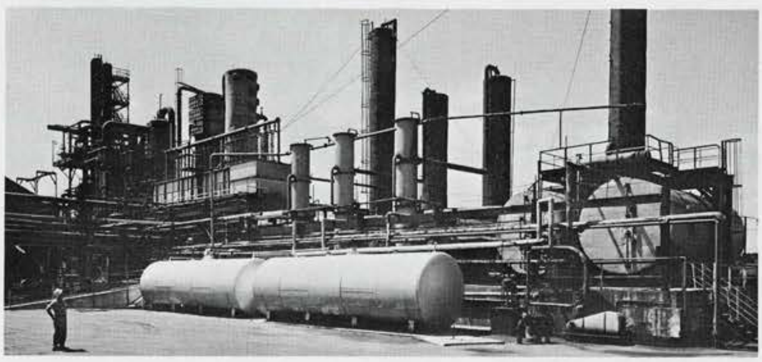
These ore unloaders are scooping iron ore from the hold of a vessel in 17-ton bites.

Open-pit mining at Bethlehem's iron mine at El Pao, Venezuela. Power shovels scoop up the ore, which lies close to the surface.



Discharging incandescent coke from oven. The coke is then quenched under sprays of water to prevent it from burning in the open air.

Coal mine at Bethlehem's Johnstown, Pa., Plant is the only steelmaking facility in the U.S. located directly above large deposits of coking coal.



By-products of coke-making are sold to chemical industries for conversion into many familiar products.

Coal

Coal is another of the basic raw materials of steelmaking. It is used to make *coke* which, in turn, is used as fuel in the blast furnaces where iron is made. Coking coal, a special type of bituminous or "soft" coal, is mined principally in western Pennsylvania, West Virginia, Kentucky (Bethlehem has mines in these states) and in Virginia, and Alabama.

Machinery has taken the place of pick-and-shovel work in many bituminous coal mines. Mechanical cutters slice into the solid walls of coal, clawing it into chunks which are gathered up mechanically and loaded into cars. Sometimes all these jobs are handled by a single machine. Finally, in large plants on the surface, the coal is crushed, sorted, washed, and blended in preparation for use in the coke ovens.

Coal is "Baked" in Coke Ovens

Coke ovens, which are located at the steel plant, are large rectangular ovens, usually arranged side by side in batteries of 60 or more. The newest ovens are approximately 40 feet long, about 13 feet high, and between 1 and 2 feet wide.

Crushed coal is dumped into the oven through openings in the top. The oven is closed, heated to about 2000 degrees F and kept at this temperature for 19 or 20 hours, while the intense heat is driving off the various gases in the coal. The solid matter which remains is pushed from the oven while glowing with heat and is quenched under sprays of water. The result is coke, a firm, porous, gray substance, about 85 per cent carbon.

Coke is the ideal fuel for the blast furnaces. It burns rapidly with intense heat and supplies the carbon needed to make carbon-monoxide gas which plays a vital part in the blast-furnace process. Furthermore, coke has a strong enough structure to support the tremendous weight of the iron ore and limestone which are charged with it into the blast furnaces.

Process Yields Valuable By-Products

For every ton of coke, an oven produces 16,000 to 18,000 cubic feet of *coke-oven gas*. This gas is extremely important both as a source of chemicals and as a fuel for use within the steel plant.

The gas passes from the ovens into a system which recovers the primary by-products such as tar, ammonium sulphate, naphthalene, pyridine, and light oils. These basic chemicals are further processed to yield tar-acid oils, benzol, toluol, xylol, etc. Other industries use these chemicals to make nylon, synthetic rubber, aspirin, TNT, moth balls, perfumes, dyes, sulfa drugs, plastics, and thousands of other well-known products.

After the coal chemicals have been extracted, the gas that remains is used as fuel for the coke ovens, the open-hearth furnaces, and other plant processes.

Limestone

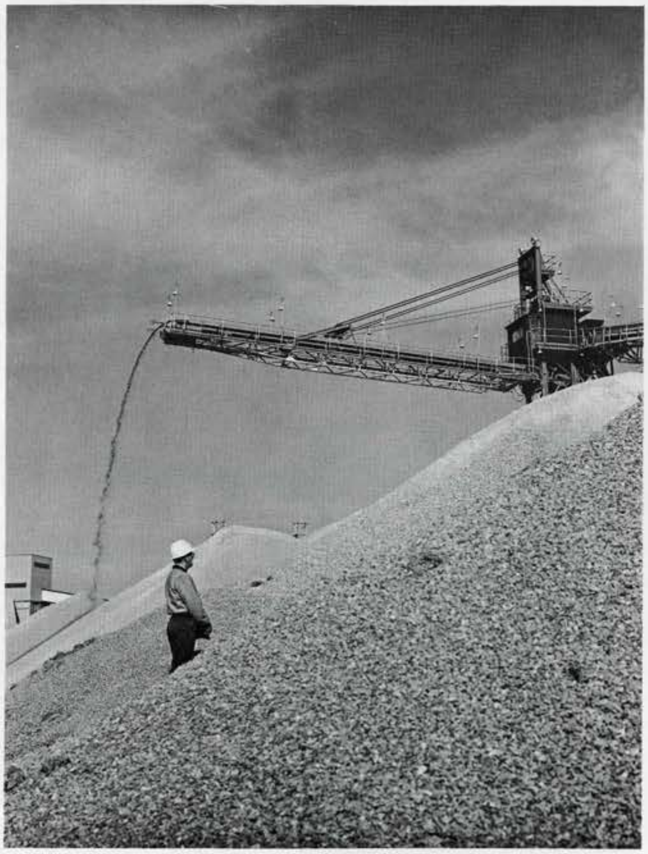
Limestone, a gray rock consisting mainly of calcium carbonate, is used in blast furnaces and, to a smaller extent, in the open-hearth furnaces. Limestone acts as a cleanser or *flux*, soaking up the impurities and forming a scum-like *slag*. Limestone for use in steelmaking comes from quarries not far from the plants. It is cleaned and crushed in preparation for use.

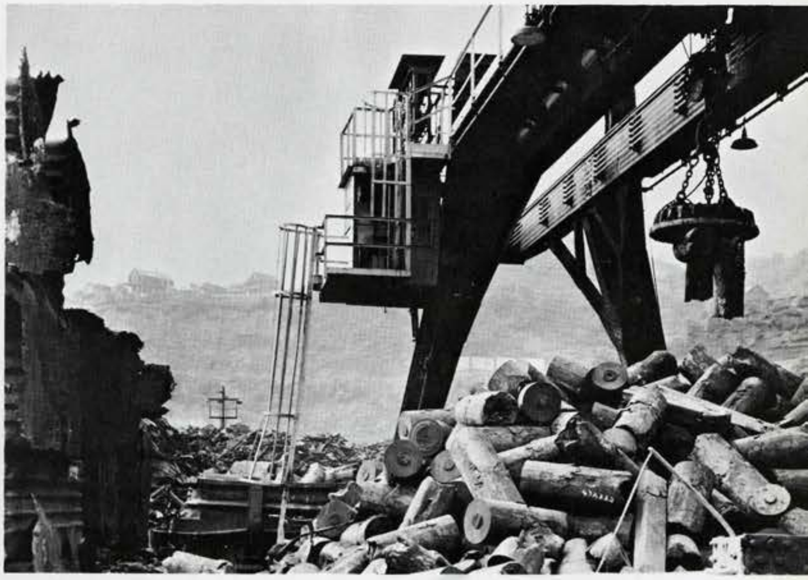
Scrap Metal

One of the most important sources of new steel is used steel and iron. No matter how old and rusty the metal may become, it can always be melted down and converted into new steel. In fact, steel plants that do not have blast furnaces often make steel entirely from ferrous scrap. But under ordinary steelmaking conditions about 60 to 70 per cent of the iron content of steel comes from molten pig iron and 30 to 40 per cent from scrap.

Broadly speaking, two kinds of scrap are used in steelmaking. "Home" scrap comes from within the steel plant itself. For every ton of steel produced, only about three-quarters of a ton is actually shipped out. The remaining quarter-ton, which is discarded during processing, is returned to the steelmaking furnaces.

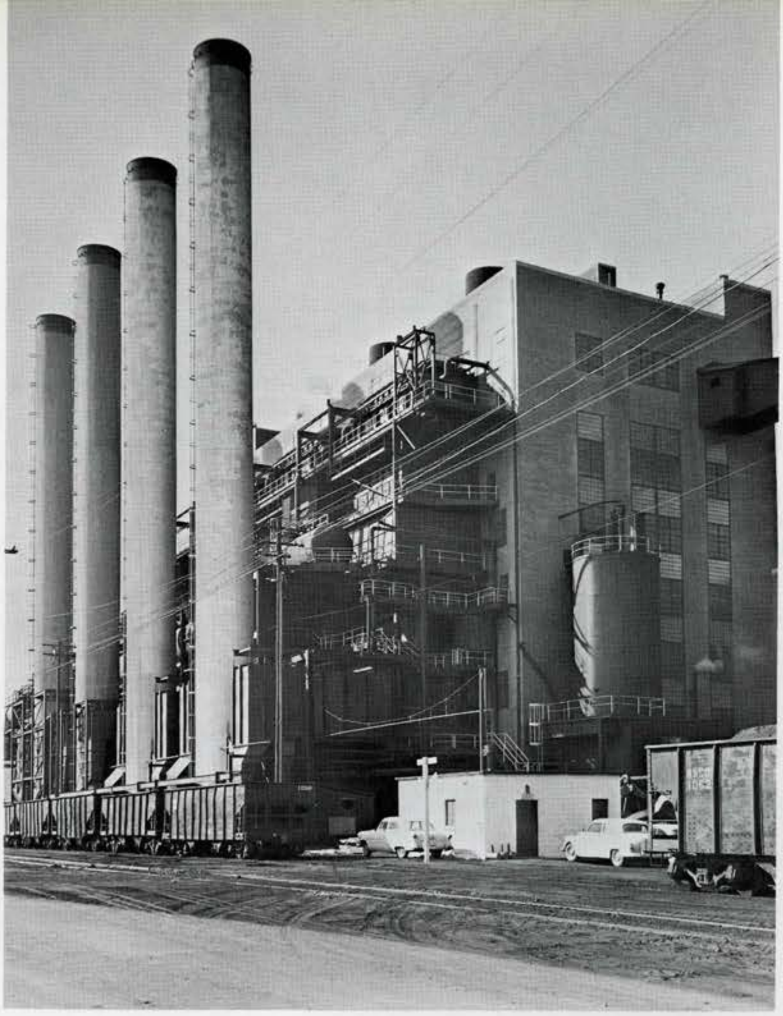
"Purchased" scrap comes from sources outside the plant, usually scrap dealers who collect steel or iron in any form that is not otherwise useful, or that has outlived its usefulness. Examples are wornout or obsolete equipment and parts, such as dismantled machinery, locomotives, ships, automobiles, trucks, buses, old railway cars and rails, and obsolete military equipment. Another source is the chips and shavings that accumulate in factories and machine shops.





Discarded iron and steel called "scrap" is an important raw material in steelmaking.

This quarry in Pennsylvania supplies limestone which is stockpiled before shipment to steel plants.



Electric Power

The power needed to produce 1 ton of steel (to operate the furnaces, rolling mills, and other plant facilities) is about 700 horsepower-hours. The same amount of electric power would supply the average household for about two months.

A large steel mill, such as our Lackawanna Plant, requires electrical installation as large as those of a city of 100,000 population. The plant's Electrical Department is responsible for the operation of 12,000 or so electric motors and generators of all sizes. It keeps in working order over 8,000 miles of electrical cable, as well as the intricate electrical and electronic control systems used throughout the plant.

Electric power for Bethlehem's Sparrows Point Plant is generated in this huge steam plant which uses blast-furnace gas for fuel.

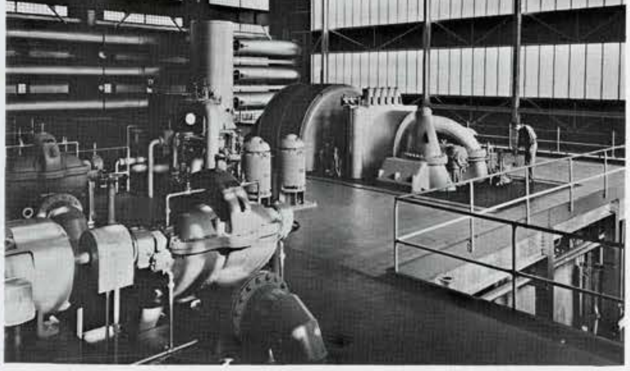
Water

Steelmaking takes an average of 25,000 gallons of water for each ton of steel produced. The water is used to cool equipment and structures such as blast furnaces and open hearths, to generate steam, to clean and cool gases, and to wash scale from steel during processing. More than 90 per cent of this water is just "borrowed." After use it is cleaned and returned to its source, often a river beside the steel plant.

Air

It is an amazing fact that the air used in steelmaking actually outweighs the solid raw materials. The fuels used in steelmaking could not burn without the oxygen in the air, nor could other important chemical reactions take place. From 4 to 4½ tons of air must be supplied to a blast furnace in order to make 1 ton of pig iron. Another ton or so of air is used in converting the iron into steel by the open-hearth process.

Large reservoirs, lakes, and rivers supply modern steel plants with adequate quantities of water.



This 11,150-horsepower turbo-blower supplies air for blast furnaces. It takes about 5 tons of air to make 1 ton of steel.

Bethlehem's Sparrows Point Plant, near Baltimore, is the largest steel plant in the country.

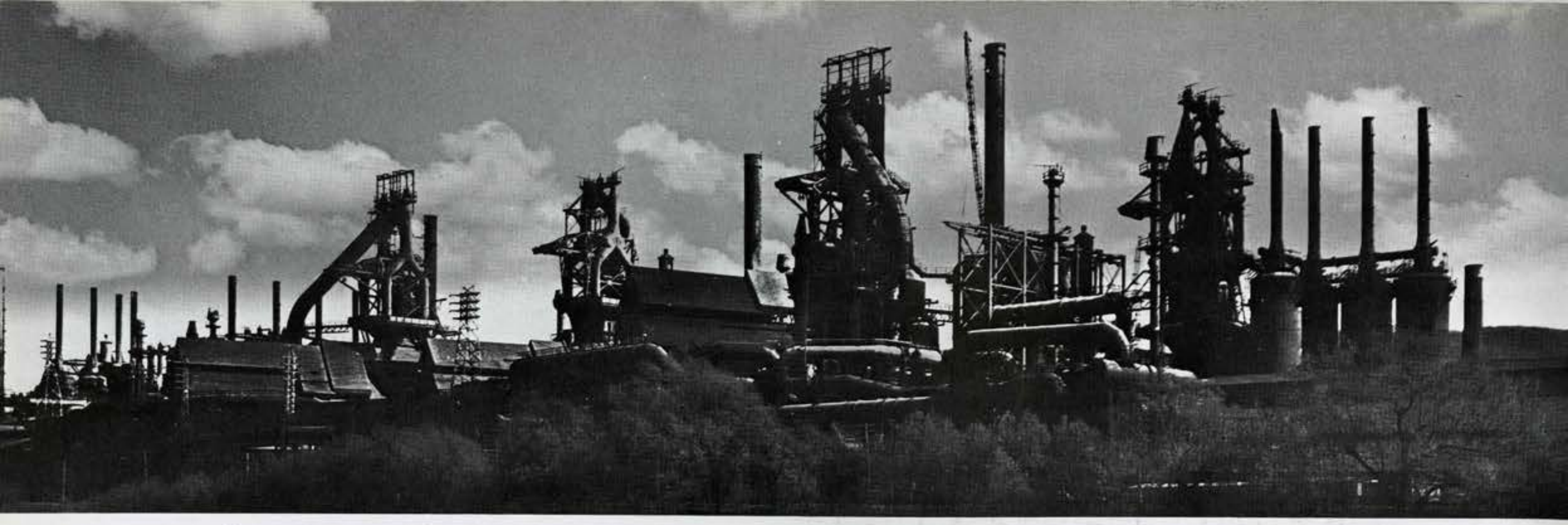
Steel Plants Are Like Large Cities

If you were to visit a large steel plant, you would soon see how much like a city it is. For example, our Sparrows Point, Md., plant, largest in the country, has over 750 buildings and 40 miles of paved roads, which, like the vast array of mechanical steelmaking equipment, must be kept in constant repair. Like other steel plants, Sparrows Point is served by a terminal switching line railroad. With over 100 miles of track, it connects the industries within its operating area with major public carriers, plus handling in-plant shipments.

A plant fire department is a completely equipped organization that protects personnel and property throughout the plant. Modern pumping trucks and other fire-fighting equipment are ready for any emergency.

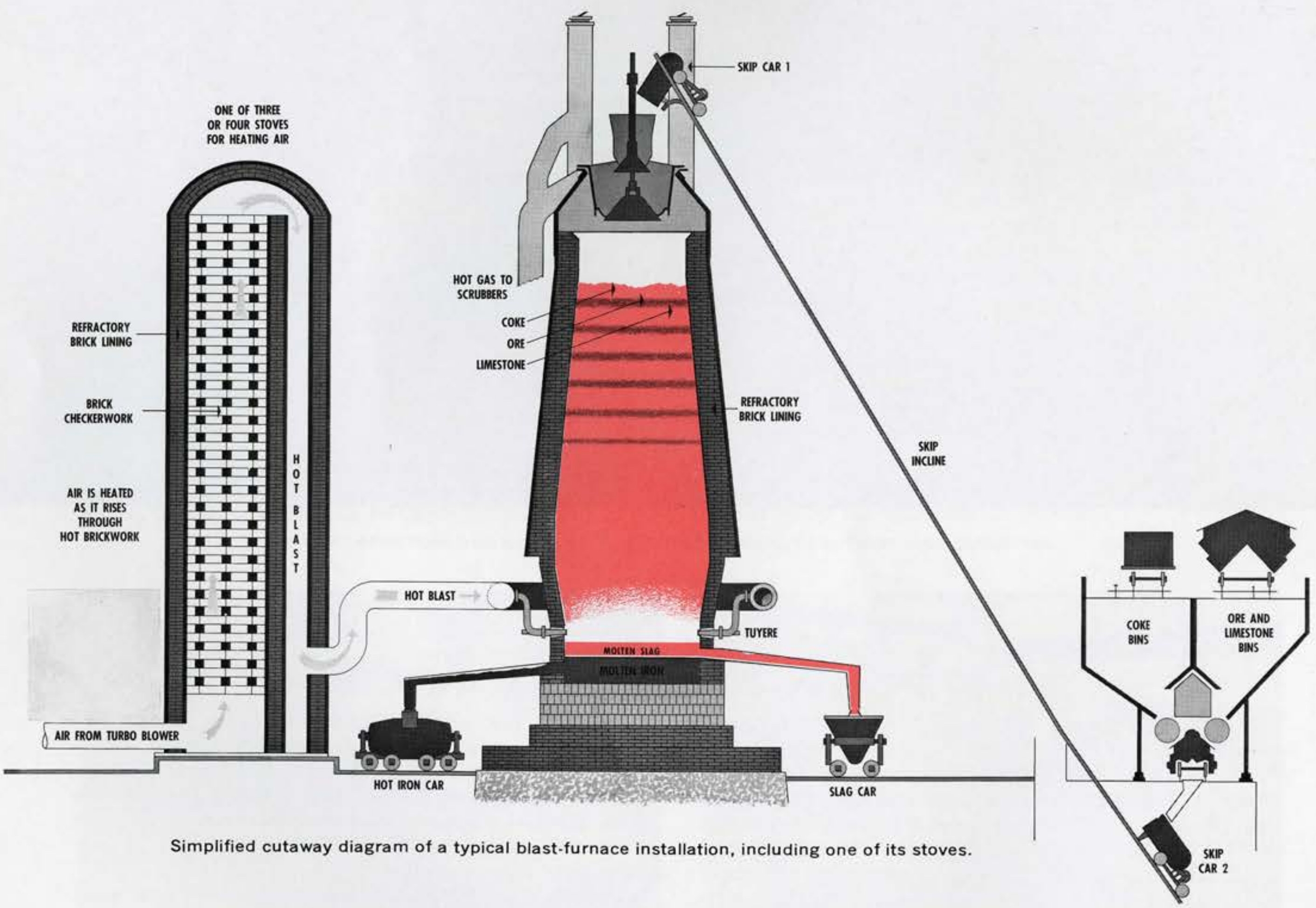
A uniformed patrol force, much like a city's police force, handles inspections and identifications at plant entrances, controls traffic, and generally assists in any emergency that may arise.

Today's steel plants are also equipped with hospital and dispensary services. At Sparrows Point these services include facilities for handling emergency illnesses and physical examinations, plus ambulance, X-ray, laboratory, and other medical services.



Spectacular skyline of the Bethlehem Plant along the Lehigh River. The blast furnaces tower over other steel-plant structures.

MAKING IRON IN THE BLAST FURNACE



Simplified cutaway diagram of a typical blast-furnace installation, including one of its stoves.

Iron ore is converted into pig iron by means of a series of chemical reactions that take place in the blast furnace.
First—heated by a hot blast of air from the stoves, the coke burns, creating gases.
Second—these gases react with iron oxides in the ore, removing the oxygen and leaving metallic iron.
Third—the limestone creates a slag which absorbs much of the silica and other impurities from the ore.

Blast furnaces operate continuously. Molten iron is tapped every five or six hours.

A blast furnace, together with its stoves and other equipment, makes a huge and complicated structure. But its basic design is quite simple. As shown in the diagram, the blast furnace is essentially a tall, brick-lined steel shell, approximately cylindrical in shape. The typical blast furnace is over 200 feet in height over-all, with a hearth diameter of from 20 to 30 feet, and a daily output of between 800 and 3000 tons of iron. For example, Furnace "B" at our Bethlehem Plant is 237 feet high with a hearth about 29 feet in diameter. It has produced over 92,000 tons of iron in a month.

Skip cars, running up and down an inclined track, carry the *charge*—iron ore, coke, and limestone—from bins in the stock house to the top of the blast furnace where they are dumped into the furnace through a hopper.

The very large pipes that are an important part of the blast furnace bring preheated air to the furnace and carry away the gases that are produced.

Preheating Air for Blast Furnace

Three or four tall cylindrical structures, sometimes over 100 feet high, stand close to the blast furnace. These are the *stoves* that heat the air before it is blown into the furnace. They contain thousands of heat-resisting bricks arranged in a checkerboard pattern which permits gas and air to pass through. First, gas from the blast furnace is burned in one of the stoves, heating the bricks. Then the gas is diverted to another stove and the air to be blown into the furnace is routed through the first stove. As the air rushes through the hot brickwork it absorbs heat from the hot bricks, raising its temperature to the range of 1,000 to 1,800 degrees F.

How the Blast Furnace Works

The raw materials are charged into the furnace in alternate layers of iron ore, coke, and limestone. The hot air from the stoves is blown through nozzles called *tuyeres*, near its base. The oxygen in the air reacts with the carbon in the coke, forming carbon-monoxide gas and creating intense heat. The gas rises through the charge, combining with the oxygen in the iron oxides and reducing the ore to metallic iron at a temperature of about 3000 degrees F. The molten iron trickles down through the charge and collects in a pool on the hearth.

At the same time, the intense heat converts the limestone into lime, which combines with most of the silica and other impurities from the iron ore and coke, forming molten *slag*. This slag drips down to the hearth where it floats on top of the heavier iron.

The iron is tapped every five or six hours; the slag is removed more frequently. These *casts* of iron average from 150 to 350 tons, according to the size of the furnace. The molten iron, called "pig iron," is taken to the steel-making department of the plant where it is converted into steel by the processes described on the following pages.

Blast furnaces operate continuously, day and night, except when they are shut down for repairs, or for relining, which is normally required every four or five years.

Uses of Blast-Furnace Slag and Gas

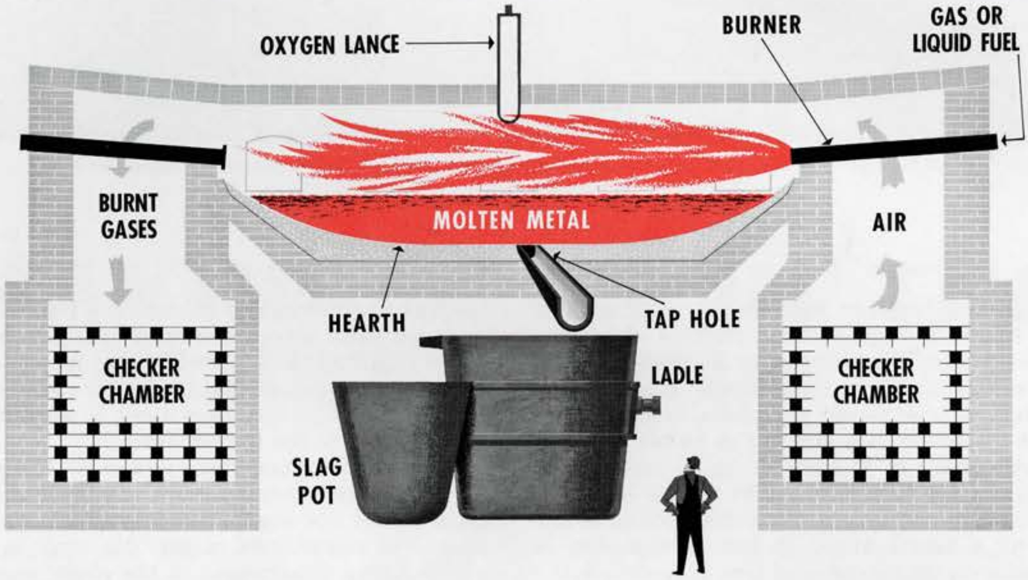
For every ton of iron, the blast furnace produces about six tons of gas and half a ton of slag. After the gas has been cleaned, some of it is used in the stoves. The remainder serves as fuel for other processes in the plant.

The slag, poured into pots mounted on cars, is hauled away to the slag dump. Large quantities of slag are sold for use as aggregate in concrete. Some is processed into mineral wool, commonly used to insulate homes.

Characteristics and Uses of Pig Iron

Iron from the blast furnace may contain about four per cent carbon, one per cent or less silicon, one per cent or less manganese, and much smaller percentages of phosphorus and sulphur. Pig iron is hard and brittle, lacking steel's great strength, ductility, and resistance to shock. Articles made of iron (then called *cast iron* because they are shaped by pouring, or "casting" molten pig iron into molds) are rigid and have great compressive strength, so that they will support a very heavy weight; but they generally are brittle, and shatter readily under blows. However, cast iron has many uses, such as for automobile-engine blocks, and for a wide variety of machinery parts.

MAKING STEEL



Simplified cutaway diagram of a typical open-hearth furnace, equipped with oxygen lance. Oxygen may be injected through one or more lances. In some cases, to improve combustion, it is introduced through the burners.

Steel is refined pig iron. *The refining process further reduces the amount of impurities present in the metal. Technically speaking, steel is iron combined with carbon, the carbon content ranging from a few hundredths of 1 per cent up to about 1.40 per cent. All steel also contains certain amounts of manganese and silicon, and, when desired, other elements.*

Over 90 per cent of all steel made is classified as ***carbon steel,*** *meaning that it contains a regulated amount of carbon, small amounts of manganese, and only slight traces of other elements. The remaining 10 per cent or so consists of* ***alloy steels.*** *An alloy steel is steel to which have been added carefully determined amounts of alloying elements such as manganese, nickel, chromium vanadium, molybdenum, etc. These alloying elements impart certain highly desirable properties to the steel, such as exceptional strength, toughness, and resistance to corrosion.*

Three steelmaking methods are widely used. *One of these is the* ***open-hearth process,*** *which is quite flexible in its use of molten pig iron and scrap in widely varying proportions. The* ***electric-furnace process*** *is often used to produce alloy and special steels, or as an alternative to the open hearth, particularly where steel scrap is readily available. The* ***basic oxygen process*** *is rapidly increasing in importance. This process can produce a 250-ton heat of steel in just 50 minutes. The* ***bessemer process*** *is primarily of historical interest.*

Open-hearth charging floor at the Saucon Division of the Bethlehem Plant, where steel is made for rolling into structural shapes.

Open-Hearth Process

Most steel produced in the United States, including both carbon and alloy grades, is made in *open-hearth furnaces*. The name "open hearth" comes from the fact that the pool of molten metal covered with slag lies on the hearth of the furnace, exposed to the sweep of flames. The excess carbon is oxidized by oxygen from the iron oxide, while the slag absorbs impurities. In this way the molten metal is refined into steel.

A modern open-hearth furnace may be about 100 feet long and 26 feet wide. As shown in the diagram, there are doors on the front or *charging* side of the furnace. The back or *tapping* side of the furnace has a tap hole through which the finished steel flows from the furnace into a ladle. This hole is kept sealed with a plug of a special kind of clay until the steel is ready for tapping.

Air is Preheated in Checker Chambers

Beneath the furnace are two *checker chambers*. They contain bricks arranged in a checkerboard pattern, permitting the alternate passage of air and exhaust gases.

Preheated air from one checker chamber enters at one end of the furnace, where it mixes with gas or other fuel. This air-fuel mixture is blown into the furnace, burning as it sweeps across the pool of molten metal in the hearth. The hot exhaust gases pass out the other end of the furnace into the opposite checker chamber, where they heat the brickwork to a high temperature. Every 10 or 15 minutes the direction of flow is reversed, so that while the brickwork in one chamber is being heated by the hot exhaust gases as they rush from the furnace, the hot checkerwork in the other chamber is heating the air that is entering the furnace.

How the Open-Hearth Furnace Works

First, limestone is put into the furnace. Its purpose in the open hearth is the same as in the blast furnace: it removes some of the impurities and builds up a slag. Next comes iron ore (or some other source of iron oxide) which supplies the oxygen needed to oxidize the excess carbon. Then steel scrap is placed in the furnace. In present day practice, the scrap charge in an open-hearth furnace is about 30 to 40 per cent; the other 60 to 70 per cent is molten pig iron. After the scrap has been partly melted, the molten pig iron is poured into the furnace.

Next follows the *refining* or *purification* period, during which the excess carbon is oxidized and other impurities are carried away as gases or are absorbed by the slag. The flames sweeping across the surface of the molten metal bring it to a temperature of about 2900 degrees F. Many furnaces are equipped with oxygen lances so that during this period a rich stream of oxygen can be directed into the bath, greatly speeding up the process of oxidation.

From time to time during the refining period samples are taken of the metal and sometimes of the slag. These samples are rushed to the metallurgical laboratories for quick checking and analysis, which provides information necessary for proper control of the refining operation.

If alloy steel is being made, the alloying materials are added at the proper time.

The entire process of making a *heat* of steel may take 8 to 10 hours, or considerably less in a furnace using oxygen. When the steel has been refined to the exact specifications called for, the heat is tapped. The plug in the tap hole at the rear of the furnace is punctured with a rocket-like explosive charge. The steel gushes out in a bright stream, down over a spout and into a huge ladle. The slag, which leaves the furnace after the steel, spills over into a smaller container called a *slag pot* or *thimble*, in which it is taken to a storage area.

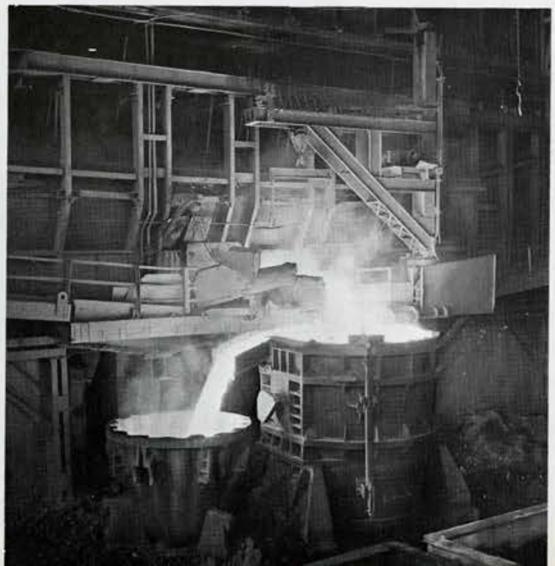
Molten Steel Poured into Ingot Molds

Most modern open-hearth furnaces produce from 150 to 375 tons of steel in each heat. After tapping, the furnace is charged again and the process is repeated.

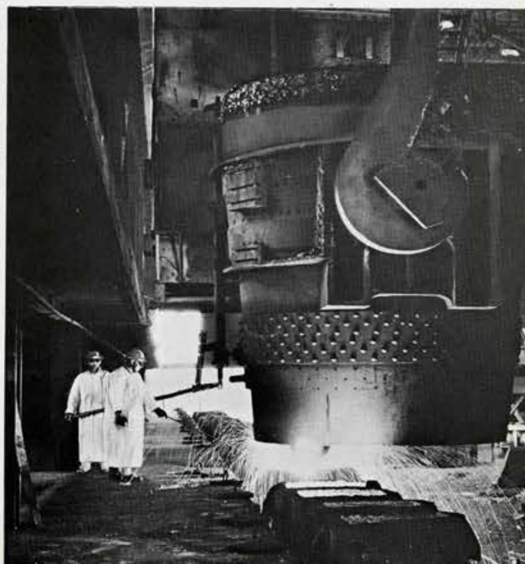
Steel made in the open hearth, or by other processes as described in the following pages, is poured or *teemed* into ingot molds where it cools and solidifies. The ingot is the first solid form of steel. Ingots usually range between 5 and 25 tons, although much larger ingots have been poured for special purposes.

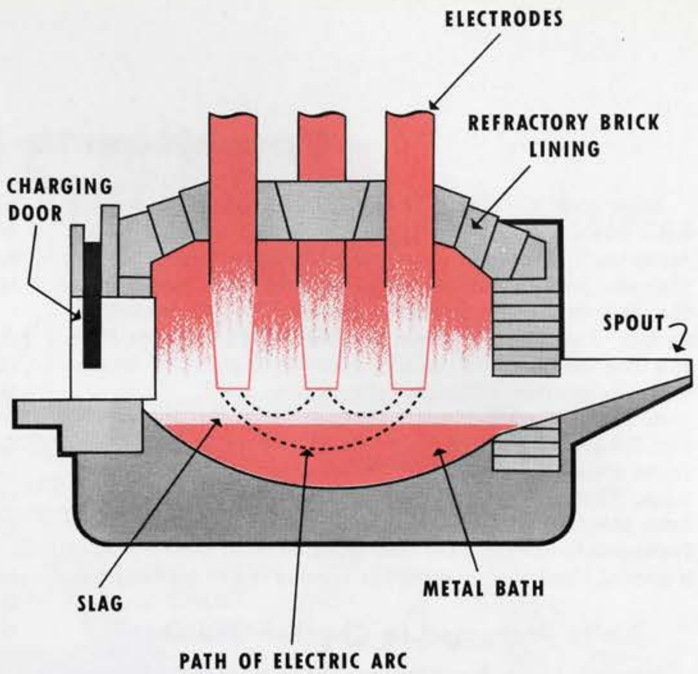
Analysis of samples from the furnace is calculated and transmitted electronically.

Tapping an open hearth. Molten steel fills the ladle; the slag spills over into the slag pot.



Teeming ingots. The steel is poured into molds where it solidifies.





Electric-Furnace Process

Most electric-furnace steel is made in furnaces of the *electric-arc type,* in which the "bath" of molten metal is heated by an electric arc. Both the temperature and the atmosphere can be very closely controlled, making the electric furnace ideal for producing steel to exacting specifications: high-alloy steels, stainless steels, or special steels requiring very close metallurgical control.

However, in recent years there has been a growing trend toward the production of carbon steels in the electric furnace, especially in smaller plants, and in locations where large supplies of ferrous scrap are available.

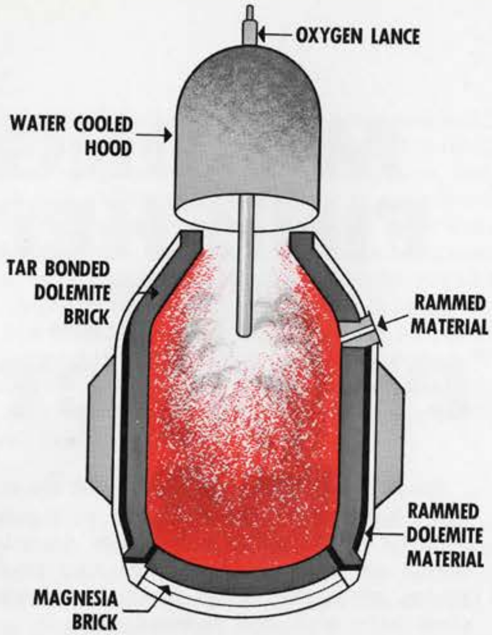
Electric furnaces vary in capacity from 5 to 100 tons. They somewhat resemble a teakettle in shape, and are tilted to pour out the finished steel through a spout. Three carbon electrodes extend down through the roof of the furnace. The metallic charge is inserted through a door on one side or through the top of the furnace which can be swung to one side.

How the Electric Furnace Works

The initial charge consists of carefully selected steel scrap. The electrodes are lowered and the current is turned on. The intensely hot arcs between the electrodes and the scrap quickly form a pool of molten metal directly under the electrodes and, in effect, enable the electrodes to bore into the scrap. After the charge is about 70 per cent melted, iron ore and burnt lime are added, and melting is completed. At this point, samples of the bath are analyzed in the metallurgical laboratory.

The next step depends on the kind of steel being made. If it is carbon steel, the operation is rather similar to that of the open hearth. If an alloy steel is being made, the initial slag is removed and a second slag is made to permit close control of the final analysis. All additions to the bath—the materials added to form the second slag and the alloying materials—are in the form of carefully dried material of known composition. The entire process takes from 4 to 12 hours, depending on the type of steel.

An electric furnace is tilted to pour its steel into the huge ladle below.



Basic Oxygen Process

In reading the preceding pages, you have perhaps realized that oxygen, the life-supporting element in the air we breathe, is as vital to steelmaking as it is to life itself. That fact was well known to the ironmasters of a century ago. They knew that oxygen would speed up the steelmaking process and make it more efficient. But, until very recent years, pure oxygen was extremely costly, and was not available in the vast quantities required for steelmaking. Therefore it was necessary to rely on other sources—for instance, air (21 per cent oxygen), and iron ore (iron oxide).

Today, however, we can install oxygen-making equipment at or near steel plants, providing abundant quantities at reasonable cost. How to most effectively take advantage of this fact has been one of the chief aims of steel industry research in recent years.

As described on pages 14 and 15, many open-hearth furnaces are now equipped with oxygen lances or special types of oxy-fuel burners. The exact procedures vary, but the net result has been to speed up production by 30 per cent or more. Similarly, progress has been made toward improving blast furnace performance through the use of oxygen.

The Basic Oxygen Process

Several new oxygen steelmaking processes have been developed, some of which are still in the experimental stages, while others have been operating successfully, though on a relatively small scale, for a number of years.

The best known is the Basic Oxygen Process. Although in general appearance the basic oxygen furnace resembles the old bessemer converter, it is an entirely new development, designed expressly to get the best results with oxygen in steelmaking. Whereas in the converter air bubbled up through the bath, in the basic oxygen furnace, a lance blows oxygen down from the top. By this method steel of excellent quality can be made at an amazingly high rate of speed—roughly one heat an hour.

After a basic oxygen furnace is loaded with steel scrap, it is charged with molten iron. It takes about 5 minutes to do both.

Powerful tongs lift an ingot from the soaking pit where it was thoroughly heated to the rolling temperature.

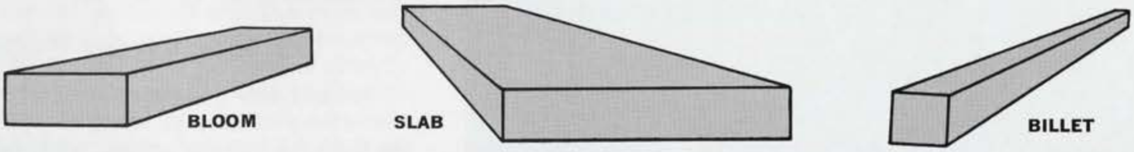
MAKING FINISHED STEEL PRODUCTS

Steel leaves the open-hearth and electric-furnace departments in the form of ingots. The sections of this book that follow describe how ingots are made into *finished steel products*—plates, strip, sheets, tin plate, bars, structural steel, wire, pipe, and railroad rails.

Broadly speaking, ingots are processed into finished steel products in two steps. First, the ingot is reduced in cross-section by hot-rolling it into semi-finished steel products—*blooms*, *slabs*, and *billets*. Second, the blooms, slabs, and billets are processed into finished steel products.

Preparing the Ingot for Rolling

After the molten steel has been poured, or teemed, into ingot molds, it is allowed to cool to the point where it solidifies. At the proper time, the ingot mold is removed from the ingot by "stripping." A special crane grips the mold and lifts it away from the ingot—or lifts the ingot out of the mold—depending on the type of mold.



A long train of glowing ingots being taken to the soaking pits following stripping.

The outside of the ingot naturally cools and solidifies faster than the inside. At the time the mold is removed the ingot is comparatively cool on the outside, but the interior is still extremely hot, usually in a semi-molten condition. Before the ingot can be rolled, both the outside and the inside must be at the same temperature. This is done by heating it in a special type of gas-fired furnace called a *soaking pit*. The ingot is lowered into the pit and heated to about 2200 degrees F. It is kept at that temperature for from four to eight hours. When removed from the pit, the ingot has been uniformly heated, and is soft and plastic enough to be shaped by the rolling mills.

Blooms, Slabs, and Billets

Semi-finishing mills are of three principal types: *blooming mills*, *slabbing mills*, and *billet mills*. Blooms are either square or rectangular in cross-section. Blooms are the form of semi-finished steel that is processed into structural steel and railroad rails.

Blooms are sometimes further reduced in size to billets before being processed into finished products. Billets are used to make bars and rod. Rod is the material from which steel wire is made.

Slabs are relatively flat, their width being three, four, or more times their thickness. Slabs are used to make plates, strip, sheets, and other flat-rolled steel products.

Blooms and slabs are made by squeezing the hot, plastic ingot between two horizontal steel rolls rotating in opposite directions. The distance between the rolls is adjusted so that the rolls are always slightly closer together than the thickness of the steel passing through. The ingot gets longer and thinner as it passes between the rolls.

The rolls are mounted in heavy housings, or *roll stands*. A stand with two rolls is referred to as *two-high;* a stand with three rolls, one above the other, is *three-high*. The ingot is carried to and through the stands on a path of rollers. These rollers, which are rotated by electric power, are mounted on the long table of the mill.

Blooms and slabs are frequently made on two-high *reversing* mills. Since the direction of rotation of the rolls can be reversed, the ingot is passed back and forth between the rolls, which are brought closer together at each pass, until the steel has been reduced to the desired cross-section. Other mills are three-high and are not reversible. The ingot is passed between the bottom and middle rolls, then raised and passed between the middle and top rolls.

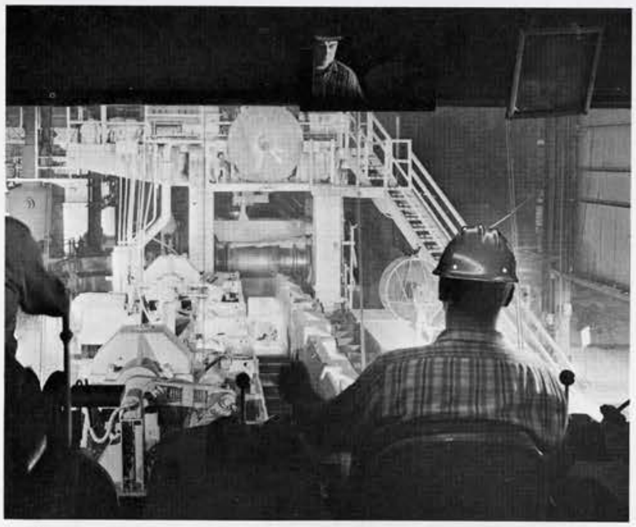
Billet mills, on the other hand, are often of *continuous* design. That is, the mill consists of a series of roll stands (each of which is much smaller than the stands in blooming and slabbing mills) arranged one after the other so that the steel being rolled passes successively through each stand and emerges from the last stand as a finished billet.

Hot-Rolling Makes Steel Denser, Tougher

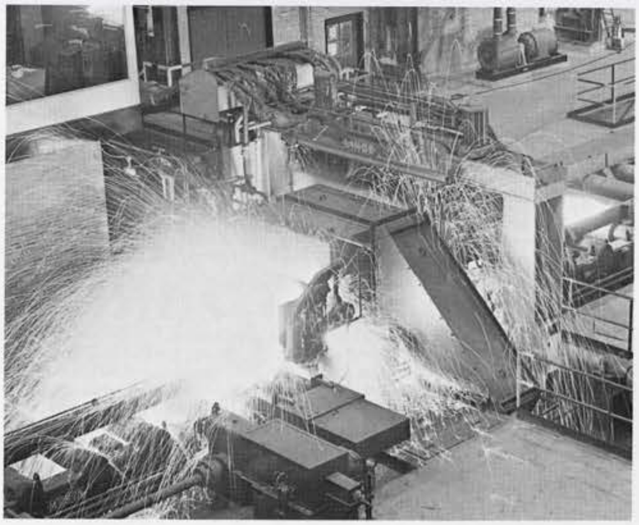
Hot-rolling not only reduces the steel to the desired shape and size but improves its quality. Steel consists of a mass of metallic crystals or grains. In the ingot these grains are relatively large and are distributed in such a way that the steel is not suitable for most purposes. Hot-rolling breaks down the grains into smaller size, making the steel denser, tougher, and more workable. The quality of the steel is improved in this way not only while the ingot is being reduced to bloom, billet, or slab, but also during the finishing processes that follow.

After the blooms and slabs have been rolled their irregular ends are cut off or *cropped* by powerful shears. The cropped ends contain certain irregularities which if not eliminated would cause imperfections in the finished product. The discarded ends are an example of the "home" scrap used in the steelmaking furnaces.

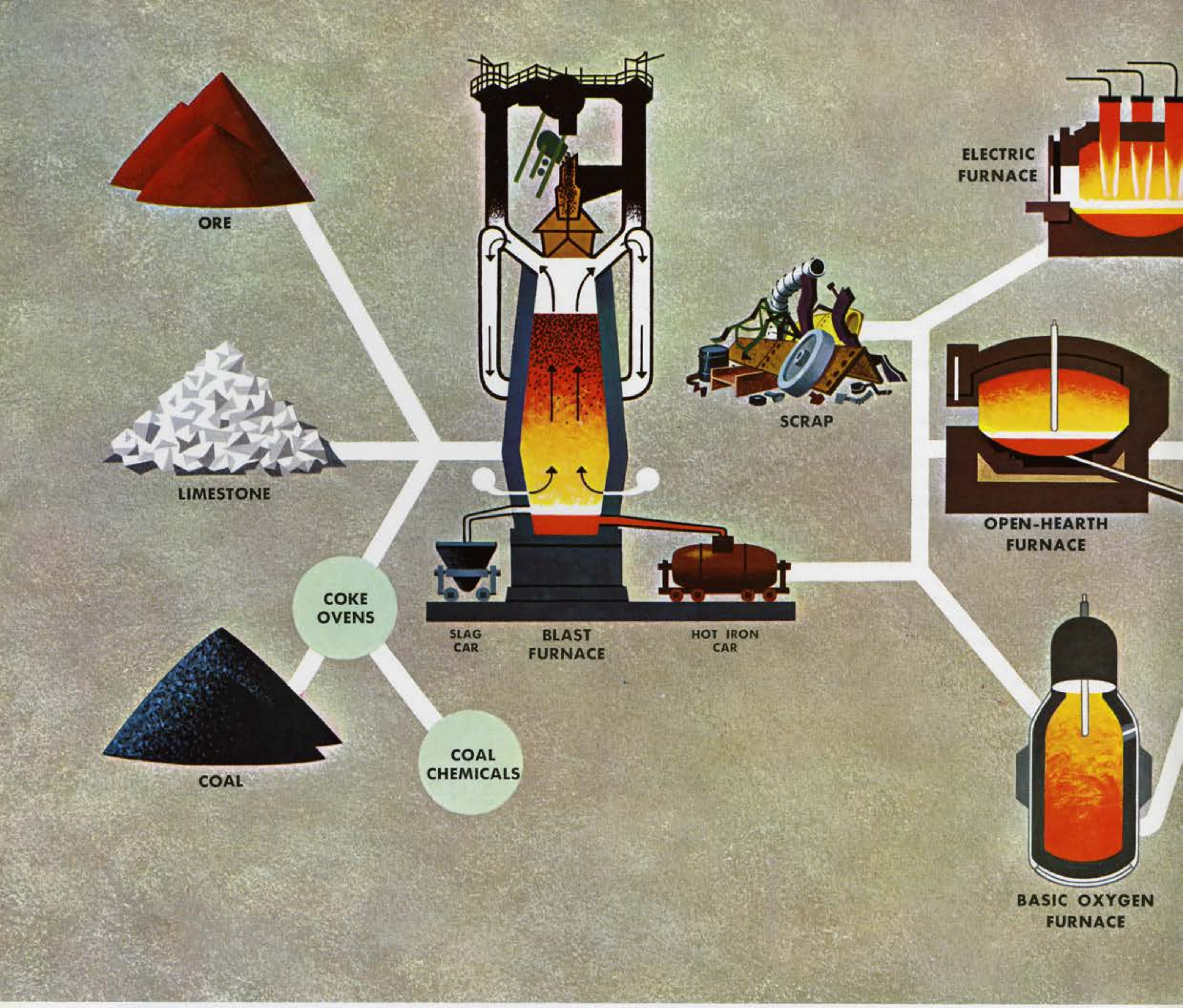
After they have been cut into shorter lengths that are more easily handled in the finishing mills, the blooms, billets, and slabs are carefully inspected for defects. The inspector marks all surface flaws which are then removed by grinding, chipping, or scarfing.



Rolling an ingot in a reversible blooming mill.



Removing surface imperfections by automatic scarfing.



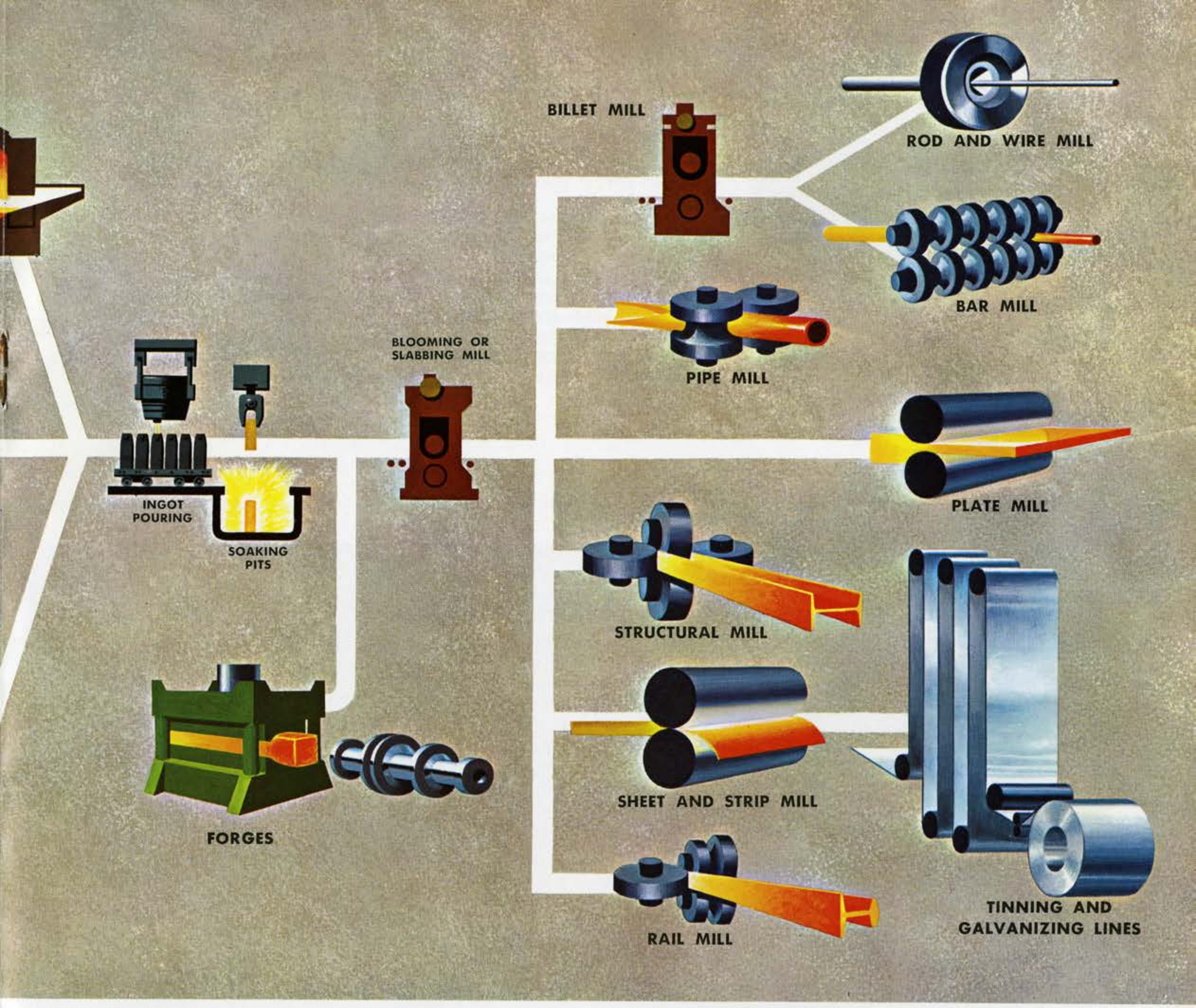
ORE...TO IRON TO FINISHED STEEL

PIG IRON is produced in the blast furnace. A blast of hot air is blown upward through the charge of iron ore, coke, and limestone. The coke burns, giving off gases which reduce the ore to metallic iron. The limestone combines with impurities and forms slag.

OPEN-HEARTH FURNACES produce the major tonnage of steel. Molten pig iron, iron and steel scrap, iron ore, and limestone are charged into the furnace. Flames sweep across the hearth, melting the charge and supplying the heat for refining the steel.

ELECTRIC-ARC FURNACES are especially suitable for making steel to exacting specifications. The charge of selected steel scrap and limestone is melted. Heat for melting and refining is supplied by an electric arc.

BASIC OXYGEN FURNACES can produce heats of steel in an amazingly short time—roughly one heat an hour. Because of this speed, as well as the fact that the steel produced is of excellent quality, oxygen steelmaking is gaining rapidly in importance.



INGOTS are made by pouring molten steel into cast-iron molds. After the steel has solidified, the ingots are removed from the molds and prepared for rolling by reheating in soaking pits until the temperature in every part of the ingot is the same.

SEMI-FINISHING means the rolling of ingots into blooms or slabs. Sometimes blooms are rolled into smaller sections, called billets. The semi-finished steel—bloom, slab, or billet—is then further rolled into the finished product. Rolling not only shapes the steel but also improves its mechanical properties.

SOME INGOTS ARE FORGED into shape by large hydraulic presses or hammers. Smaller forgings are made from heated billets or bars.

WIRE is made from coiled rod produced from billets on high-speed continuous rod mills. The rod is drawn to the required gage through a series of dies of gradually diminishing size. Some wire is then coated with zinc or other protected coating.

BARS are hot-rolled from billets. Each pass through the rolls elongates and further reduces the billets in cross-section. Grooves in the surface of the rolls produce the proper bar shape.

PIPE is made from "skelp." In the continous butt-weld process, the skelp is heated, then formed and welded. Electric resistance-welded pipe is formed cold, then welded electrically.

PLATES are usually rolled from reheated slabs on large single-stand mills. Some plates are rolled to their final width on mills with vertical as well as horizontal rolls; others are sheared to width after rolling.

SHEETS AND STRIP are rolled from slabs on high-speed continuous mills. After hot-rolling, some of this material is further reduced by cold-rolling, then annealed and given a final cold-rolling to improve its surface and mechanical properties.

COATINGS of tin or zinc are applied to cold-reduced sheets to protect the steel against corrosion. Steel sheets coated with tin are known as tinplate, and those coated with zinc are called galvanized sheets.

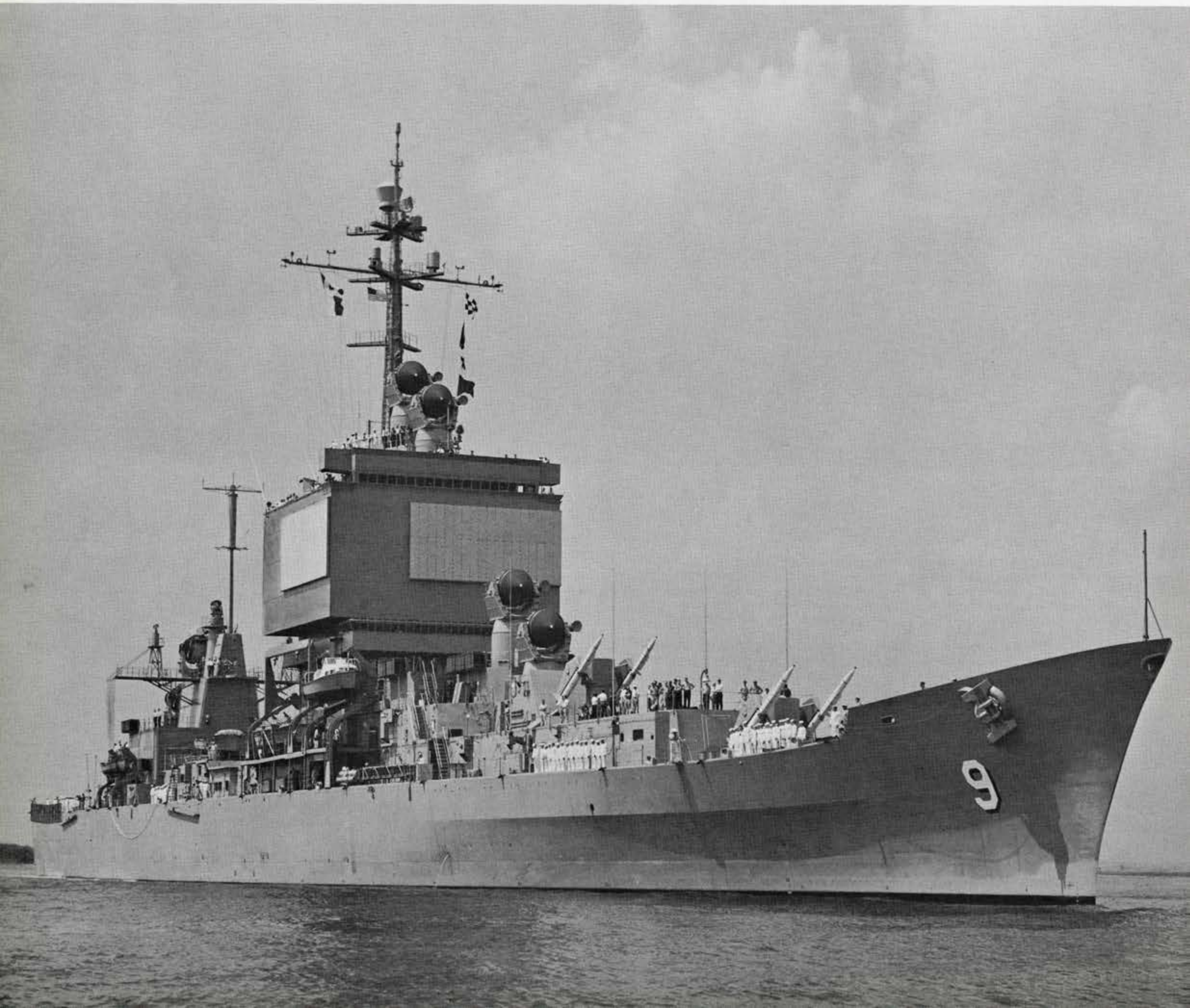
STRUCTURAL STEEL and RAILS are rolled from blooms. Standard structural shapes are produced on mills equipped with grooved rolls. Wide-flange sections are rolled on Grey mills which have ungrooved horizontal and vertical rolls.

This bank vault door is one of many uses for heavy steel plate.

Plates

Plates are one of the basic forms of finished steel. They range in thickness from about 3/16 inches to over 12 inches. Plates are used in the fabrication of girders and other components of bridges and buildings, and in the hulls and decks of ships. The bases that support large machines, as well as many machinery parts, are frequently made from plates. Boilers, oil and water storage tanks, gas holders and propane tanks, large-diameter pipe for water, oil and natural gas, and innumerable varieties of industrial processing equipment are other typical examples of steelplate construction.

Many thousands of tons of steel plates and other steel products were used in constructing the U.S.S. Long Beach, the nation's first nuclear-powered surface warship, built by Bethlehem Steel.



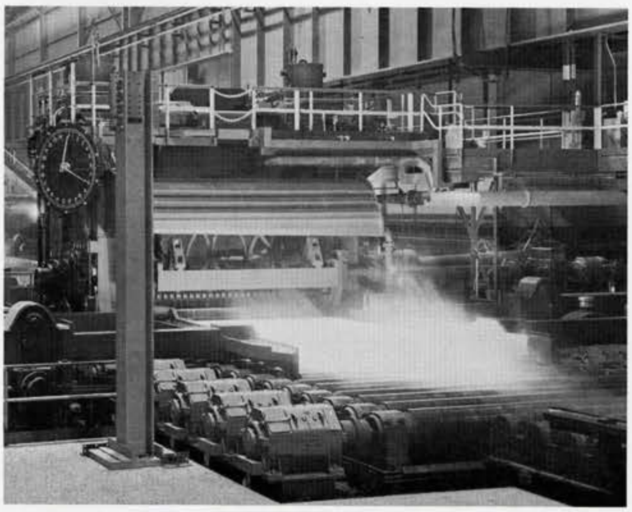
High-strength steel plates as well as plates of special analysis to resist abrasion and corrosion are commonly made today.

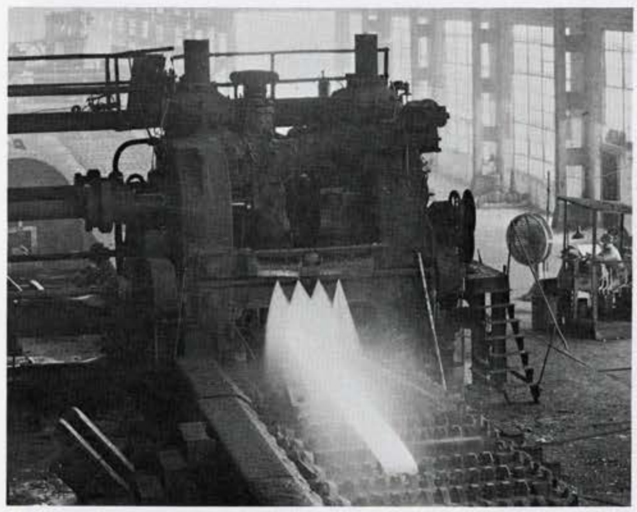
Two Methods of Rolling Plates

Plates are rolled from slabs on either of two types of plate mills: *sheared* or *universal*. Plates produced on sheared-plate mills must be cut on all sides to the desired dimensions after rolling. Universal-plate mills, having a set of vertical *edging* rolls in addition to their horizontal rolls, roll plates to the desired width, with straight and parallel rolled edges, so that shearing is not necessary.

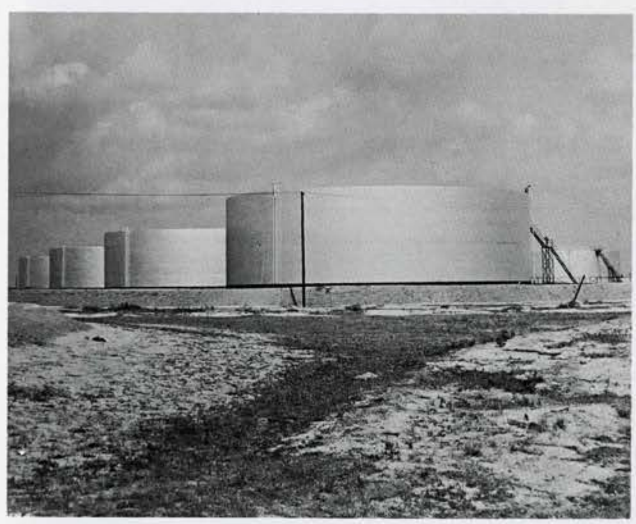
Plates in the lighter gages can also be produced on the continuous hot-sheet mill, which is described in the following section.

Before it is rolled, the slab is placed in a furnace where it is slowly heated to the rolling temperature. At the proper time the hot slab is removed from the furnace and taken to the universal or sheared-plate mill for rolling to the ordered thickness and dimensions. After passing through the levelling rolls for final flattening, the plates are sheared or gas-cut to size.


Rolling plate from slabs of steel on sheared-plate mill at our Burns Harbor, Indiana, plant.


Universal mill rolls plates to proper width and thickness.


Highway and railroad bridges are often built largely of girders made up of bolted, riveted, or welded steel plates and angles.


These huge oil storage tanks, as well as water tanks, propane tanks, gas holders, and boilers, are fabricated from steel plates.

Sheets and Strip

Of all the forms of finished steel products, none is more widely used than flat-rolled steel—*sheets* and *strip* ("strip" is a technical term designating relatively narrow sheets, and will not be used further in this description). Automobile manufacturers use huge quantities for auto bodies. Many types of metal furniture—desks, chairs, and filing cabinets—are made from steel sheets. So are household appliances—refrigerators, ranges, and washing machines—as well as metal containers, such as barrels and drums. The list is virtually endless.

Sheets can be coated with vinyl paint and vinyl laminate for special purposes. A new product, Bethnamel, is coated with porcelain enamel for such products as household appliances and sanitary ware.

The Continuous Mill in Action

The first step in making steel sheets is hot-rolling on the *continuous hot-sheet mill,* one of the production marvels of our time.

First, the slab is heated to the proper rolling temperature. The glowing slab is pushed from the furnace onto a line of revolving rollers which carry it to the *scale-breaker,* a set of rolls which breaks up the oxide scale formed on the surface of the slab during heating. A powerful water spray then washes away the loose scale.

The slab moves through the roughing stands which squeeze it down to about one-fifth its original thickness, and stretch it to about five times its original length.

From the roughing stands the slab passes through a second scale-breaker and also a shear which cuts off the uneven ends formed during roughing.

Next, the slab enters the *finishing stands*—a series of six huge roll stands. When it enters these stands it is 5 to 6 times as long as the original slab. When it leaves, it is about 50 to 60 times its original length. Since each stand reduces the steel by about one-third in thickness, each succeeding set of rolls must be adjusted to run half again as fast as the preceding set. The steel lengthens so rapidly that before the trailing end has

Sheet steel emerging from a continuous hot-sheet mill. In the background a partially reduced slab nears the finishing stands.

After cold rolling, steel is softened by annealing, then passed through this skin-pass mill which stiffens and polishes the steel.

entered the first stand, the leading end has passed through all six stands, raced straight down the long runout table at a speed of from 20 to 25 miles per hour, and has reached the coilers, about 1200 feet from the heating furnaces.

A trap door directs the fast-moving steel down into the coiler, which is located beneath the runout table. In less than 20 seconds it has been wound tightly into a heavy coil. The coil is ejected, then placed on a mechanical conveyor which carries it to storage.

Sometimes the steel is cut into sheets instead of being coiled. This is done by a *flying shear* located immediately back of the last finishing stand. The shear, which is equipped with rotating knives, automatically cuts the steel into sheets of the desired length. These sheets then travel down the long runout table to be stacked by an automatic piling device.

Further Rolling on Cold-Reduction Mill

Much of the sheet steel rolled on the hot-sheet mill is further processed on the *cold-reduction mill*, which can produce thinner steel than it is feasible to roll on the hot mills. Cold rolling also finishes the steel to more accurate dimensions, and gives it a smooth, bright surface as well as improved mechanical properties. Cold-reduced sheets, generally after further processing, can be drawn or pressed into a wide variety of shapes such as automobile bodies.

Steel is Cleaned Before Cold-Rolling

The cold-reduction process requires that the metal be quite clean and free of the scale that forms during hot-rolling. This scale is broken on a mechanical scale breaker and removed by *pickling*, or passing the hot-rolled steel through a hot solution of dilute sulphuric acid. After pickling, the steel is washed, first in cold water, then in hot water and in steam, to remove any remaining traces of scale and acid. Then it passes between two rubber rolls which squeeze off the water. It is dried by jets of warm air, and is lightly coated with oil to prevent rusting before rolling begins.

Cold reduction is usually done on three-, four-, or five-stand, four-high mills. By sheer pressure the huge rolls reduce the cold steel to perhaps one-tenth its original thickness. The process is so fast that up to 5000 feet or more of cold-rolled sheets can be produced per minute.

After leaving the cold-reduction mill, the steel, now with a smooth, lustrous surface, is coiled again and may later be sheared to sheet sizes.

A great deal of cold-rolled sheet steel, particularly of the lighter gages, is coated with other metals—zinc or tin. Zinc-plating, or *galvanizing*, and tin-plating are described on the following pages.

Annealing and Skin-Pass Rolling

Cold working hardens steel, making it excessively stiff. The necessary softness and ductility are restored by *annealing*. This is accomplished in either batch-type or continuous annealing furnaces. After this the steel is passed through a *skin-pass mill*, usually consisting of a single four-high stand. Skin-pass rolling reduces the thickness slightly, gives the steel a bright sheen, and restores just the correct amount of stiffness. Shearing may follow. Finally, the sheets or coils are inspected for proper finish, temper, gage, and flatness.

Galvanized Sheets Have Many Uses

Large quantities of sheet steel are *galvanized*, coated with zinc for protection against rust or corrosion. Galvanized steel is used to make products such as automobiles, water pails, garbage cans, and rural mail boxes, for roofing and siding, and for ductwork in heating, ventilating, and air-conditioning systems.

Heavier gages of galvanized sheets are made from hot-rolled sheets; lighter gages are made from sheets that have been cold-rolled. The zinc coating is applied by passing steel sheet through a bath of molten zinc. This method, called *continuous galvanizing*, is an extremely fast, efficient operation in which a long coil is fed through the bath, then cut into sheets.

Gleaming coils of sheet steel, ready for shipment from the steel plant to a wide variety of customers.

Attractive furniture as well as many household appliances and cabinets are made from hot-rolled, cold-reduced sheets.

Tinplate

You can realize the importance of *tinplate* when you consider that about half of all the food we eat is packaged in cans made of tinplate. Many people are surprised to learn that so-called "tin cans" actually consist of more than 99 per cent steel and less than 1 per cent tin. The purpose of the light coating of tin on the outside and inside is to protect the steel from corrosion, and to impart an attractive, durable surface.

Preparing Steel for Tinplating

The first step in making tinplate is the preparation of thin sheets called *tin-mill blackplate* (not to be confused with ordinary steel plate). This is done by cold-rolling as described earlier, although slightly different equipment must be used in order to reduce steel to the extreme thinness required for tinplating.

Before the tin coating can be applied, blackplate must meet two requirements. First, it must be almost surgically clean. Second, it must be slightly etched so that the tin will readily adhere to its surface. These requirements are met by pickling the coils or sheets in a very dilute solution of sulphuric acid which removes any surface rust or specks of dirt, and lightly etches the metal.

Two Methods of Tinplating

Electrolytic tinplating, like many other technical advances, was developed under the pressure of wartime necessity. During World War II there was a shortage of tin. As a much lighter coating can be applied electrolytically than by the older hot-dip method, the electrolytic process was developed to conserve the available tin supply. However, heavy coatings can also be applied economically by this process, if desired.

Electrolytic tinning, which is faster and more efficient than the hot-dip method, is a continuous process. Long coils of prepared tin-mill blackplate are fed through an electrolytic bath, in which a uniform coating of tin is deposited on the steel by the action of an electric current. In this and subsequent finishing operations,

Soft drinks in cans made from tinplate chill fast, taste delicious. Cans store compactly, won't break. No deposits, no returns.

Food and beverages packaged in cans made of tinplate account for millions of tons of steel every year.

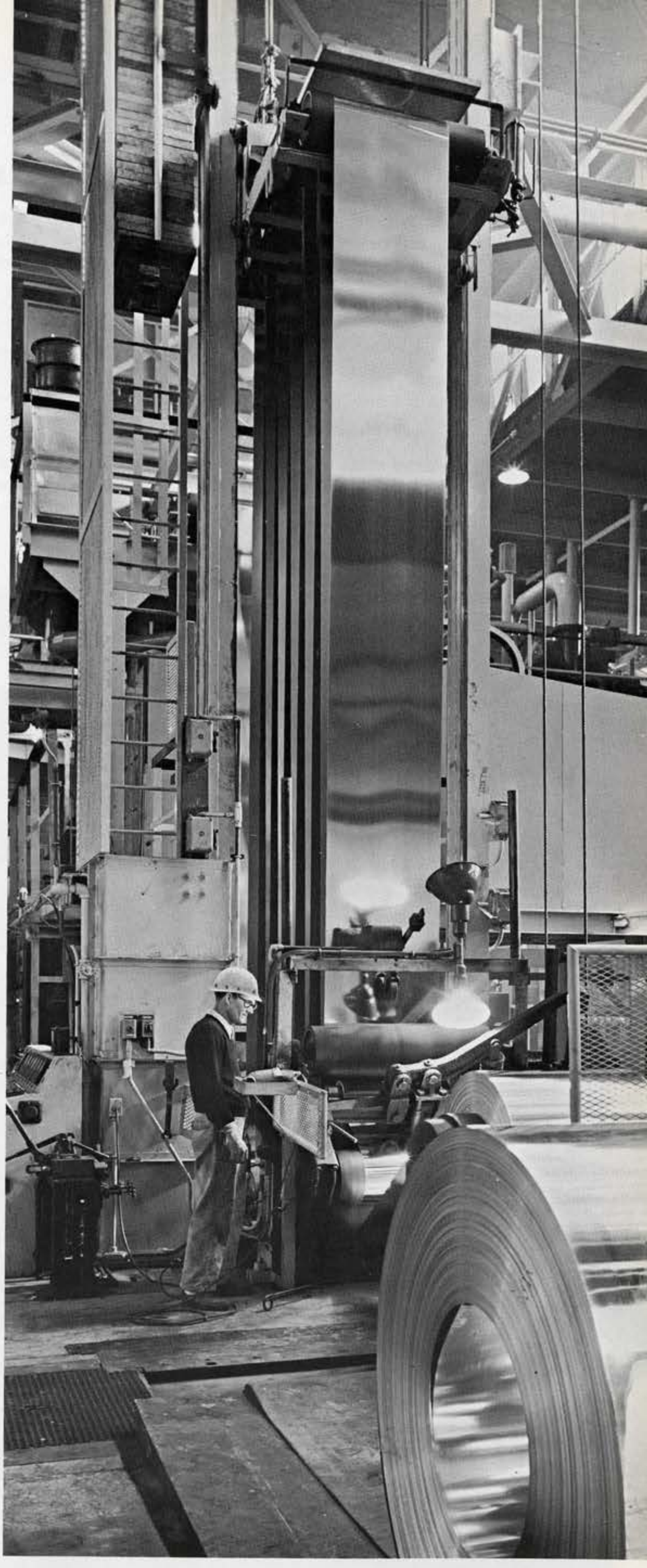
the tinplate is subjected to rigid mechanical and visual inspections. It is sold either in coils or in cut lengths.

Hot-dip tinplating is the older method of producing tinplate. In this process, sheets of tin-mill blackplate are fed automatically into rolls which guide the sheets through a pot of molten tin and up through a pot of palm oil containing rolls which control the thickness of the tin coating and distribute the tin evenly over the sheets.

"Thin" Tinplate

Double-reduced tinplate, commonly called "thin" tinplate, is first cold-reduced to an intermediate thickness, then annealed to regain its original ductility and softness. It is then cold-reduced again to the final desired thickness, and electrolytically plated. This final cold reduction produces tinplate, which, while extremely thin and light in weight, has sufficient strength to be substituted for the thicker and heavier material formerly used in certain cans.

Tin mill blackplate is widely used in making venetian blinds, toys, and other light articles. Steel in this form is strong and flexible.



Steel coated with tin by the electrolytic process leaves the plating line. This steel is sold either in coils or in cut lengths.

Structural Shapes

The dominant building material of the Twentieth Century is the *structural steel shape*. Structural shapes and, in particular, the *wide-flange* (H-shaped) beams which were first produced in America by Bethlehem in 1907, made possible today's towering skyscrapers. Many of the majestic buildings and bridges that are the construction marvels of our time derive their strength from sturdy structural steel shapes.

Rolling Structural Steel

Structural steel is produced in a number of *standard sections:* I-beams, channels, angles, tees, and zees. They are made by passing steel blooms between grooved rolls, the action of the rolls squeezing the hot plastic steel into the grooves. In this way the bloom is altered a little more from its original shape on each pass until, passing through the final grooved rolls, it emerges with the desired shape and size.

It is obviously no simple matter to change the cross-sectional shape and area of a large, square bloom into an I-beam. The process may require as many as twenty-six roll passes. The first few passes are chiefly designed to reduce the bulk of the bloom. Succeeding passes gradually form the blank into the final shape.

While standard structural shapes are formed on mills

Skyscrapers have sturdy skeletons of structural steel.

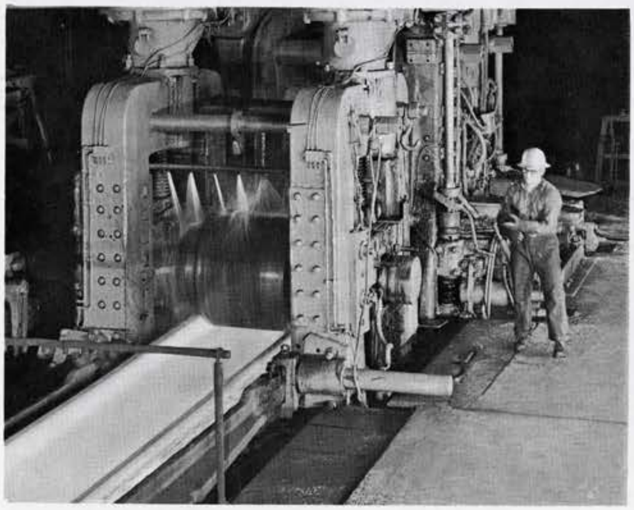
with grooved horizontal rolls, wide-flange shapes are rolled on special reversible two-stand mills known at Bethlehem as *Grey mills*. In the universal mill the horizontal rolls work on the center portion or *web* of the beam between the flanges and on the inside faces of the flanges and the vertical rolls work on the outside faces of the flanges only. In the edging mill the overall flange width is regulated.

After they have been rolled to the desired cross-section, structural shapes are cut to length and straightened.

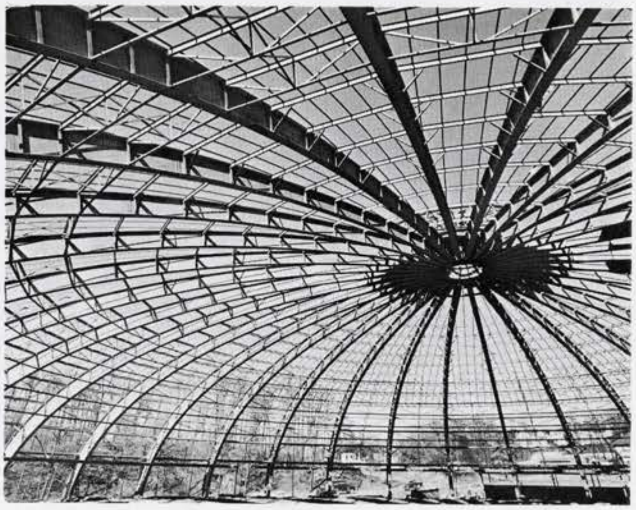
Today structural shapes as well as steel plate are often made of new high-strength steels which allow builders and designers to have stronger, yet lighter weight structures.

Fabricating and Erecting Steel Structures

Bethlehem not only produces structural steel shapes, but also fabricates and erects steel structures of all types. The steel frameworks of many of America's landmarks—the Golden Gate, Chesapeake Bay, and George Washington bridges, New York's Waldorf-Astoria Hotel and Chicago's Merchandise Mart—were fabricated and erected by Bethlehem's Fabricated Steel Construction Division.

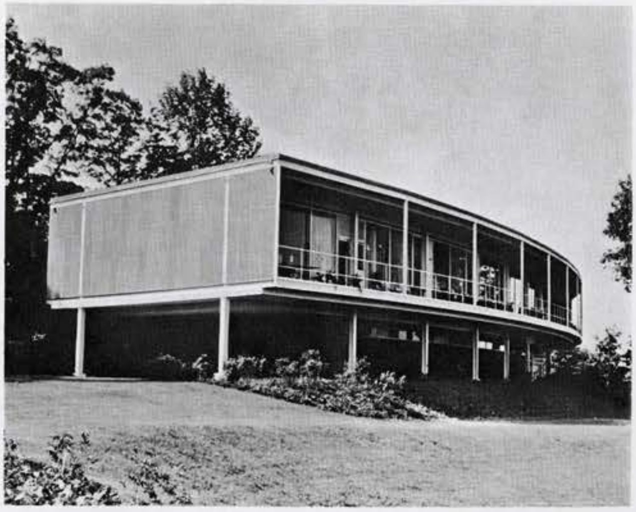


Rolling a structural beam. The flat portion is the web, which connects the two flanges. Bethlehem is the nation's largest producer of structural shapes.

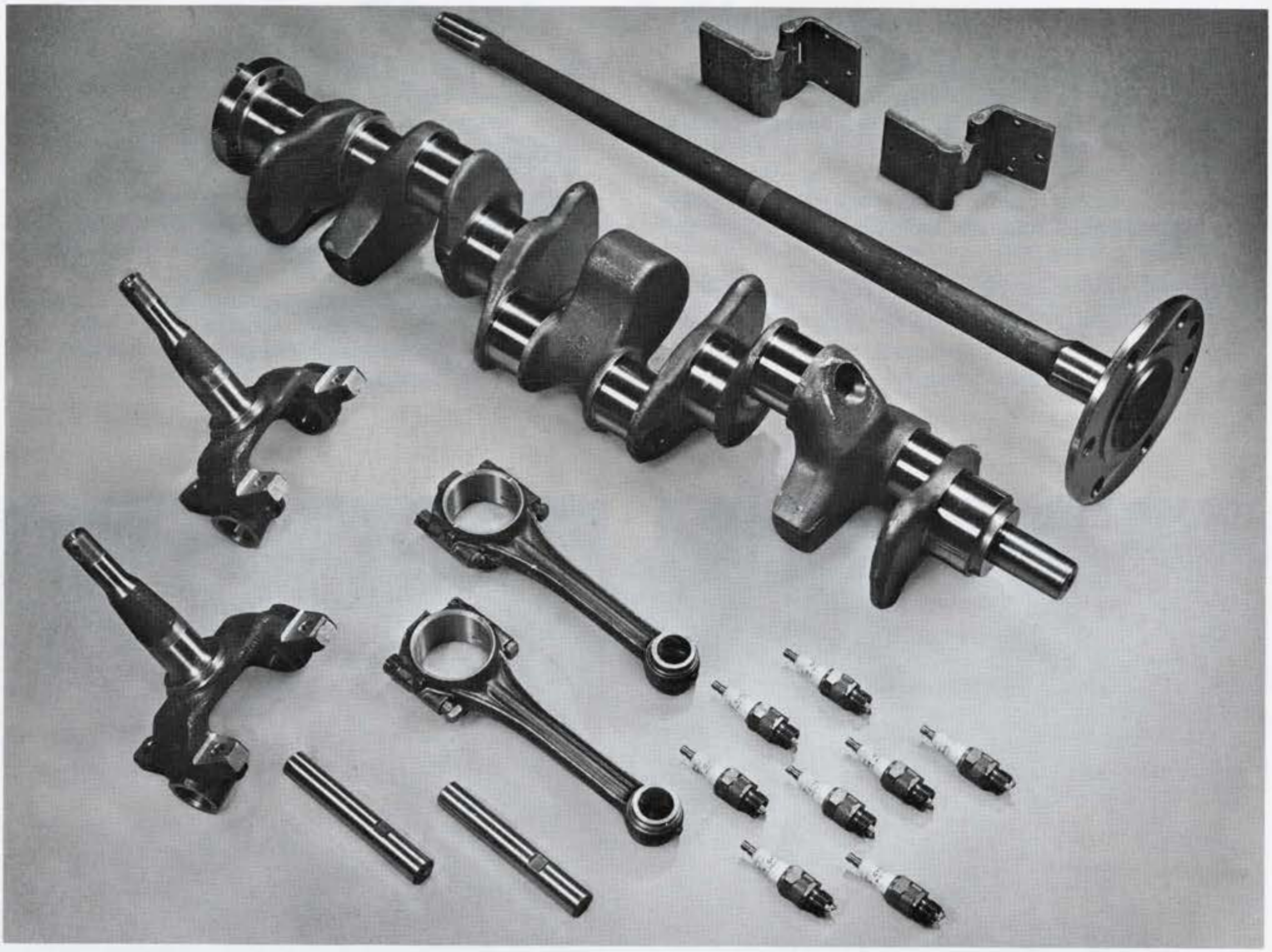


This is the structural steel framework for a college sports arena. Because of the strength possible with steel design, there are no columns to obstruct spectators' vision.

One of the world's major bridges is the George Washington, built by Bethlehem, and to which Bethlehem recently added a much-needed lower deck.



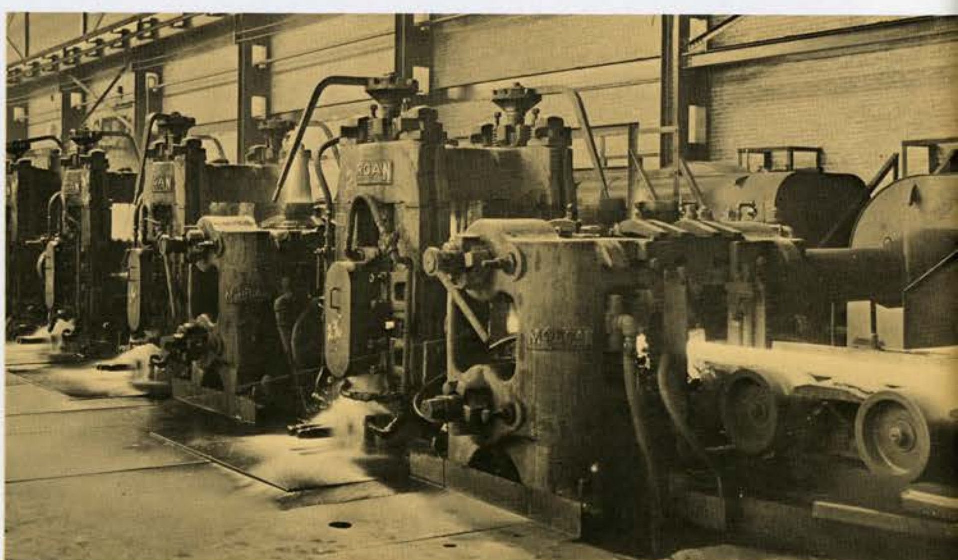
Many of the most attractive new houses are framed with steel, which is sometimes left exposed for its beauty. Steel frames allow use of steep-sloping sites.



Intricate parts for automobile are made from steel bars.

Assortment of common wrenches, representative of the many hand tools forged from bars.

This highly mechanized continuous bar mill has great productive capacity for high-tonnage rolling.



Bars

The important role of *steel bars* is brought home by the fact that over 500 pounds of bar steel go into the average passenger automobile. Such parts as connecting rods, spark plugs, valves, springs, door hinges, and truck tire rims are fabricated or forged from various grades of carbon or alloy steel bars, or special shapes rolled as bars. The average farm tractor contains 900 pounds of steel bars; the average diesel locomotive, over 17,000 pounds. Many everyday hand tools—knives, axes, hammers, pliers, and wrenches—and various parts of every type of power-driven machinery are made from steel bars. In addition, many thousands of tons of concrete reinforcing bars are used every year in highways, bridges, buildings, dams, and construction of all kinds.

Steel bars come in many different shapes, the most common ones being round, square, hexagonal, flat—and bar-size angles.

Bars Are Rolled on Merchant Mills

There are many types of bar mills, all of which are commonly called *merchant mills.* They vary from the highly mechanized continuous bar mill to the hand mill, where workmen use long-handled tongs to guide the steel through the rolls.

Continuous mills, having great productive capacity, are used to produce high tonnage products—the simple *standard bar sections,* which include reinforcing bars.

Other types of mills are not as fast but are more flexible, and are generally used to produce the more complex *special bar sections,* shaped to customers' requirements.

From Billet to Bar in 2 Minutes

In a modern high-speed continuous bar mill, the hot billet, between 3 and 6 inches square in cross-section and from 15 to 40 feet long, leaves the furnace and enters the roughing stands. Growing steadily slimmer and longer, and accelerating to speeds up to 30 miles an hour, the steel flashes to the cooling beds in the shape of a long bar. The entire process, from heated billet to finished bar, usually takes less than two minutes.

The processing after cooling varies considerably, according to the type of bars rolled, and may include straightening, cutting to specified lengths, heat-treating, bending, or other operations. A large part of the total bar output serves as the raw material for cold-drawing, forging, upsetting, machining, and other operations.

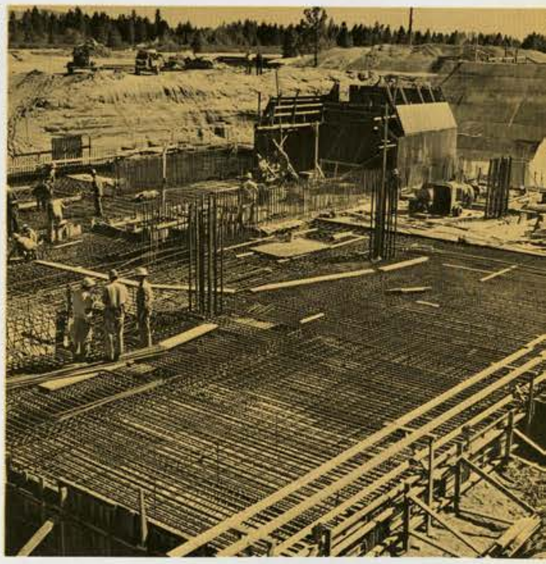
Cold-Drawn Bars

A considerable tonnage of hot-rolled bars is cold-drawn through stationary dies. This process gives the bars better mechanical properties, imparts a smoother, brighter surface, and finishes them to more exact dimensions. It also improves the steel's machinability.

Steel bars are used to make fasteners of all kinds and sizes.

Farm machinery and equipment also require many parts made from steel bars.

Concrete highways, dams, and structures of all kinds are reinforced with steel bars.



Attractive household items are made from a variety of sizes of steel wire.

Rod and Wire Products

Steel wire is one of the most versatile and most widely used of all steel products. It has thousands of applications, including innumerable products that we use every day. Fasteners of all sorts, from spikes to staples, nails, screws, paper clips, pins, tacks, and many types and sizes of bolts are made from steel wire. Springs for machinery and for furniture, farm fences, mesh for screen doors, bicycle spokes, coat hangers, chains, and kitchen utensils—all are made from steel wire.

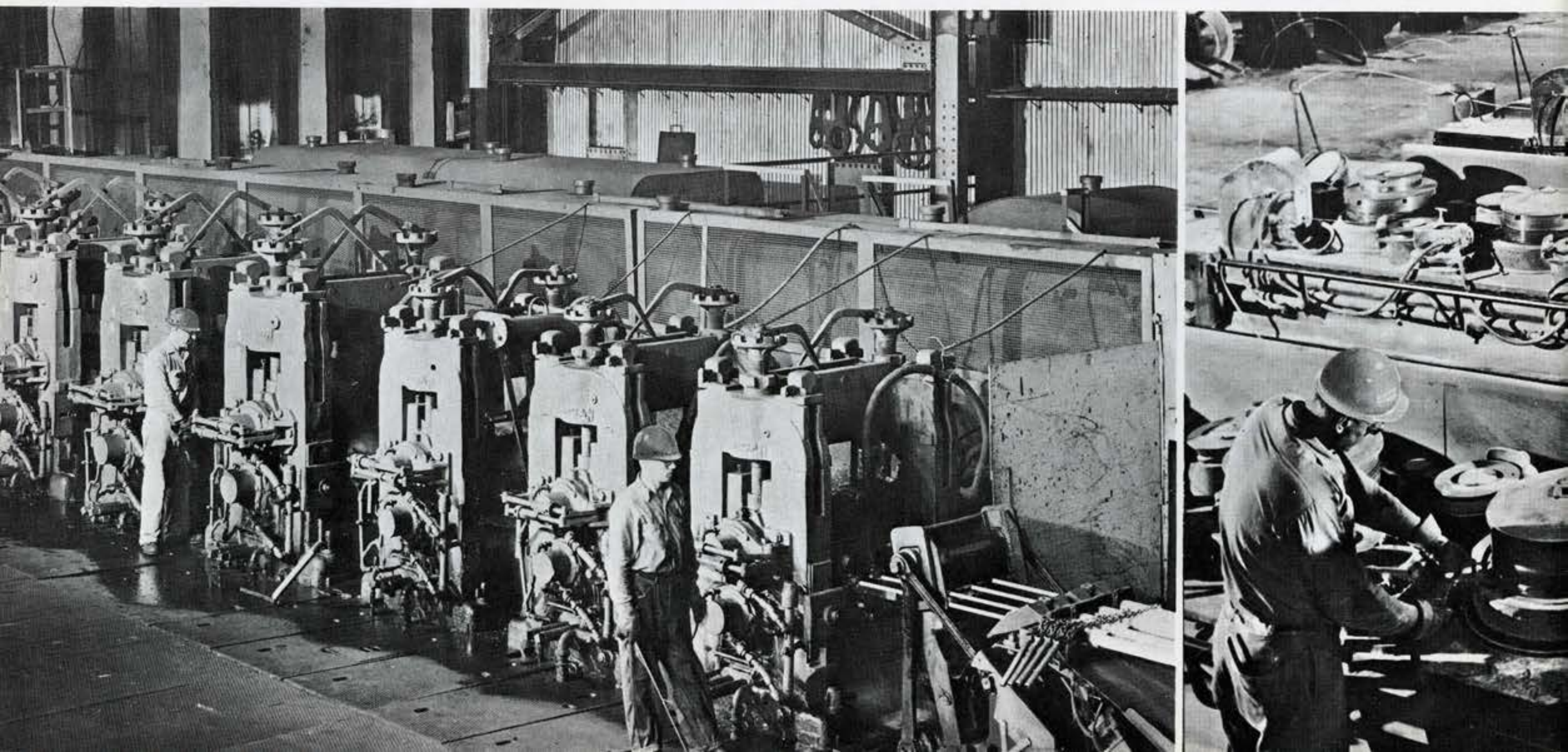
All steel wire is cold-drawn from rods. Rods, in turn, are hot-rolled from billets, generally between 2 and 3¼ inches square in cross-section, and from 30 to 38 feet long. Depending on the design of the mill being used, from two to four billets producing an equal number of strands of rods may be rolled simultaneously, side by side.

Rolling Rods from Billets

These billets are uniformly heated to the proper rolling temperature in a special furnace, then fed into a *continuous rod mill.* Continuous rod mills of the most modern type generally consist of two main sections—a set of roughing stands and a set of finishing stands. The total number of stands is usually over sixteen, and averages over twenty.

As they enter the "bite" of the first roughing stand, the billets are traveling at about 10 miles an hour. They pass from stand to stand, growing thinner and longer—and therefore moving faster—at each pass, until the finished rod speeds from the last finishing stand at 40 to 50 miles an hour. The rods are then quickly coiled.

Rolling rods from billets on a high-speed continuous mill. The entire operation takes less than two minutes.



During the hot-rolling process a 30-foot-long billet may be lengthened to nearly a mile. The whole operation takes just a little over one minute. Concrete reinforcing bars, as well as rods, are turned out by some rod mills.

Drawing Wire from Rod

Wire is made by pulling rod through tapered holes or *dies* slightly smaller in diameter than the rod itself. In this way the diameter of the rod is decreased while the length is increased. The usual arrangement is to cold-draw the rod through a series of successively smaller dies, until the finished wire is of the desired diameter.

In preparing rod for wire-drawing, the first step is to remove the oxide scale which forms after hot-rolling. This is done by pickling the coiled rod in hot dilute sulphuric acid. When the scale has been removed, the rod is bathed in water which washes away the acid. Next, the rod is dipped in a lime solution, then is baked in an oven to "fix" the lime coating. This coating serves as a base for the lubricant that eases the rod through the dies.

The prepared coil is placed on a reel at the wire-drawing machine, the end of the rod is pointed and started through the tapered die. These dies are made of hard, rigid substances, much harder than the rod itself.

After passing through the die, the rod is passed around a power-driven drum or *block*. As this block revolves, it pulls the rod through the die. In continuous wire-drawing, the rod is drawn through a series of dies and around a series of blocks.

Continuous wire-drawing is similar to continuous rolling, in that the steel is gradually reduced in cross section and its length proportionately increased. Therefore, as the wire moves along from die to die each succeeding drum must rotate faster to accommodate the lengthening wire. On leaving the last die the smaller sizes of wire may travel as fast as 20 miles an hour.

Heat-Treating Restores Ductility

The tremendous strain of cold-drawing hardens the steel to the point where it cannot be drawn any further. The wire's softness and capacity for cold-working is restored by annealing the wire during intermediate stages of drawing and after final drawing.

Another important operation in the production of steel wire is *patenting*. This is a special heating process which is used to prepare wire rod of high carbon content for drawing, and also to condition the wire at intermediate stages during the drawing operation. Patenting consists of passing individual strands of rod or wire through a long furnace, then cooling the steel rapidly in air or in a bath of molten lead.

A great deal of wire is coated to prevent rust or corrosion. Bethlehem uses two galvanizing (zinc coating) processes—*hot-dip* and *bethanizing*, and Bethalume (aluminum coating).

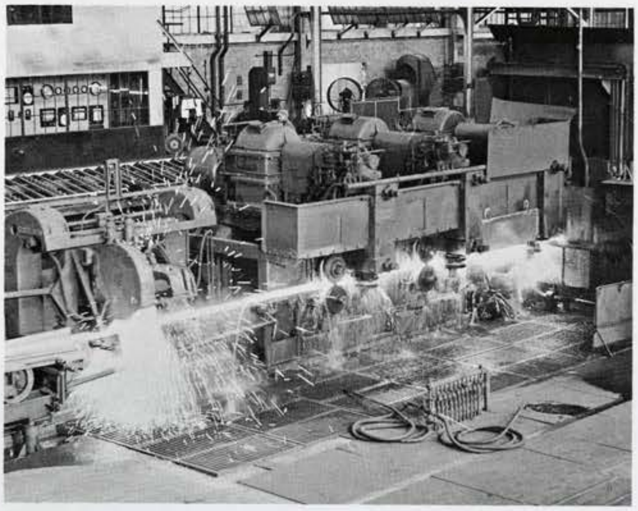
Wire Rope and Strand

By combining a number of steel wires into strands, and combining strands into wire rope, a product of great strength is obtained that is the muscle in equipment used in mining, logging, construction, petroleum, elevators. Strand is used in power and telephone lines.

Battery of modern wire-drawing machines. Rod enters at the left, is reduced in size as it passes through successive dies, and is coiled.

Steel wire safeguards a future mink coat. Its "bethanized" coating (electrolytic zinc) prevents damage to valuable fur.

In the electric resistance-welding process, skelp from the forming rolls (left) is welded automatically.



Small diameter pipe is formed by continuous butt-welding. Skelp is welded into pipe as it passes through sets of rolls.

Large-diameter steel pipe is made by welding curved plates.

Tubular Products

Tubular products—pipe and tubes—are either welded or seamless. *Welded pipe* is made by forming flat steel into cylindrical shape and welding the edges together in a long welded seam. *Seamless pipe* is made by piercing solid bars and billets, and therefore has no weld seam.

Steel pipe is made in diameters ranging from fractions of an inch up to 12 feet or more. The smaller sizes are extensively used in plumbing, heating, and refrigeration systems, and in countless structural applications. The large sizes are used mostly in cross-country pipe lines for oil and gas, and in water and sewage systems.

Steel tubing, or pipe which varies from standard steel pipe in dimensions or grade of steel, is available in a great variety of tubular shapes for special purposes. It may be used in pipe lines for a variety of gaseous or liquid products. And it has a multitude of structural uses, ranging from household furniture to jet aircraft.

At Bethlehem Steel, welded pipe is produced by the continuous butt-welding process or the electric resistance- and electric fusion-welding processes.

Continuous Butt-Welding

Butt-welded pipe from ½ inch to about 4 inches in diameter is usually made by the continuous process. Long strips of steel, called "skelp," are fed into a furnace and heated to the welding temperature. The

Rust-resisting galvanized steel pipe is used in the plumbing and heating systems of many buildings.

skelp then moves through a series of roll-passes, consisting of pairs of horizontal and vertical rolls. The rolls form the moving skelp into a cylinder, welding together the heated edges. The pipe is cut to length as it leaves the rolls.

After it has cooled, the pipe is straightened and finished. The strength of the weld is tested hydrostatically, by sealing the ends and pumping in water under high pressure. Pipe is often galvanized, by coating it with zinc, to protect it from corrosion.

Electric Resistance-Welding

Bethlehem pipe ranging from about 5$\frac{9}{16}$ to 16 inches outside diameter, inclusive, is made by the modern electric resistance-welding process. Coils of skelp of a thickness, or *gage*, corresponding to the pipe wall desired, but of a width slightly greater than the circumference, is first uncoiled and edge-trimmed to required width. The edges are then shot-blasted to provide a clean surface for making contact with the welding electrodes.

After cleaning, the skelp enters a series of forming rolls which gradually form it into a tube with the long edges not quite closed. At speeds up to 120 ft per minute, the tube then passes into the welding rolls. Here, rolls on the sides and bottom of the tube squeeze its edges together. At the same time, electrodes in the form of circular discs, feed high-voltage current across the seam, heating the steel. This combination of heat and pressure welds the edges together in a uniformly sound weld.

The pipe now is cut to length, and the lengths pass through more sets of rolls which reduce their diameter slightly, bringing them to exact size, and which straighten them. After the ends are threaded or beveled, and the pipe has passed the hydrostatic and other tests, it is ready for shipment.

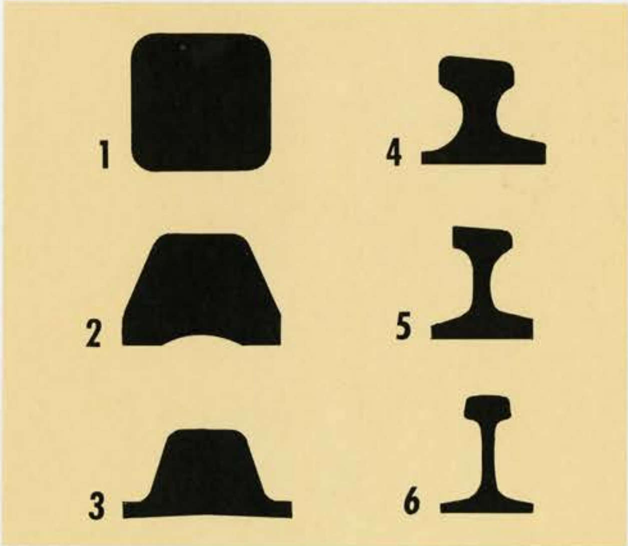
Electric Fusion-Welding

Electric fusion-weld pipe is made at steel mills in sizes up to perhaps 150 inches in diameter. Larger sizes are usually made wherever the pipe is to be used, since it is impossible to transport them by rail or truck. Pipe from 16-18 inches up to a maximum of about 42 inches is used for the long distance transmission of oil and natural gas. Water lines range from those sizes up to as large as 8 or 9 feet in diameter. Pipe in diameters upwards of 9 to 10 feet is usually used for special purposes such as penstocks for hydroelectric projects.

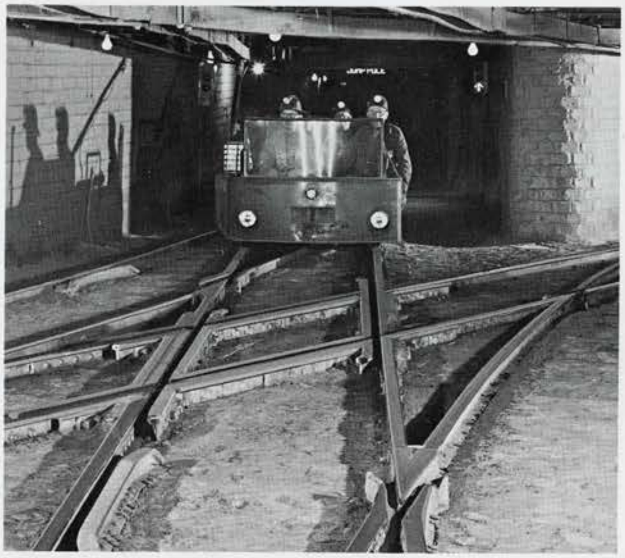
Large diameter pipe is made from plates, usually 40 feet long and sometimes over 1 inch thick. First, all four edges of the plate are beveled in preparation for welding. The plate is then formed into a cylinder, and held in this shape by temporary or "tack" welds. It is then fully welded on a large electric fusion-welding machine. Each length is hydrostatically tested, then coated, lined, and wrapped with protective materials if required.

Making Seamless Tubing

Seamless pipe and tubing is made from a form of semi-finished steel called "tube rounds," by a number of methods. In one process a preheated tube round passes between a pair of rotating crossed rolls. The action of the rolls forces one end of the round against a piercing plug or *mandrel*. The combined rolling action and the pressure of the rolls tend to open the round at its center. The mandrel controls and completes this piercing action. The result is a rough tube which is finished by passing it through a set of rolls over a ball.



These simplified diagrams illustrate how a bloom is shaped into a rail.



Steel rails are used in many underground haulage systems.

Rails

Steel rails for America's railroads were first made in this country on a commercial basis in 1867 at what is now Bethlehem's Johnstown, Pa., Plant. Today, rails are still an important finished steel product. The safety of millions of travelers depends on the quality of these rails. Rails have to stand up under fast, heavy trains and endure the strains caused by severe weather conditions.

Large quantities of heavy rails are produced for railroads. Lighter and specialized design rails are made for haulage systems in mines and for various industrial uses. Besides producing rails, Bethlehem fabricates track layouts, including curves, crossings, and turnouts.

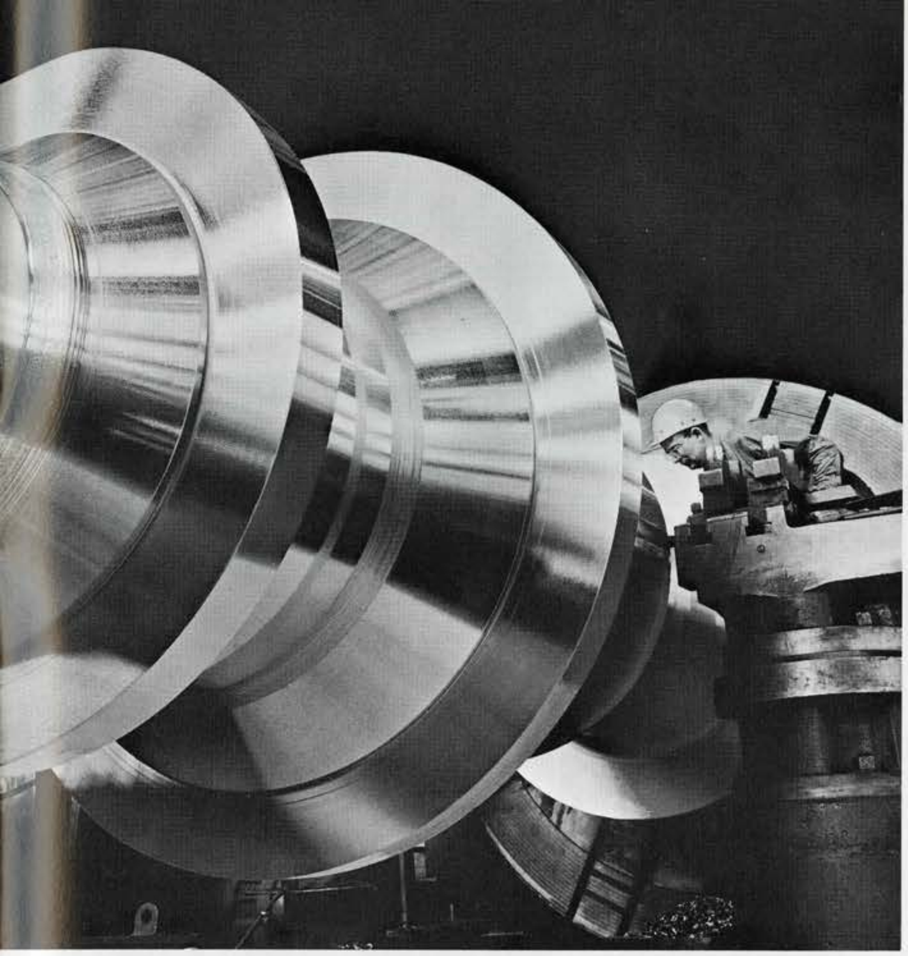
Rails Are Rolled from Blooms

A roughing mill reduces and forms the reheated bloom into the approximate size and shape of a rail. Then, passing through a number of finishing stands, the steel is formed into T-shaped rails, sometimes as long as 120 feet, which are hot-sawed to standard 33- or 39-foot lengths.

After cooling to some extent on the mill hot beds, the heavier rails used in main-line service are placed in long covered metal boxes for *controlled-cooling*. This process eliminates dangerous transverse fissures or "shatter cracks" which might otherwise form during cooling. Another Bethlehem development is *end-hardening*, a method of heat-treating which hardens the ends of rails so they can withstand wheel battering at rail joints.

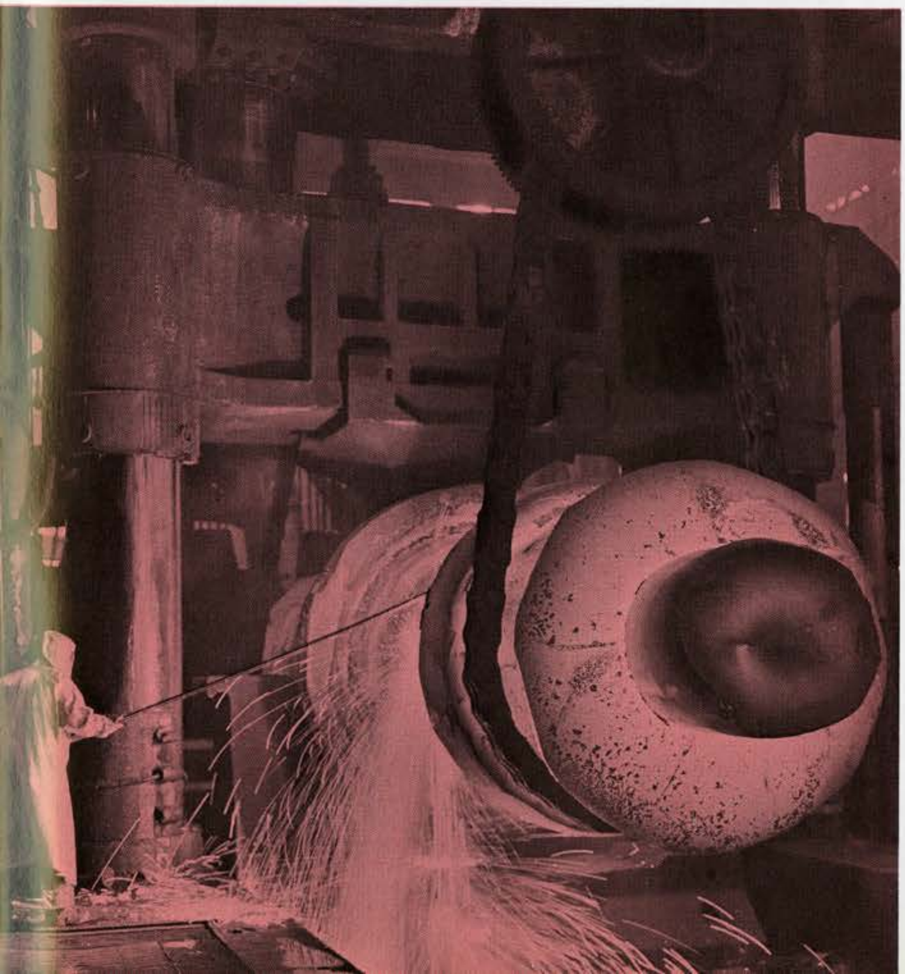
In order to provide rails than can better stand up under the severest conditions of modern railroading, Bethlehem has introduced heat-treated rails and trackwork. Heat-treatment, which includes oil-quenching and tempering, improves the physical properties of rails for use at points of unusual stress.

Heat-treated rails have special strength properties and are used by the major railroads at points of stress.



A forging is machined with watch-like precision. Few manufacturers can match the Bethlehem Plant's arsenal of machine tools.

In the jaws of a huge press, a vacuum-poured ingot takes the rough shape of the rotor for a turbine to generate electricity.



Forgings

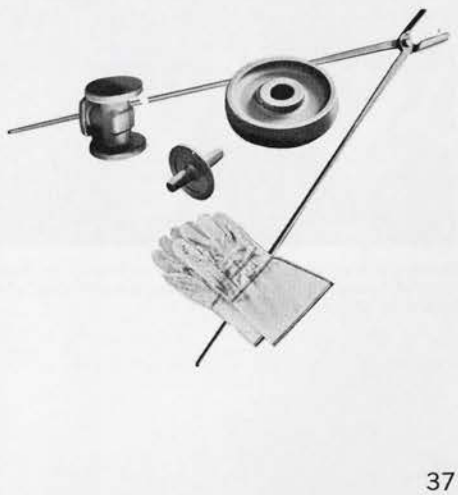
Some steel items are manufactured by forging. Heated ingots, billets, or bars are pressed or hammered to size and shape. In forging, the hot steel is kneaded or worked in all directions to give it uniform strength and toughness. Bethlehem's forge departments have mechanical and hydraulic presses, hammers, and drop-forging units to make forgings of nearly any size and shape, from a small crane hook to a giant turbine rotor.

Machining is another of the important manufacturing operations. Iron and steel products are cut, planed, turned, broached, bored, milled, or ground to give them the exact dimensions and surfaces needed. Six machine shops, including a complete tool-manufacturing shop, are equipped with the modern machine tools and high-capacity cranes required to handle this work.

Forgings or bars often require heat-treatment to give the steel the desired structure or properties. This includes such operations as stress relieving, annealing, normalizing, quenching, and tempering. Modern heat-treating furnaces with precision control equipment are available for this purpose.

Vacuum-degassed steel is used for specific critical applications.

Pouring molten steel into ingot molds or ladles under vacuum conditions releases most of the hydrogen gas; this eliminates the most troublesome problem in the production of heavy forgings, and results in forgings of a quality heretofore unobtainable.



Research:

the challenge of the future

Keeping steel and steel products competitive in all the many markets they serve requires the combined efforts of many, including salesmen, production men, and others. But it is to research that the industry in general and Bethlehem in particular looks for new and more efficient ways of making steel, as well as for new products and improvements to existing steel products. Already entirely new products have been developed through research that take advantage of steel's great strength, economy, and versatility.

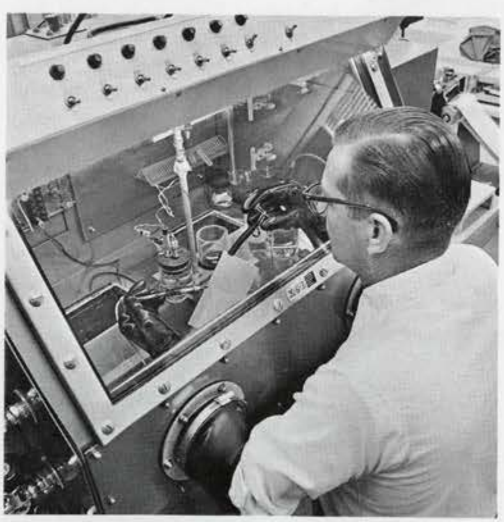
The Homer Research Laboratories at Bethlehem, Pa., have been planned and are equipped to develop the technology needed to keep steel as the nation's most versatile metal.

Here are spacious and advanced facilities for research in raw materials technology, reduction and refining, forming and finishing, engineering of control systems, and product design.

From Laboratories like these will come the steels of the future and the practical ways of making them.

Pouring an experimental melt of 300 pounds of steel.

Many research projects relate to weldability and welding techniques. This is the control panel of a modern welding machine used by Bethlehem research scientists.



Studying the complex surface chemistry of tinplate requires, among other conditions, a controlled atmosphere in which to work.

This experimental disc pelletizer forms fine-grained ores into pellets for further processing into material suitable for blast furnace feed.

Products of Bethlehem Steel

Hot-rolled sheets, cold-rolled sheets, galvanized sheets—carbon and low alloy ▪ Culvert sheets ▪ Bethnamel enameling sheets ▪ Galvannealed sheets ▪ Electro-galvanized sheets ▪ Prepainted sheets ▪ Electrolytic tin mill coated sheets ▪ Chromized sheets ▪ Wide-flange structural sections ▪ American standard beams, angles, and channels ▪ Hollow structural sections ▪ Sheared, universal, and strip mill plates—carbon and alloy ▪ Flanged and dished heads ▪ Electrolytic tinplate ▪ Hot-dip tinplate ▪ Blackplate ▪ Double-reduced tinplate and blackplate ▪ Hot-rolled carbon and alloy steel bars—standard and special section ▪ Steel blooms, billets, and slabs—carbon and alloy ▪ Wire rods ▪ Manufacturers' wire—bright, galvanized, Bethanized, and aluminized ▪ Nails, staples, barbed wire, bale ties, and automatic baling wire ▪ Welded wire fabric ▪ Slabform ▪ Bridgform ▪ Bridge railing ▪ Concrete reinforcing bars ▪ Cold-formed shapes ▪ Sheet piling ▪ H-piles ▪ Piling pipe ▪ Continuous butt-weld pipe ▪ Electric-resistance weld pipe ▪ Oil and gas transmission line pipe ▪ Culvert pipe ▪ Rails, tie plates, and joint bars ▪ Tool steels and specialty steels

Steel bridges, buildings, and other fabricated structures of all kinds ▪ Ships, ship repairs, ship machinery, and equipment ▪ Tanks and pressure vessels ▪ Large diameter water pipe ▪ Galvanized power transmission towers ▪ Fabricated reinforcing bars ▪ Steel joists ▪ Highway guard rails, beam and cable ▪ Frog and switch material and prefabricated special trackwork ▪ Freight cars, industrial cars, and car parts ▪ Wheels and axles for railway and industrial equipment

Bolts, nuts, rivets, spikes, and other industrial fasteners ▪ Mine roof bolting and supports ▪ Sucker rods ▪ Wire rope ▪ Bethanized, galvanized, and aluminized strand ▪ Stress-relieved strand ▪ Wire rope slings and spliced products ▪ Ferromanganese ▪ Coal chemicals—including tar, benzene, toluene, xylene, and ammonium sulphate ▪ Forgings—press, hammer, drop, and circular ▪ Hardened steel rolls ▪ Ordnance ▪ Steel, iron, and brass castings ▪ Ingot molds and stools ▪ Tunnel segments ▪ Iron ore and manganese ore ▪ Stone and slag

Facilities of Bethlehem Steel

STEEL PLANTS

Bethlehem, Pa. ▪ Johnstown, Pa. ▪ Lebanon, Pa. ▪ Steelton, Pa. ▪ Williamsport, Pa. ▪ Lackawanna, N.Y.
Sparrows Point, Md. ▪ Burns Harbor, Ind. ▪ Los Angeles, Calif.
South San Francisco, Calif. ▪ Seattle, Wash.

FABRICATING WORKS

Bethlehem, Pa. ▪ Leetsdale, Pa. ▪ Pottstown, Pa. ▪ Chicago, Ill. ▪ Torrance, Calif.
Pinole Point (Richmond), Calif.

SHIPBUILDING AND SHIP REPAIR YARDS

East Boston, Mass. ▪ Hoboken, N.J. ▪ Baltimore, Md. ▪ Sparrows Point, Md.
Beaumont, Tex. ▪ San Francisco, Calif. ▪ San Pedro, Calif.

OTHER MANUFACTURING UNITS

Boston, Mass ▪ Albany, N.Y. ▪ Buffalo, N.Y. ▪ Staten Island, N.Y. ▪ Dunellen, N.J.
Elizabeth, N.J. ▪ Philadelphia, Pa. ▪ Baltimore, Md. ▪ Fairfield, Md. ▪ Richmond, Va.
Charlotte, N.C. ▪ Raleigh, N.C. ▪ Detroit, Mich. ▪ Romulus, Mich. ▪ Clearing, Ill.
Minneapolis, Minn. ▪ Jacksonville, Fla. ▪ Miami, Fla. ▪ Hallandale, Fla.

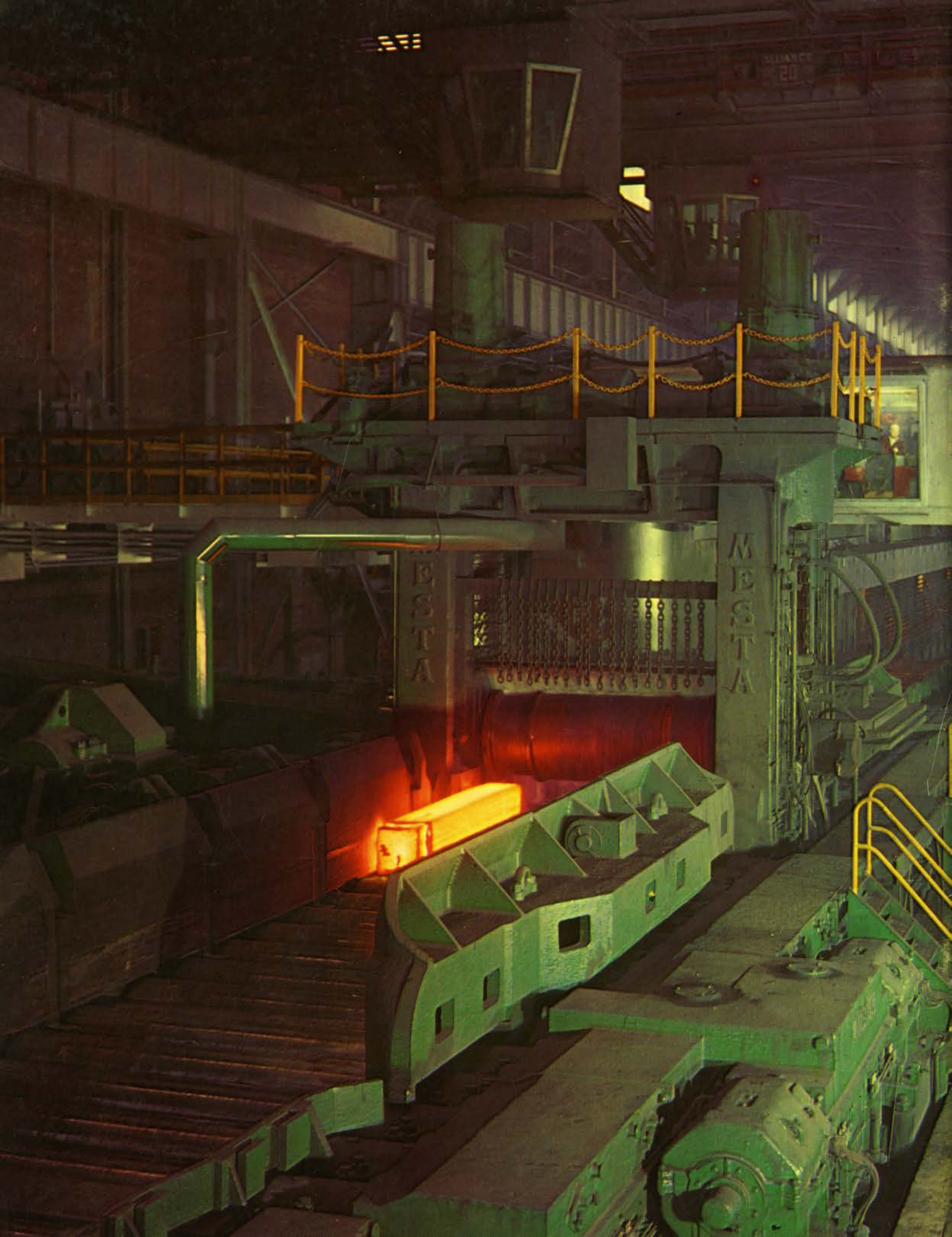
BETHLEHEM STEEL EXPORT CORPORATION

25 BROADWAY, NEW YORK, N. Y. 10004

INSIDE BACK COVER: This glowing ingot, emerging from a soaking pit, is ready for rolling.

BACK COVER: Reducing a hot-steel ingot to a bloom in the rolls of a blooming mill.

Booklet 1918—B
672, Printed in U.S.A.


MESTA
MESTA