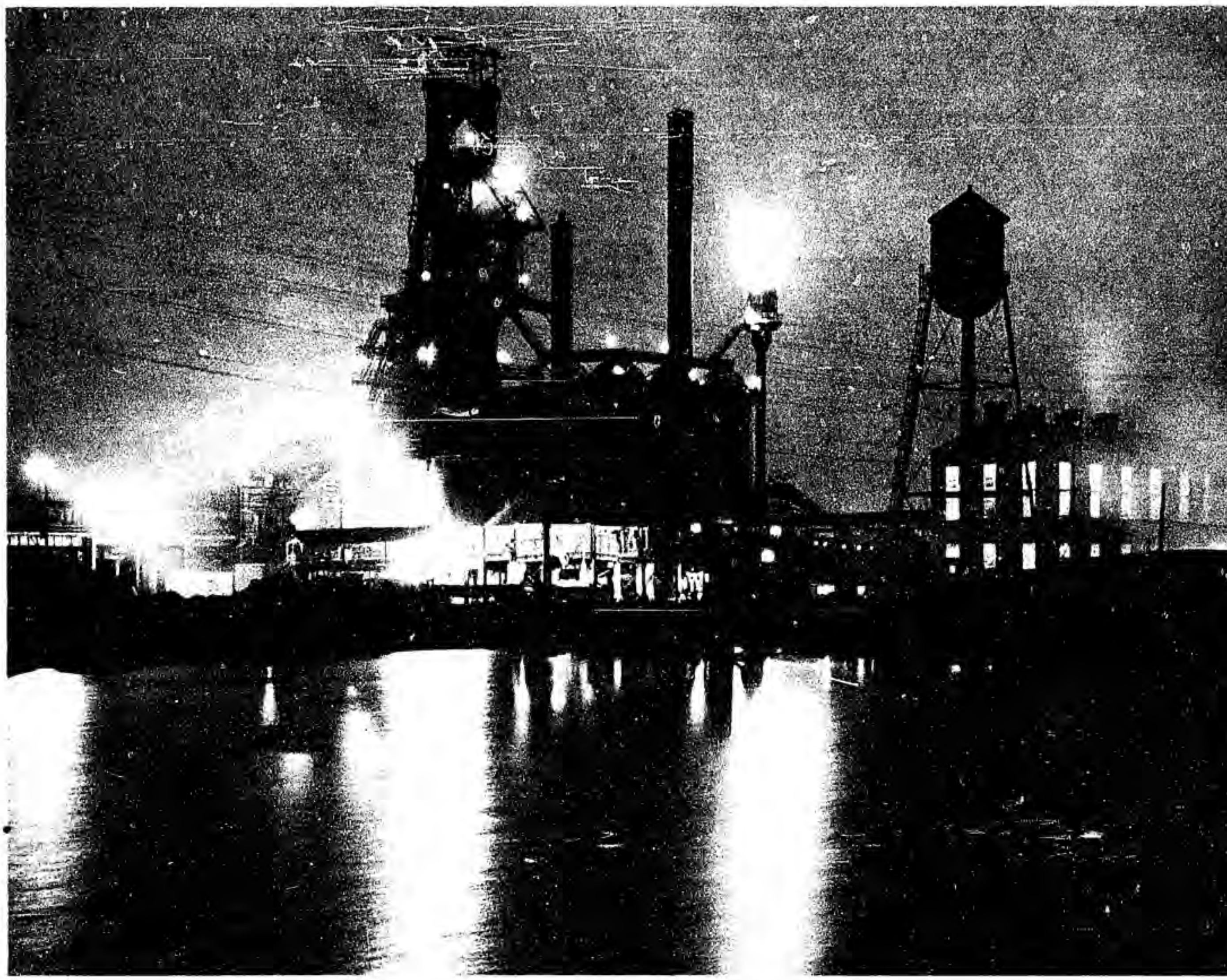
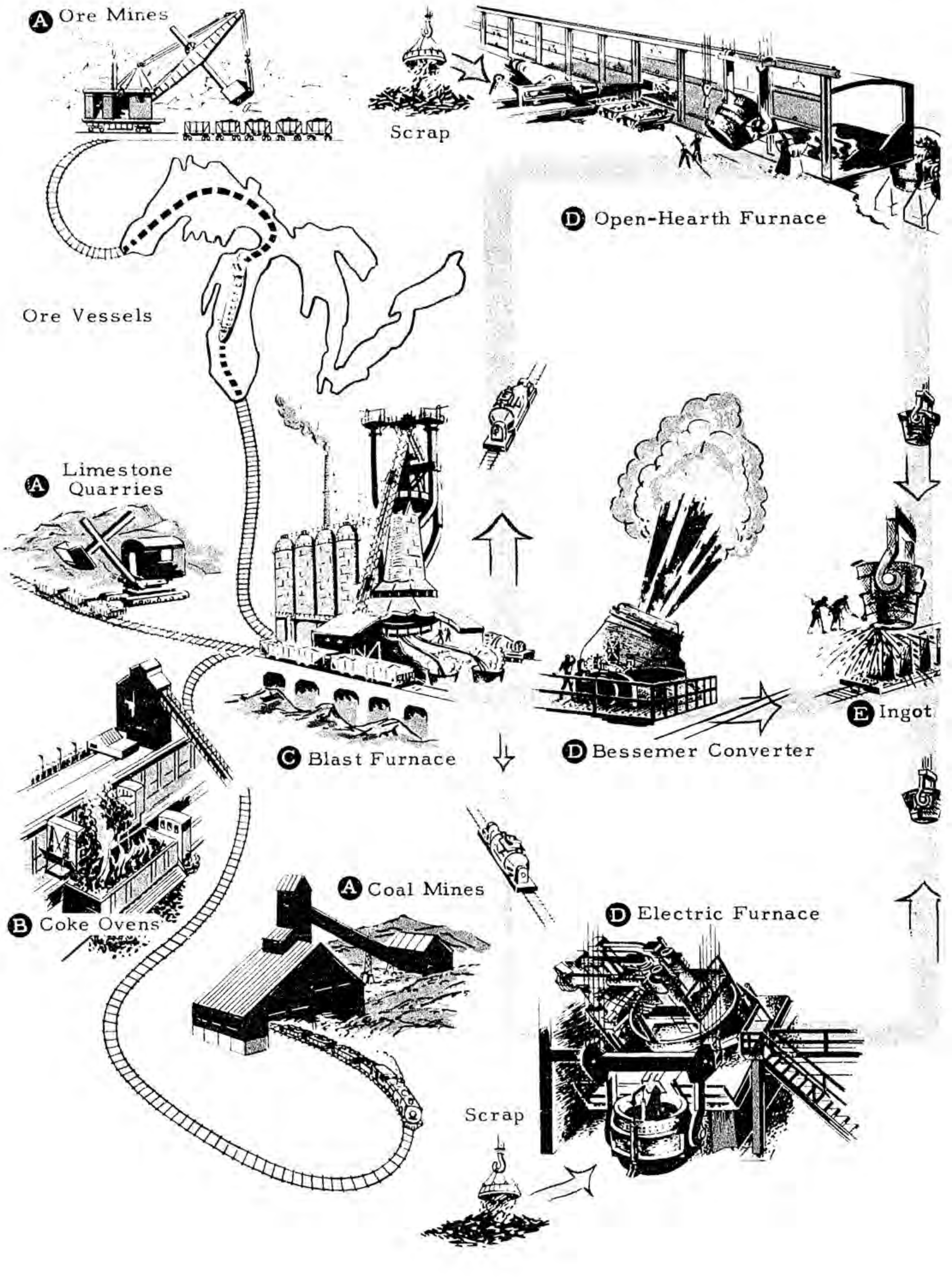
STEEL MANUFACTURING



Steel is produced by a series of chemical and physical processes from raw materials which are extracted from the earth. These notes on steel manufacturing contain a flow chart of the steel-making process; a pictorial representation of the buildings, equipment, and operations of an integrated steel mill; and an illustrated description of the more important manufacturing operations.

Photo, Courtesy Armco Steel Corporation

FLOW CHART OF T



STEEL MAKING PROCESS

A The three principal raw materials, iron ore, coal, and limestone, are mined and shipped over water and rail routes to the steel mills.

B Coal is converted into coke in by-product coke ovens.

C Pig iron is extracted from iron ore in the blast furnace. The coke and limestone are the reducing and purifying agents.

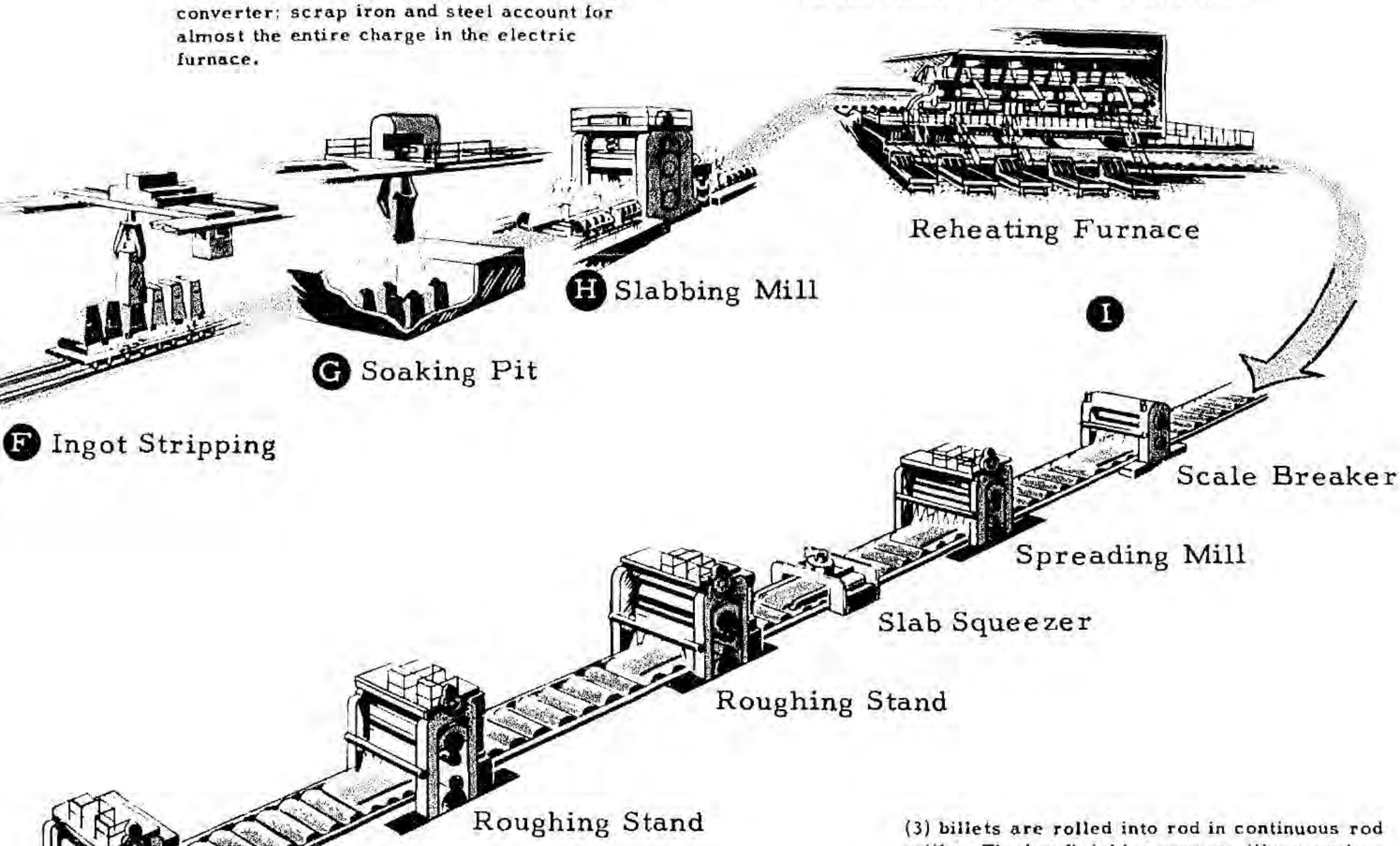
D Steel is made by refining pig iron and scrap in the open-hearth furnace, Bessemer converter and electric furnace. Pig iron and scrap are used in about equal proportions in the open-hearth furnace; pig iron accounts for almost the entire charge in the Bessemer converter; scrap iron and steel account for almost the entire charge in the electric furnace.

E The steel-making furnaces are tapped and the molten steel is poured or "teemed" into an ingot mold.

F After cooling the mold is stripped away from the ingot.

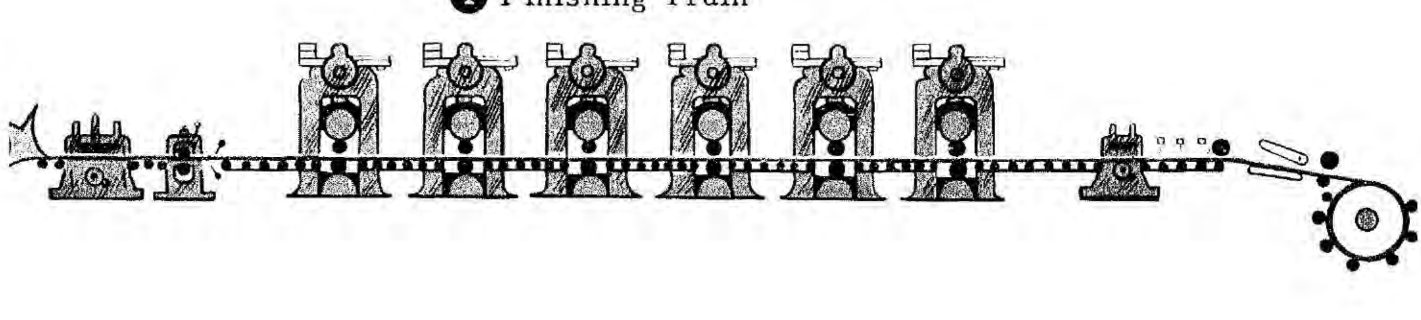
G Ingots are heated in soaking pits to a uniform rolling temperature.

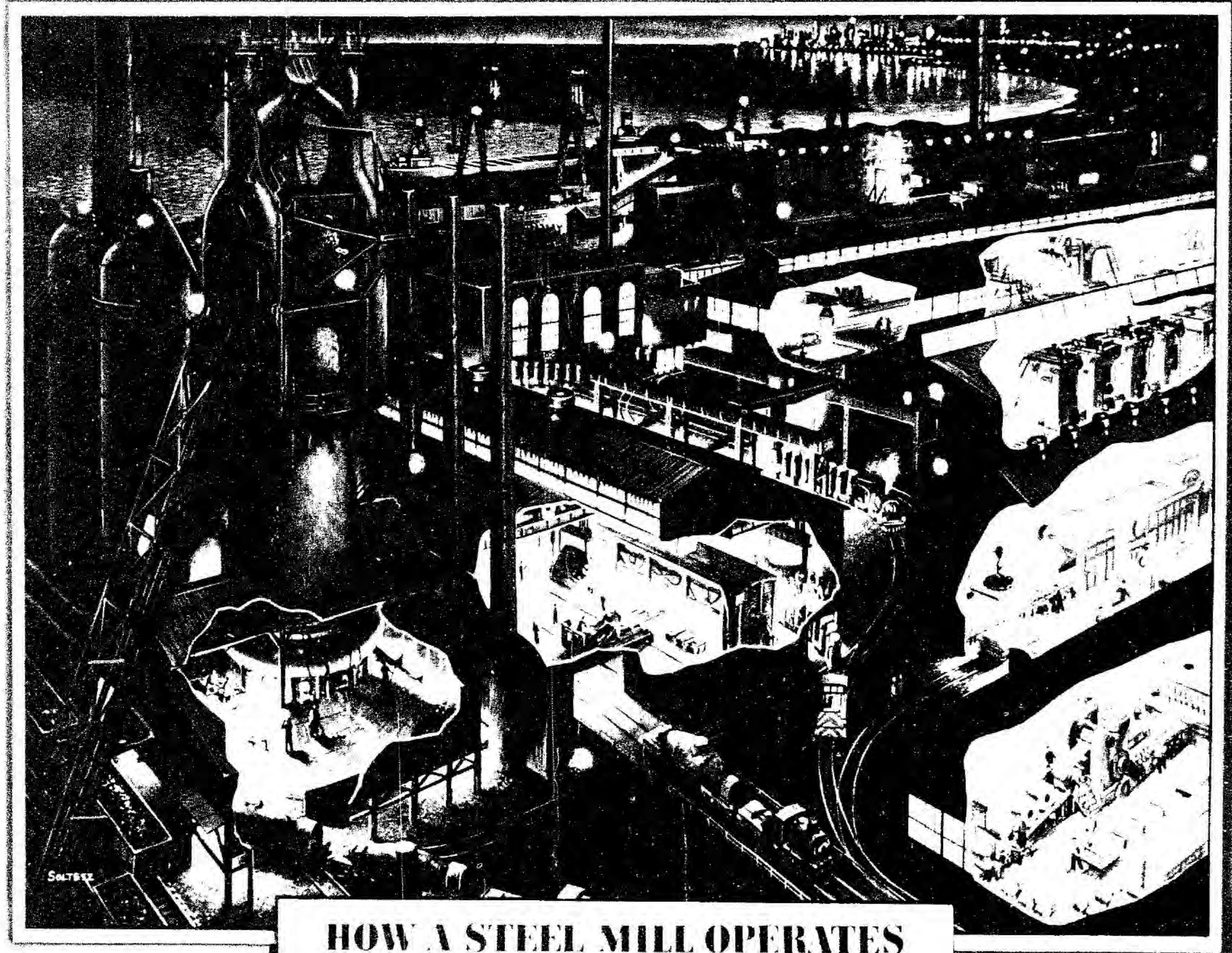
H Ingots are rolled into three semi-finished forms: (1) blooms in the blooming mill, (2) slabs in the slabbing mill, and (3) billets in the billet mill. To roll billets the ingot is first reduced to a bloom, which is then further reduced to a billet in the billet mill.



I Semi-finished forms are rolled into a variety of products in hot finishing mills: (1) blooms are rolled into structural shapes and rails in structural and rail mills, (2) slabs are rolled into flat-rolled products such as coil, sheet and strip in continuous hot strip mills, and (3) billets are rolled into rod in continuous rod mills. The hot finishing process illustrated below is the continuous rolling of slabs into coil, sheet and strip. Further finishing of flat-rolled products is frequently performed in cold finishing mills. The coil is given a further reduction in thickness and a variety of coated finishes depending on the end use of the product.

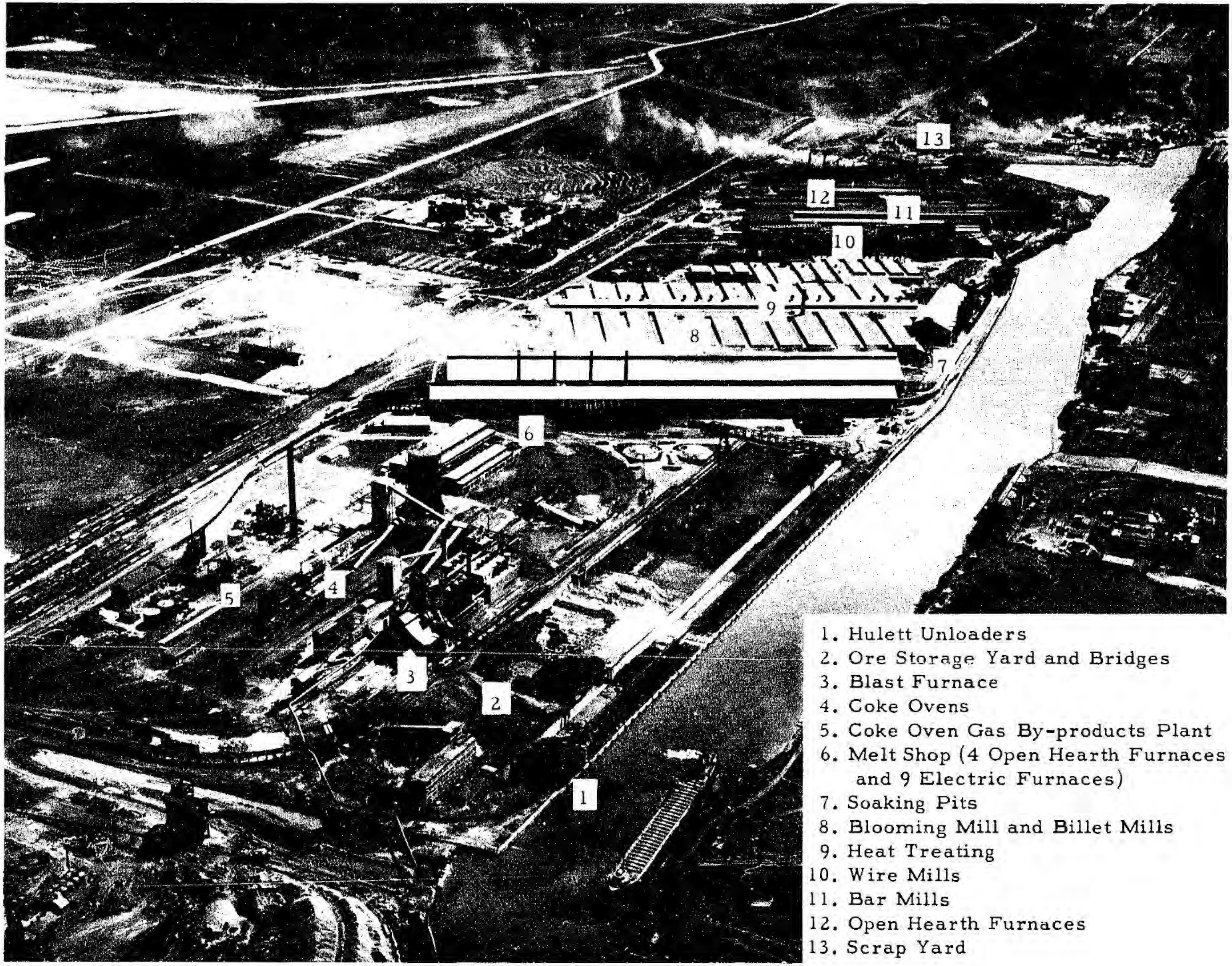
I Finishing Train





HOW A STEEL MILL OPERATES

Prepared by the Armstrong Cork Company, makers of Industrial Insulations, in cooperation with the American Iron and Steel Institute



1. Hulett Unloaders
2. Ore Storage Yard and Bridges
3. Blast Furnace
4. Coke Ovens
5. Coke Oven Gas By-products Plant
6. Melt Shop (4 Open Hearth Furnaces and 9 Electric Furnaces)
7. Soaking Pits
8. Blooming Mill and Billet Mills
9. Heat Treating
10. Wire Mills
11. Bar Mills
12. Open Hearth Furnaces
13. Scrap Yard

Photo, Courtesy Republic Steel Corporation

1. Open Pit Mining

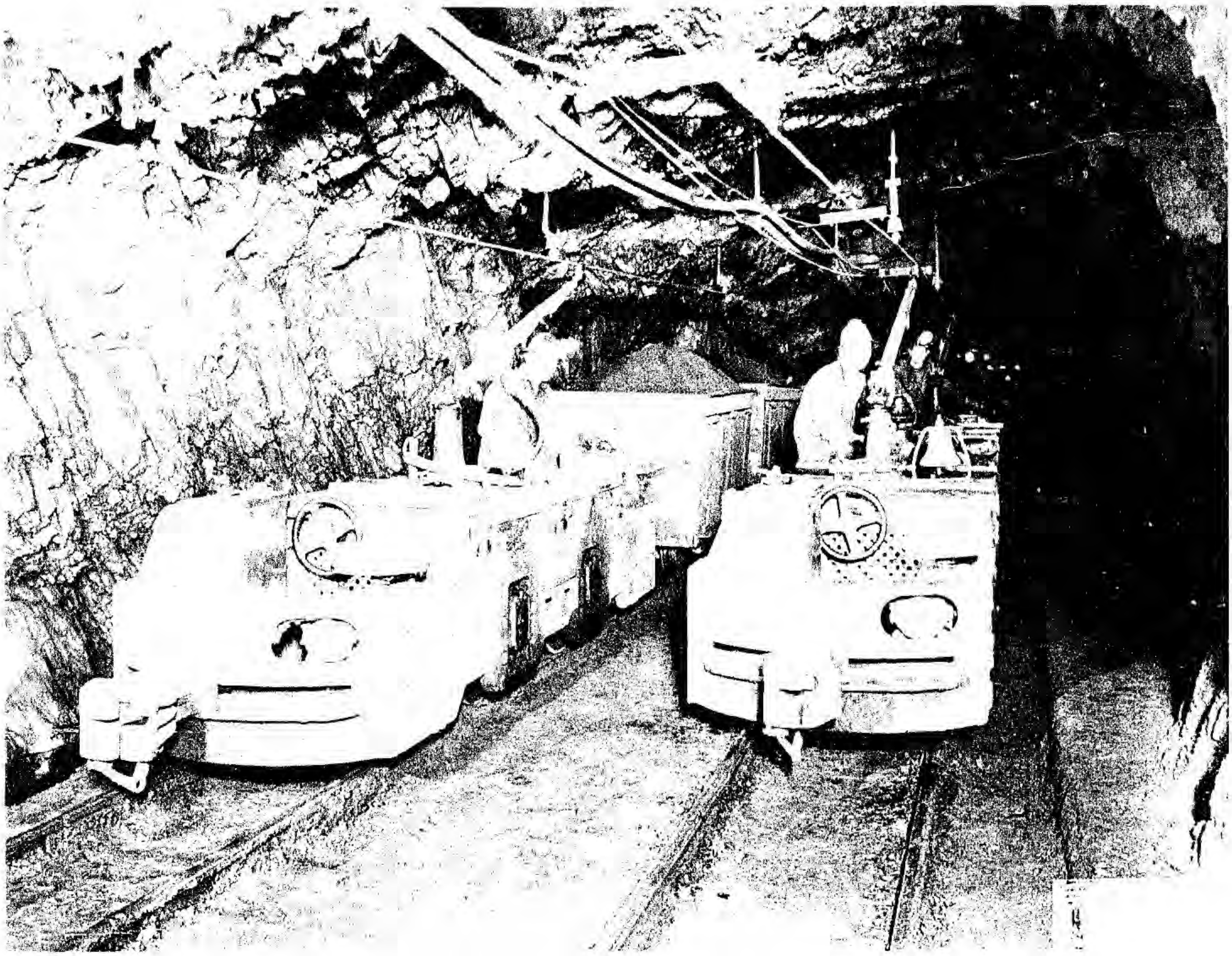
I - RAW MATERIALS

1. Mining Iron Ore: Iron is commonly found in nature as an oxide mixed with other compounds. The concentration of iron in iron ore suitable for commercial processing varies from 35% to 65%; iron bearing earthen matter below 35% in concentration is abundant, but has not yet been used extensively for making steel. The major source of iron ore at present in the United States is the Mesabi Range in the Lake Superior region. Iron ore from this region averages 52% in iron content.

Approximately 75% of all ore mined in the United States is by the open pit method while the remaining 25% is mined by the underground method. In open pit mining, a surface layer of boulders, sand and gravel is removed, after which power shovels scoop up the ore and load it into railroad cars.

Underground mining is similar to coal mining. Shafts are sunk into the earth in varying depths, and passageways are dug into the ore bodies. Blasting loosens the ore and it is then hauled to

Photo, Courtesy United States Steel Corporation



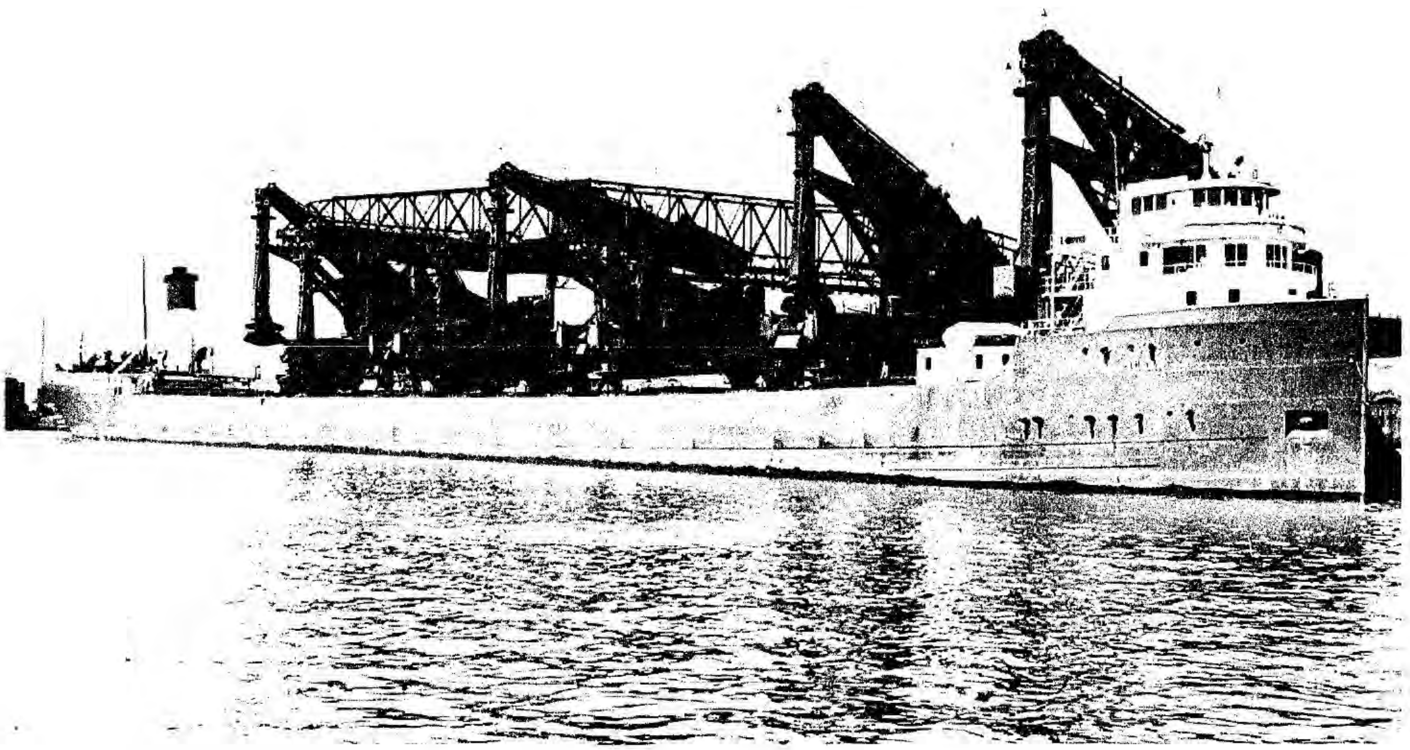
1. Underground Mining

the main shaft for transportation to the surface in skip cars.

The selection of the particular method of mining ore depends on the quality of the iron ore and how far below the earth's surface it is located. Underground mining is more costly than open pit because of the added costs of sinking shafts and operating underground. If a sufficiently rich yield of ore is expected, the higher costs of underground mining are warranted. In 1948, the average labor cost per gross ton for mining ore in Michigan was $.52 for open pit and $1.83 for underground mining. One disadvantage of open pit mining is that it is not a continuous operation. Severe weather conditions during the winter months curtail open pit mining for a substantial part of the year in certain localities.

Large capital expenditures are required for the development of iron ore sites. It has been estimated, for example, that $250,000,000 will be invested in the new Quebec-Labrador ore fields for town sites, 400 to 500 miles of railroad, and for mine operating equipment.

Photo, Courtesy United States Steel Corporation

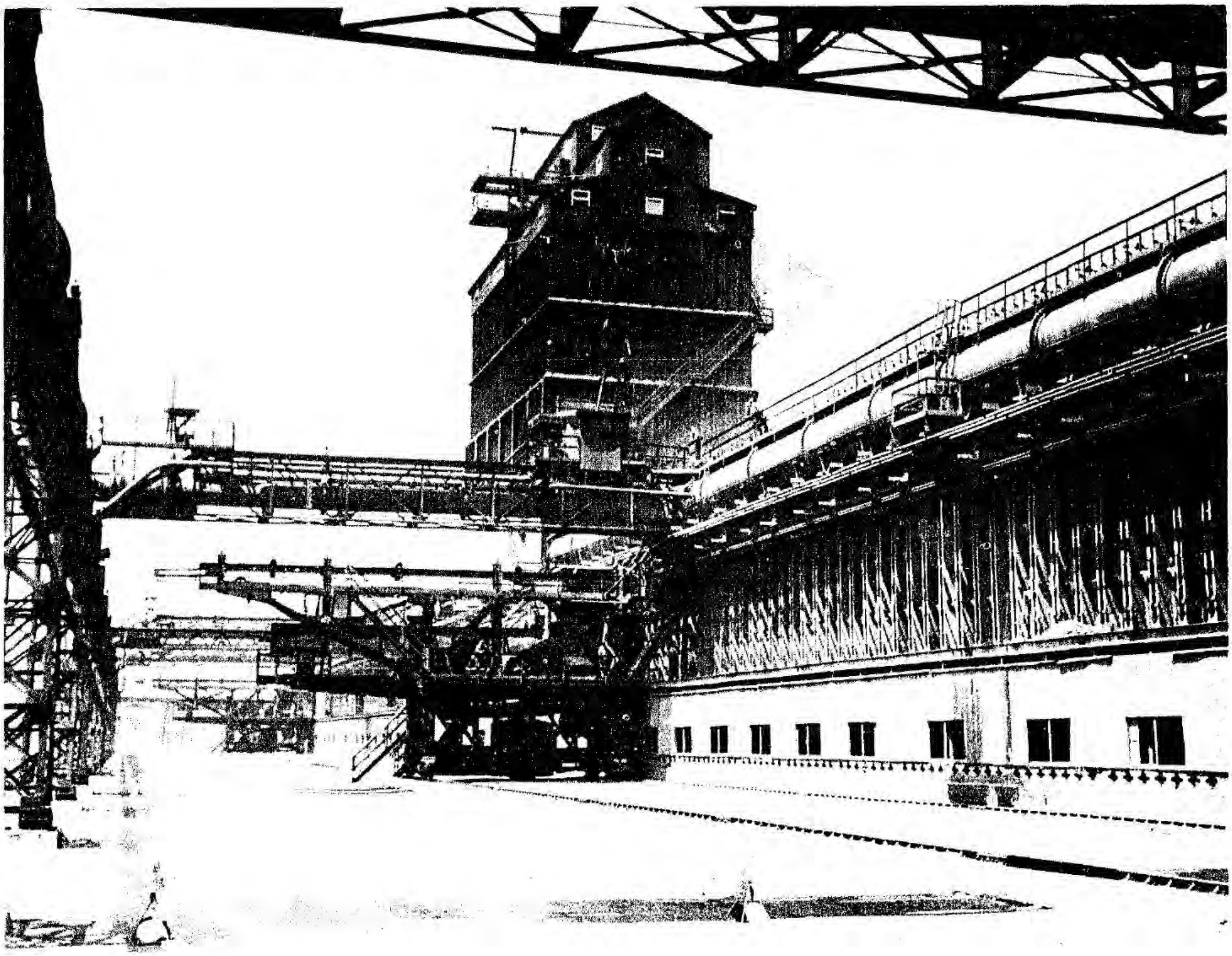


2. Unloading Iron Ore at Lake Port

2. Transporting Iron Ore: Since most of the iron ore in the United States is located near Lake Superior, an extensive transportation system has been developed for moving ore from the mines to the blast furnaces near the lower lake ports. Railroads run from the mine terraces to sorting yards near the lake, a distance ranging from 65 to 80 miles. The ore is classified according to chemical content so that the proper mix of raw materials can be obtained for the particular grades of steel to be produced. Sorted ore cars are moved from the yards to loading docks into which the ore is dumped. Some docks hold more than 150,000 tons of ore.

The iron ore stored in the loading docks is delivered by gravity feed into specially constructed ore boats of 12,000 ton average capacity. The loading operation requires from 3 to 6 hours. The vessels proceed to the lower lake ports where they are unloaded. Electric unloaders which can remove 17 tons of ore in one scoop empty the ships in about 5 hours. The ore is then trans-shipped by rail to the blast furnaces or is stockpiled for use when winter closes lake shipping.

Photo, Courtesy United States Steel Corporation



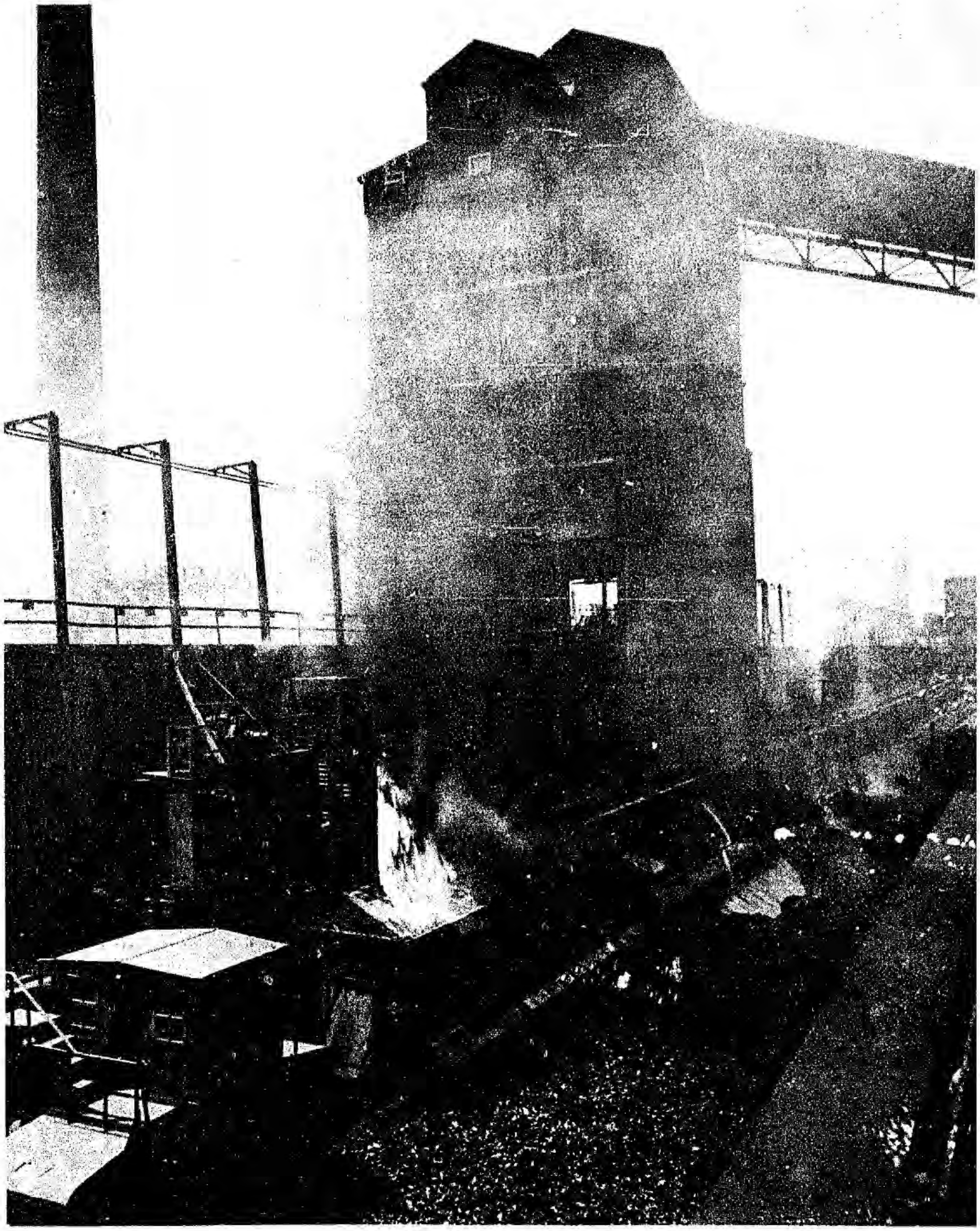
3. Power Ram Pushing Coke Through Ovens

The equipment required for ore movement is both specialized and costly. For example, a unit of five 17-ton unloaders, 5 bridges for further ore handling, and the required docking facilities costs over $17,500,000; a modern 18,500-ton ore boat costs about $5,000,000.

3. Coke and Limestone: Coke is used as a reducing agent and a source of heat and carbon in producing pig iron. Consisting of 90% carbon, it is produced by heating special metallurgical coal in a closed vessel. Coke is superior to ordinary coal, charcoal or wood for use in the blast furnace because of its higher carbon content and greater strength and porosity.

There are two methods of manufacturing coke: (1) the by-product, and (2) the beehive. The by-product method accounts for most of the coke production in the United States. Its main advantage over the older beehive process is that it captures the outgoing gases which can then be converted into raw materials for aviation gasoline, dyes, explosives, and many other chemical products.

Photo, Courtesy United States Steel Corporation



3. Coke Falling into Hot Car

The by-product coking process is carried out in a battery of as many as 90 rectangular ovens in a row, each from 30 to 40 feet long, 6 to 14 feet high, and 11 to 22 inches wide. A modern oven can be charged with 16 to 20 tons of crushed and screened coking coal. Heating chambers in which gas is burned as the source of heat for the process are located on each side of the individual ovens. After about 19 hours of heating at 1600° to 2100°F. the doors on both ends of an oven are opened. A power ram proceeding down a track from one oven to the next pushes the coke out the opposite end into a "hot car." The hot car is taken to a quenching tower near the ovens and a spray of

Photo, Courtesy United States Steel Corporation

water quenches the coke. The coke is then screened and delivered to storage bins which are adjacent to the blast furnaces.

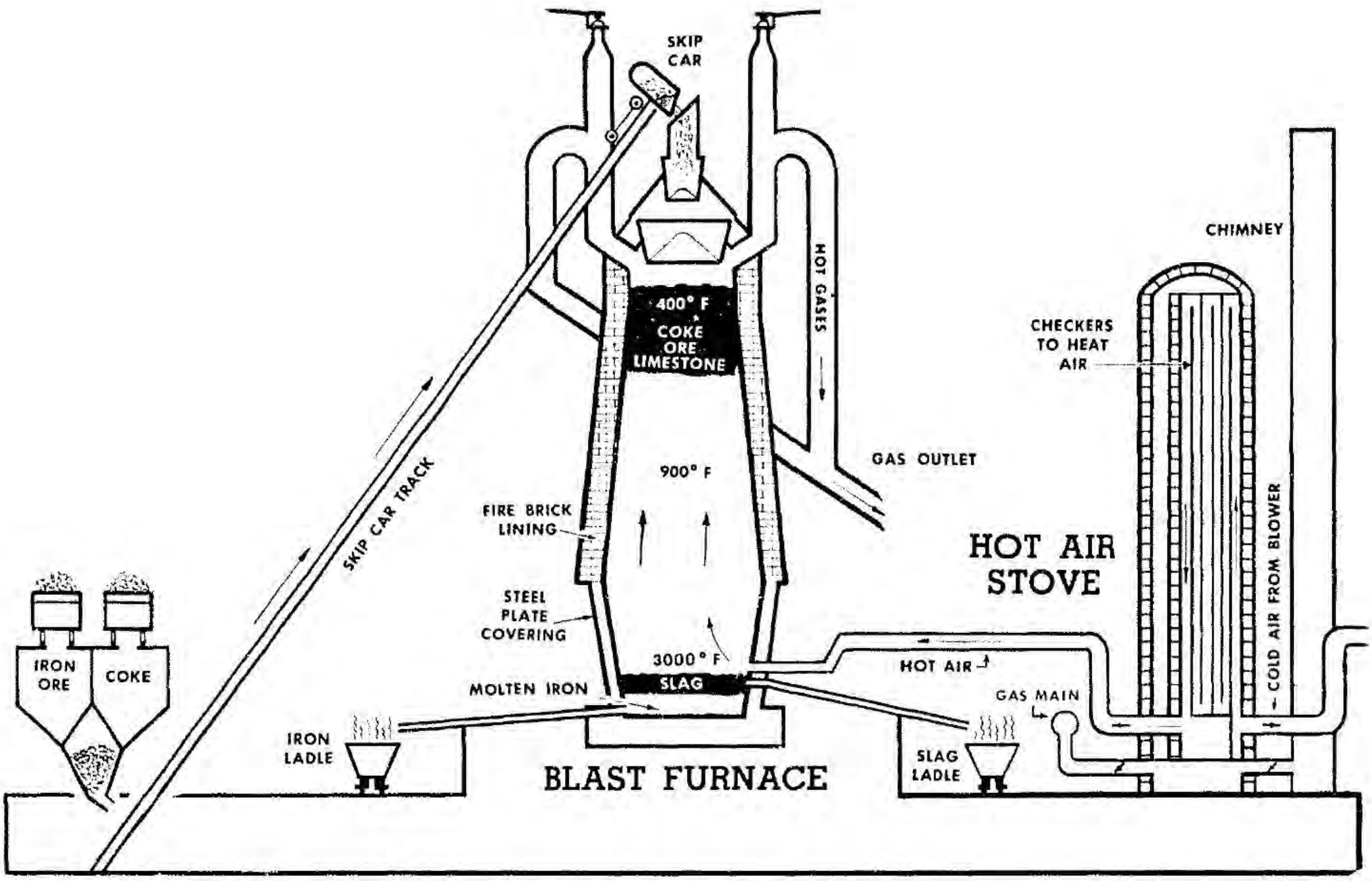
A battery of 30 by-product coke ovens costs $2,000,000 and has an average life of 17 years. Workers manning coke ovens operate equipment for conveying and crushing the coal, lubricate conveyor belts, operate electric loading cars, level coal as it is charged into the ovens, remove and position oven doors, operate the power ram for pushing coke from the ovens, clean air ports, clean or replace nozzles in oven batteries, and operate stills for removing oils from the coke oven gas. Their wage rates range from $1.41 to $2.16 per hour.

A third important raw material is limestone, an abundant rock whose main constituent is calcium carbonate. It is used in both the iron and steelmaking processes. In both instances it serves to remove impurities and forms a slag which floats on top of the iron or steel and can be drawn off separately. Limestone is generally quarried in sites near the blast furnaces and is delivered to the steel mills after it has been crushed and screened.

II - MAKING PIG IRON

4. Blast Furnace: Pig iron is produced in the blast furnace from iron ore, coke, and limestone. Pig iron may be used in foundries for the production of gray iron castings or may be further processed into steel in the steelmaking furnaces. Pig iron differs from steel primarily in that it has a higher carbon content and contains impurities such as phosphorus, silicon, sulfur, and manganese. It is hard and brittle and must be shaped by casting rather than by the rolling processes used for steel.

Skip cars running up an inclined track charge iron ore, coke, and limestone into the top hopper of the blast furnace in alternate layers. Blasts of hot air are injected at the bottom of the furnace through pipes or "tuyeres" which extend several inches inside the furnace. There are 10 to 20 such tuyeres distributed around the circumference of the furnace. The hot air serves to support the combustion of the coke. As the coke burns, the oxygen in the iron ore is absorbed. The charge gradually moves downward in the furnace into progressively higher temperature zones until the iron becomes molten and forms in a pool at the bottom of the furnace. The limestone absorbs the ash from the coke and some of the silicon, manganese, and sulphur from the iron ore to form a slag. The slag floats on top of the metal bath and is tapped periodically during the heat into a slag car.

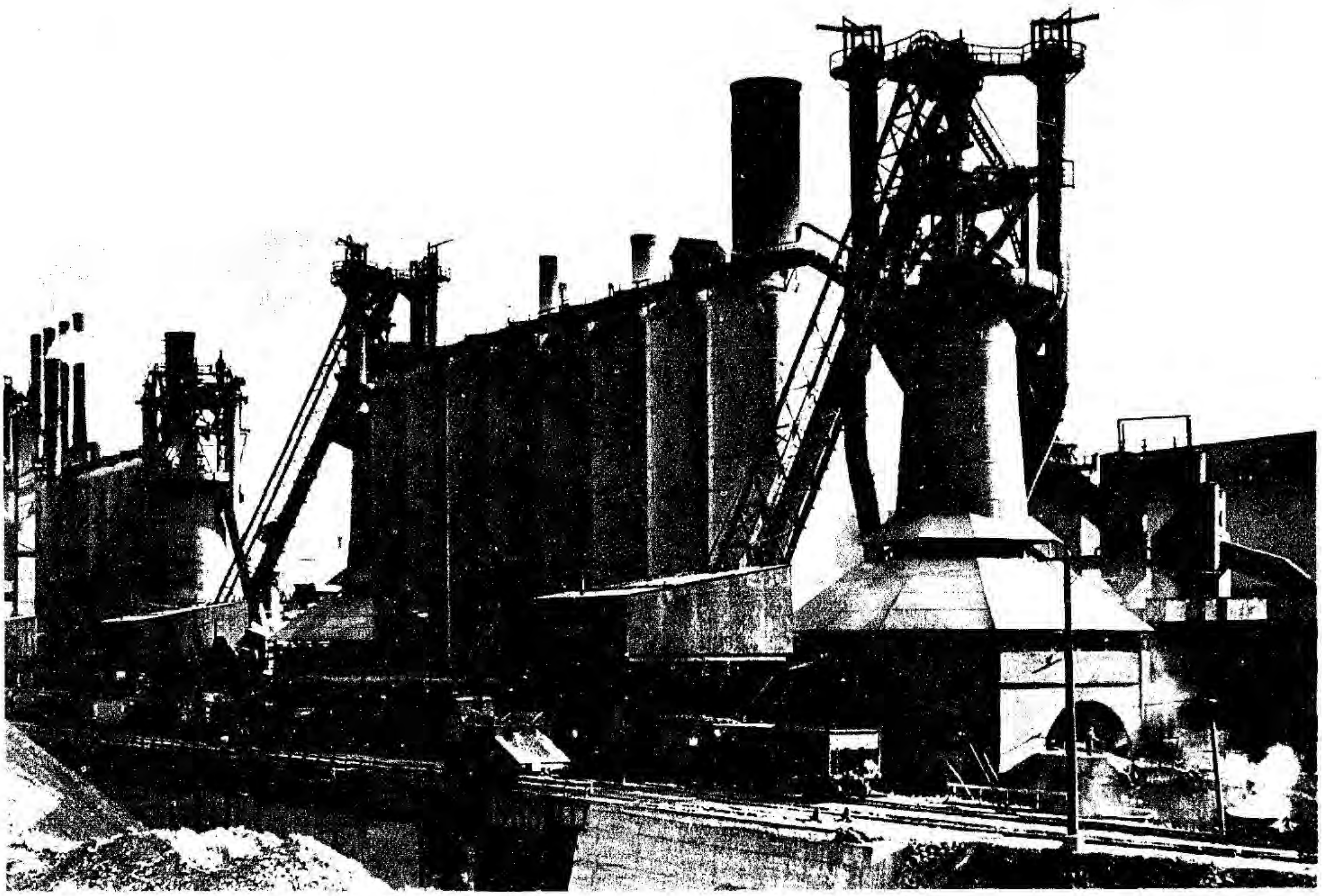


4. Diagram of Blast Furnace

The hot gases generated during the heat are filtered and fed into stoves which contain a checker-work system of brick. When the bricks in one stove have been heated sufficiently the gas is turned off and cold air is fed through the brick checkerwork. As the air passes through the checker system, it is heated and then forced into the furnace through the tuyeres.

The bricks in the stove cool after several hours and the process is reversed so that hot gas is fed into the stove. Since the smelting process must operate continuously, 3 or 4 stoves are required to supply hot air into the furnaces. While one stove is supplying the furnace with hot air, the rest are being heated. Some of the gas generated in the blast furnace may also be used as fuel for the open-hearth furnaces.

Diagram, Courtesy Inland Steel Company

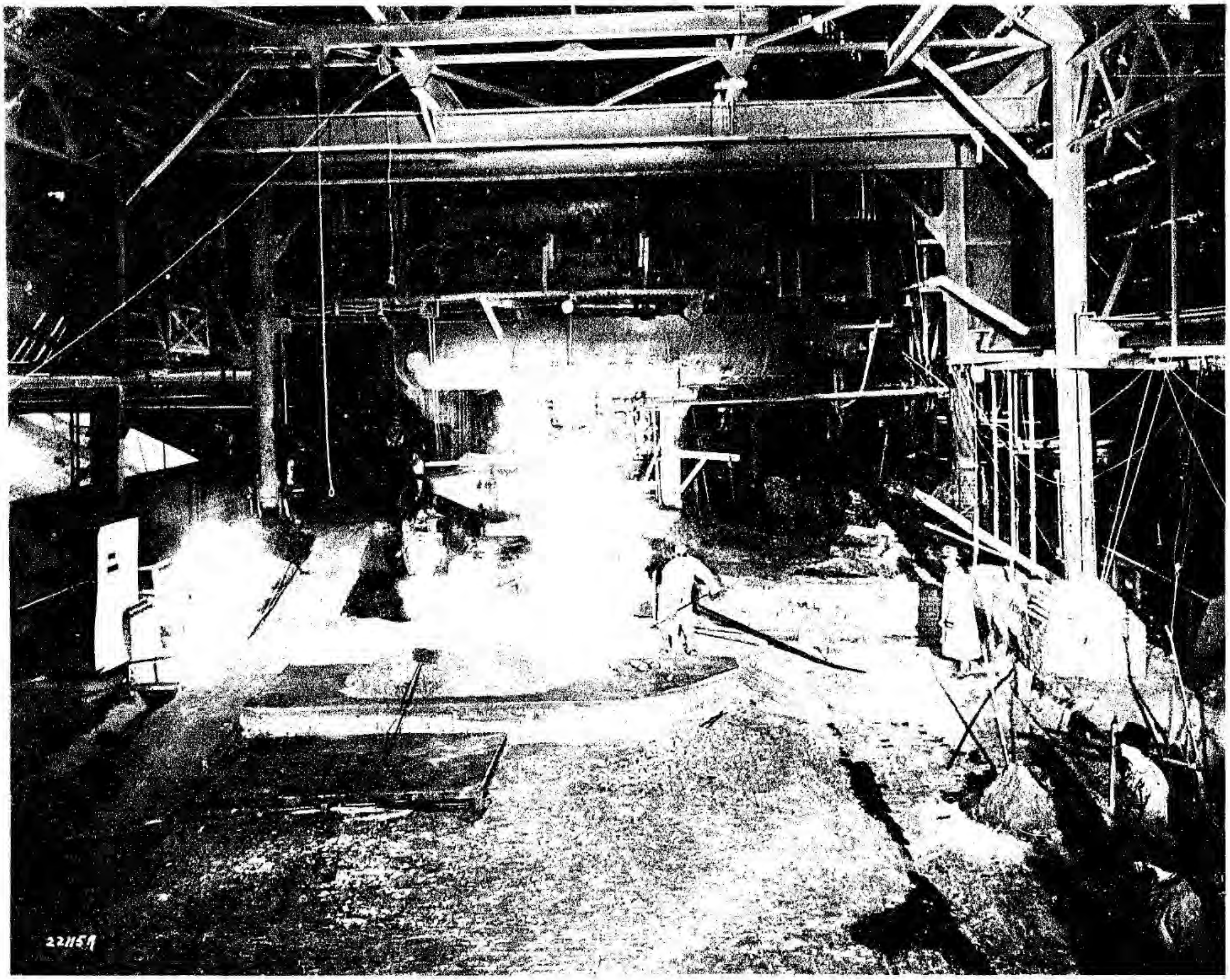


4. Blast Furnaces and Heating Stoves

The furnace is tapped every 4 to 6 hours and molten iron flows out into a big ladle. In an integrated mill the hot metal is tapped into a "thermos bottle" car for transporting directly to the open-hearth furnaces. Some metal is also cast into pigs which are sold to foundries and nonintegrated steel mills.

A blast furnace operates on a continuous basis and may run for a period of 5 to 10 years before it must be shut down to replace the brick lining in the interior. The relining work usually requires a shut-down period of about 3 months and involves a cost of $200,000 to $1,000,000.

Photo, Courtesy United States Steel Corporation



4. Tapping a Blast Furnace

A blast furnace with 3 stoves costs about $17,000,000. Output may range from less than 400 to 1,500 tons of metal a day. One ton of pig iron is produced from 1.7 tons of iron ore, 0.9 tons of coke, and 0.4 tons of limestone. A 1,300 ton blast furnace would consume daily:

26 -	90-ton railroad cars of ore
23 -	50-ton railroad cars of coke
10 -	50-ton railroad cars of limestone
6	cars of slag, scrap, etc.
65	cars

A blast furnace is manned by a foreman and a crew of 50 to 100 on each shift.

Photo, Courtesy Bethlehem Steel Company

III - MAKING STEEL

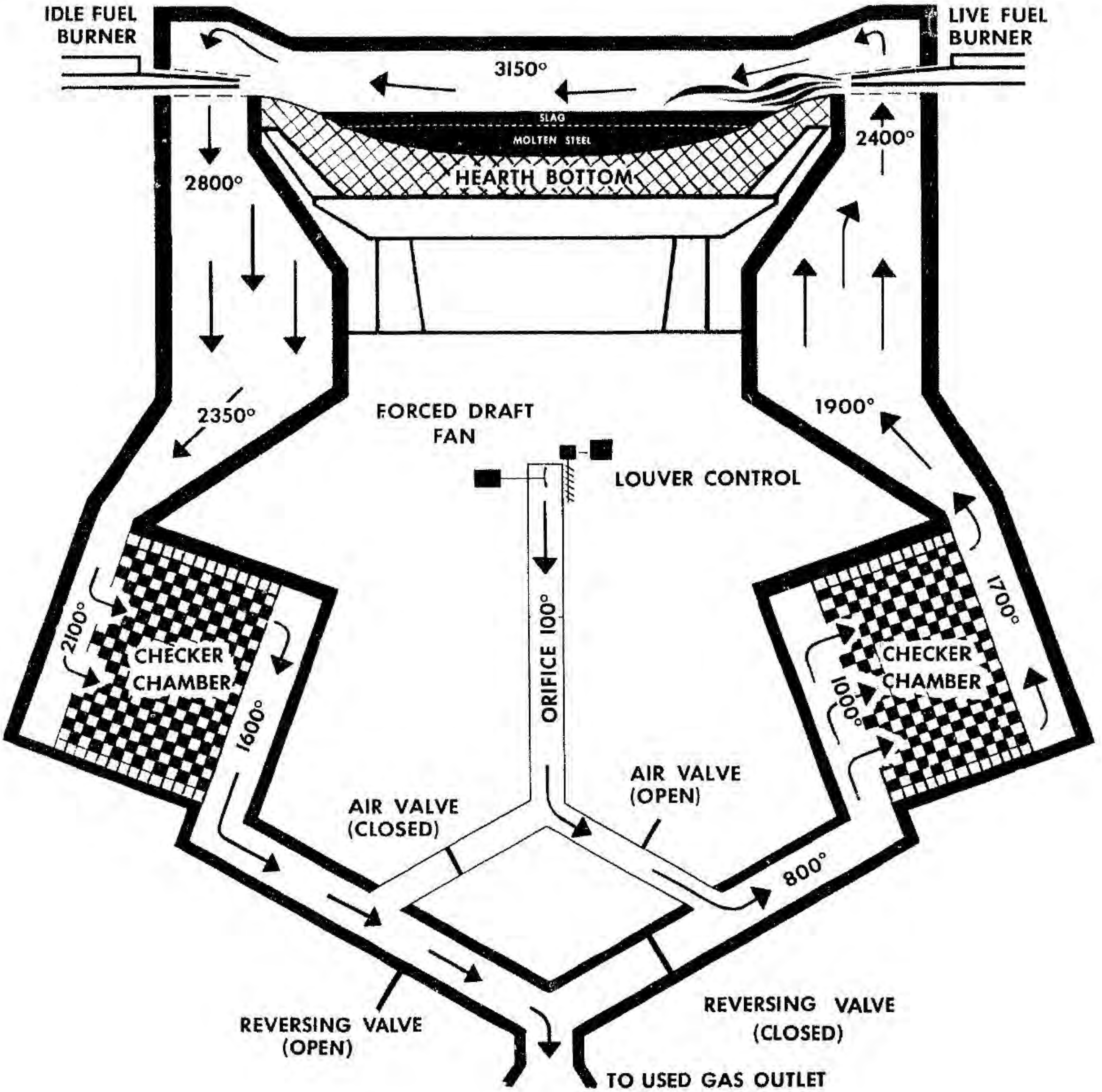
Pig iron and steel are both alloys of iron and carbon. The chief difference between them is the amount of carbon that is present in the alloy. Steel has a carbon content of less than 1.7% Approximately 92% of the steel produced in the United States is plain carbon steel, which consists solely of iron and carbon with a minimum of impurities such as sulphur, silicon, or phosphorus. Alloy steels differ from carbon steel in that controlled amounts of alloying elements such as nickel, chromium, molybdenum, and tungsten are added to give the end product special characteristics. Steel with 18% chromium and 8% nickel, for example, yields stainless steel which is used for surgical instruments and food machinery.

Steel is produced from pig iron and scrap by (1) The open hearth furnace, (2) The Bessemer converter, or (3) The electric furnace.

5. The Open Hearth Furnace: Open hearth furnaces are rectangular brick structures with a shallow, saucer-like hearth upon which the refining process takes place. Above each end of the furnace there is a burner from which a flame is swept across the hearth. Natural gas, blast furnace gas, oil, or other fuels are burned with heated air coming from the checker chambers located at each end of the furnace. The heating system for the air supply is "regenerative." While the right burner supplies the fuel, preheated air flows from the right hand checker chamber. The outgoing burnt gases flow through the left hand checker chamber heating it preparatory to reversing the flow. After 10 or 15 minutes the flow of fuel and air across the furnace is reversed and the incoming air is heated by the hot bricks in the left hand chamber. This regenerative process maintains the temperature in the furnace, speeds the cycle, and economizes on fuel consumption.

6. Charging the Open Hearth Furnace: An open hearth charge consists of limestone, iron ore, scrap, molten pig iron, and spiegeleisen. The limestone absorbs silicon, phosphorus, and sulphur and forms a slag which floats on top of the molten metal. The iron ore acts as an oxidizing agent, and along with the oxygen in the air, serves to reduce the carbon content of the pig iron to the desired level. The spiegeleisen is a deoxidizer which serves to remove the excess oxygen remaining after the reaction.

Scrap iron and steel usually account for between 45% and 55% of the open hearth furnace charge. One of the important features of the open hearth furnace is that it utilizes scrap thus reducing the molten pig iron requirements. About 50% of the scrap requirements are met by the use of "home" scrap, the end croppings from ingots, billets, and other rolled products. The remaining 50% of the scrap requirements are met through purchased scrap which is obtained from dealers who accumulate and sort scrap from various sources. There are 75 classifications of scrap which differentiate it according



5. Diagram of Open Hearth Furnace

to chemical content, size, and cleanliness. The price of scrap varies according to location of the markets and local supply-demand conditions. As scrap prices increase, there is a tendency to reduce the scrap charge in the furnaces and to increase the molten pig iron charge. The reverse tendency exists as scrap prices decline.

The solid materials, limestone, iron ore, and scrap are charged into the furnace first. Predetermined quantities of these materials are delivered to the furnaces in steel charging boxes on flat cars. A charging machine running the length of the open hearth floor picks up each box with a long steel arm. The box is inserted into the furnace, its contents are emptied, and the empty box is replaced on the flat car. After the solid materials have been charged, the heating

Diagram, Courtesy Inland Steel Company

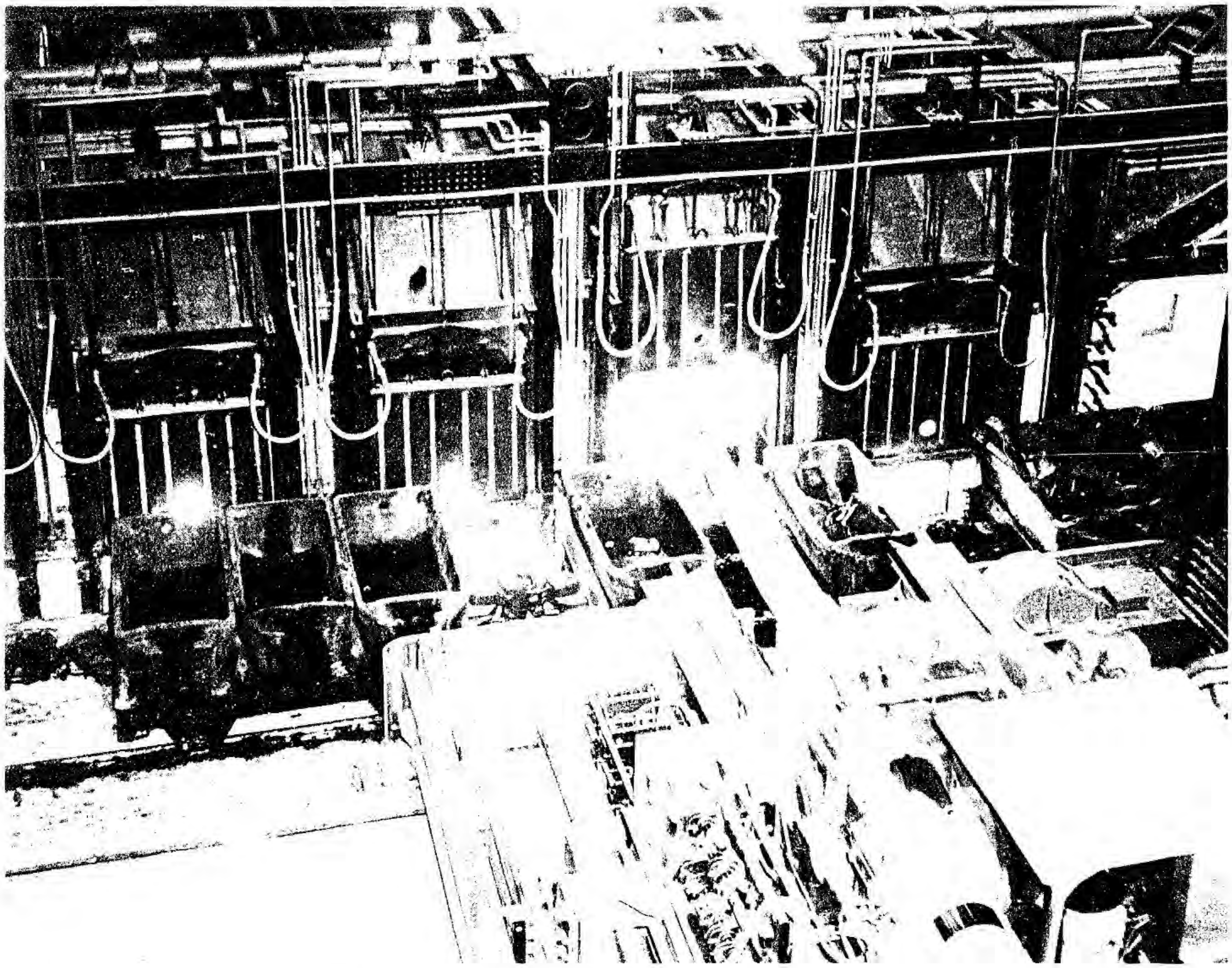
6. Charging Molten Pig Iron to the Open Hearth

process begins and the materials melt in about 2 hours. The molten pig iron is then poured into the furnace from a ladle.

During the refining process, periodic samples of the heat are taken and analyzed to determine whether quality specifications are being met. Adjustments are made during the heat to compensate for deviations from specifications. In addition, periodic temperature checks are made with a pyrometer as another step in quality control. A heat is completed in from 8 to 12 hours. A furnace charge consists of approximately 7% limestone, 4% iron ore, 44% scrap, and 45% molten pig iron. One ton of charging materials yields about 0.9 tons of steel.

<u>7. Tapping the Open Hearth Furnace</u>: Upon completion of a heat, the open hearth furnace is tapped. The clay that seals the tapping hole is bored and burned away. The molten metal flows into a tapping ladle which is stationed below the furnace. The slag floats on top of the molten steel and overflows into slag pots which are located on the floor below the ladle. About 5 to 10 minutes are required to complete the tapping of an open hearth furnace.

Photo, Courtesy United States Steel Corporation

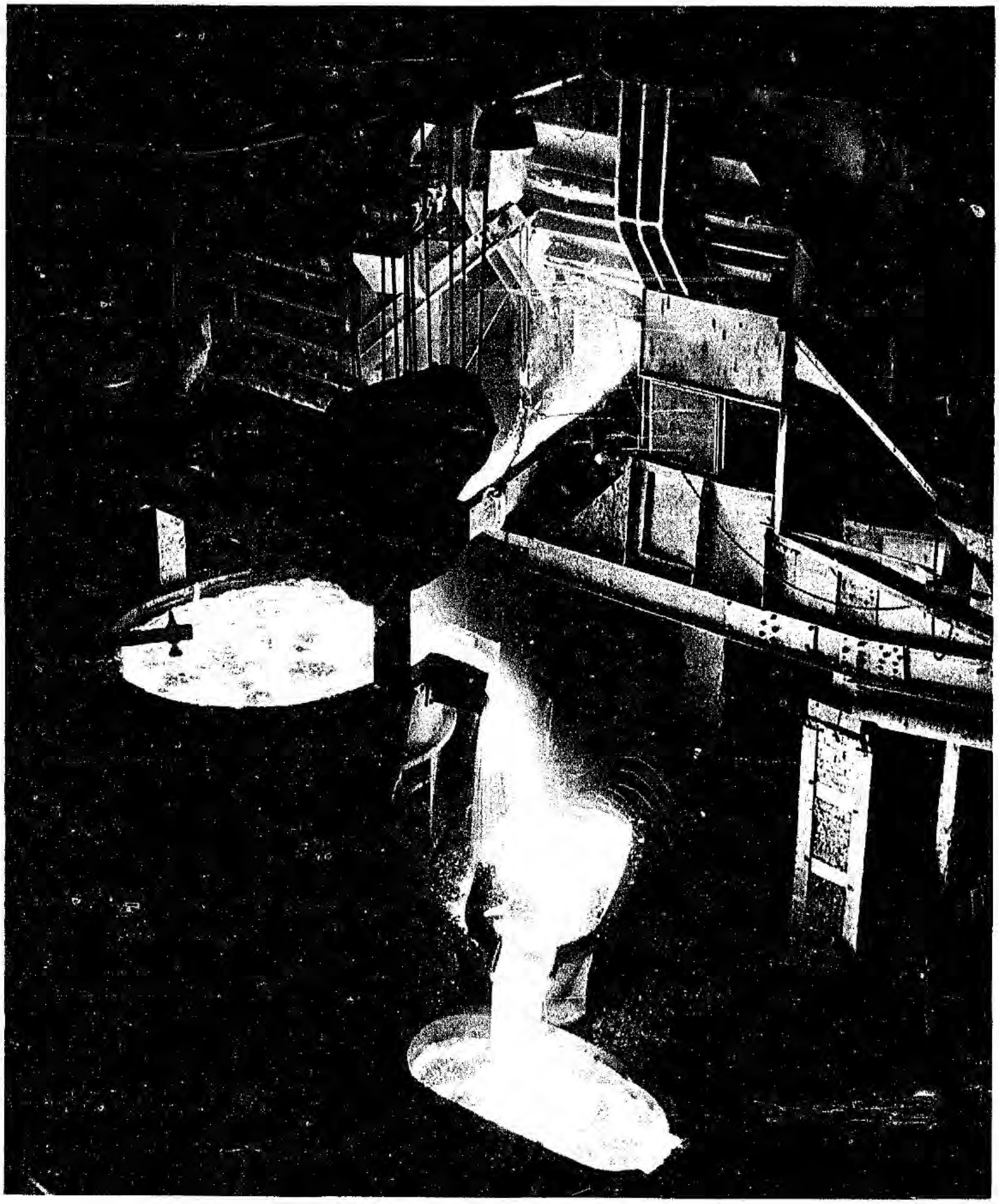


6. Charging Scrap to the Open Hearth

An open hearth department in a steel mill usually consists of between 6 and 14 furnaces. Most modern furnaces produce between 150 and 275 tons of steel per heat; the world's largest furnace turns out 550 tons per heat. At current prices a single furnace costs about $6,000,000 and has a normal operating life of 25 years. Open hearth furnaces generally operate on three shifts a day at full capacity. Every 60 to 180 heats, the furnace roof must be relined with brick. Front walls must be replaced every 85 to 125 heats; end walls, after 450-550 heats.

About 90% of the steel produced in the United States is made by the open hearth process. The predominant position of the open hearth process results from two factors: (1) its flexibility with regard to fuels and charging materials, and (2) its convenience for quality control. Fuels which can be used to fire open hearth furnaces include natural gas, producer gas, coke oven gas, oil, or blast furnace

Photo, Courtesy United States Steel Corporation

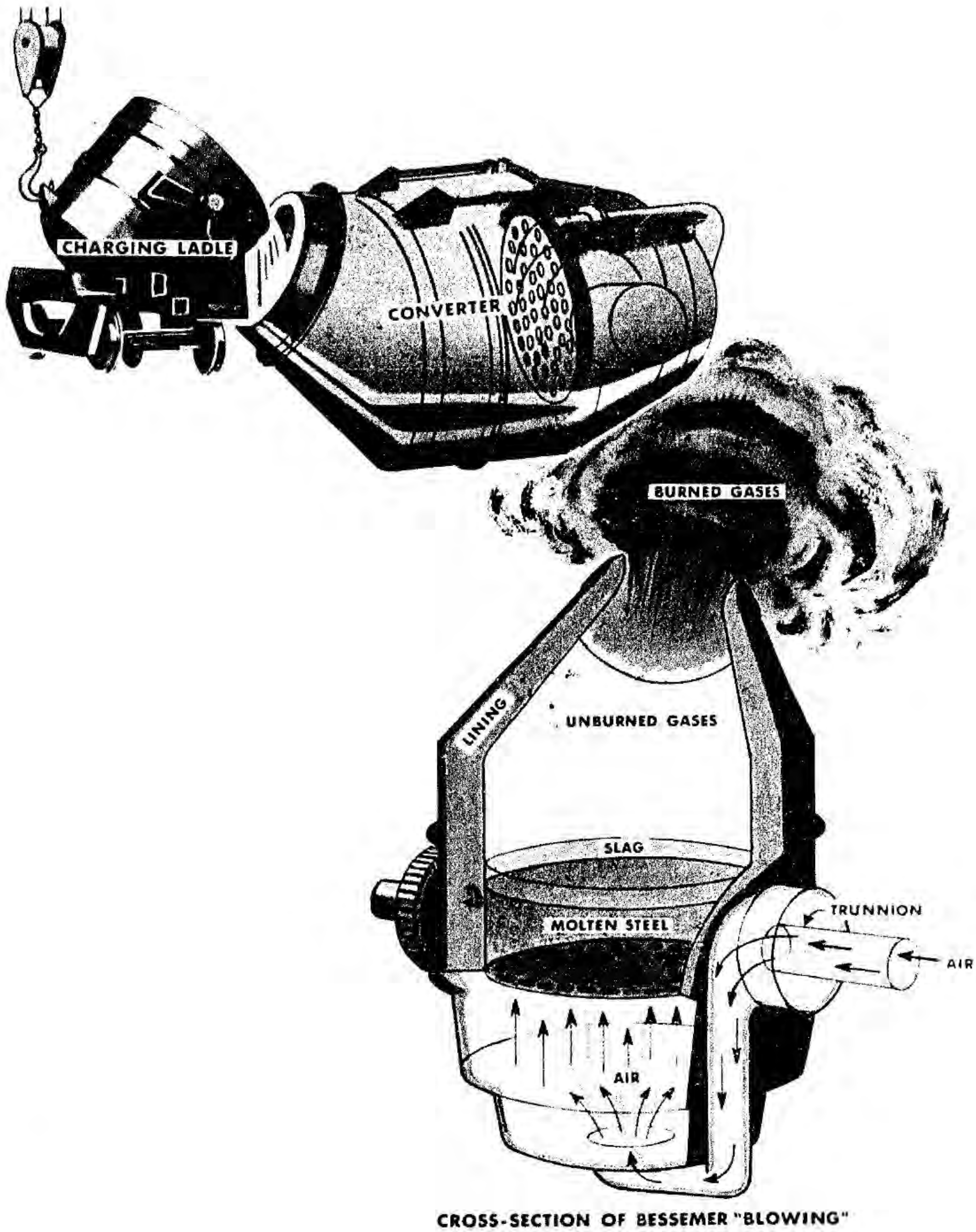


7. Tapping the Open Hearth

gas. The metal charge to the furnace can contain as much as 75% scrap or as little as 25% scrap depending on the relative price of scrap vs. pig iron. The open hearth furnace facilitates quality control because the cycle is sufficiently long to permit periodic sampling and interim analysis of the heat.

A bank of 6 open hearth furnaces is manned by a "melter" and 18 helpers. The melter supervises the charging, tapping, and maintenance of the furnaces. An open hearth "first helper" receives about $2.50 per hour.

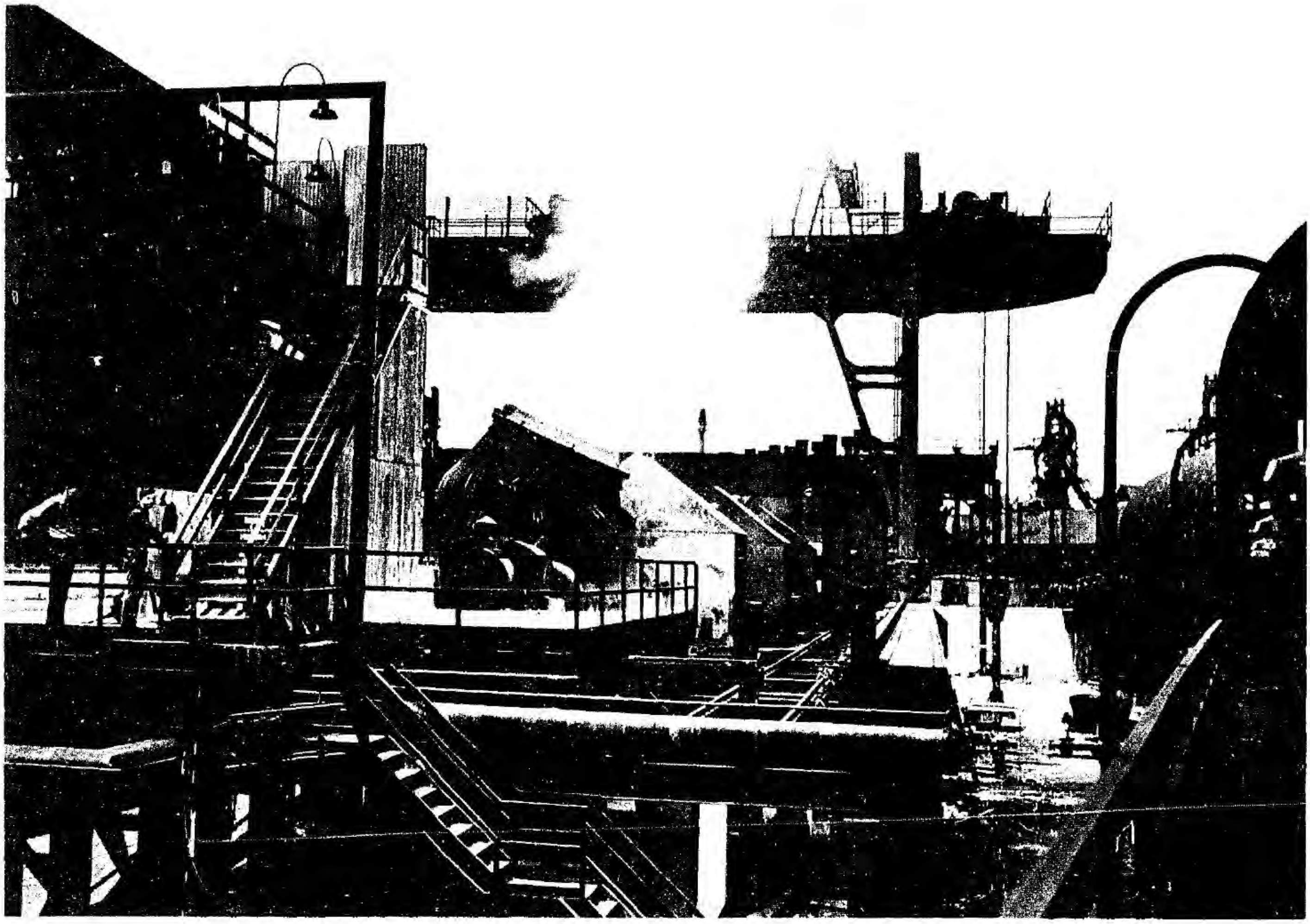
Photo, Courtesy United States Steel Corporation



8. Charging and Blowing a Bessemer Converter

8. The Bessemer Converter: The Bessemer converter is a pear shaped vessel which usually has a capacity of from 5 to 25 tons of steel. Molten pig iron is refined in the Bessemer process by blasting cold air through the metal. The Bessemer converter is lined with refractory brick and its bottom is perforated to admit the blast of air. Cold air is supplied at 20 to 30 pounds per square inch from blowing engines. The engines are connected with the air jets by a line which passes through the hollow trunion supporting the converter.

Diagram, Courtesy American Iron and Steel Institute



8. Blowing a Bessemer Converter

In operation, the converter is tipped over into a horizontal position to receive its charge of molten pig iron. The molten metal cannot clog the air holes or "tuyeres" at the bottom of the converter while it is in the horizontal position. The blast of cold air is turned on as the converter is rotated to an upright position. The oxygen in the air combines with silicon and manganese to form a slag and with carbon to form carbon monoxide, which passes off as a gas. The chemical reaction during the process generates sufficient heat to keep the metal in a molten state.

In 12 to 18 minutes the blow is completed, the blast of air is shut off, and the converter is tilted to a pouring position. The steel flows into a ladle from under a blanket of slag which remains in the converter until the pouring is completed. The converter is then turned upside down and the slag flows into cinder cars. Alloying elements are added to the molten metal while it is in the ladle.

The Bessemer process for making steel is fast. One converter can produce about 830 tons of steel a day. The refractory lined bottom must be replaced about every 20 heats or "blows." The

Photo, Courtesy United States Steel Corporation

whole converter must be relined every 625 to 675 blows. The crew operating a Bessemer converter consists of a "blower" and a small group of helpers. The blower supervises the operations and receives about $2.56 an hour.

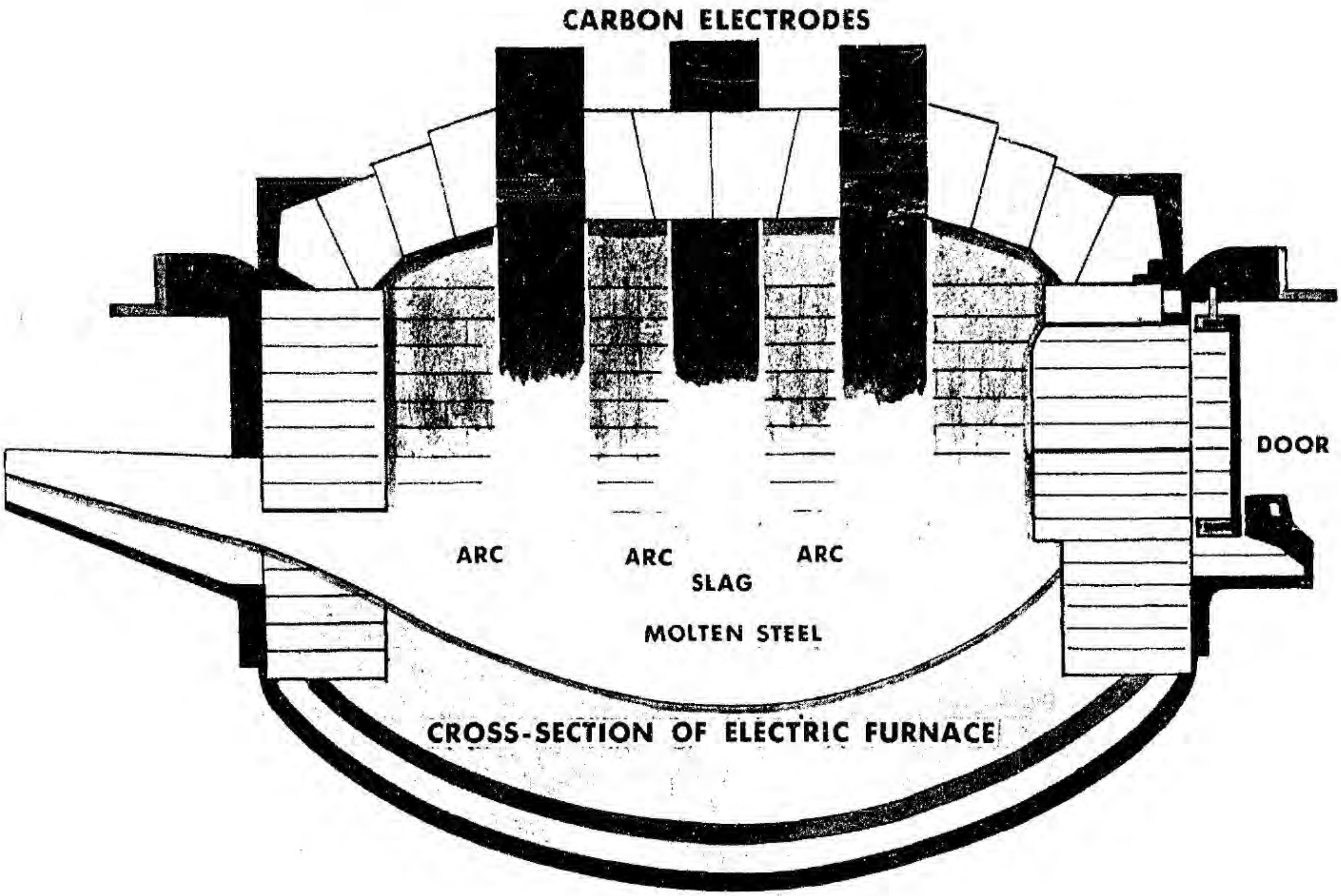
Despite its speedy cycle, the Bessemer converter has been diminishing in importance in steel making for several reasons: (1) The process does not remove phosphorus and sulphur, and thus necessitates the use of scarce ores with a low content of these elements; (2) The Bessemer process is relatively inflexible since its charge must consist almost entirely of molten pig iron; (3) The sampling of a heat and adjustment of the charge content is not possible during the "blow" and hence precise control of the chemical content is difficult.

To combine the advantages of speed in the Bessemer process with the quality control features in the open hearth process, the technique of "duplexing" has developed. In duplexing, molten Bessemer steel is used as a raw material in the open hearth charge. The use of Bessemer steel in the charge makes it possible to reduce the open hearth cycle by about 25%. Nearly 25% of the Bessemer steel produced at the present time is charged into open hearth furnaces.

9. The Electric Furnace: The electric furnace is used primarily for the production of high alloy steels. The shape of the electric furnace resembles a tea kettle. It consists of a cylindrical steel shell with a domed top and is lined with refractory brick. It is mounted on rockers so that the furnace can be tilted to pour steel and slag through a spout. Three electrodes which carry electric current to the charge protrude through holes in the top of the furnace.

The electric furnace is charged with steel scrap through doors on the side of the furnace. The electrodes are lowered to within an inch of the charge, and current passes from one electrode to another through the metal. The current produces a temperature in the arcs in excess of 3000°F. The current applied may amount to 12,000 amperes at 140 volts during the melting period. The scrap charge becomes molten and is constantly circulated since the metal immediately under the electrodes is hotter than the metal near the walls of the furnace.

Scrap steel is refined in the electric furnace in two stages. In the first stage iron ore is added to the charge to remove manganese and phosphorus and to reduce the carbon content. A slag is formed during this first part of the process which floats on top of the metal bath and may be skimmed off with wooden rakes. In the second stage of the process other compounds are added which absorb remaining impurities into a second slag. The proper alloying metals are added and periodic samples of the melt are analyzed to determine the quantities of materials required to produce to the exact specifications desired in the steel. The heat is then tapped by tilting the furnace; the slag is prevented from flowing by a skimmer on the furnace spout.



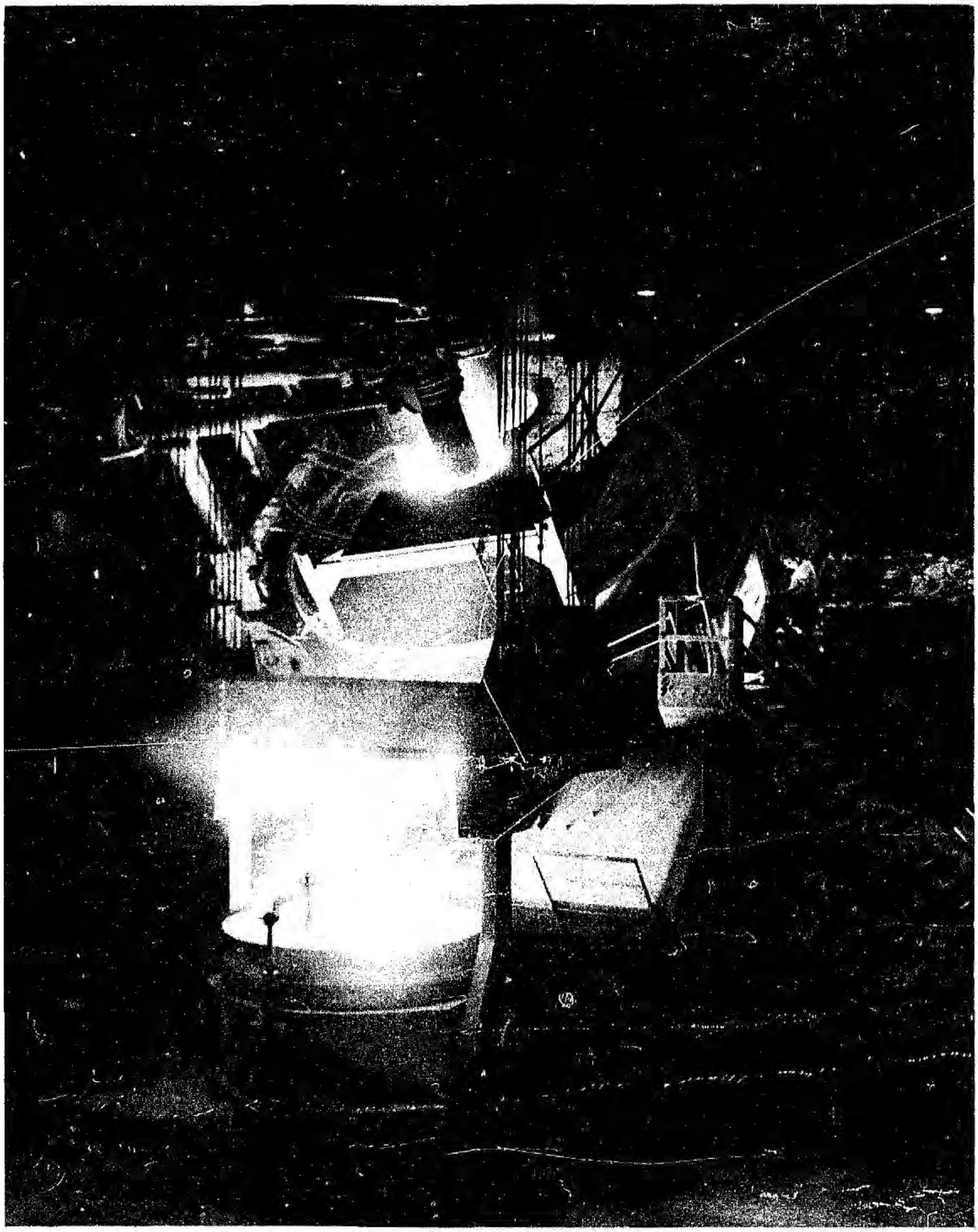
9. Cross-Section of an Electric Furnace

Electric furnaces have a capacity ranging from 5 to 75 tons per heat. The cycle for an 8 1/2 ton heat is 5 3/4 hours with a cold charge and about 4 hours with a molten charge. Operating 24 hours a day, an electric furnace can produce from 60 to 90 tons of steel. An electric furnace of 25-ton capacity costs about $3,250,000. The roof must be relined about every 50 heats and the sidewalls about every 250 heats.

A bank of electric furnaces is manned by a melter and two helpers per furnace. In addition to supervising the operations, the melter determines the quantities of alloys to be added to the steel. The helpers operate the furnaces and make minor repairs.

The electric furnace as a steel process has several advantages over the other processes: (1) higher temperatures can be attained and controlled more accurately; (2) more exact product specifications can be achieved since the oxygen entering the process

Diagram, Courtesy American Iron and Steel Institute

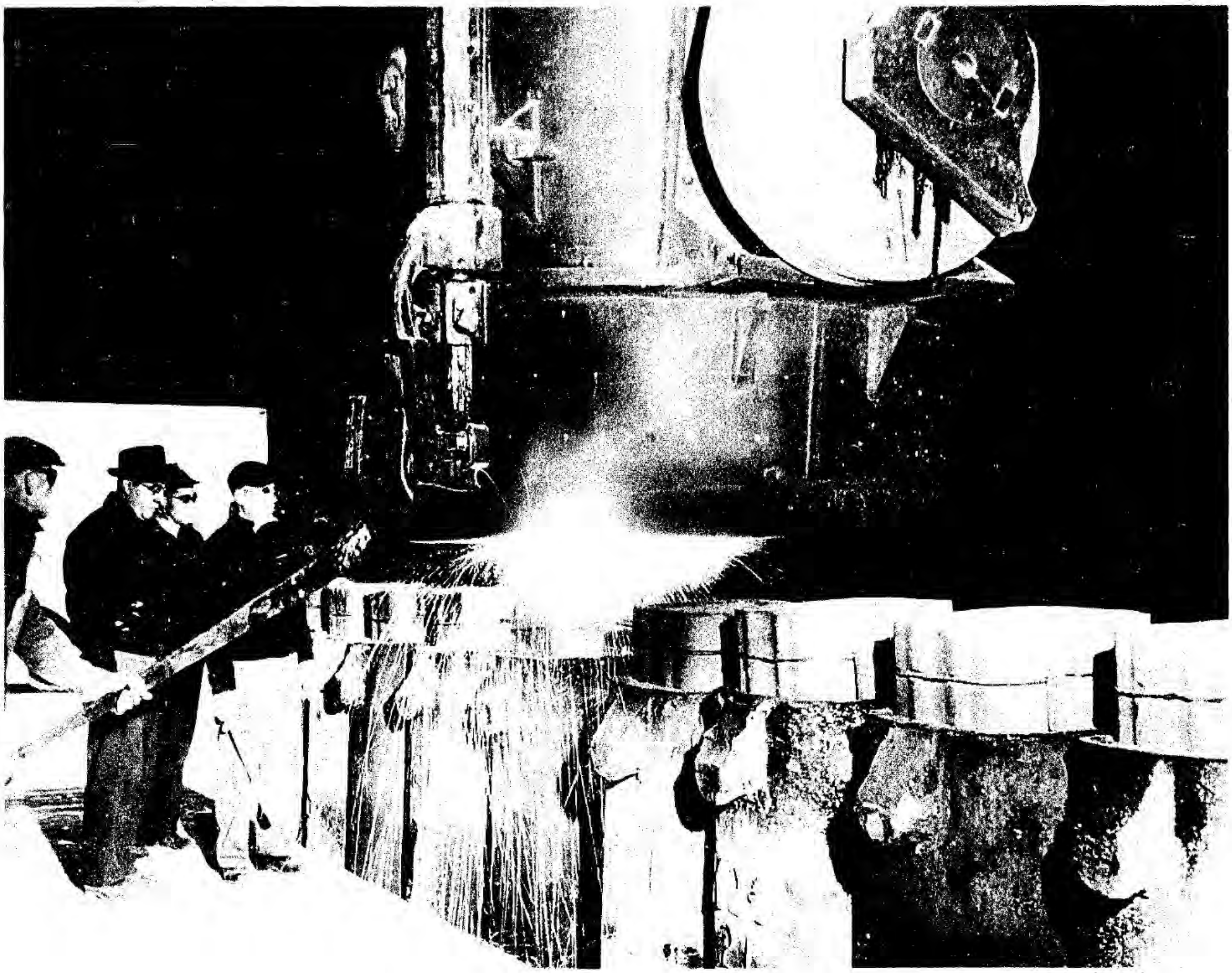


9. Tapping an Electric Furnace

is controlled to prevent the formation of harmful oxides in the finished product; (3) the loss of costly alloying elements by oxidation is minimized.

The disadvantages of the electric furnace process are first, it requires a large amount of expensive electric energy, and second, the productive capacity of electric furnaces is relatively low.

Photo, Courtesy United States Steel Corporation



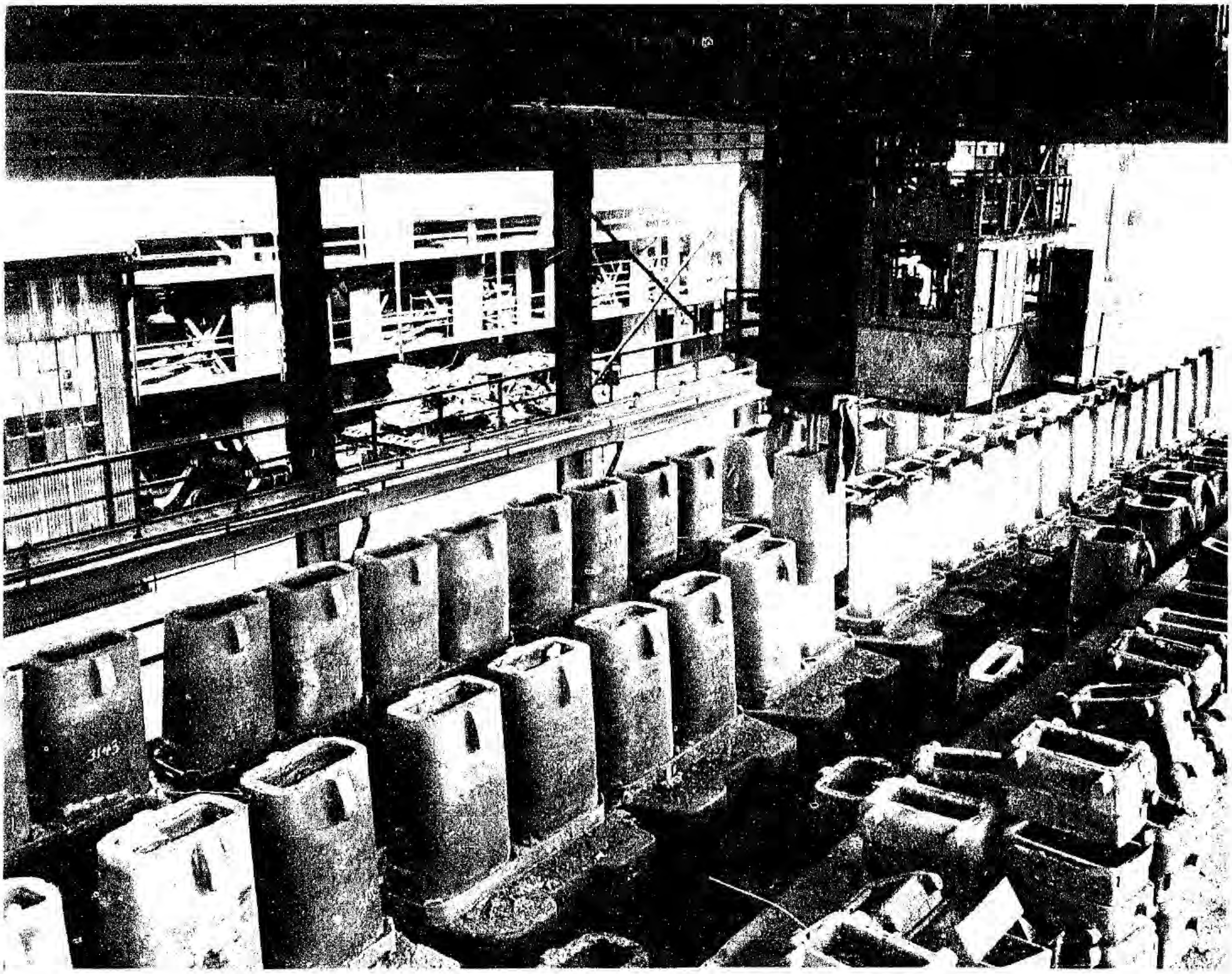
10. Teeming Steel into Ingot Molds

10. Teeming Ingots: Steel tapped from the steel-making furnaces is in a molten state. Before further processing takes place, it must be solidified into ingot form suitable for the semifinishing operations. In the "teeming" operation, steel is cast into ingots which range in size from 5 to 25 tons for open hearth steel and from 1 to 5 tons for Bessemer and electric furnace steel.

The molten steel is tapped from the furnaces into a refractory-lined ladle which may have a capacity of as much as 225 tons. The ladle has a controllable spout in the bottom so that the steel can be drawn off free of slag. The ladle is carried by a crane to a line of molds on flat cars which are placed near the steelmaking furnaces. The ladle passes over each mold, filling it with molten steel.

Ingot molds are made of cast iron, with lugs on the sides for engagement by stripper cranes. Preparatory to teeming,

Photo, Courtesy United States Steel Corporation



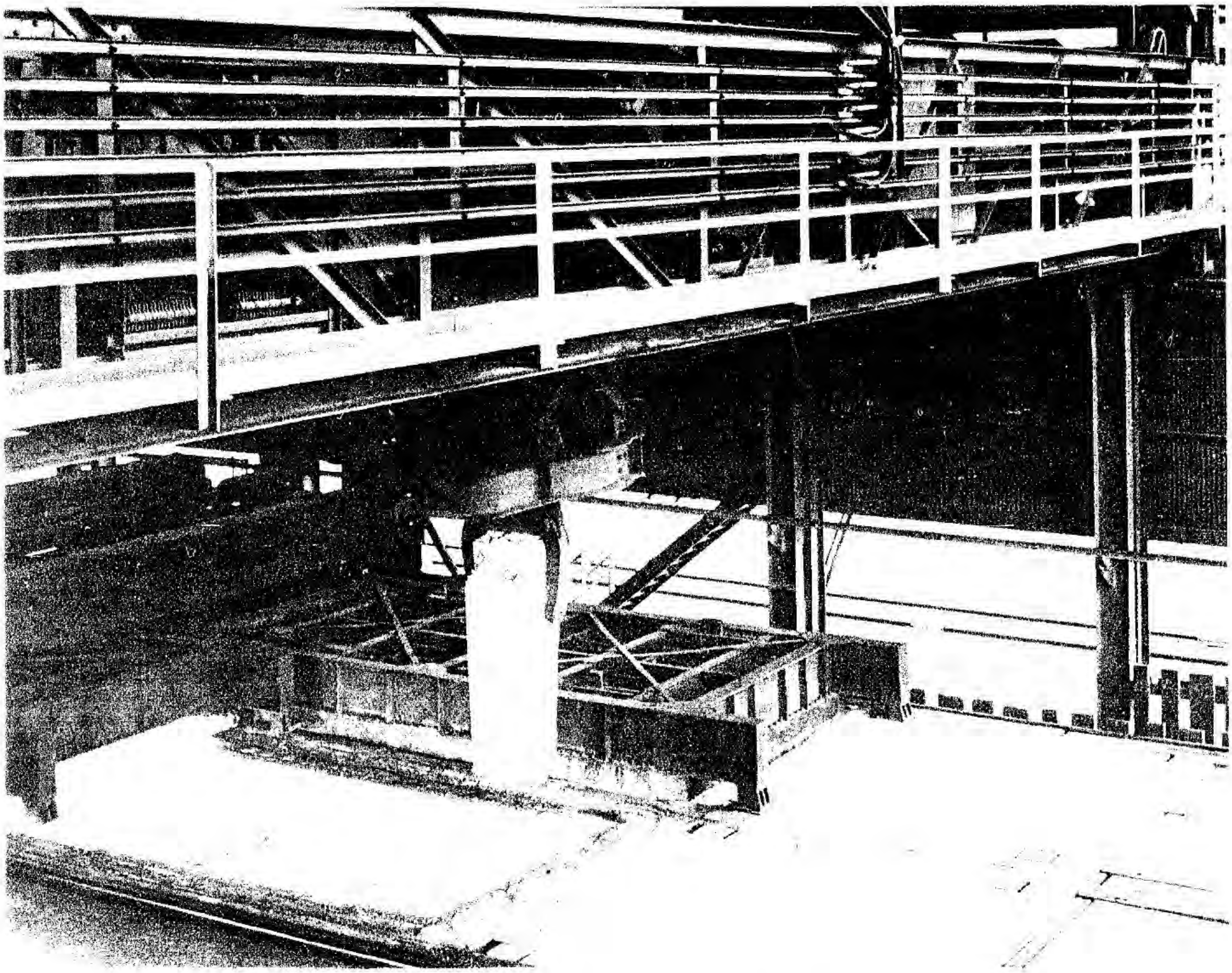
11. Stripping Molds From a Line of Ingots

the molds are preheated and coated with tar, creosote, or soot to facilitate the subsequent stripping operation. A typical mold can be used for casting only about 65 ingots after which it is scrapped.

To improve the surface finish of high quality steel products, the technique of "bottom pouring" is often employed in teeming. The ingot mold is filled from the bottom with a runner guiding the flow of molten steel. Bottom pouring prevents the steel from splashing against the side of the mold as it does during the conventional teeming process.

11. Stripping: The steel is allowed to cool in the ingot molds for approximately one hour during which time it solidifies and shrinks sufficiently to permit stripping. An "ingot stripper" engages the lugs on the sides of the mold while a plunger between the jaws of the stripper holds the ingot down until the mold is pulled free. The molds are stripped as soon after teeming as possible in order to keep to a mini-

Photo, Courtesy Armco Steel Corporation



12. Ingot Being Lifted From a Soaking Pit

mum the time required to heat the ingots back up to rolling temperatures.

12. Soaking Pits: A certain loss of heat after teeming cannot be avoided and it is therefore necessary to heat the ingots to proper rolling temperatures. The heating takes place in the soaking pit which is a gas-or-oil-fired floor furnace. The soaking pit is usually equipped with automatic regulators which control temperatures, pressures, and fuel-air ratios. Overhead cranes carry the stripped ingots and lower them into the pit. The ingots remain in the pit for 4 to 6 hours at temperatures of about 2200° F. Soaking time varies depending on the size of the ingots and their temperatures upon being placed into the pit. During the soaking time, all parts of the ingot are brought to a uniform temperature.

Soaking pits can usually hold 4 to 8 ingots. The construction cost of a new soaking pit amounts to about $200,000.

Photo, Courtesy Bethlehem Steel Company

IV - SEMIFINISHING

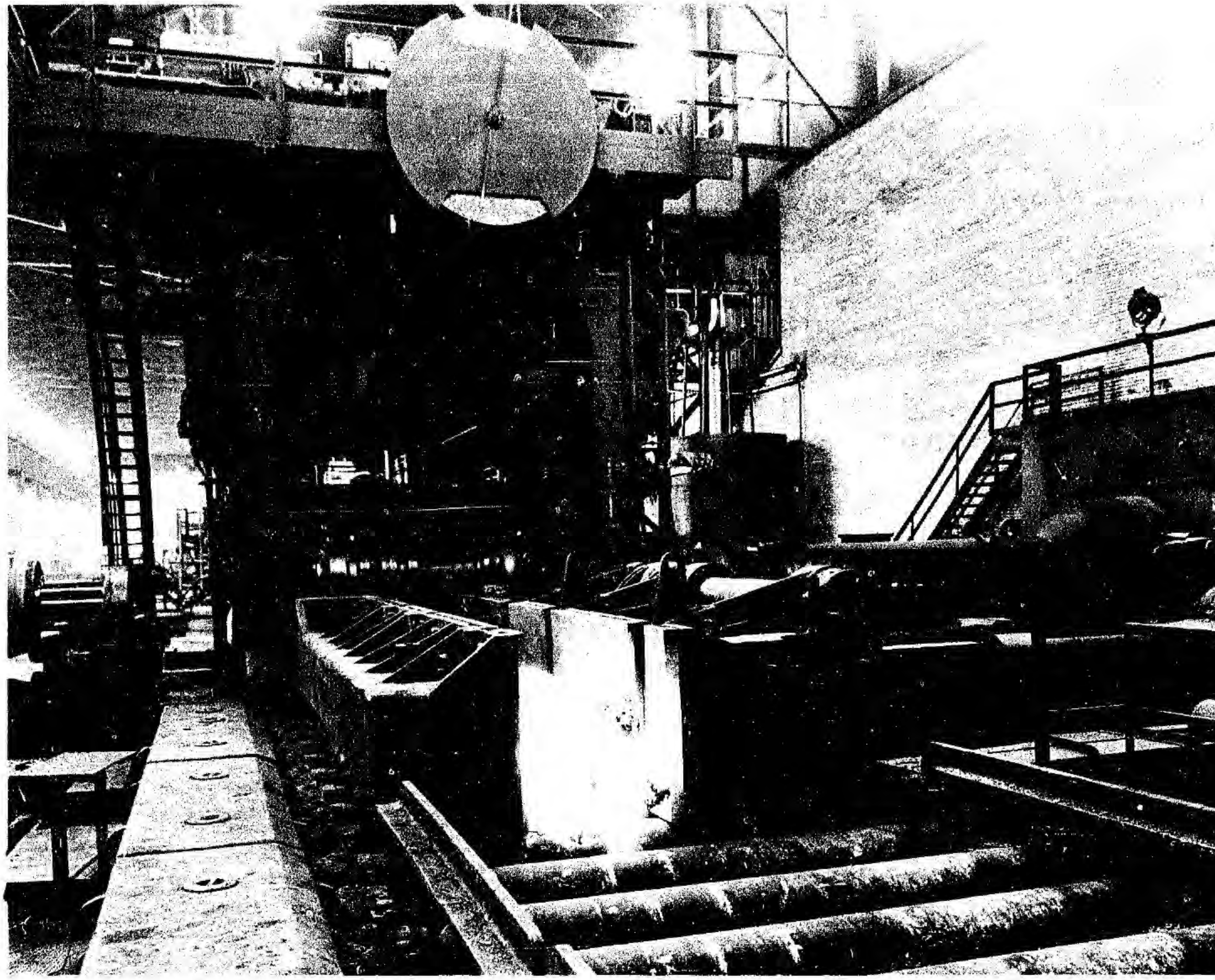
In the semifinishing operations ingots are reduced to more convenient shapes for final working. The semifinishing operations also have important effects on the physical properties of the steel. Ductility especially is improved by the elimination of cavities and the breakdown of coarse crystal formations. The two most common semifinishing operations are forging and rolling. In the following paragraphs the major steps in the rolling process will be described.

Semifinishing mills are classified both as to construction and product. The terms two-high, three-high, and four-high are used to designate the number of rolls in each stand. A two-high mill consists of two working rolls between which the steel is passed. A three-high mill has three working rolls; the steel is worked back and forth in such a mill, passing in one direction through the lower and middle rolls and in the other direction through the middle and upper rolls. A four-high mill consists of two working rolls supported by two backing-up rolls which serve to keep the working rolls from bending as the metal passes through them. The two-high and four-high mills may run continuously in one direction or be reversed to permit the steel to be worked back and forth in several passes.

The terms blooming, billet, and slabbing mill are used to refer to the semifinished products which the mill rolls. A bloom is square or rectangular in cross-section with an area 36 square inches or more. A similarly shaped product with a cross-sectional area of 2 1/4 to 36 inches is a billet. A slab is not limited as to cross-sectional area. Shapes in either the bloom or billet cross-sectional area range are termed slabs if their width equals or exceeds twice their thickness. A blooming mill may also be used to produce billets and slabs. In most cases, however, these products are turned out on specialized billet or slabbing mills.

13. Blooming Mill: The blooming mill is used to reduce ingots to blooms. The most common blooming mill is a single two-high reversing stand. The ingot may be passed back and forth between the rollers as many as 20 times before the desired size and shape is attained. The first pass through the mill breaks the oxide scale on the ingots which is created by the action of oxygen in the air on the hot metal. Water at high pressure is directed against the ingot to flush the scale off and thus prevent it from being pressed into the steel in the rolling processes.

A "roller" and his assistants in a "pulpit" overlooking the mill control the speed and direction of the rolls, the space between the rolls, and the manipulators which turn the ingots between passes. The roller constantly must balance temperature of ingot against speed and amount of reduction per mill pass. If the ingot temperature is too high, many of the improvements in physical properties due to hot working are lost. If the temperature is too low for the rate of reduction



13. Ingot About to Enter a 54" Blooming Mill

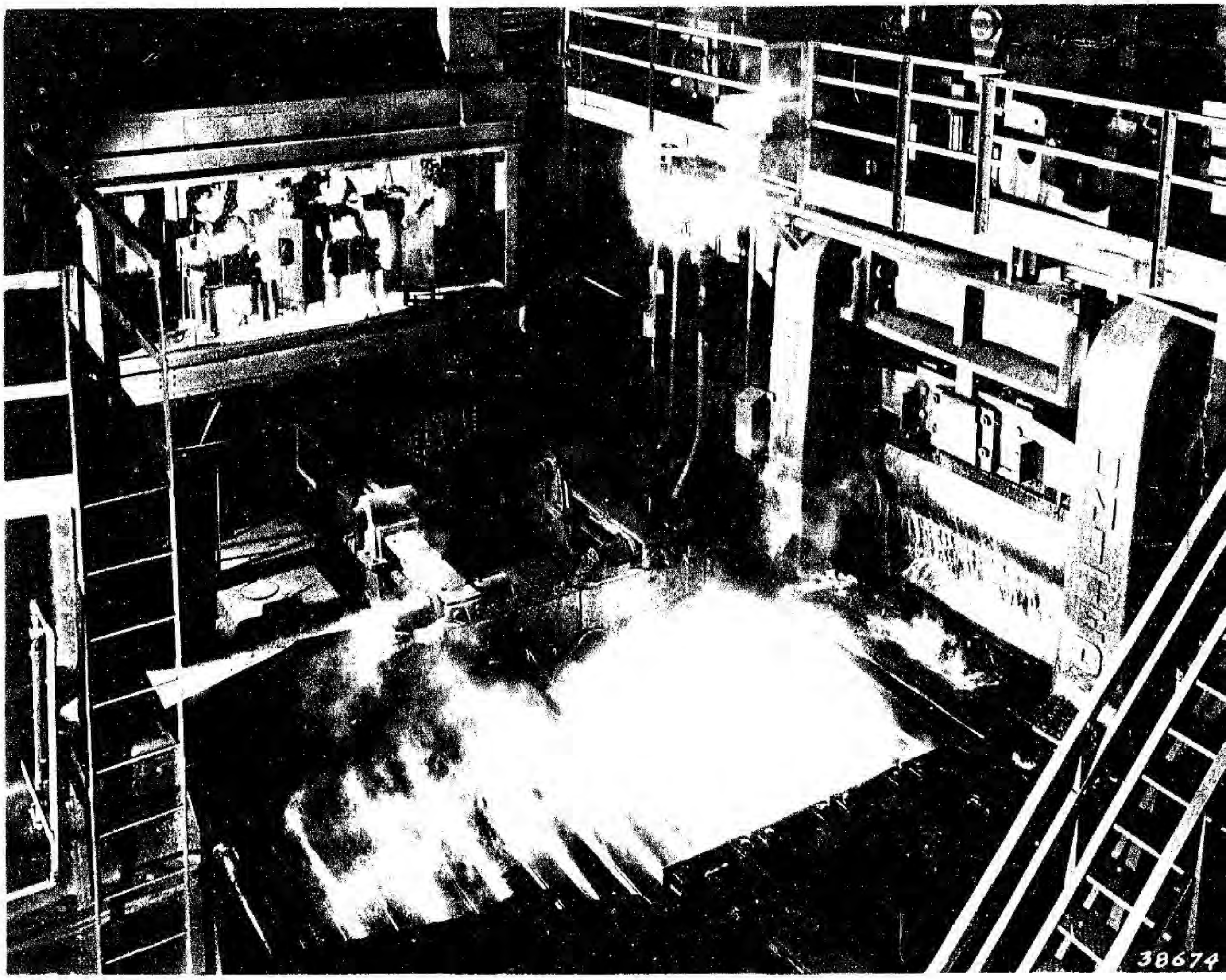
used, the resulting high resistance to deformation may break the rolls. Rollers received about $2.61 per hour in 1950.

In a three-high blooming mill the top and bottom rolls turn in the same direction and the middle roll turns in the opposite direction. The ingot may thus be passed back and forth through the stand without changing the direction of rotation of the rolls; tables at each side of the stand are raised and lowered so that the bloom alternately passes between the top and bottom pair of rolls.

A large two-high blooming mill might be powered by a 7,000 h.p. electric motor, have rolls 46 inches in diameter, and be capable of rolling slabs up to 52 inches in width. Such a mill, including auxiliary equipment, requires an investment of about $10,000,000.

14. Billet Mill: The billet mill follows the blooming mill in the sequence of operations and reduces blooms to billets. A billet mill may consist of a single three-high stand or of a series of two-high stands set in tandem, called a continuous mill. In the three-high stand the bloom is

Photo, Courtesy United States Steel Corporation

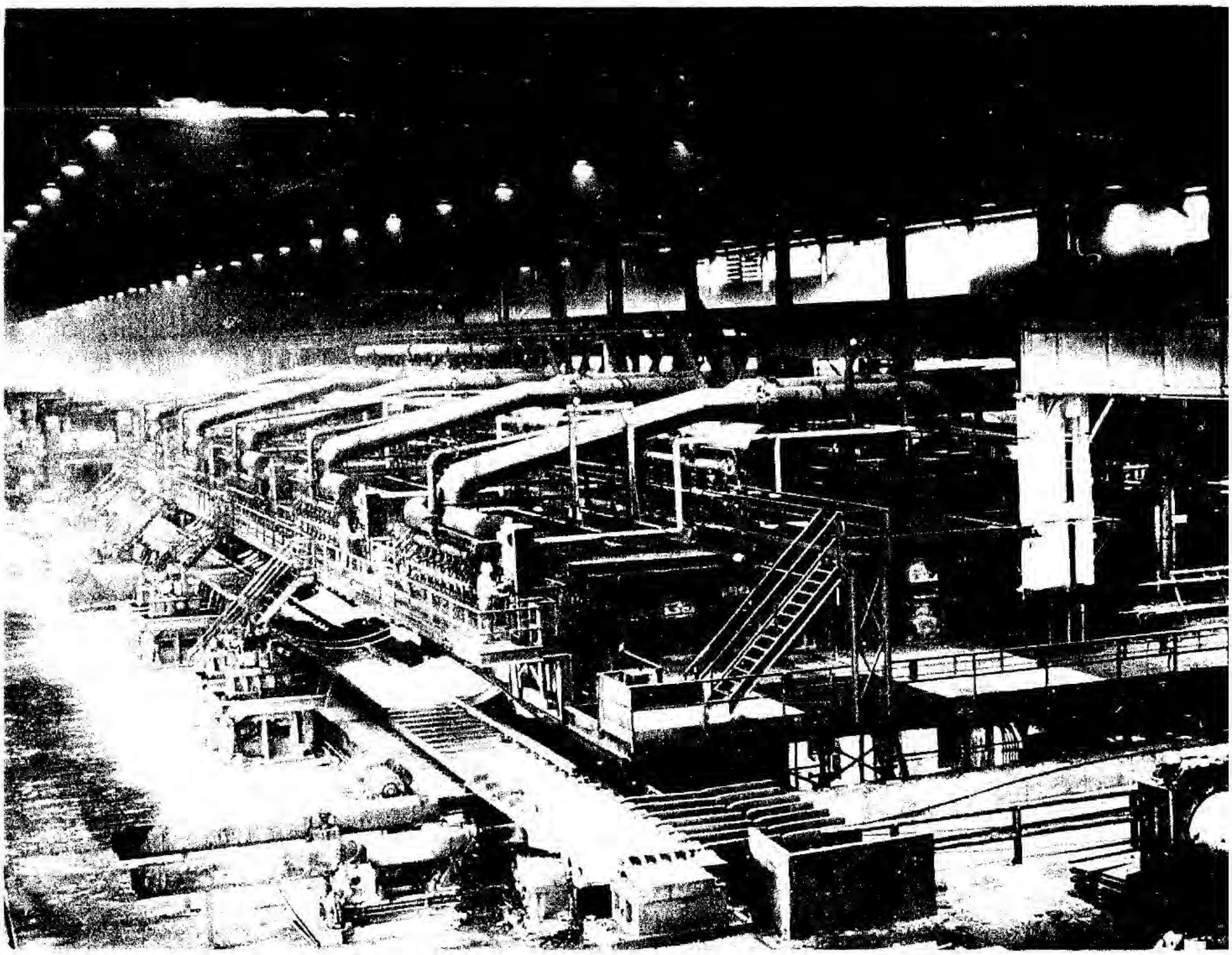


15. Slabbing Mill and Control Pulpit

worked back and forth in the manner described above for the three-high blooming mill. In the continuous mill the steel moves from stand to stand and the necessity for reversal of motion or adjustment of roll clearance between passes is eliminated. A typical continuous billet mill has 10 stands, with the bloom entering the first at a speed of about one-half mile per hour and leaving the last at nearly 5 miles per hour.

15. Slabbing Mill: The slabbing mill is used to reduce ingots to slabs. A slabbing mill consists of a single two-high or four-high stand of rolls. In either the two-high or four-high stand the ingot is passed back and forth between the rolls until the desired reduction in size is accomplished. In the four-high stand only two of the rolls make contact with the ingot. These are known as the "working" rolls and may be of smaller diameter than would be the rolls of a comparable two-high mill. The decrease in size lessens the power required to make a given reduction in steel thickness per pass and makes possible a better working of the steel. The "backup" rolls are of larger diameter than the working rolls and are not power driven.

Photo, Courtesy Armco Steel Corporation



17. Slab-Heating Furnaces

16. Cropping and Inspecting: Since the bottoms and tops of the ingots do not produce good steel, the ends of the semifinished shapes must be cropped by shears after rolling. The pieces are then inspected for imperfections. Seams, slivers, and scabs are removed by chipping, grinding and burning operations.

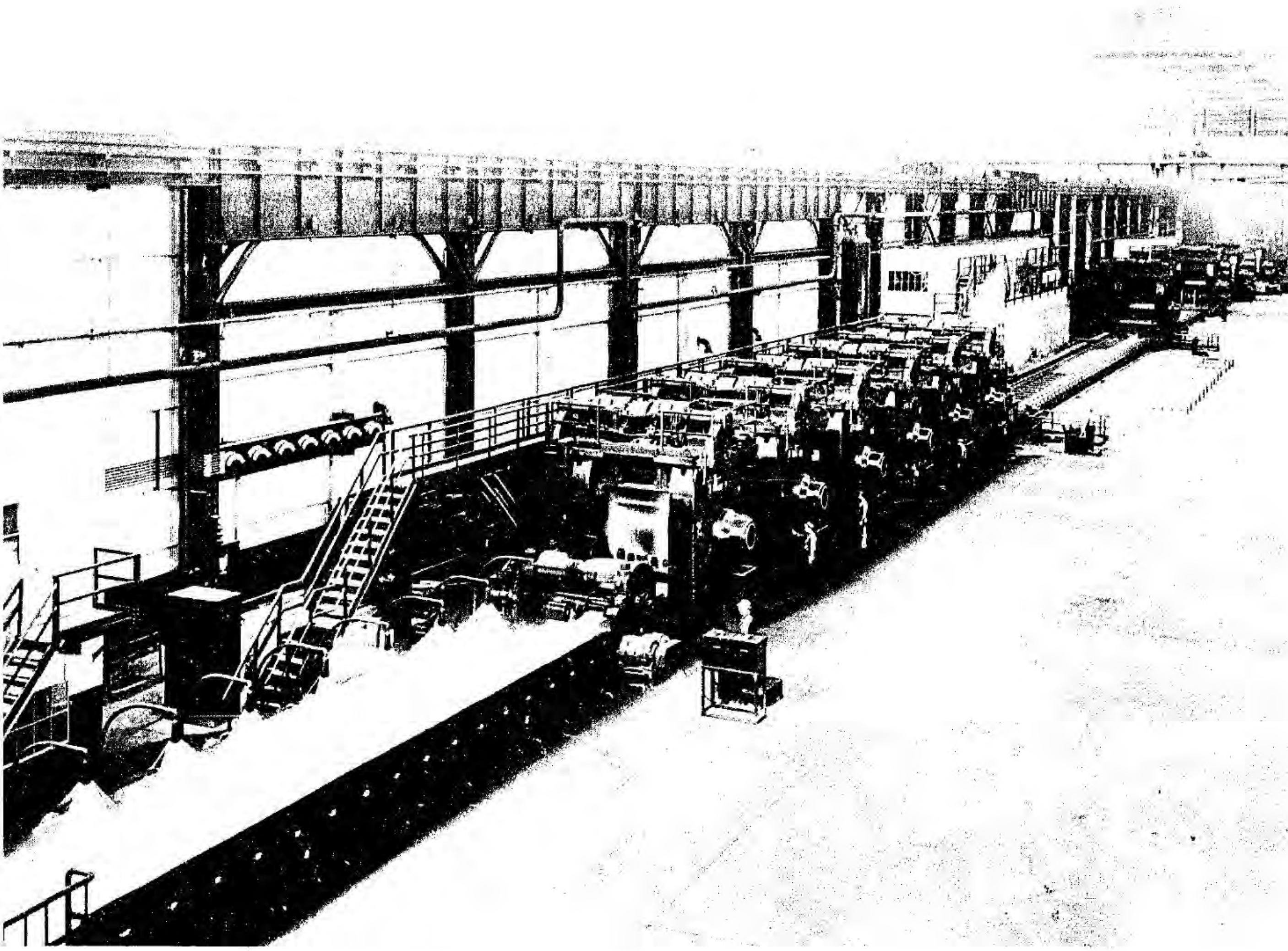
V - FINISHING

The steel finishing processes may be divided into two broad categories depending on whether the steel is worked hot or cold. In most instances, the cold finishing operations are proceeded by hot finishing operations.

The following discussion will be confined to the processing of hot and cold rolled strip.[1] It must be emphasized, however,

Photo, Courtesy United States Steel Corporation

[1] The terms "sheet" and "strip" are often used interchangeably in the steel trade. Technically, however, strip is defined as steel not over 1/4 inch thick and not over 12 inches wide. Sheet is defined as steel not over 1/4 inch thick but over 12 inches wide. Plate is the term generally used for steel between 1/4 and 1 inches in thickness.



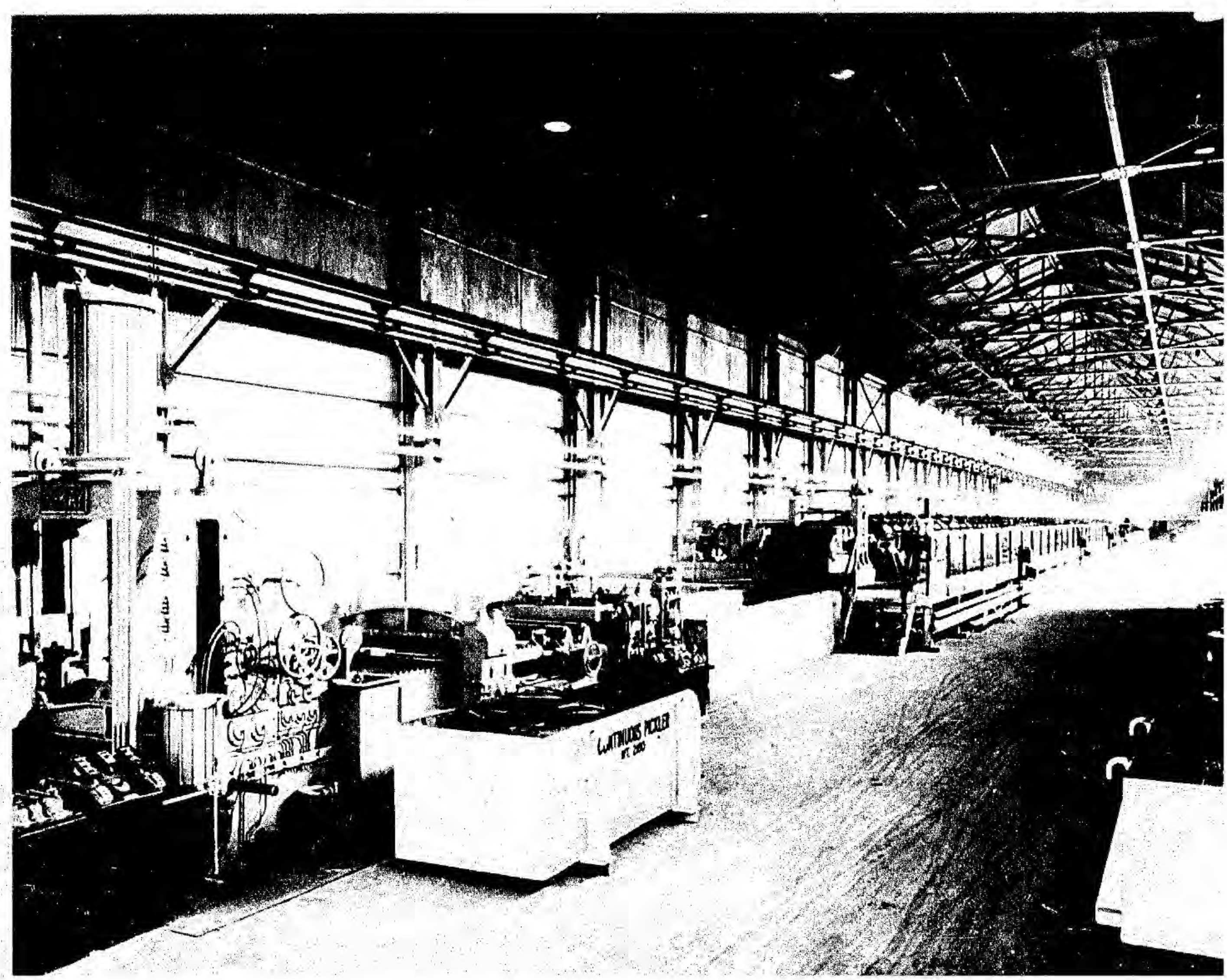
17. Continuous Hot Strip Mill

that this is but one of many products formed by one of many finishing processes. For instance, rails and structural sections are rolled directly from blooms. Bars of various shapes, seamless tubing, and wire are made from billets. Plate, sheet, and strip are rolled from slabs. Pipe and tube are formed from strip. After the cold rolling processes described here, tinning operations may follow.

17. Hot Finishing: Hot rolled strip is suitable without further processing for purposes where a smooth, scale-free surface is not required. In hot rolling, the semifinished shape, which may be a slab or billet, is first raised to the proper temperature, 2,200 to 2,400 degrees Fahrenheit, in a gas-fired furnace. Then it is pushed onto a conveyor leading to the continuous strip mill. In the first stand of rolls, called a scale-breaker, the scale is loosened by the action of the rolls and removed by jets of water at 1,000 pounds per square inch.

The continuous hot strip mill consists of a succession of four-high stands in tandem connected with roller tables. The first stands, known as roughing stands, are spaced so that only one stand will engage the metal at a time. The second and last group of stands, known as the finishing train,

Photo, Courtesy United States Steel Corporation



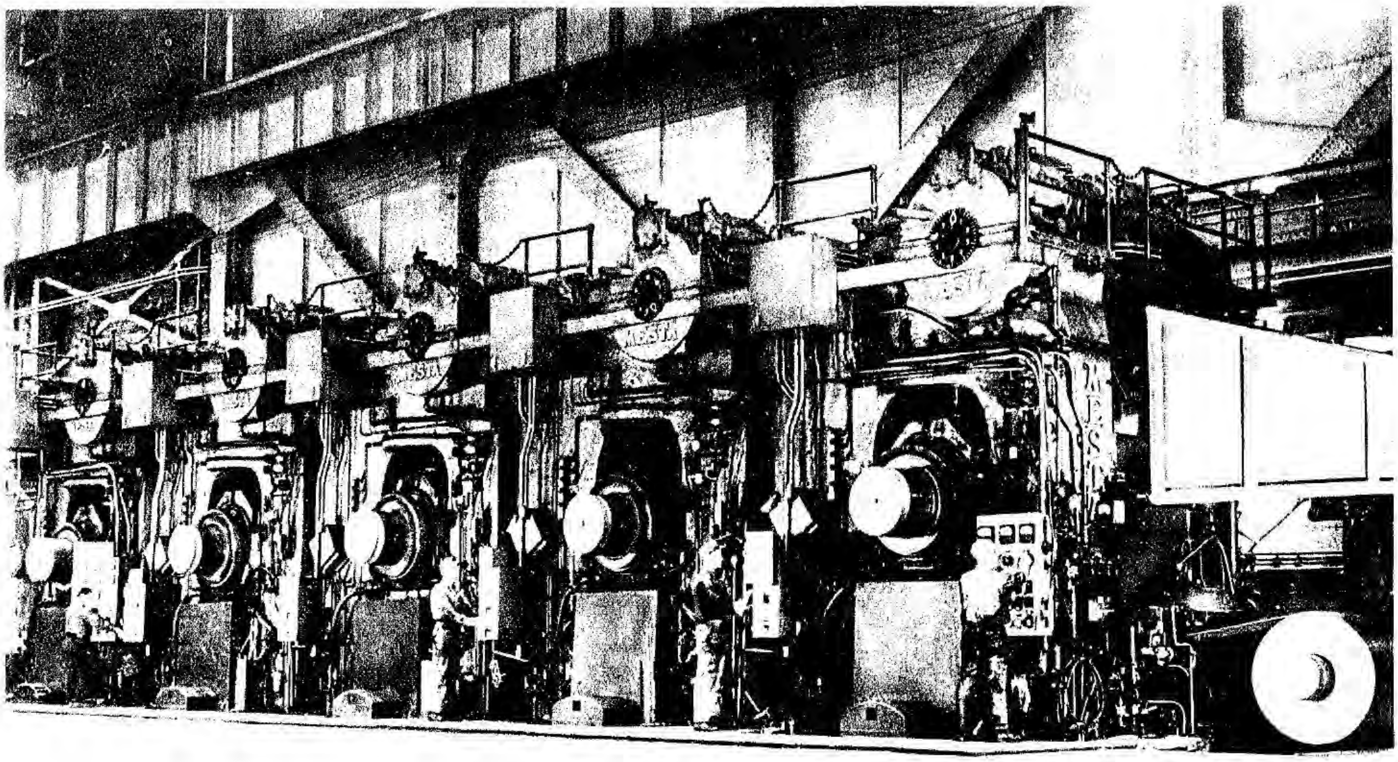
18. Continuous Pickler for Cold Strip Mill

are spaced close together and all stands are frequently in contact with the same piece of steel at the same time. As the steel is reduced in thickness its length increases, and it is therefore necessary that the rollers in the successive stands operate at progressively higher speeds to prevent buckling between stands. The largest continuous mills handle some 2,100,000 tons of steel a year. A ten-stand hot strip mill with auxiliary equipment represents a $30,000,000 investment at 1951 prices.

About 38 skilled workers are required to man a continuous hot mill. Some operators control the equipment by levers and buttons in pulpits above or to the side of the mill. Others are shear operators, coiling machine operators, samplers, weighers, inspectors, crane men, or maintenance men. Their pay ranges from $1.36 per hour, for a scrapman who removes shear scrap, to $2.66 per hour for a roller who directs the whole operation.

18. Cold Reduction: Cold rolling serves (1) to reduce sheet and strip to gages below 0.05 inch, (2) to increase strength, hardness, and stiffness, and (3) to improve surface finish.

Photo, Courtesy American Iron and Steel Institute



18. Four-high, five stand tandem cold mill

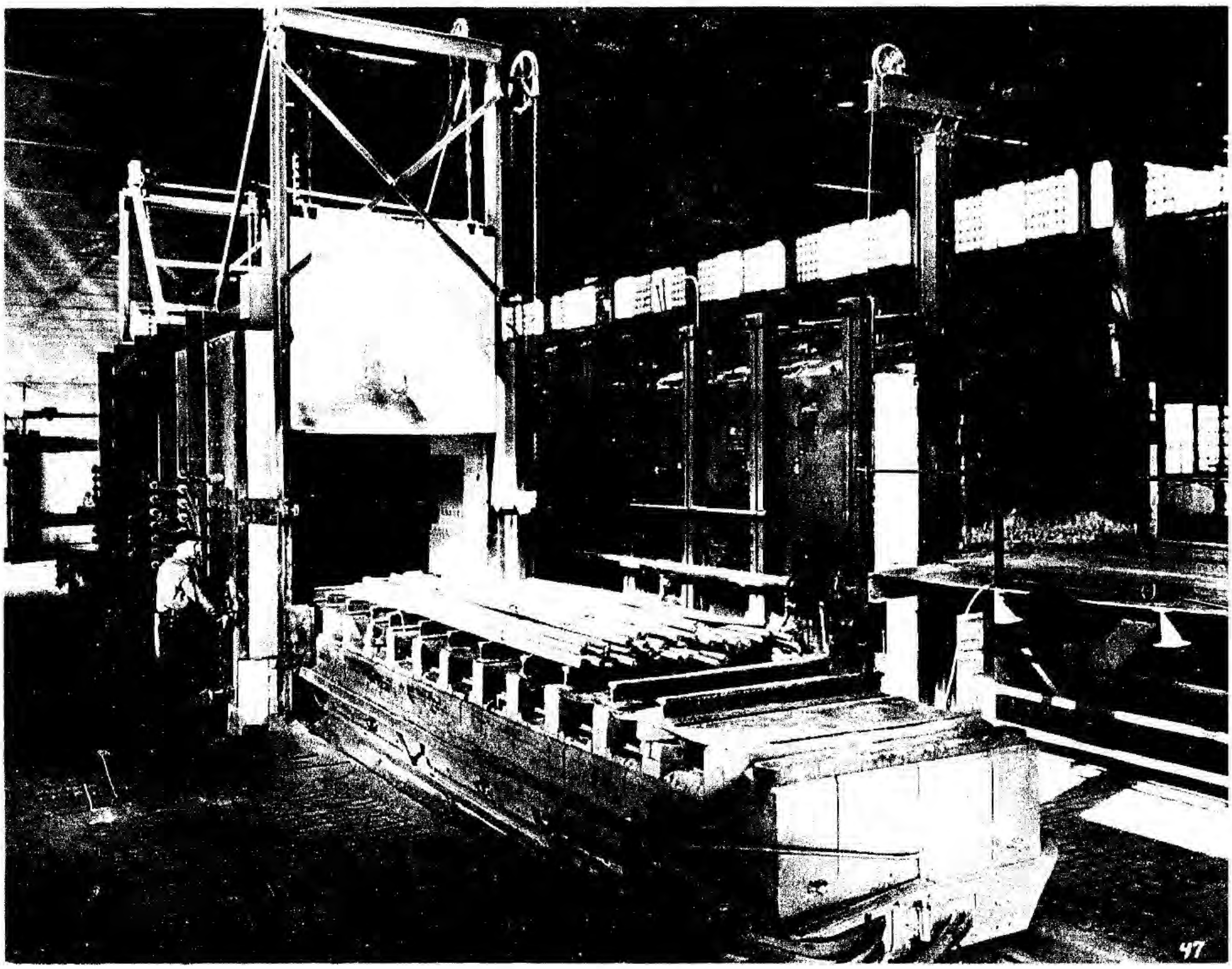
The cold rolling process takes hot rolled strip through the following steps:

(a) Scale breaker: The steel is first passed through a set of rollers and under water jets to remove the mill scale.

(b) Continuous pickler: The strip metal is next drawn through a 190°F. bath of 8 to 12 per cent sulfuric acid contained in rubber-lined tanks. This bath removes oxide from the surface. The strip is cold water rinsed, hot water rinsed, steamed, dried, and finally oiled to prevent rust.

(c) Cold reduction mill: In the cold reducing mill the strip, at atmospheric temperature, is passed through a varying number of four-high stands, depending on the thickness desired. Sensitive controls regulate the speed and metal thickness. The total reduction in thickness achieved may be from 40 per cent to 85 per cent. A five-stand mill can reduce a coil of strip metal originally 1/16 of an inch thick and 1,400 feet long to a thickness of 1/90 inch and a length of 7,600 feet in about 4 3/4 minutes. Such a mill will produce finished steel at a linear speed of up to 66 miles per hour.

Photo, Courtesy Mesta Machine Company



18. Annealing Furnace

(d) Annealing furnace: After cold rolling it is generally necessary to anneal the steel because it tends to work-harden during the rolling process. By heating the steel in a furnace to about 1,300°F. and then allowing it to cool slowly, internal stresses are relieved and the steel is softened. Deep drawing and other further processing is then possible. The complete heating and cooling cycle takes from 36 to 72 hours.

(e) Tempering mill: After annealing, a single-stand, four-high tempering mill is usually employed to give the cold rolled strip a 1 to 3 per cent reduction. This rolling operation serves to bring the steel up to the desired hardness, stiffness, and surface finish.

The investment required for a complete cold reduction operation such as described in this section was $25 to $30 million in 1950.

The crews in cold rolling departments received from $1.56 to $2.61 per hour in 1950.

Photo, Courtesy American Iron and Steel Institute

VI - SUMMARY

The preceding pages have outlined the major operations in the iron and steel-making process. The following diagram indicates the balance of equipment in a recently modernized, integrated steel mill.