1. NAME OF PROPERTY

Historic Name: Carrie Blast Furnaces Number 6 and 7

Other Name/Site Number: N/A

2. LOCATION

Street & Number: North side of Monongahela River .5 miles west of Rankin Bridge Not for publication: N/A

City/Town: Rankin, Munhall, and Swissvale Boroughs Vicinity: N/A

State: PA County: Allegheny Code: 003 Zip Code: 15218

3. CLASSIFICATION

Ownership of Property		Category of Property	
Private:	X	Building(s):	___
Public-Local:	___	District:	X
Public-State:	___	Site:	___
Public-Federal:	___	Structure:	___
		Object:	___

Number of Resources within Property

Contributing	Noncontributing	
3	2	buildings
___	1	sites
16	5	structures
___	___	objects
19	8	Total

Number of Contributing Resources Previously Listed in the National Register: None

Name of Related Multiple Property Listing: N/A

4. STATE/FEDERAL AGENCY CERTIFICATION

As the designated authority under the National Historic Preservation Act of 1966, as amended, I hereby certify that this ____ nomination ____ request for determination of eligibility meets the documentation standards for registering properties in the National Register of Historic Places and meets the procedural and professional requirements set forth in 36 CFR Part 60. In my opinion, the property ____ meets ____ does not meet the National Register Criteria.

Signature of Certifying Official Date

State or Federal Agency and Bureau

In my opinion, the property ____ meets ____ does not meet the National Register criteria.

Signature of Commenting or Other Official Date

State or Federal Agency and Bureau

5. NATIONAL PARK SERVICE CERTIFICATION

I hereby certify that this property is:
___ Entered in the National Register
___ Determined eligible for the National Register
___ Determined not eligible for the National Register
___ Removed from the National Register
___ Other (explain):

Signature of Keeper Date of Action

6. FUNCTION OR USE

Historic: Industry/Processing/Extraction Sub: Manufacturing facility
Energy facility

Current: Vacant/Not in Use Sub:

7. DESCRIPTION

ARCHITECTURAL CLASSIFICATION: No Style

MATERIALS:
Foundation: Brick, Concrete
Walls: Brick, Concrete, Steel
Roof: Tin, Corrugated Metal, Steel Plate
Other: Structural steel

Describe Present and Historic Physical Appearance.

Overview

Carrie Blast Furnaces Numbers 6 and 7 are located on the north side of the Monongahela River in the boroughs of Rankin, Munhall, and Swissvale, and the Hot Metal Bridge is located in the boroughs of Rankin and Munhall, Pennsylvania, approximately seven miles east from the confluence of the Monongahela and Allegheny Rivers in downtown Pittsburgh. The furnaces are exceptional examples of pre-World War II-era integrated smelting technology in the Pittsburgh District. The district is a distinct iron-producing region that encompasses production facilities in the city of Pittsburgh and the surrounding area, including much of western Pennsylvania, northern West Virginia, and parts of eastern Ohio. During the late nineteenth and early twentieth centuries the district was the leading producer of iron and steel in the world. The district's proximity to western markets and to the Connellsville coal fields, the leading producer of high-grade metallurgical fuel, encouraged iron and steel producers to build huge integrated production facilities during a significant period in American industrial development. Integration, in fact, became a primary characterization of the region. Integrated blast furnace plants, like Carrie 6 and 7, are distinguished from merchant plants in that they produce iron for associated steel works, rather than for sale on the open market. The design, layout, and operations of the Carrie furnaces were dictated by the larger demands of the steel works, and rolling mills for hot metal and electrical power. Typical of the riverfront iron and steel mills of the Pittsburgh District, the furnaces and their auxiliary plant are built upon an alluvial plane within the narrow corridor of the Monongahela River Valley with access to both river and rail distribution. The furnaces are set back about 450' from the river and separated by a large ore yard. Carrie 6 and 7 and much of their auxiliary plant are built on a northwest to southeast axis parallel to the river. The site is heavily overgrown with vegetation and is a popular target for graffiti artists. The contributing and noncontributing resources of the proposed NHL district are all that remain of the former Carrie Blast Furnace Plant.

Common among integrated blast furnace plants of the early twentieth century, the two stacks were operated as a pair, sharing raw material stocking and handing equipment, hot blast stoves, blowing engines and other auxiliary equipment. This helped ensure maximum efficiency and continuity of operations during periodic load swings in the ironmaking system. The twenty-seven resources that comprise the proposed district include the two furnace stacks and their ancillary equipment, hot blast plant, blowing engine house, AC power house, gas processing equipment, material storage and handling equipment, and hot metal bridge. The approximately 13-acre district encompasses the component technologies and processes of integrated iron production from the inventory and stockpiling of raw materials, to the production and distribution of hot metal. The proposed district has a discontiguous boundary including the cluster of resources associated with ironmaking and the footprint of the hot metal bridge.

The proposed district, however, represents a small part of a twentieth century integrated steel mill. When the mill shut down in 1984 the blast furnace plant had seven furnaces sprawled over nearly 100 acres of land on the north side of the Monongahela River. A high percentage of that land was built over with associated mill buildings, material handling equipment, production equipment, and ancillary structures. The twenty-seven resources nominated are the only remaining material culture of the blast furnace plant. Located on the south side of the Monongahela River, the former site of the Homestead Steel Works is connected to the Carrie plant by the hot metal bridge, built in 1900-1901. As a contributing resource to the proposed district, the hot metal bridge provides the only physical element of the former integration of iron and steel production at the Homestead Works. At the time of its construction, it incorporated the heaviest span ever built, and it is one of the few surviving examples of heavy-load industrial bridge construction in the Pittsburgh area. Specialized ladle cars filled with molten iron were run continuously from the blast furnaces of the Carrie plant to the open-

hearth furnaces at the Homestead Works, where the iron was converted into steel and worked into beams, plates, and other shapes at Homestead's extensive finishing mills. In 1912, five years after the construction of Carrie 6 and 7, the Homestead Works sprawled across 279 acres of riverfront property on both the north and south sides of the river.[1] The Homestead Steel Works operated from 1881 to 1986, and since its closure, has been systematically dismantled. Carrie 6 and 7 produced iron for the Homestead Works from 1907 to 1978, and all iron production at the Carrie Blast Furnace Plant was phased-out in 1984. Since that time the Carrie plant, except for Carrie 6 and 7 and their auxiliary equipment, has been torn down. Site map 2 shows the existing resources outlined in the context of the former blast furnace plant, excluding the hot metal bridge.
The assemblage of resources associated with pre-World War II integrated iron production at Carrie 6 and 7, along with the hot metal bridge connection to the site of the former Homestead Steel Works, provide a comprehensive view of a system of iron production central to American industrial and economic power. The twenty-seven resources associated with Carrie Blast Furnaces 6 and 7 are extremely rare examples of American industrial material culture. There are no complete furnace plants from this period still in existence in the United States, and all other non-operative blast furnaces in the Pittsburgh District have been torn down since the collapse of the region's steel industry in the 1970s and 1980s.[2]

The following description of the extant resources for Carrie Blast Furnaces Numbers 6 and 7 is organized by their function in the ironmaking process. It proceeds from the delivery and storage of raw materials, through the production of iron, slag, and furnace gases. The description of extant resources is based upon general observations and not a detailed inventory of existing equipment. These resources are very complex and include an unknown number of auxiliary equipment that coordinated the operation of the furnaces. During the period in which this property was actively under study it was privately owned by the Park Corporation of Cleveland, Ohio. Prior to acquisition by a public entity, access to the site was severely limited.[3] Moreover, most parts of the site were not accessible because of concerns over the current condition of trestles, ladders, and steps. Consequently, the condition of many critical areas, including the furnace tops, the interiors of the hoist houses, casting floors, and many other areas, remains unknown.[4]

The twenty-seven resources are divided between the raw material storage and handling equipment, and the primary auxiliary equipment directly related to smelting operations. The former group includes such resources as the ore yard, ore bridge and stockhouse associated with material handling operations, while the latter group includes the furnace stacks, hot blast plant, charging equipment, blowing engine house, and other resources associated with metallurgical functions. Because of the extensive use of by-product gas in modern blast furnace and steel plant operations, the processing of waste gases and the subsequent generation of electrical power will also be considered in the description of the extant resources associated with production at Carrie 6 and 7. Although considered separately for the purpose of describing the site by process function and production flow, the individual resources were coordinated in an integrated manufacturing system. Developments in one process had an effect in the overall efficiency and productive capacity of all other processes. Balance of operations and synchronized control over production systems were vital to successful manufacture. Refer to site map 1 for a bird's-eye view of all contributing and noncontributing resources associated with the district, except the hot metal bridge. Site map 3 shows the bridge in relation to the existing resources and the former plant. Site map 2

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[1] Carnegie Steel Company, *General Statistics and Special Treatise on the Homestead Steel Works* (Pittsburgh: Carnegie Steel Company, 1912), 13.

[2] Mark Brown, "United States Steel Homestead Works," Historic American Engineering Record, HAER No. PA-200 (Washington, DC: U.S. Department of the Interior, National Park Service, 1990), 76; and Kenneth Warren, *Triumphant Capitalism: Henry Clay Frick and the Industrial Transformation of America* (Pittsburgh: University of Pittsburgh Press, 1996), 181-186.

[3] The private owners allowed the author on the site twice, each time for an hour or less.

[4] It is important to keep in mind, however, that these restrictions were also experienced at other furnace plants visited by the author. Without detailed documentation of these sites, a complete picture of their current integrity cannot be made. Such an assessment is outside the scope of this nomination.

shows the entire Carrie Blast Furnace Plant, ca. 1944. The existing resources associated with the proposed NHL are outlined. All other resources associated with the plant have been demolished. Site maps 4 and 5 both show the proposed boundary of the district.

Index of Extant Resources

RESOURCE	YEAR BUILT/REBUILT	CLASSIFICATION	STATUS	CONDITION
Stationary Car Dumper	1926	1 structure	Contributing	good
Ore Yard	1906-1907	1 structure	Contributing	good
Ore Bridge	1951	1 structure	Noncontributing	good
Stocking Trestle	1906-1907/1926	1 structure	Contributing	fair
Stock House	1906-1907/1926	1 structure	Contributing	fair
Carrie Furnace No. 6	1906-1907/1926/1936	1 structure	Contributing	good
Carrie No. 6 Hoist House	ca. 1936	1 building	Contributing	good
Carrie No. 6 Cast House	1906-1907/1926/1936	1 building	Contributing	good
Carrie Furnace No. 7	1906-1907/1926/1936	1 structure	Contributing	good
Carrie No. 7 Hoist House	ca. 1936	1 building	Contributing	good
Carrie No. 7 Cast House	1906-1907/1926/1936	1 site	Noncontributing	ruin
Carrie 6 and 7 Hot Blast Stoves	1936	6 structures	Contributing	very good
Hot Blast Stoves Draft Stack	1936	1 structure	Contributing	very good
Carrie No. 6 Dustcatcher	1936	1 structure	Contributing	good
Carrie No. 6 Gas Washer	1968	1 structure	Noncontributing	good
Carrie No. 6 Electrostatic Precipitator	1956	1 structure	Noncontributing	good
Carrie No. 7 Dustcatcher	1936	1 structure	Contributing	good
Carrie No. 7 Gas Washer	1968	1 structure	Noncontributing	good
Carrie No. 7 Electrostatic Precipitator	1956	1 structure	Noncontributing	good
Carrie 6 and 7 Blowing Engine House	1907/1956	1 building	Noncontributing	fair
AC Power House	1907/1909/1917	1 building	Noncontributing	fair
Hot Metal Bridge	1900-1901	1 structure	Contributing	good

Raw Material Storage and Handling

Twentieth-century integrated steel works relied on blast furnaces for two primary products—basic iron for open-hearth steelmaking furnaces and furnace gas for power generation. The blast furnace plant is the first stage of production that moves from the inventory of raw materials, to the manufacture and distribution of hot metal. Ironmaking is a resource-intensive process that requires huge quantities of raw materials, heat, and water. During the 1920s, 1930s, and 1940s, Carrie 6 and 7 consumed between 3.5 and 4 tons of raw materials for every ton of iron produced.[5] This material consisted of iron ore, coke, limestone, and often scrap iron. For cooling systems, the Carrie 6 and 7 required over five million gallons of water a day. Although each furnace was originally designed to manufacture about 500 tons of iron per day, innovations in operational techniques, improved equipment, and increased furnace capacity pushed production to an average of about 700 tons of iron per day by the late 1920s. This required a daily consumption of 2500-3000 tons of raw materials for each furnace.[6] By expanding the productivity of individual furnace units, U.S. Steel increased the ironmaking

[5] As will be discussed in Section 8, consumption of raw materials per ton of iron produced declined during the 1950s and 1960s due to improved raw materials.

[6] Jacob A. Mohr, "Method of Charging Raw Materials Into the Blast Furnace," *Yearbook of the American Iron and Steel Institute* (New York: American Iron and Steel Institute, 1919), 231-232.

capacity of the Carrie Furnace Plant from about 980,000 tons in 1912, to 1.2 million tons in 1926, and to over 2 million tons a year by the end of World War II. At that time, Carrie 6 and 7 were each producing between 900 and 1000 tons of hot metal every day, and between 300,000 and 350,000 tons a year. Further advances in furnace practice and improvements in raw material quality in the 1950s and 1960s increased production at Carrie 6 and 7 to their maximum of about 2000-2500 tons a day (1000-1250 tons for each furnace), until the furnaces were taken off-line in 1978.[7] Such advances in output are a defining characteristic of American blast furnace development. They are important in assessing the relative integrity and significance of the extant resources at Carrie 6 and 7 that were continually modernized to improve ironmaking at the facility during their most significant years of operation between 1907 and 1941. Each progressive increase in furnace output was dependent upon the larger integrated system of auxiliary equipment, most notably raw material handling and storage.

Successful and efficient operations required that blast furnaces be operated continuously, placing great demands on the raw material stocking and handling systems. The tremendous increases in furnace capacity and the tendency to consolidate multiple furnaces into individual plants during the late nineteenth and early twentieth centuries required large storage facilities for stockpiling ore during winter months when shipping on the Great Lakes was closed. During the height of the shipping season, hundreds of rail cars moved through the Carrie Furnace Plant marshaling yards every day, the contents of which had to be sorted by grade and stockpiled in a systematic manner to insure rapid retrieval and minimal physical destruction. Excessive handling broke down raw materials reducing their effectiveness in the furnace. During operations, this material was constantly moved to the stockhouse, weighed, and loaded into skip cars. These cars were raised to the furnace top at the rate of over 1,500 pounds of material every minute. Early twentieth-century innovations in material handling technology exhibited at Carrie 6 and 7 were largely responsible for the tremendous increases in furnace productivity nationwide. These advances removed the mechanical thresholds imposed on an earlier generation of manually-operated furnaces. Although larger capacity and more modern equipment was integrated into the existing raw material storage and handling systems at Carrie 6 and 7, the layout and function of the plant are the same as it was when the furnaces were originally built.

Stationary Car Dumper: Manufactured by the Cleveland-based Wellman-Seaver-Morgan Company, the stationary car dumper was installed during modernization efforts at Carrie Furnaces 6 and 7 in 1925-1926. It served the ore yards of Carrie furnaces Nos. 3 and 4, and furnaces 6 and 7, replacing the smaller capacity car dumper built for Carrie 3 and 4 in 1900. The steel-frame structure is approximately 50’ wide x 60’ long x 60’ high, and is located at the southeastern edge of the ore yard for Carrie 6 and 7. The Stationary Car Dumper is equipped with an L-shaped cradle powered by four 150-hp motors capable of overturning incoming rail cars, emptying their contents into a receiving bin equipped with an automatic discharge chute. As the bin filled, its contents were dropped into transfer cars that moved the material to the proper ore yard unloading pit. The original operator’s pulpits, motors, and pullies are intact. Prior to the use of car dumpers, rail cars filled with ore and limestone had to be unloaded by hand, an exceedingly arduous and time-consuming task. The current car dumper may be the oldest in existence in the United States. Car dumpers were common features among

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[7] Carnegie Steel Company, *General Statistics and Special Treatise on the Homestead Steel Works*, 13; American Iron and Steel Institute, *Directory of Iron and Steel Works in the United States and Canada*, 20th ed. (New York: American Iron and Steel Institute, 1926), 88-89; and American Iron and Steel Institute, *Directory of Iron and Steel Works in the United States and Canada*, 25th ed. (New York: American Iron and Steel Institute, 1948), 89; and American Iron and Steel Institute, *Directory of Iron and Steel Works in the United States and Canada*, 34th ed. (New York: American Iron and Steel Institute, 1977), 300. Increases in productivity at Carrie 6 and 7 during the 1950s and 1960s were generally made through improvements in raw material quality and changes in operational techniques, such as increasing the blowing rate and blast temperature which did not require significant changes to existing auxiliary equipment.

large-capacity inland blast furnace plants that received their ore and limestone by rail.[8] It is a contributing resource to the proposed NHL.

Two transfer cars are extant on the stationary dumper. A 1940s-era electric trolley-style transfer car is located on the south side of the dumper trestle adjacent to the end-of-line railroad stop. A bottom-drop ore transport car is located on the lower trestle of the stationary car dumper. This vehicle has the markings, "RR CAR 120 USS."[9]

Ore Yard: The ore yard for Carrie furnaces 6 and 7 was built in 1906 by the Riter-Conley Company, one of the most important furnace-building firms in the Pittsburgh District. The ore yard is a large rectangular pit that extends along a northwest-southeast axis, parallel to the two furnaces and their hot blast stoves. Located between the river and the furnaces, the ore yard is approximately 135' wide x 580' long x 25' deep, open to the east and west, and enclosed by concrete retaining walls to the north and south. Along the river side of the ore yard is a 10' wide x 500' long unloading pit that received ore and limestone from the transfer cars. The unloading pit was an intermediate storage area from where ore and limestone was moved to its specific place in the main ore yard by the ore bridge. The ore yard was of a sufficient capacity to stock raw materials used at Carrie 6 and 7 during the close of the ore-shipping season in winter months. Narrow gauge rails run along the top of the northern and southern walls of the ore yard to accommodate the movable ore bridge. The ore yard is the only resource from the original 1906-1907 construction of the furnaces and is a significant contributing resource to the proposed NHL district. The south wall of the ore yard is heavily overgrown with vegetation and has been marred by graffiti.

Ore Bridge: The Dravo Engineering Corporation built the current ore bridge in 1951 to replace two smaller (7.5 ton capacity) ore bridges built in 1906. The riveted-steel ore bridge spans the ore yard on a northeast-southwest axis. It is composed of an 186' long warren truss span 100' above the ore yard that carries an electrically-powered trolley and hoisting machinery equipped with a 15-ton scoop bucket. The span is supported by two pier legs, each fastened to a motor-powered, eight-wheeled railroad truck that operated on the rail lines located on the northern and southern walls of the ore yard.

The operation of the ore bridge was critical to iron production at Carrie 6 and 7. Its function was to segregate the raw materials by grade into individual piles in the ore yard, mix the ore if necessary, and retrieve the ore and transport it to electrically-powered transfer cars that filled the stockhouse bins. The importance of proper furnace burdens (the mixture of ore, limestone and fuel that comprised a furnace charge) to the operation of the furnaces made the coordinated functioning of the ore bridge and ore yard of primary importance to the overall efficiency, of the blast furnace plant. The 1951 ore bridge was installed to improve the speed, efficiency and capacity of stocking operations at Carrie Furnaces 6 and 7. Although the bridge is important to the interpretation of iron production at the site, its installation after the period of significance makes it a noncontributing resource to the proposed NHL.

Stocking Trestle: The stocking trestle, often referred to as the "high-line," was originally built in 1906 and enlarged in 1926 to accommodate increased furnace capacity. The trestle is an elevated concrete and steel platform 38' wide x 550' long adjacent to the northern wall of the ore yard that supports one side of the trestle. Standard gauge rail tracks run on top of the platform over which transfer cars loaded with ore, limestone, and coke moved to load the stockhouse bins suspended below the trestle platform. Unlike the ore and limestone stored in the ore yard, coke was brought directly from U.S. Steel's by-product coke plant in Clarion,

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[8] Brown, "United States Steel Homestead Works," 86-87; J. E. Johnson, *Blast Furnace Construction in America* (New York: McGraw-Hill Book Company, 1917), 29-30.

[9] Tour of Carrie Blast Furnace site, September 10, 2002.

Pennsylvania, by bottom-drop railroad hopper car that discharged their load directly into coke bins through grated openings in the rail tracks. Coke stored in an open stockyard would deteriorate quickly from exposure to the elements.

Stockhouse: Originally built in 1906 and modernized in 1925-1926, the two and one-half story, 38' wide x 550' long stockhouse is located directly below the stocking trestle. The northern and southern walls are concrete, and composed of a continuous line of 20' arches that have been largely in-filled with brick.[10] The eastern and western ends are open to facilitate the movement of scale cars through the stockhouse. Directly beneath the stocking trestle is a system of suspended raw material bins capable of holding a twenty-four hour supply of raw materials for the two furnaces to guard against possible breakdowns in flow from the ore bridge. Running underneath the bins was a rail line that supports the operation of the scale cars. The tracks are no longer extant. Scale cars were continuously loaded with the appropriate mixture of ore, limestone and coke that they delivered to the skip pit dug into the stockhouse floor. The skip pit is located below the level of the scale cars at the bottom of the skip hoist of each blast furnace. Scale cars dumped their load of ore, limestone, and coke into skip cars that transported the charge to the furnace top by way of the skip hoist (see description below). Because of the use of high volatile by-product coke that fractures easily and contains a high quantity of dust (referred to as coke breeze) detrimental to furnace operations, the coke bins were equipped with vibrating screens and a coke breeze hopper to remove the dust before the coke was loaded into the skip cars. An automatic coke breeze skip hoist lifted the material from the hopper into a coke breeze storage area. Coke breeze was later utilized for a variety of purposes, including firing boilers and as filler for sintering operations.

The original 1906 stockhouse installation utilized parabolic bins with electrically operated discharge doors, manufactured by the Brown Hoisting and Conveying Machine Company of Cleveland, Ohio. Five men and two scale cars were required for stocking operations at each furnace. As part of the modernization of the furnace plant in 1925-1926, continuous hand-operated doors replaced the Brown-designed doors, and the controls of the skip hoist, furnace bells, and stockline recording device were coordinated so that only one man was required for stocking operations of each furnace. In effect, the larryman's job was reduced to merely running the skip since the operation of the bell at the furnace top was geared to the operation of the hoist.[11] Larryman pulpits are located above the skip pit for each of the furnaces. Most of the operator's controls and gauges are intact within the stockhouse, but because of limited access to these areas, their current condition is unknown.

The stocking trestle and stockhouse are in fair condition. The walls of the stockhouse and the bins are in very good condition, but the steel plates and tracks on the upper level of the stocking trestle have deteriorated and many are missing. The previous property owner did not allow access to the top of the trestle and the extent of the deterioration is unknown. Both the stocking trestle and stockhouse are considered contributing resources of the proposed NHL. They are extremely rare examples of 1920s material handling technology, and allow for the interpretation of early twentieth-century furnace stocking operations.

<u>Primary Auxiliary Equipment</u>

The fundamental principles of iron smelting have not changed for hundreds of years despite the tremendous changes in the scale and auxiliary equipment associated with modern iron production. A central feature of the blast furnace plant is the furnace stack itself—a large, vertical, steel cylinder lined with refractory brick.

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[10] At one time these arches were open to provide light, ventilation, and access to the interior of the stockhouse. It is unclear when or why these arches were in-filled, but it is likely that protection from the elements would have been a primary reason.

[11] James E. Lose, "The Operation of Large Hearth Furnaces Using coke Made From One Hundred Per Cent. High Volatile Coal," *Yearbook of the American Iron and Steel Institute* (New York: American Iron and Steel Institute, 1927), 85-86. The larryman was responsible for the operation of the stockhouse larry cars, or scale cars, that transported raw materials from the stock bins to the skip cars for transport to the furnace top.

Proceeding from the top to the bottom, the interior of the furnace is divided into three sections—the shaft, the bosh, and the hearth. Directly below the charging bell at the top of the shaft is the stockline, generally the narrowest part of the furnace in modern practice, where the materials are charged and begin their descent through the stack. The furnace shaft expands in diameter as it extends downward to the bosh, the widest portion of the furnace, then tapers inward to the furnace hearth where molten iron and slag are collected and drawn off.

Many early metallurgical textbooks compare the profile of a blast furnace to the glass chimney of an oil lamp. This shape facilitates smelting, allowing for the controlled descent of the raw materials through the furnace. Blast furnaces operate on the counter-current principle; that is, a descending mass of cold stock meeting an ascending current of hot gases. Therefore, material flow is critical to successful iron smelting. The gas, comprised primarily of carbon monoxide, imparts its heat to the descending stock and acts to deoxidize the iron ore. The gas is formed by the combustion of coke with preheated air blown under pressure through openings, called tuyeres, located around the circumference of the hearth. Coke has two primary functions. It provides the carbon necessary for the reduction of iron ore, and generates the heat required by the process. Its porous structure also keeps the stock column open, allowing for the reducing gases to rise. Limestone, or other fluxing material such as dolomite, combines with the impurities in the ore, including silica, alumina, and manganese, at about 2000°F. This forms the material slag (or cinder), which, due to its low specific gravity, floats on top of the molten iron in the furnace hearth and is drawn off through an opening called the cinder notch. Iron is tapped from the furnace at about 2700°F from an opening at the base of the stack called the iron notch. These processes occur continuously, and for efficient operations there must be uniformity of combustion, gas distribution, and stock descent. Any imbalance in the process leads to irregular operations, poor iron quality, and the potential for unsafe working conditions.[12]

Carrie Furnace No. 6: Except for their larger size and more elaborate charging equipment and furnace tops, Carrie 6 and 7 do not appear much different than the original stacks built in 1907 or the rebuilt stacks of 1926. They are constructed on the original foundation and they share the same physical relationship to their auxiliary plant as the earlier generation stacks. Carrie 6 and 7 are laid out on a northwest-southeast axis, with Carrie No. 6 occupying a site to the southeast of Carrie No. 7. The center lines of the two furnaces are 257' apart. Furnaces 6 and 7 were rebuilt for the last time during the modernization of the Carrie Furnace Plant in 1936, and are typical of the large capacity stacks of the period. They are cupola-style blast furnaces. Cupola-style stacks were first used for smelting iron in Europe and introduced to the United States in the 1850s. It was not until the late 1860s and early 1870s, however, that cupola-style stacks surpassed the heavy, stone constructed blast furnaces as the most common type in the United States.[13] Unlike the heavy, often tapered load-bearing walls of stone furnaces, cupola-style furnaces are supported by a relatively light, column and mantle structure. The columnar plate steel shell that supports the stack is set into a steel ring, called the mantle, which is supported by multiple steel columns. The bosh and hearth, located below the mantle, were independent of the upper shell, making maintenance to the lower zones of the furnace much more efficient. The columns provided much greater access to the exterior equipment of the furnace, allowing for better placement of tuyeres, cooling plates and other accessories. The transition to cupola-style stacks was based upon a number of factors, including their operational advantages, lower construction cost, and greater strength as furnaces were built even larger.

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[12] There are many good "textbook" descriptions of the blast furnace available for researchers. For instance, see Bradley Stoughton, *The Metallurgy of Iron and Steel*, 2nd ed. (New York: McGraw-Hill, 1913), 18-44; J. M. Camp and C. B. Francis, *The Making, Shaping and Treating of Steel*, 2nd ed. (Pittsburgh: Carnegie Steel Company, 1920), 130-171; H. M. Boylston, *An Introduction to the Metallurgy of Iron and Steel* (New York: John Wiley, 1928), 79-127.

[13] Significantly, the first generation coke-fueled blast furnaces in Pittsburgh built between 1859 and 1865 were among the first western furnaces built on the cupola plan. Their success and technological advantages over stone-constructed stacks were critical to the diffusion of these types of furnaces to other western districts.

Both furnaces are 92' high with shells constructed of 2.5" thick steel plates lined with refractory brick. The thickness and composition of the refractory brick varies depending upon its location in the furnace. Areas subjected to the extreme heat and chemical reactions of smelting, such as the hearth and the bosh, were lined with a thicker level of brick, often of a different chemical composition. Blast furnaces were typically relined every couple of years, and a great deal of engineering effort went into extending the life of furnace linings for longer production campaigns. A campaign lasted from one relining to the next, and success was often judged by the tons of iron produced during a single campaign. During their most productive years when they averaged 1000 tons of iron a day, Carrie 6 and 7 were relined about every 700,000 tons, or roughly every two years. Cooling plates are imbedded into the hearth and bosh walls to protect the furnace lining, but there is limited stack cooling above the mantle because of the relatively small capacity of the stacks. Both furnaces have 23'6" diameter hearths, 27' boshes, and a total working volume of 31,588 feet. Ten steel columns support each stack. There are sixteen, 7" diameter tuyeres equally spaced around the circumference of the hearth. The hot blast is blown through the tuyeres into the furnace hearth to support combustion. The hot blast comes from the stoves through a hot blast main that feeds into a bustle pipe that circles each furnace. Under normal operating conditions, the pressure inside the bustle pipe was equalized to insure that the blast was delivered to each tuyere at a uniform volume and pressure. This helped insure complete combustion across the bosh necessary for proper stock descent. Iron was tapped from an iron notch located on the north side of each furnace 3' above the bottom of the hearth (see description of *Cast House* below). Each furnace was equipped with a main and auxiliary slag notch. The main slag notch for Carrie No. 6 is located 7'3" above the bottom of the hearth, 72° from the iron notch on the eastern side of the furnace. The auxiliary slag notch for Carrie No. 6 is 7'9" above the bottom of the hearth 72° from the main slag notch, also on the eastern side of the furnace. Carrie No. 7 has a similar configuration of slag notches, but they are located on the western side of the furnace.

The receiving and subsequent charging of raw materials into the furnaces was dependent upon a system of interconnected equipment that extended from the stocking bins discussed above, to the furnace top. The mechanical charging system includes skip cars, skip hoist, hoist house, and top distributor. Each unit formed a component in the process of keeping material flowing continuously to the furnaces and was designed to prevent any bottlenecks in smelting operations. Both Carrie 6 and 7 have double-track skip hoists that extend from the skip pits dug into the floor of the stockhouse, to a receiving hopper on the furnace top. Skip cars, four of which are still extant, continuously traveled up and down the skip hoist to keep the furnaces filled with raw materials.

Carrie Furnace No. 6 Hoist House: A 40' square x 30' high brick hoist house raised on steel stilts is located to the rear of each furnace. Inside the hoist house for both furnaces are the controls for charging operations, including 350 hp electric Otis winches that manipulated the skip cars and the controls for the 4' and 3' pneumatic cylinders and air receivers that raised and lowered the furnace bells. The furnace tops are equipped with McKee double-bell revolving distributors manufactured by the Arthur G. McKee Company of Cleveland, Ohio. After the charge was dumped into the receiving hopper that revolved for controlled placement of the charge, a small bell would lower, allowing the charge to fall onto the larger diameter bell. The small bell would then close to seal the distributor, and the large bell opened, dropping the charge into the furnace in a systematic manner. Uniformity of these procedures was extremely important to successful furnace operations. Four large diameter pipes extend upward from the furnace tops to reduce the velocity of the gas as it exits the furnaces. These are discussed below in connection with the gas cleaning system. Collectively, the blast furnaces and their mechanical charging equipment are contributing resources to the proposed NHL.

Carrie Furnace No. 6 Cast House: The No. 6 cast house is a 60' tall x 175' long x 60' wide steel-framed structure built on a north-south axis directly behind Carrie No. 6 blast furnace. The structure is clad with brick and has a steel plate roof supported by cambered Fink trusses. The cast house roofs of both Carrie 6 and 7 extend around the bottom of the furnaces creating a skirt-like structure to shelter various operations around the base of the stacks. The concrete floor of the cast house is one story above ground level to facilitate the loading of iron transport cars. The cast house is open on its north side to allow for movement of iron and slag transport cars into and out of the structure. A system of iron and slag runners comprised of refractory brick-lined channels are built into the cast house floor to move iron and slag away from the furnace. Iron runners are equipped with cable operated gates to better coordinate the flow of iron to the proper discharge area. The slag was channeled through a spray of water that solidifies the slag into granules that were carried in a refractory brick-lined water flume to a cinder pit located behind furnace No. 7. A separate slag flume from Carrie 7 also transported slag to the shared cinder pit. The pneumatic-powered drill, mud gun, and mud gun control house used in tapping operations are still extant inside the cast house. The No. 6 cast house is an extremely rare example of a complete 1930s-era cast house, and is a contributing resource to the proposed NHL.

Carrie Furnace No. 7: See description above for Carrie No. 6. Carrie furnace No. 7 is built to the same specifications as Carrie furnace No. 6, and is equipped with the same auxiliary components.

Carrie Furnace No. 7 Hoist House: See description above for Carrie furnace No. 6 hoist house. The No. 7 hoist house was built to the same specifications as the No. 6 hoist house, but it is located directly behind Carrie furnace No. 7.

Carrie Furnace No. 7 Cast House: Except for a part of the cast house adjacent to the furnace, the elevated concrete and brick casting floor, rail bays, and the mud gun, the cast house for Carrie No. 7 is no longer extant. The ruin of the cast house is considered a noncontributing site to the proposed NHL district due to its loss of integrity.

Carrie Furnace No. 6 and 7 Hot Blast Plant : In 1906, Carrie 6 and 7 were equipped with eight Massick & Crooke's hot blast stoves, widely considered to be the most efficient hot blast stoves on the market and perhaps the most common stoves used in new furnace construction during the early twentieth century. The eight stoves were each 90' high x 21' wide, arranged in two rows of four stoves located between the furnaces. They were three-pass central combustion stoves, meaning that gas and air were burnt at the bottom center of the stove, rose through the center combustion chamber, down through the side checker brickwork, or heating chamber, and back up through the checkers before exiting through top chimneys (hence, 3 passes). Hot blast stoves operate on the regenerative principle; heat is stored in the checker brick and then passed to the incoming cold blast from the blowing engines. The gas is then directed through the hot blast main into the bustle pipe that surrounds the outside circumference of the blast furnace. Multiple stoves were always used in modern practice to insure a uniform supply of hot blast, and piping arrangements usually allowed for any stove to operate on any furnace. Much of the piping from the blowing engine house to the furnaces has been dismantled, but approximately 90 percent of the piping around both furnaces, their hot blast plants, and gas cleaning systems is intact. Because of the large quantity of flue dust generated when smelting Mesabi ores (this is discussed in the Statement of Significance section), the original stoves at Carrie 6 and 7 were lined with 9" checker openings to minimize the buildup of dust that would reduce their efficiency and increase maintenance costs. The large checkers, however, also reduced the stove's heating capacity, but with four stoves the furnaces were able to maintain a constant operating temperature of about 1100°F when blowing 30,000 cubic feet of air per minute. During modernization efforts in the late 1920s, the stoves were relined with 4.5" checkers and their height was increased 20'.[14]

[14] Brown, "United States Steel Homestead Works," 89-90; Lose, "The Operation of Large Hearth Furnaces," 83-84; also refer to the textbooks mentioned in fn. 11. All of these offer good descriptions of the construction and operation of hot blast stoves in modern blast furnace practice.

The current stoves were built in 1936 to increase the heating capacity of the plant in proportion to the increased output of the furnaces. Six stoves are located in two rows of three stoves between the two furnaces. The stoves closest to the river generated heat for Carrie No. 6, and are built on a higher foundation that makes them appear to be taller than the stoves for Carrie 7. All of the stoves are 104' high and 24' wide, with 82' of Kennedy multiple-checker brickwork with 2" x 2" flue openings, giving the hot blast plant a total heating surface of nearly 2.2 million square feet. Unlike the original Massick and Crooke's stoves, the extant stoves are two-pass with side combustion chambers typical of hot blast plants built during the 1930s. Waste gas was directed into underground flues that fed into a single draft stack located adjacent to Carrie No. 7 that served all six stoves. As was common with stove construction in the late 1930s and 1940s, they are welded and reinforced with steel lozenges to withstand higher operating pressures. The stoves were able to generate a straight-line blast temperature of 1100°F, but modifications in the heating and cooling cycles and the increase of gas flow into the combustion chambers allowed operators to attain blast temperatures as high as 1800°.[15] The six stoves and draft stack that comprise the hot blast plant are in very good condition and considered contributing resources to the proposed NHL.

Carrie Furnaces No. 6 and 7 Gas Cleaning Systems: During the early twentieth century, the increasing use of fine Mesabi ores and the industry-wide efforts to maximize the use of blast furnace waste gas for ancillary processes, including powering blowing engines, firing hot blast stoves and generating power, forced furnace engineers to develop effective gas cleaning systems. Gas cleaning systems were first developed in the late nineteenth century but more effective systems were introduced in the early twentieth century as metallurgists learned more about the added thermal efficiency of clean gas. The gas cleaning system for both Carrie 6 and 7 is comprised of three separate processes. Each furnace is equipped with a dust catcher, gas-washing tower, and electrostatic precipitator located between the hot blast plant and the blowing engine house (six structures). The dust catcher and gas washers are considered primary systems that cleaned gas for use in boilers and hot blast stoves. The electrostatic precipitators cleaned gas more thoroughly than dust catchers or washers, and were considered a secondary cleaning system. This equipment could be used individually or in combination depending upon the subsequent use of the gas. Carrie 6 and 7 were equipped with dust catchers and gas washers since their 1907 construction, but did not have electrostatic precipitators until 1956.

Gas exited the furnace top through four large-diameter pipes, or uptakes, equally spaced around the furnace stockline to minimize the tendency of gas to channel in one area. The extant uptakes, added during the 1936 rebuild, extend vertically approximately 30'. These pipes reduced the velocity of the gas exiting the furnace allowing the heavier particles of dust to fall back into the furnace stack. Each uptake is fitted with a bleeder valve to release gas to the atmosphere when the volume and pressure became too great for the system to handle. From the uptake, the gas was directed into a large diameter downcomer, a steel pipe lined with refractory brick that channeled gas directly to the dust catcher, the first stage of the cleaning system. The dust catcher is a large, pear-shaped cylindrical container, about 30' in diameter that further reduces the velocity of the gas entering from the downcomer. Heavier particles of ore dust and coke ash suspended in the gas collected at the bottom of the dust catcher where it was removed through a trap door. Installed during the 1936 renovations to the facility, the dust catchers for both Carrie 6 and 7 are extremely rare examples of pre-World War II gas-cleaning equipment and are contributing structures to the proposed NHL. On average, this equipment would process 75,000 lbs. of dust every day cleaned from the waste gas. The existing gas washing towers and electrostatic precipitators were installed during the 1950s and 1960s to improve the efficiency of the gas cleaning system and to maximize the thermal value of the gas. Because these four structures were installed after the period of significance they are noncontributing to the proposed NHL.

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[15] W. A. Knepper and W. W. Campbell, "Temperature Distribution in the Blast Furnace Stove," *Blast Furnace, Coke Oven and Raw Materials, 1958 Proceedings* (New York: American Institute of Mining, Metallurgical and Petroleum Engineers, 1958), 115-124; Brown, "United States Steel Homestead Works," 89-90.

Carrie 6 and 7 Blowing Engine House: The blowing engine house was constructed in 1906-1907 to house the blowing engines for both Carrie No. 6 and 7. The building is a 220' long x 104' wide x 84' high steel-framed structure with brick and corrugated metal walls, metal roof and concrete floor. The monitor roof is supported by a modified Fink truss structure of riveted-steel construction. Some pieces of the sheet metal roof are missing, exposing the interior of the building to the elements. The structural members of the steel frame are exposed on the long sides of the building but are covered by shallow brick pilasters on the gable ends. Decorative brick corbeling extends below the gable eaves. Two rows of narrow arched windows surround the building on all but the southwest end that was shortened by 80' in 1936 to make room for the installation of new gas washers for furnace number 6. These washers were later replaced by electrostatic precipitators in 1956. The building is currently empty. A portion of a large, 48" diameter steel pipe extends from the blowing engine house from its northwest corner. This pipe connected the blowing engine house to the AC power house. A similar portion of pipe exits the blowing engine house on the furnace side of the building. This fed into the primary blast main that served as the conduit to the hot blast plant. Blast and gas flow was circular and continuous from the blowing engine house to the hot blast plant, to the furnaces, to the gas cleaning system, to the AC power house, and then back to the blowing engine house.

The blowing engine house was equipped with four horizontal, four-cycle, double-acting, twin-cylinder gas engines with 42" gas cylinders, 72" air cylinders and 54" stroke. Common for furnace plants with gas powered blowing engines, two steam-powered twin-cylinder compound horizontal blowing engines were also installed to blow the furnaces if there was a problem with the gas supply. Carrie 6 and 7 did not have its own boiler house and relied on steam produced at the power plants of Carrie 1 and 2 and Carrie 3 and 4. The blowing engines were manufactured by the Allis-Chalmers Corporation, Milwaukee, Wisconsin, one of the nation's leading builders of heavy-duty mill engines during the late nineteenth and early twentieth centuries. During the 1920s plant modernization efforts, these engines were modified to increase their efficiency and wind capacity in proportion to the enlarged furnaces. The gas cylinders were enlarged to 44" and the air cylinders were enlarged to 74", and automatic plate inlet and discharge valves were installed. With the modifications the engines were capable of blowing each furnace with about 50,000 cubic feet of air per minute, compared to their previous wind capacity of about 30,000 cubic feet per minute. These blowing engines were put out of service in the mid-1950s when the low-pressure turboblowers that served furnaces 1 and 2 since 1924 were switched to furnaces 6 and 7. These were relatively small turbo-blowing units manufactured by Ingersoll-Rand, with a capacity of about 55,000-65,000 cubic feet of air per minute at a pressure of about 18 pounds per square inch. They were located in the No. 3 power house located adjacent to Carrie furnaces 3 and 4. While these turboblowers did not greatly increase the wind capacity at Carrie 6 and 7, turboblowers were much more efficient than gas engines and delivered a blast of much greater uniformity. In comparison, the turboblowers installed to drive the much larger Carrie 3 and 4 furnaces had a capacity of 135,000 cubic feet of air per minute at 42 pounds per square inch.[16] The original gas and steam-powered blowing engines for Carrie 6 and 7 are no longer extant in the building, which was later used to house a locker room and blacksmith shop equipped with a steam hammer and two natural gas forges.

AC Power House: The AC power house was built in 1906-1907 to generate electrical power for the Carrie facility and the Homestead Steel Works. The building is laid out on a north-south axis from a point about 50' to the northeast of Furnace No. 6. The steel-framed building is six stories high and measures 90' wide x 377' long, with brick and metal walls. Modified Fink trusses support the building's corrugated metal roofing. The gabled eaves of the southern end of the building are accented with decorative brick corbelling. The building has been used as a spare storage building for an undetermined period of time and currently contains parts of switch gears, air compressors, and motor-generator sets.

[16] *Directory of Iron and Steel Works in the United States and Canada*, 34th ed., 300.

The construction of the AC power house was part of a company-wide effort of U.S. Steel to centralize electrical power generation among their plants in the Pittsburgh District. U.S. Steel was a leader in the country in the utilization of blast furnace gas in gas engines used to both blow the blast furnaces and to power electrical generators. Increasing demands for electrical power necessitated an 88' extension to the building soon after the plant was completed in 1907, at which time the power house contained five gas engines and one steam turbine operating AC generators. In 1917, an additional 66' addition was added to accommodate the installation of new generators. This installation corresponds to the construction of the electrically-powered 110" plate mill at the Homestead Steel Works. Apart from the dismantling of the engines and generators, the building remains in the same condition today as it did in 1917.

Both the blowing engine house and the AC power house lost much of their historic integrity with the removal of their original equipment. They are important examples of early twentieth century industrial architecture, but are considered noncontributing resources to the proposed NHL district.

Hot Metal Bridge: The hot metal bridge was built in 1901 by the Keystone Bridge Works of the American Bridge Company, formerly a subsidiary of Carnegie Steel. It was built in conjunction with the expansion of the Carrie plant that included the construction of furnaces 3 and 4. The bridge is composed of a massive Pennsylvania through-truss main span of 500', a smaller Baltimore through-truss span of 252' to the north, and two plate girder approach spans to the south that each measure about 122'. Six sandstone piers support the bridge. Because of the tremendous load it had to support the bridge was constructed with extremely heavy structural members, and its 500' main span was the heaviest span ever built at the time. The bridge carries two rail tracks and a sidewalk. The upstream track is a standard gauge railroad line integrated with the Baltimore and Ohio Railroad and used for the transport of raw materials and heavy industrial goods. The tracks on the downstream side, or hot metal side of the bridge, carried ladle cars filled with molten iron destined for the Homestead Works open hearth furnaces. To insure against accidental spillage of molten iron onto river traffic, the hot metal track was fitted with high steel plate walls lined with refractory brick. These rail lines were integrated with the Union Railroad that connected all of Carnegie Steel's Monongahela Valley steel mills. The bridge provided the only direct link for hot metal transport between the Carrie furnaces and the Homestead Steel Works from 1901 until the facility closed in 1984.[17] The hot metal bridge was one of the first heavy-load bearing bridges built in America for the transport of molten iron and steel, and is a nationally significant cultural resource of the river-based industrial district of the Pittsburgh region that shows the highly integrated nature of the region's manufacturing facilities.

<u>Summary</u>

The assemblage of resources that encompass the proposed NHL furnace district, including raw material storage and handling facilities, furnace stacks, cast and hoist houses, hot blast plant, blowing engine and AC power houses, and other ancillary equipment, provide a complete view of iron production at an integrated steel works during the early twentieth century. The existing hot metal bridge, moreover, provides a physical link between the Carrie Furnace Plant and the former site of the Homestead Steel Works. There is a high-level of integrity of pre-World War II furnace technologies uncommon among the few blast furnaces of the period still in existence in America. The changes that were made to the plant between 1907 and America's entry into World War II, furthermore, reflect the dominant technological advances in iron production during the first half of the twentieth century. The district is one of the few remaining places in America that pre-World War II integrated blast furnace practice can be studied and understood. The resources associated with the proposed NHL are also the

[17] "The Carnegie Steel Company Bridge at Rankin," *Iron Age* 66 (October 4, 1900): 14; "The New Carrie Furnaces," *Iron Age* 67 (March 7, 1901): 11; Brown, "United States Steel Homestead Works," 93-94.

only remaining production components of the former Homestead Steel Works, one of America's most significant industrial plants of the nineteenth and twentieth centuries. The completeness of the existing furnace district, the significant technologies it represents, and its location in the nation's primary iron and steel production center makes Carrie Blast Furnaces Numbers 6 and 7 a nationally significant example of American industrial material culture.

8. STATEMENT OF SIGNIFICANCE

Certifying official has considered the significance of this property in relation to other properties:
Nationally: X Statewide:__ Locally:

Applicable National Register Criteria:	A X B__ C X D
Criteria Considerations (Exceptions):	A__ B__ C__ D__ E__ F__ G
NHL Criteria:	1 and 4
NHL Criteria Exceptions:	N/A
NHL Theme(s):	V. Developing the American Economy 1. Extraction and Production VI. Expanding Science and Technology 2. Technological Application VIII. Changing Role of the United States in the World Community 2. Commerce
Areas of Significance:	Industry Engineering
Period(s) of Significance:	1906-1941
Significant Dates:	1906-07, 1925-26, 1936-37
Significant Person(s):	N/A
Cultural Affiliation:	N/A
Architect/Builder:	Unknown
NHL Comparative Categories:	XII. Business XVIII. Technology: Engineering and Invention F. Extraction and Conversion of Raw Materials G. Industrial Production Processes

State Significance of Property, and Justify Criteria, Criteria Considerations, and Areas and Periods of Significance Noted Above.

SUMMARY STATEMENT OF SIGNIFICANCE

Built in 1906-1907, Carrie Furnaces 6 and 7 are the only remaining pre-World War II era blast furnaces in the Pittsburgh District, the nation's largest iron and steel production district for much of the nineteenth and twentieth centuries.[18] They are two of only a handful of remaining modern, pre-World War II blast furnaces in the United States that retain a large percentage of their original equipment. In the post-World War II years, U.S. Steel focused its iron-producing modernization efforts at Homestead's Carrie 3 and 4 furnaces. This has had a major impact on the current integrity of the furnaces; they retain much of their original 1920s, 1930s, and 1940s-era equipment. The furnaces are exceptionally significant examples of what was variously referred to as "Northern" or "Mesabi" practice—a technological style based upon the peculiar smelting qualities of Mesabi ores in the context of northern integrated steel production.[19] Because of their function in the integrated steel works and the raw materials they used, these furnaces incorporated different technologies and operational practices than blast furnaces in other districts, such as the Sloss Furnaces of Birmingham, Alabama, that smelted predominantly local ores for the foundry pig iron market. Carrie 6 and 7 represent extremely rare examples of a once common type of American iron production system. The existing resources show how these technologies were adapted to changing engineering theories, raw material supplies, and increasingly mechanized operations during the pre-World War II years making them nationally significant in engineering under NHL Criterion 4. The advances in ironmaking technologies that are reflected at Carrie 6 and 7 are inherently linked to their significance in American engineering and industrial history and reflect the dominant technological concepts of American ironmaking during the first half of the twentieth century. These advances, moreover, were critical to the development of mass-production in the American steel industry that made Pittsburgh the leading iron- and steel-manufacturing district in the world. The furnaces are the only remaining non-operative blast furnaces in a city with the most significant tradition of furnace engineering worldwide. By the 1870s, Pittsburgh was the locus of innovative iron-making technologies which techniques diffused to other iron producing districts in the United States. The highly mechanized and integrated operations of the Carrie Furnace Plant are also reflective of broader changes in American industrial production during the early twentieth century—a period some historians refer to as the "second industrial revolution."[20] Their associations with larger changes in American industrial development and the fact that they are the only remaining pre-war blast furnaces in the greater Pittsburgh industrial district, an area historian John Ingham refers to as "the very

[18] According to the statistical data of the American Iron and Steel Institute, the Pittsburgh District encompassed production facilities in the city of Pittsburgh and the surrounding region, including western Pennsylvania, northern West Virginia, and parts of eastern Ohio not associated with the Youngstown District. The social, cultural, and economic links between the city of Pittsburgh and the surrounding region are discussed in Edward K. Muller, "Metropolis and Region: A Framework for Enquiry Into Western Pennsylvania," in *City at the Point: Essays on the Social History of Pittsburgh*, edited by Samuel P. Hays (Pittsburgh: University of Pittsburgh Press, 1989), 181-211.

[19] Some metallurgical engineers and other observers of the American iron and steel industry also referred to these types of furnaces as representing "Pittsburgh" practice, because of the high level of integration among the city's blast furnaces, and the prevalence of Mesabi ores and by-product coke made from high volatile bituminous coal. The region's blast furnaces smelted a larger proportion of Mesabi ores than was typical in other districts because of their low cost and Pittsburgh's locational disadvantages from the primary supplies of iron ore.

[20] A description of the concepts associated with the "second industrial revolution" in relation to the iron and steel industry can be found in David Montgomery, *Worker's Control in Industrial America: Studies in the History of Work, Technology and Labor Struggles* (Cambridge, England: Cambridge University Press, 1979). Although many scholars use the term "second industrial revolution," there are many divergent views on what changes characterized this revolution. For the purpose of assessing the significance of the Carrie blast furnaces, we are concerned primarily with changes in the organization of industrial production, which for the iron and steel industry had its antecedents in the Bessemer steel rail industry of the late 1860s and 1870s. See Thomas J. Misa, *A Nation of Steel: The Making of Modern America, 1865-1925* (Baltimore: Johns Hopkins University Press, 1995); and Walter Licht, *Industrializing America: The Nineteenth Century* (Baltimore: Johns Hopkins University Press, 1995), 133-165.

cockpit of America's industrial transformation," also makes them nationally significant in industry under NHL Criterion 1.[21]

BACKGROUND

The Carrie Blast Furnace Plant served two primary functions for the Homestead Steel Works. Most importantly, it produced basic iron, a low phosphorous, low sulphur iron well suited for the steelwork's open-hearth furnaces.[22] And second, it produced by-product gas that was utilized to generate electrical power. In many areas of the Monongahela Valley, power plants operating on blast furnace gas generated enough excess electricity to serve all the needs of the larger industrial facility, as well as the surrounding communities. Blast furnaces were defining elements in the steel town landscape and they were as interwoven into the communities as any ethnic church or social hall. As their name implies, Carrie 6 and 7 were the sixth and seventh furnaces constructed at the Carrie Blast Furnace Plant—the last stacks built at what was the second largest furnace plant in the Pittsburgh District during the pre-World War II years. By increasing the output of individual furnace units at the Carrie Plant, U.S. Steel increased its annual ironmaking capacity from about 980,000 tons in 1912 to over 2 million tons by the end of World War II. At that time, Carrie 6 and 7 were each producing between 900 and 1000 tons of iron a day, or between 300,000 and 350,000 tons every year.[23]

The tall, cylindrical blast furnace stacks represent a relatively small but important component of the modern, integrated blast furnace plant. The increasing scale and expanding functions of the blast furnace plant in steel production during the first half of the twentieth century required extensive auxiliary equipment to process the huge volumes of iron ore, limestone, coke, and air that went into the blast furnaces, and the molten iron and production wastes that came out. During the 1940s, Carrie 6 and 7 each consumed between 3 and 4 tons of solid materials and approximately 3.5 tons of air to produce one ton of iron, more than .5 tons of slag, and between seventy and eighty pounds of dust that was carried out of the furnaces with the waste gases. Slag is the largest by-product of iron smelting and is composed primarily of the earthy material found in iron ore, such as silica, that combines with the limestone during smelting operations. As furnace production increased so did the production of slag, as the furnaces were engineered to process larger quantities of raw materials. Effective means of handling production wastes were as critical to efficient furnace operations as the ability to handle molten iron. Another important output from the blast furnaces that had to be processed was furnace gas, a combustible mixture of carbon monoxide, carbon dioxide, nitrogen, hydrogen, and methane. Every day about 100 tons of iron-bearing dust was removed from the gas exiting furnaces 6 and 7. This dust was recharged into the furnaces after being sintered into a usable form.[24] At the height of their production (between 2000 and 2500

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[21] This quote is from John N. Ingham, *Making Iron and Steel: Independent Mills in Pittsburgh, 1820-1920* (Columbus: OH State University Press, 1991), 49.

[22] During the first half of the twentieth century, census reports listed six primary grades of iron: basic, Bessemer, low phosphorous, foundry, malleable, and forge/mill irons (there was also a miscellaneous classification for specialty grades of iron). Each grade had a specific niche in the market, whether the iron was consumed in a steel works or sold for iron castings. By mixing certain ores and controlling such variables as the temperature and time in the furnace, producers controlled the grade of iron their furnaces produced. By the 1919 census, basic iron accounted for about 50 percent of the nation's total output due to the expansion of the open hearth process as the primary steelmaking technology in America. Prior to the 1919 Census, Bessemer iron was the leading product of American blast furnaces because of the dominance of the Bessemer steelmaking process. The Carrie Furnace Plant produced basic iron exclusively, from the time Carnegie bought the plant in 1898 to U.S. Steel's eventual closing of the plant in 1984.

[23] Carnegie Steel Company, *General Statistics and Special Treatise on the Homestead Steel Works*, 13; and American Iron and Steel Institute, *Directory*, 25th ed., 89.

[24] Initially dust was recharged into the furnaces raw, or more typically wet, but later dust was sintered into a more usable physical form. A sintering plant was installed at the Carrie furnaces in the mid-1950s. Much of the statistical information on inputs and outputs as well as general operational practices in the Pittsburgh District comes from M. W. Reed and Associates, "Summary of Lectures and Topic Outline for Steel Plant Design on Blast Furnaces," unpublished work compiled for the Carnegie-Illinois Steel Company of United States Steel, Pittsburgh, Pennsylvania, 1944. Collection of Author. As can be seen on site map 2, a sintering plant was located due west of the existing ore yard for Carrie 6 and 7.

tons of hot metal per day for both furnaces), Carrie 6 and 7 produced about 250 million cubic feet of gas per day with the potential to generate large quantities of power. Despite its rather limited thermal value that averaged between 80 and 100 BTU per cubic foot of gas, blast furnace gas was cleaned of entrained particles of ore dust and coke ash and utilized to fire boilers and hot-blast stoves, generate electricity, and drive blowing engines. In the years between the World Wars, electrical power became increasingly important in steel mill operations nationwide as many new rolling mills and other processes were powered by electricity. The Monongahela Valley steel mills of U.S. Steel, including Homestead, were among the first in the country to utilize central power plants fueled by blast furnace gas to generate both AC and DC electrical currents.[25] Such low-waste technologies increasingly characterized modern blast furnace and steel plant operations after the turn of the century. The existing resources associated with Carrie Blast Furnaces Number 6 and 7 incorporate all the components of this system, from the production of hot metal to the processing of furnace gas.

The scale of the auxiliary equipment for a modern integrated blast furnace plant was proportional to the ironmaking capacity of the furnaces, and engineers continually adapted plants to new innovations that had a technological or economic benefit on plant-wide operations. The overall efficiency of Carrie 6 and 7 was dependent upon the coordinated functions of the entire manufacturing system and not the individual operations of component technologies. Broader economic considerations of iron and steel companies, and the locational characteristics of individual districts also dictated what technologies and techniques were integrated into existing manufacturing systems. Changes in market demands and raw materials forced engineers to develop new technologies to suit current conditions. Because of this, American ironmaking has been characterized by tremendous variations in plant design, process technologies, and operational practices. What benefited one plant operating under a certain set of variables may not have benefited another.

Carrie 6 and 7 were continually improved and modernized over their primary productive years between 1907 and 1941. These efforts were geared toward maximizing the efficiency and output of the plant and improving overall labor productivity. The transformations of the plant during this period are inherently linked to the furnace's significance in American engineering and industrial history for they demonstrate how existing production facilities were adapted to changing engineering knowledge, production technologies, raw materials, and economic realities. They also reveal larger patterns in the markets and the geographic structure of the American iron and steel industry during the twentieth century. The post-war decision of U.S. Steel to modernize Carrie 3 and 4 as the large-volume producers for the Homestead Works had a major impact on Carrie 6 and 7. In the thirty-three years after the war that Carrie 6 and 7 remained active, there was no increase in the size of the stacks and relatively few changes in their auxiliary plant equipment. Consequently, there is a high level of integrity of the 1920s, 1930s, and 1940s-era equipment at Carrie 6 and 7 that is uncommon among the few extant blast furnaces originally built prior to World War I. This is particularly significant considering the tremendous changes in blast furnace engineering that occurred during the 1960s, 1970s, and 1980s. Indicative of these changes, many of the large furnaces of today, such as the L Furnace at Bethlehem Steel's Sparrows Point Works near Baltimore, Maryland, are capable of producing more than 9000 tons of hot metal every day, roughly six times the output of either Carrie Furnace 6 or Furnace 7.[26]

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[25] Owen R. Rice, "Some Characteristics of Blast Furnace Gas," *Yearly Proceedings of the Association of Iron and Steel Engineers* (Pittsburgh: Association of Iron and Steel Engineers, 1946), 91-125.

[26] Lawrence P. Storm, "First Full Reline of Bethlehem's L Blast Furnace," *Iron Age* 68 (December 1991): 48. Today the L Furnace is the second largest blast furnace in North America.

The Late Nineteenth Century Iron and Steel Industry in Pittsburgh

The American iron and steel industry was changing rapidly during the second half of the 1890s, particularly in the Pittsburgh District, which by 1900 manufactured 40 percent of the nation's iron and steel.[27] Iron and steel production was increasingly consolidated into massive manufacturing facilities, rationally organized to maximize the flow of production from the inventory and stockpiling of raw materials, to the manufacture and distribution of finished steel goods. Geared toward high-volume, high-speed manufacturing, these modern factory complexes took advantage of the economies of large-scale production.[28] Market fluctuations and growing competition among the nation's iron and steel companies brought on a period of intensive backward and forward integration as producers actively improved the efficiency of their operations through control of raw material supplies, rail distribution networks, and finishing mills. Carnegie Steel was the most aggressive participant in this movement, gaining control of valuable ore lands in the Great Lakes Region, as well as the Pittsburgh, Bessemer and Lake Erie Railroad that provided a direct link between the ore docks of Lake Erie and their Pittsburgh mills. Carnegie had already acquired the most valuable coal and coking operations in the Connellsville Region of southwestern Pennsylvania in the 1880s through his partnership with Henry Clay Frick. The greater efficiency of Carnegie's Pittsburgh operations allowed him to undersell his leading competitors, the Illinois Steel Company (merged into the Federal Steel Company in 1898), the Lackawanna Iron and Steel Company, the Cambria Steel Company, and the Bethlehem Steel Company. As other producers' shares of the nation's total iron and steel production declined during the recession of the mid-1890s, Carnegie Steel's share continued to increase as a result of their greater efficiency in operations and aggressive business tactics. By 1897, Allegheny County alone, which includes the city of Pittsburgh, produced 539,000 tons of steel rails, compared to 437,000 tons for the whole state of Illinois, the next largest producer.[29] Protected from the often-severe price fluctuations of raw materials and freight rates, Carnegie Steel invested heavily in plant modernization and expansion during the late nineteenth century, maximizing the capacity and efficiency of its operations in the years before the formation of the United States Steel Corporation in 1901.[30] As historian John Ingham wrote, "(Carnegie's) techniques of mass production, high throughput, accountability, control, and professional bureaucratic management came to characterize large-scale American industries increasingly in the twentieth century."[31]

Efficient production required a balance between different operations within integrated, mass production firms. Over-capitalization into steelmaking furnaces, for instance, created production bottlenecks if a work's ironmaking capacity could not supply the increased demands for pig iron. Such was the case among the Carnegie mills in Pittsburgh during the mid-1890s. Expansion of steelmaking capacity at their Edgar Thomson, Homestead, and Duquesne Works increased their output of steel from under one million tons in 1892 to nearly 3 million tons in 1898. During the same period, the output of Carnegie's blast furnaces—including the two Lucy furnaces located north of the city of Pittsburgh on the Allegheny River and the furnace plant of the Edgar Thomson Works—only increased from about 750,000 tons to just under 1.2 million tons annually. To compensate for this deficit, the company bought large quantities of high-priced pig iron from merchant blast furnaces located in the Shenango and Mahoning River Valleys of northwestern Pennsylvania and northeastern Ohio. Exacerbating the problem, the Homestead Works, which was quickly becoming Carnegie Steel's largest production facility, had no blast furnaces to supply its increasingly huge steelmaking capacity. Although pig iron from Carnegie's other blast furnaces was readily transported to the Homestead Works over the company's

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27 See Ingham, *Making Iron and Steel*, 50-52.

28 Alfred D. Chandler, *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, MA: Harvard University Press, 1977), 258-269.

29 Warren, *Triumphant Capitalism*, 113-138.

30 Kenneth Warren, *The American Steel Industry, 1850-1970: A Geographical Interpretation* (Oxford, England: Clarendon Press, 1973), 105.

31 Ingham, *Making Iron and Steel*, 49.

Union Railroad, built in the early 1890s, deficiencies in ironmaking capacity were becoming increasingly problematic and costly- particularly after the construction of a new open-hearth plant at Homestead in 1898 that was considered the most modern American open hearth plant in existence. Distribution and re-melting of iron from other furnace plants, moreover, increased overall operation costs, a factor unacceptable to Carnegie's approach to industrial production. Carnegie Steel rectified the problem through the construction of a new blast furnace plant at Duquesne and the purchase and subsequent modernization of the Carrie Furnace Plant located across the river from the Homestead Works. As a result of these moves, Carnegie Steel increased its monthly capacity of pig iron by 90,000 tons during the spring of 1899.[32] This was an aggressive tactical move for Carnegie Steel that had a tremendous impact on the industrial communities around Pittsburgh.[33]

The Carrie Furnace Company and Homestead Steel Works

Iron production at the Carrie Furnace Plant began during the first half of the 1880s, a period of unprecedented expansion for American iron-making. Spurred by the increased demand for steel rails and the nation's recovery from the economic panic of the late 1870s, annual pig iron production nationally increased from about 3.9 million tons to over 9.3 million tons between 1880 and 1890.[34] During this time, the number of blast furnaces in the Pittsburgh District increased from eleven to twenty-one, and the district became the nation's leading producer of pig iron.[35] In 1884, the Carrie Furnace Company, established by James S. Brown, E. L. Clark, H. C. Fownes and W. C. Fownes, blew-in a 70' high merchant blast furnace with an average daily capacity of about 100 tons of pig iron.[36] Pittsburgh's huge local market provided a ready outlet for the company's iron, and in 1889 it added another stack designated Carrie Number 2, increasing its daily capacity to 500-600 tons of pig iron.[37] According to an 1894 site map, the Carrie Furnace Plant was a well-equipped merchant iron-making facility with its own coke ovens and metallurgical laboratory. The rational layout of furnace components and connecting rail lines were more common among integrated iron and steel producing operations of the period.[38] During the mid-1890s, the Carrie Furnace Company was one of the last independent iron producers in Pittsburgh, a district characterized by a high level of integration. As early as 1894, the owners of the Carrie Furnace Company found it difficult to compete in an integrated market and began to look for potential buyers

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[32] Warren, *Triumphant Capitalism*, 158; and William Sisson, "A Revolution in Steel: Mass Production in Pennsylvania, 1867-1901," *IA: Journal of the Society for Industrial Archeology* 18 (1992): 87.

[33] During the late nineteenth century Andrew Carnegie openly discussed the options of consolidating iron production in the Great Lakes Region closer to the primary sources of iron ore. Believing that the key to low cost was access to fuel, however, Carnegie decided to expand iron production at his Pittsburgh facilities with ready access to the Connellsville coal region of southwestern Pennsylvania. See USX Records, *Pittsburgh Regional History Center*, Library and Archives Division, Pittsburgh, Pennsylvania.

[34] Stoughton, *Metallurgy of Iron and Steel*, 13.

[35] "Statistics of the Production of Pig Iron in the United States in 1872, 1873, and 1874, with Statement of Stock on Hand, December 31, 1874," *Iron Age* 15 (June 17, 1875): 19; "Current Furnace Capacity," *Iron Age* 46 (October 16, 1890): 665.

[36] Blast furnace plants were generally divided into two types, merchant facilities that produced pig iron for sale on the open market, and integrated facilities that produced iron for consumption in ancillary steel works. Some merchant facilities specialized in a particular grade of iron, such as foundry iron, but often merchant producers manufactured iron of varying grades depending upon what the local market demanded at the time. Integrated furnaces were more attuned to the demands of the steel works for either Bessemer-grade or basic iron depending upon the type of converting furnaces they used. While there were many similarities, merchant and integrated blast furnace plants varied in the types of technologies they adopted, their selection of raw materials, methods of operation, and organization of labor. Integrated facilities were also typically much larger operations with multiple blast furnaces, often as many as eight or twelve, and could take advantage of the economies of consolidating production, materials and labor into integrated operations.

[37] Brown, "United States Steel Homestead Works," 76; James H. Bridge, *The Inside History of the Carnegie Steel Company: A Romance of Millions* (New York: Aldine, 1903), 166.

[38] "Map of Property Belonging to The Carrie Furnace Company Situated at Kroling Station, B & O Railroad in the Borough of Rankin, Allegheny County, Pennsylvania, September 1894—AH Sheet 200," in the Bill Gaughn Collection, 94:3, *Archives of Industrial Society*, Hillman Library, University of Pittsburgh, Pittsburgh, Pennsylvania. It is important to note that while the plant was by all means a modern merchant facility, it did not incorporate the technologies common among the integrated blast furnace plants of the Pittsburgh District.

for their two blast furnaces. According to historian Kenneth Warren, there is also evidence that they contemplated building their own open-hearth steelmaking furnaces and finishing mills in an effort to remain competitive with the larger producers in the Pittsburgh District.[39]

Carnegie Steel's subsequent purchase of the Carrie furnaces in 1898 was clearly motivated by their need for iron-making capacity at the Homestead Works, but there were other factors at work that help illuminate broader changes in the steel industry during the late 1890s. While the larger iron and steel companies, such as Carnegie Steel, were the most active in integrating their production processes, many smaller firms also sought to improve the efficiency of their operations through integration. Specialty companies such as American Steel and Wire and National Tube, that were once large purchasers of steel from Carnegie, began to consolidate their operations with other smaller producers. These smaller holding companies began to build their own blast furnaces and open hearths to manufacture their own steel. By focusing on specialized niche markets such as springs or nails, which could not easily be supplied by companies like Carnegie Steel, these smaller companies were able to compete in the increasingly diversified metals market. Concerned with these developments, Carnegie began to contemplate building finishing mills to produce wire, nails, tube, tool steel, and other products that were in increasing demand in the marketplace. Most historians agree that the effort to keep Carnegie out of this sector of the steel trade was a primary catalyst in the formation of U.S. Steel in 1901, which combined the huge capacity of Carnegie Steel with the same specialty producers Carnegie saw as a threat.[40] Carnegie's concern over the production capacity of his competitors may have influenced his decision to purchase the existing Carrie furnaces rather than build new stacks. Adjacent to the Carrie site was a plant of the Consolidated Steel and Wire Company, owned by John W. Gates, who had been approached by the Carrie Furnace Company about buying the furnaces in the mid-1890s. With the construction of open hearth furnaces and blooming mills, the Consolidated Steel and Wire Company could have effectively integrated their production and impinged on Carnegie Steel's trade. A clear understanding of this potential development and his longtime antagonism toward Gates—who in 1898 became president of Illinois Steel and Carnegie Steel's primary competitor—may have influenced Carnegie's decision.

The takeover of the Carrie furnaces by Carnegie Steel was not without operational or logistical problems. Not only were the furnaces relatively small and outdated compared to Carnegie Steel's other blast furnaces in Pittsburgh, but their location on the opposite side of the Monongahela River made the movement of hot metal from the blast furnaces to Homestead's open hearth furnaces more difficult and costly. How could thousands of tons of hot metal be transported across the river every day? Different ideas were suggested, including using barges or some sort of bucket and cable conveyor system, but these ideas were impractical. Although considered the most expensive option, Carnegie Steel decided to build an extremely heavy bridge that could accommodate the transfer of hot metal, pig iron, and raw materials over the river.[41] With the question of integration solved by the completion of the hot metal bridge in 1901, the existing Carrie 1 and 2 furnaces were significantly modernized, and two new furnaces, Carrie 3 and 4, were brought on-line in 1901. A fifth furnace was added in 1903 and Carrie furnaces 6 and 7 were completed in 1907, making the Carrie Furnace Plant the second largest in the Pittsburgh District next to the Edgar Thomson Works, which had nine stacks at the time.[42] With completely integrated iron and steelmaking facilities the Homestead Works and Carrie Furnace Plant emerged at the turn of the century as the largest steel works in the world, and one of the most important industrial facilities in twentieth century America. Assessing the national significance of the Homestead Works, *New York Times* writer William Serrin observed:

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[39] Warren, *Triumphant Capitalism*, 181-183.

[40] Ibid., 269-300; and Abraham Berglund, *The United States Steel Corporation: A Study of the Growth and Influence of Combination in the Iron and Steel Industry* (1907; repr., New York: AMS Press, 1979), 54-73.

[41] Warren, *Triumphant Capitalism*, 181-184.

[42] Ibid., 178-185; Bridge, *Inside History of the Carnegie Steel Company*, 165-166; David Brody, *Steelworkers in America: The Nonunion Era* (Cambridge, MA: Harvard University Press, 1960), 10.

Its products helped the nation move west, shaped its skyline, bridged and dammed its waters, helped make it a world naval power, and helped it enter the Space Age. When the mill began, the nation's population was 51.5 million, the Industrial Revolution was in its infancy, and America was innocent and isolated; when the mill went down, the nation's population was 240 million, the Industrial Revolution—based on steel—had changed America and the rest of the world irrevocably, and America was the world's dominant nation in every imaginable way.[43]

In 1879, the Pittsburgh Bessemer Steel Company, organized by a syndicate of Pittsburgh iron and steel producers, began construction of the Homestead Steel Works about a mile down river from Carnegie's Edgar Thomson Works that began operations in 1875. Although the company was initially organized to manufacture Bessemer steel ingots for sale on the open market, the new mill was expanded to produce steel rails in direct competition to Carnegie's rapidly growing rail trade. The Pittsburgh Bessemer Steel Company, however, failed to join the Bessemer Steel Association, a consortium of producers that controlled Alexander Holley's important patents for the manufacture of Bessemer steel and established production quotas among its members. The lack of Holley's patents, coupled with the company's labor troubles placed it in a vulnerable position during a sharp depression in the rail market in 1882. In October of 1883, the company sold its operations to Andrew Carnegie, who quickly upgraded the Bessemer plant and, most significantly, transformed the plant from a rail producer to a producer of structural shapes and plate. During the 1880s and 1890s demand for structural steel increased dramatically as America began to rebuild its cities and bridges with steel. As Thomas Misa has argued, the changing market for steel during the 1880s illuminated the problems with the high volume, low quality model of Bessemer rail production. Misa has shown that deliberate collaboration between Pittsburgh steel makers and architects in Chicago led to the wider adoption of open-hearth steelmaking technologies to produce a more uniform and stronger material suited to structural use.[44] Open hearth furnaces were first constructed on a commercial scale at the Homestead Works in 1886, and in 1900 the Homestead Works produced about 1.5 million tons of open hearth steel, 25 percent of the nation's total output. The Homestead Works was one of the nation's largest producers of armor plate to supply the United States Navy in its efforts to rebuild its predominantly wooden-fleet during the late nineteenth century. Many of the Navy's premier battleships built between the 1880s and 1940s, including the USS *Maine*, were built with armor plate manufactured at the Homestead Works. By the late nineteenth and early twentieth centuries, the mill supplied nearly 50 percent of the nation's structural steel due to Carnegie Steel's aggressive marketing to the engineers and architects reshaping the skylines of Chicago and New York.[45] Steel from Homestead's structural mills revolutionized building construction technology in America and went into the construction of many of America's most prominent architectural and engineering works of the twentieth century, including the Flatiron Building, the Panama Canal, the George Washington Bridge, the Chrysler Building, the Empire State Building, Rockefeller Tower, the Golden Gate Bridge, the United Nations Building, and the Sears Tower.[46]

<u>A Tradition of Blast Furnace Engineering in the Pittsburgh District</u>

When the Carrie blast furnaces began producing iron for the Homestead Works, Pittsburgh's reputation as a center of innovative furnace engineering was well established worldwide. Since the construction of the Lucy and Isabella furnaces in 1872, and the furnaces of the Edgar Thomson Works later in the decade, Pittsburgh was widely considered the "Mecca" of European and American ironmakers. The empirical knowledge that guided

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[43] William Serrin, *Homestead: The Glory and Tragedy of an American Steel Town* (New York: Vintage Books, 1993), 59.
[44] Misa, *Nation of Steel*, 45-89.
[45] See Ingham, *Making Iron and Steel*, 60-67; Bridge, *Inside History of Carnegie Steel*, 150-166; Misa, *Nation of Steel*, 47-71; and Brown, "United States Steel Homestead Works," 17.
[46] Serrin, *Homestead*, 11.

American ironmaking since its inception in the seventeenth century was adapting to advances in metallurgical science to develop proper burdens and operating temperatures to control iron quality. Pittsburgh engineers were constructing the largest, most productive blast furnaces in the country at this time, and developed many innovations in furnace practice that came to symbolize ironmaking in the modern-era. The 1870s and 1880s were a transitional period in American ironmaking as new ideas of furnace engineering and management transformed the blast furnace into a modern tool of industrial production.[47] These advances established the foundation of modern American blast furnace practice. Discussing the blast furnaces built at the Edgar Thomson Works between 1879 and 1885, E. C. Potter, President of the Illinois Steel Company observed that they "marked the beginning of a new era in the science of iron-smelting, if, indeed, it was not the very birth of science as applied to this industry in the United States."[48]

Blast furnace developments in the Pittsburgh District became synonymous with "American Practice." While "American Practice" encompassed a wide range of operating principles and technologies, its defining characteristic for most observers of the industry was driving furnaces at increasingly higher rates to maximize their output. "Hard-driving," as this technique was called, was accomplished by blowing larger volumes of air into the furnaces at much higher pressures and temperatures than previously thought possible. Mechanically, the technique required greatly enlarged steam-powered blowing engines, expanded boiler capacity, and a hot blast plant of sufficient capacity to preheat the blast at a rate equal to the volume of wind blown into the furnace. It also required advances in refractory materials and furnace cooling systems capable of protecting the furnace shell. Such short-term production achievements were made at the expense of the long-term life of individual furnaces. It was a production model well suited to the Bessemer steel industry and America's insatiable demand for iron and steel products. While the market provided the impetus to drive production to much higher levels, it was the metallurgical coke manufactured in the Connellsville District of southwestern Pennsylvania and the easily reduced ores of the Great Lakes that made the technology commercially feasible.

During the late nineteenth century coke was produced primarily in beehive ovens, semi-spherical brick ovens in which bituminous coal was cooked to drive off its volatile matter. Unlike the dense and compact anthracite or raw bituminous coal used extensively in American ironmaking operations during the nineteenth century, coke has a very porous cellular structure that gives it an extremely high combustion rate. Consequently, coke can take the oxygen of the blast and convert it to carbon monoxide, the primary reducing gas in iron smelting, much more rapidly than other fuels. Connellsville coke was also very strong and would not crush under the weight of a large mass of raw materials in furnaces 70' or even more than 100' high.[49] During the late nineteenth and early twentieth centuries, the Connellsville District produced nearly 70 percent of the nation's total coke output, and its product was considered the standard against which all metallurgical fuels were compared. Combined with the ores of the Great Lakes that required much less time in the furnace to reduce compared to the ores of New York, New Jersey, or Pennsylvania, coke-fueled furnaces were driven harder to produce much more iron

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[47] An important factor in the transition to modern practice in America was the transfer of ironmaking technologies from Europe to the United States. New methods of furnace construction, new theories of furnace operations, and a developing scientific discourse on furnace practice emerging from areas such as England's Cleveland District, had a major impact on the development of American blast furnaces during the 1870s and 1880s. The impact of European models of furnace operations on the American industry is discussed in a forthcoming report on the modern blast furnace by the Historic American Engineering Record, National Park Service.

[48] E. C. Potter, "Review of American Blast-Furnace Practice," *Transactions of the American Institute of Mining Engineers* 23 (1894): 370; for related articles see Julian Kennedy, "Blast Furnace Working," *Transactions of the American Institute of Mining Engineers* 8 (May 1879-February 1880): 348-355; and James Gayley, "The Development of American Blast-Furnaces, With Special Reference to Large Yield," *Transactions of the American Institute of Mining Engineers* 19 (May 1890-February 1891): 932-995.

[49] For the most comprehensive analysis of Connellsville coke see John Fulton, *Coke: A Treatise on the Manufacture of Coke and Other Prepared Fuels* (Scranton, PA: International Textbook Company, 1905); and Frederick Quivik, "Connellsville Coal and Coke Region," Historic American Engineering Record Report, HAER No. PA-283 (Washington, DC: National Park Service, U.S. Department of the Interior, 1995); and Carmen DiCiccio, *Coal and Coke in Pennsylvania* (Harrisburg: Pennsylvania Historical and Museum Commission, 1996), 42-46.

at much lower costs than previous furnace operations. While typical anthracite furnaces required thirty to forty hours for smelting operations in 1880, the hard-driven coke furnaces of the Pittsburgh District required only fifteen hours. The highly productive and efficient operations of hard-driven furnaces had a significant impact on the economics of material flows in America as the demand for ore and coke rose dramatically during the last quarter of the nineteenth century, requiring substantial changes to the organization and technology of raw materials allocation and distribution systems.

Pittsburgh's proximity to low-cost, high-quality fuel, its huge local market for iron, and its tradition of engineering excellence, particularly in metalworking and steam engineering, all contributed to the development of hard-driving techniques in the district. Even after these techniques were adopted by producers in other districts, Pittsburgh engineers continued to drive their furnaces much harder than average because of advantages in fuel supply.[50] Another important factor that shaped Pittsburgh's iron industry was the industrial leadership and competitive drive of Andrew Carnegie, who invested heavily in furnace plants. Beginning with his first blast furnace venture, the Lucy Furnace Company, Carnegie pushed his engineers, workers, and furnaces to lead the nation and the world continually in total output.[51] High capitalization was necessary during this period of rapid modernization when technologies and practices changed at a staggering rate. A scrap and rebuild mentality permeated much of the American iron and steel industry as producers continually sought to maximize outputs and reduce costs. This drive for high volume production was considered by many observers to be destructive, both to capital equipment and to the men who labored in these plants. As an English visitor to Pittsburgh was told, the blast furnace superintendent who rebuilds "on the same lines as last time, without seeing his way to improve, to strengthen, and to make more effective his furnaces; we have no use for that class of men."[52] Ultimately, the changing scale and technologies of the American steel industry had a monumental impact on the organization and treatment of labor that had to adapt to the increasingly rapid and dangerous pace of modern industrial production.[53]

The innovations initiated in the Pittsburgh District diffused to other iron and steel-producing regions of the country, including Youngstown, Ohio; Chicago, Illinois; Birmingham, Alabama; and eastern Pennsylvania. In the parlance of cultural geographers, Pittsburgh can be considered a "technological hearth" of the American iron industry, a locus of technological innovation from where new methods diffused to other areas. Innovations initiated at the blast furnaces in the Pittsburgh District were increasingly important to producers during the last twenty-five years of the nineteenth century because of the tremendous expansion of the iron trade during the period and the large numbers of new furnaces built. As most historians of technology recognize, the rate of technology diffusion is generally more predominant when new production units are being built, as opposed to

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[50] The development and diffusion of hard-driving techniques, and the emergence of variant technological styles based upon market demands and raw material characteristics, is the central focus of a study on modern American blast furnace practice undertaken by the Historic American Engineering Record, National Park Service. Michael Bennett, "The Genesis of Modern American Blast Furnace Practice, 1855-1940" (Washington, DC: U.S. Department of the Interior, National Park Service, 1998). See also, Peter Temin, *Iron and Steel in Nineteenth-Century America: An Economic Inquiry* (Cambridge, MA: The M.I.T. Press, 1964), 156-163; and Joel Sabadasz, "The Development of Modern Blast Furnace Practice: The Monongahela Valley Furnaces of the Carnegie Steel Company, 1872-1913," *IA: The Journal of the Society for Industrial Archeology* 18 (1992): 94-105.

[51] Carnegie's drive to increase the output of his furnaces through any means necessary is readily apparent in the correspondence between him and the engineers of his mills. These letters can be found in the USX Collection, Historical Society of Western Pennsylvania, Library and Archives Division, Pittsburgh Regional History Center, Pittsburgh, Pennsylvania.

[52] Brody, *Steelworkers in America*, 22.

[53] For a discussion on the changing labor situation in the American steel industry see, David Brody, *Steelworkers in America*, 27-49; David Montgomery, *The Fall of the House of Labor: The Workplace, The State, and Labor Activism, 1865-1925* (Cambridge: Cambridge University Press, 1985), 40-41; John A. Fitch, *The Steel Workers* (1910; repr., Pittsburgh: University of Pittsburgh Press, 1989); and for a popular account see Charles R. Walker, *Steel: The Diary of a Furnace Worker* (Boston: Atlantic Monthly Press, 1922), 130-135.

when existing units are modernized.[54] Some producers, however, operating with different raw materials and producing iron for different markets than the integrated steel mills, developed alternative models of blast furnace operations to best suit their conditions. The Sloss Furnace NHL in Birmingham, Alabama, is an excellent example of a foundry-iron blast furnace plant that operated under different raw material, market, and labor considerations than the integrated plants of the north.[55] Despite similarities in smelting technology nationwide, variation remained a central characteristic of American blast furnace practice since producers were more likely to adopt innovations that most effectively suited their individual circumstances.

Clearly, the Pittsburgh model of hard-driven, coke-fueled blast furnaces was most salient to the emerging steel industry that sought to improve overall production efficiency through greater control over their supply of iron. This was particularly important for the high-speed operations of Bessemer steel works that required iron to be charged into the converters molten and, more importantly, that its chemical composition fall within an acceptable level of phosphorous and sulphur. These two elements, found in both iron ore and coke, were not compatible with late nineteenth century steelmaking technologies. Pig iron with high levels of these elements produced lower quality steel that was difficult to roll into finished shapes. Highly capitalized integrated producers could better control their supplies of Bessemer-grade ores and operate their furnaces to produce an acceptable quality of iron under the watchful eye of metallurgical chemists. Innovations made at the Bethlehem Steel Works, the South Works of the North Chicago Rolling Mill Company (later part of Illinois Steel), and Carnegie's Edgar Thomson Works, further improved the efficiency of steel making through the development of the "direct process" whereby iron was run directly from the blast furnaces to the steelmaking furnaces. This process saved heat and iron by removing the intermediary step of remelting pigs in a cupola furnace, thus creating a continuous flow of production. Again, such advances placed increasing strains on the labor and equipment that had to maintain a continuous production model. The demands of American steel mills for high-volume, uniform-quality iron increased the tendencies to integrate iron and steel production into larger factory systems that could take advantage of the economies of mass production. During the 1880s and 1890s, this approach to industrial production extended backward to the mining and distribution of raw materials, and forward to the operation of finishing mills until the American steel industry was the most productive and efficient in the world. Changes in production processes greatly increased the capital requirements of modern iron and steel production. In 1870, the average firm was capitalized at just over $200,000, while in 1880 the average capitalization increased to $360,000, and by 1890 it rose to over $800,000.[56] The consolidation of production functions within a massive industrial complex reinforced the tendency of the industry to centralize in districts such as Pittsburgh that had access to raw materials, a large market for products, and a large supply of labor skilled in metalworking.[57]

Within the modern American steel works mechanization and integration are inherently linked. The handling of large volumes of material, the need for coherent movement of material between production units, and the increasing scale of individual production units made mechanization necessary. This was particularly true of the modern blast furnace, which, by the 1890s, reached mechanical thresholds that overwhelmed the ability of labor

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[54] See Bela Gold, et al., *Technological Progress and Industrial Leadership: The Growth of the United States Steel Industry, 1900-1970* (Lexington, MA: DC Heath, 1984), 66-67.

[55] See Jack Bergstresser, "An Alternative Model of Pig Iron Producer: The Merchant Foundry Iron Blast Furnace of the Birmingham Industrial District, 1876-1930," Historic American Engineering Record (Washington, DC: U.S. Department of the Interior, National Park Service, 1995); Bergstresser, "Raw Material Constraints and Technological Options in the Mines and Furnaces of the Birmingham District: 1876-1930," (PhD diss., Auburn University, 1993); and Gary B. Kulik, "Sloss-Sheffield Steel and Iron Company Furnaces," Historic American Engineering Record Report (Washington, DC: U.S. Department of the Interior, National Park Service , 1976).

[56] Ingham, *Making Iron and Steel*, 50.

[57] Insightful discussions of the processes of centralization within the Pittsburgh District can be found in two essays, Muller, "Metropolis and Region," 181-211, and Herrick Chapman, "Pittsburgh and Europe's Metallurgical Cities: A Comparison," 407-438, both in *City at the Point.*

to deal with the large volumes of material passing through the plant every day. By the mid-1890s and early twentieth century, large modern blast furnaces operating on Lake Superior ores and Connellsville coke were consuming between 1500 and 2000 tons of raw materials daily to produce between 400 and 500 tons of iron. For facilities with four or more blast furnaces, material-handling bottlenecks became increasingly critical. Most engineers recognized that the modern blast furnace was reaching a production threshold that could only be broken through mechanical engineering. As one well-known engineer noted in 1896:

The evolution of the blast furnace, especially the American blast furnace, during the last third of the century has indeed been radical, making the question of getting the material to the furnace and the product away from it promptly, cheaply and regularly—the problem once satisfactorily solved by the cart or sled, the wheelbarrow and manual labor—one of great difficulty and grave importance.[58]

Again, due to the high volume production of Pittsburgh's blast furnaces the city's facilities were the locus of many innovations in new iron production technology. Reflective of this leadership in engineering was the construction of the Carnegie Steel Company's blast furnace plant at the Duquesne Steel Works in 1896. The 100' high stacks with 14'-diameter hearths were among the largest in existence and the first serviced by an automatic and integrated raw material stocking, handling, and charging system. Manual labor that handled blast furnace stocking and charging operations for centuries, was replaced by machinery that could process much larger volumes of material at higher rates of speed, and, ultimately, much lower costs.[59] Soon the Duquesne Furnaces were breaking all the world record marks for iron production and, more importantly, they shattered the existing furnace production threshold setting the stage for tremendous advances in iron production during the early twentieth century. In 1917, J. E. Johnson, widely considered the leading expert of early twentieth century American blast furnace practice, referred to their construction as marking "a distinct epoch in the history of the blast furnace in the United States."[60] The Duquesne Furnace Plant changed the conceptions of what constituted a modern integrated blast furnace plant in America, and in the immediate years after its construction, furnace engineers incorporated variations of its innovations in large-scale furnace operations nationwide. The Duquesne furnaces were torn down in the early 1990s. The transition to mechanized furnace operations was a natural progression for integrated steel works, but many observers of the industry were critical of its effects on the operation of the blast furnace. Metallurgical concerns were often superseded by the economic concerns for high-volume, low-cost production, prompting furnace superintendent Louis Grammer of Sparrows Point to argue that the function of a superintendent was becoming analogous to "train-dispatcher or burden clerk."[61] One of the more outspoken critics of this trend in furnace management was A. D. Elbers, professor of metallurgy at the Stevens Institute of Technology. In 1904, he argued:

We are now confronted by a situation which can best be explained by stating that the mechanical evolution of the blast furnace practice has outrun the knowledge of the chemical reactions of the process to such an extent that it cannot go any further until the theoretical evolution has caught up.[62]

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[58] Axel Sahlin, "The Handling of Materials at the Blast Furnace," *Transactions of the American Institute of Mining Engineers* 27 (1897): 3.

[59] Johnson, *Blast Furnace Construction in America*, 97-98; Axel Sahlin, "The Handling of Material at the Blast Furnace," 3-42; E. Gybbon, "Improvements in Mining and Metallurgical Appliances During the Last Decade," *Transactions of the American Institute of Mining Engineers* 27 (February 1897-July 1897): 452-456; Axel Sahlin, "The Brown Hoisting and Conveying Machines," *Engineering* (July 8, 1898): 42-45; and Louis Grammer, "A Decade in American Blast-Furnace Practice," *Transactions of the American Institute of Mining Engineers* 35 (1905): 124-139.

[60] Johnson, *Blast Furnace Construction in America*, 16; for a good description of the innovations initiated at Duquesne see Sabadasz, "The Development of Modern Blast Furnace Practice," 98-101.

[61] Grammer, "A Decade in American Blast Furnace Practice," 125.

[62] A. D. Elbers, "The Spooks of the Blast Furnace," *American Manufacturer and Iron World* 75 (July 21, 1904): 65.

Part of the problem confronting furnace engineers during the transition to mechanized operations was the unsuitability of certain raw materials to mechanical handling. The modern blast furnace is a sensitive apparatus that requires uniformity of operating variables to maintain safe and efficient production. Imbalances in stock distribution and descent, lower quality raw materials, or changes in blast temperature, volume or pressure, impairs the working of the furnace and can lead to high fuel consumption, poor iron quality, and at times, unsafe working conditions. The transition to mechanical charging during the late nineteenth and early twentieth centuries revealed the difficulties in insuring proper stock distribution, particularly when smelting the fine-grain iron ores of Minnesota's Mesabi Range that dominated the American iron and steel industry during the first half of the twentieth century. These problems were exacerbated by the continuous drive to increase the speed and capacity of production.

American Blast Furnaces and Mesabi Ores

Mesabi ores first entered the market during the early 1890s and quickly rose to dominance as the premier American ore because of its high iron content, averaging over 60 percent, and low cost compared to the older range ores of the Great Lakes Region. Equally important, the ore mines of the "old range" that had supplied the needs of the expanding iron and steel industry since the 1870s were rapidly being depleted. By 1900, 30 percent of the ore mined in the United States came from the Mesabi Range, and by World War I this figure reached over 80 percent.[63] The speed at which Mesabi ores entered the marketplace forced furnace engineers to adapt their operations rapidly with many problems and failed designs along the way. In many ways, the early twentieth century was just as revolutionary a period in furnace engineering as were the 1870s and 1880s when American producers were developing hard-driving techniques. Due in part to their disadvantage in ore supply compared with facilities closer to the Great Lakes, Pittsburgh blast furnaces smelted a much higher proportion of Mesabi ores during the late nineteenth and early twentieth centuries.[64] These market conditions again put Pittsburgh at the forefront of furnace innovations and established the basis for the construction of a new generation of blast furnaces that included Carrie 6 and 7.

Mesabi ores performed differently in the blast furnace than the harder, lump ores of the "old range" upon which much of American blast furnace practice was based. Their fine physical structure was comparable to dirt, and when it got wet it approached the consistency of mud. This made Mesabi ores extremely difficult to handle. When charged into the furnace, Mesabi ores were often blown back out of the stacks and into the gas mains, hot blast stoves and boiler flues, greatly reducing the efficiency of the plant's ancillary equipment. This dust often overwhelmed the system and had to be released to the atmosphere through explosion doors located at the top of the furnaces, coating surrounding neighborhoods with thick black dust. This problem was so bad that in 1903 Allegheny County officials imposed a temporary injunction against the use of Mesabi ores after complaints from community groups that the use of Mesabi ores decreased property values. This ruling was later overturned by the state supreme court because of the economic significance of Mesabi ores to the steel industry, and the importance of that industry for the Pittsburgh District.[65] When exposed to the action of the reducing gases inside the furnace, moreover, the fine Mesabi ores had the tendency to swell. As a result, the ore would get wedged into the furnace stack creating a bridge of solid material that could slip, meaning that it would break

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[63] David A. Walker, *Iron Frontier: The Discovery and Early Development of Minnesota's Three Ranges* (Minneapolis: Minnesota Historical Society, 1979), 208-214; and William T. Hogan, *Economic History of the Iron and Steel Industry in the United States*, vol. 3 (Lexington, MA: DC Heath, 1971), 15.

[64] Frank Popplewell, *Some Modern Conditions and Recent Developments in Iron and Steel Production in America* (Manchester, England: The University Press, 1906), 66-71.

[65] Notice of the injunction against the use of Mesabi ores can be found in "Furnaces Must Retain Ore Dust," *American Manufacturer and Iron World* 74 (March 31, 1904): 410; and "A Court Decision on Mesabi Flue Dust," *Iron Trade Review* 36 (January 15, 1903): 35. Symbolic of the region's industrial culture, a court later ruled that the economic and industrial rights of the companies smelting Mesabi ores was more important than the rights of the communities to have clean air.

free and fall into the hearth with destructive force. Laboratory research indicated that swelling was caused by a high level of carbon deposited on Mesabi ores during its descent through the furnace that could more than double the volume of the stock column.[66] This was a potentially serious problem as operating pressures inside American blast furnaces smelting Mesabi ores increased. Pressure explosions that often dislodged top equipment from the stack shell became a common occurrence at many plants. The introduction of Mesabi ores marked one of the most dangerous periods for furnace labor in the history of American ironmaking. Despite these serious problems, furnace engineers such as W. A. Barrows recognized the importance of Mesabi ores to the future of American ironmaking:

Notwithstanding the difficulties experienced in working Mesabi ores, the facts that they can be so cheaply mined and that ore of good chemical composition exists on this range in immense deposits, have forced their use. The rapid depletion of the Old Range reserves, particularly of ores of Bessemer grade, has rendered it absolutely necessary from an economic standpoint that the maximum percentage consistent with safe furnace-operations should be taken from this range, and that every energy on the part of the furnace superintendent should be devoted to adapt the furnace practice to this end.[67]

Among the most significant changes in the engineering of blast furnace plants operating on Mesabi ores were alterations to the charging mechanisms and more sophisticated gas cleaning systems to deal with the large quantities of flue dust. New types of rotary distributing tops were developed to thoroughly mix the charge, and new charging procedures were developed through trial-and-error methods whereby layers of coke were placed between layers of ore and limestone. Known as “stratified” charging, this method reduced pressure in the furnace because of the deep layers of porous coke between the ore that increased the permeability of the stock column. Furnace stacks were also designed wider immediately below the stockline to provide space for Mesabi ores to swell without becoming wedged in the furnace stack. Furnace tops were also built more securely to withstand the increasing pressures inside the furnaces and to better contain flue dust.[68] Most prominent to the exterior appearance of furnaces, engineers began to design elaborate uptakes, large diameter piping that extended upward from the furnace top to reduce the velocity of the gas as it exited the furnace stack. By reducing gas velocity, less flue dust was carried in the gas, and the heaviest particles were allowed to fall back into the furnace rather than be carried onto later stages of the gas processing system. Dust, however, was still a serious problem, and more advanced dustcatchers and gas washing systems were developed to clean the gas. Gas cleaning efforts became more critical to the successful operation of an integrated blast furnace plant as furnace gas was increasingly used for ancillary purposes, including running gas-powered blowing engines and power plants. It was also found that clean gas had a higher thermal value than dirty gas, making the operations of boilers and hot blast stoves much more efficient than previous practice. Combined with other technologies, such as pressure burners, the use of clean gas in modern stove practice greatly improved combustion and gas distribution and allowed operators to utilize higher blast temperatures.

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[66] O. O. Laudig, “Action of Blast Furnace Gases Upon Various Iron-Ores,” *Transactions of the American Institute of Mining Engineers* 26 (February- October 1896): 269-279; F. B. Richards, “Note on Slips and Explosions in the Blast-Furnace,” *Transactions of the American Institute of Mining Engineers* 28 (February-October 1898): 604-608, and 911-919; and F. Louis Grammer, “Flue-Dirt and Top-Pressure in Iron Blast-Furnaces: A Study on the Influences Controlling Them,” *Transactions of the American Institute of Mining Engineers* 34 (1904): 92-105.

[67] W. A. Barrows, “The Use of High Percentages of Mesabi Iron-Ores in Coke Blast-Furnace Practice,” *Transactions of the American Institute of Mining Engineers* 35 (1905): 141.

[68] The construction of more stable and air tight furnace tops to withstand increasing pressures and contain furnace dusts was pioneered by Julian Kennedy, an important iron and steel engineer who gained great fame as the superintendent of the Edgar Thomson Work’s blast furnace plant in the early 1880s. See Kennedy, “Some Modifications in Blast Furnace Construction,” *Iron Age* 79 (February 28, 1907): 650-653.

The internal lines of blast furnaces operating on Mesabi ores also began to change as hearths were being built larger and boshes, the widest part of the furnace, were lowered to improve combustion and the flow of material through the stack. Similar to technological developments in steel works that maximized the flow of materials through the plant, throughput became a dominant concept for furnace engineers operating on the easily reduced Mesabi ores. The wider hearth and lower bosh not only increased the working volume of blast furnaces, but it facilitated a rapid descent in the stack conducive to high-volume, high-quality iron production.[69] The development of large-hearth furnaces greatly increased the productive capacity of American blast furnaces, and by the 1920s and 1930s, the most advanced, large-hearth furnaces were producing upwards of 1000 tons of iron per day.[70] The mechanization of furnace operations and the use of Mesabi ores altered American ironmaking during the first half of the twentieth century and made the blast furnace a tool of modern industrial production. It is within this context of extraordinary technological changes that Carrie 6 and 7 achieved their national significance in American engineering history as examples of highly integrated and mechanized blast furnaces operating on the fine ores of the Mesabi Range.

Innovations at Carrie Furnaces 6 & 7

Soon after Carnegie Steel's takeover of the Carrie Furnace Plant (1898), it significantly upgraded and expanded the facility to meet the requirement of the Homestead Steel Works for pig iron. The original two furnaces were dismantled and rebuilt 90' high with hearth diameters 12'-6". The Riter-Conley Manufacturing Company, an important furnace construction firm in Pittsburgh, also built new furnaces, designated Carrie 3 and 4. According to the industry's leading trade journal, *Iron Age*, the furnaces were built in record time, and at a height of 105' with 23' boshes and 15' hearths, were considered "the largest and probably the most complete blast furnaces in the world."[71] Carrie 3 and 4 reflected a trend toward larger furnaces that had begun in England during the 1850s and America during the 1870s. Improvements were made on the mechanical equipment of the furnaces over the Duquesne plant built five years earlier. Among these were the use of a double-skip car hoisting system that improved the speed and capacity of charging operations. Unlike the single hoist that required the skip car to go through a complete cycle for a single charge, the double hoist accommodated two skip cars synchronized to alternate filling and dumping procedures. The furnaces were also among the first in the country to utilize a car dumper that mechanically emptied rail cars, greatly facilitating raw material handling operations at the plant. Although the furnaces were each designed to produce between 600 and 700 tons a day, Carrie No. 3 soon set a world record production mark of 790 tons in one day.[72] Furnace records, however, can be misleading. They were often staged and do not reflect the efficiencies—or inefficiencies—of everyday operations. In reality, Carrie 3 and 4, like other 100' furnaces built at the turn of the century to smelt Mesabi ores, experienced severe operational problems due to irregular stock movement inside the stack. While tall furnaces were considered more efficient in smelting hard, refractory ores, such "jumbo" furnaces, as they were called, proved inadequate for Mesabi ores. In 1905, furnace engineer Edward Uehling argued, "millions of dollars have been worse than wasted in the erection of furnaces of excessive height, which could have been saved if the problem had been properly studied in advance and the logical conclusions followed, instead of blindly copying others with the general idea of 'going one better'."[73] Another prominent furnace engineer

[69] Generally, the longer iron was forced to stay in the blast furnace the more chance it had to combine with impurities such as silica which lowered the quality of the iron.

[70] Henry M. Howe, "The Shape of the Iron Blast Furnace," *Engineering and Mining Journal* 86 (September 12, 1908): 507-511; J. G. West, "Principle Changes in Blast Furnace Lines," *Blast Furnace and Steel Plant* 6 (August 1918): 323-330; Walter Mathesius, "Development of Large Furnace Hearths," *Blast Furnace and Steel Plant* 8 (November 1920): 588-592; and Arthur G. McKee, "The Development of the Modern Blast Furnace," paper presented to the American Iron and Steel Institute Annual Meeting, September 1934, collection of the Hagley Museum and Library, Wilmington, Delaware.

[71] "The New Carrie Furnaces," *Iron Age* 67 (March 7, 1901): 11.

[72] Bridge, *Inside History of the Carnegie Steel Company*, 166; Sabadasz, "Modern Blast Furnace Practice," 100-101.

[73] Uehling's criticisms are found in the discussions of Louis Grammer's paper "A Decade in American Blast-Furnace Practice,"

observed in 1916, "With the results for the years 1902-1907 before us, during which period the percentage of fine Mesabi ores was on the increase, it is readily seen that our general blast furnace practice was going backward. [Since that time] Many changes were made in design, equipment and practice."[74] Between 1897 and 1905, the number of blast furnaces in the Pittsburgh District increased from thirty to forty-two, but the total ironmaking capacity of the region's furnaces doubled from about 2.6 million tons to over 5.4 million tons annually.[75] The construction of Carrie 6 and 7 in 1906-1907 was influenced by U.S. Steel's experiences with excessively large furnaces and reflected more sound ideas of furnace engineering that established a new model for smelting Mesabi ores. Typical of the development of American blast furnace practice, innovations made at the Carrie plant quickly diffused to other ironmaking facilities.

Excavations for Carrie 6 and 7 began early in 1906, and by April contractors were able to begin erecting the steel shells and structural framework. As was typical for U.S. Steel, company engineers designed the furnaces and established their specifications, but much of the construction work was contracted out to local engineering firms. The Pittsburgh iron and steel fabrication firm, Riter-Conley, received the contract for much of the construction work on the stacks and hot blast stoves, and the American Bridge Company was hired to install the ore handling equipment. Riter-Conley, one of the premier furnace building firms in Pittsburgh since the 1870s, was responsible for erecting the stacks and hot blast stove shells, piping, and other steel work which U.S. Steel masons would later line with the proper refractory brick. Unlike the 105' high Carrie 3 and 4 furnaces, Carrie 6 and 7 were built 85' high with 22' boshes and 14' hearths. Each furnace had a capacity of 500-600 tons of iron per day.[76] The construction of Carrie 6 and 7 revealed the latest engineering theories related to smelting Mesabi ores. As one English visitor to the Carrie plant observed in 1906, "the consensus of opinion is at present in favour of a blast-furnace with a maximum height of 80 or 85 ft., for the treatment of fine ores."[77]

When Carrie 6 and 7 were built U.S. Steel was moving toward the use of gas engines, first developed in Europe, for blowing their furnaces and powering electrical generators in their Monongahela Valley plants. Not only were gas engines considered more efficient at the time, but the high level of integration among the city's blast furnaces and steel works provided a ready outlet for excess electrical power. Moreover, the large Pittsburgh furnaces consolidated into multiple-furnace plants generated large volumes of gas, much of which was being wasted. It was estimated that a blast furnace plant utilized about 30-40 percent of its gas for generating steam and preheating the blast, with the remaining 60-70 percent available for ancillary purposes. Carrie 6 and 7 were equipped with four gas-powered blowing engines and two steam blowing engines to drive each furnace with about 30,000 cubic feet of air per minute. Steam engines were required to get the furnaces on line before they began to generate gas, or if the supply of gas became irregular. Generally, steam engines were not used in everyday operations.[78] According to an inventory by Mark Brown for the Historic American Engineering Record, the original gas cleaning system was comprised of dustcatchers and primary washers, along with secondary baffle washers, screen washers and Theissen rotary washers.[79] As gas exited the furnace it was channeled through a series of dry washing equipment such as dustcatchers and screen (or filter-type) washers, and wet washing equipment such as the Theissen rotary washers that forced the gas through water to further

976; for other discussions of Mesabi ores and furnace height see Guy R. Johnson, "Furnace Construction and Fine Ores," Iron Trade Review 29 (May 7, 1896): 9; Howe, "The Shape of the Iron Blast Furnace," 510-511.

[74] George W. Vreeland, "The Distribution of Raw Materials in the Blast Furnace," *Yearbook of the American Iron and Steel Institute* (New York: American Iron and Steel Institute, 1916), 106-173.

[75] "The Preeminence of Pittsburgh in Transportation," *Iron Age* 77 (March 22, 1906): 1022-1023.

[76] "Five New Blast Furnaces to be Built," *Iron Age* 77 (April 19, 1906): 1343.

[77] Popplewell, *Some Recent Conditions and Modern Developments in Iron and Steel Production in America*, 67-68.

[78] Brown, "United States Steel Homestead Works," 89-91; Sabadasz, "Modern Blast Furnace Practice," 101; "Blast Furnace Development in the Pittsburgh District," *Iron Age* 77 (May 10, 1906): 1567; David Roberts, "The Development of the Blast Furnace Blowing Engine," *Proceedings of the Institution of Mechanical Engineers* (July 1906): 384-387; Charles M. White, *Blast Furnace Blowing Engines: Past, Present—and Future* (New York: Newcomen Society of England, American Branch, 1947), 19-21.

[79] Brown, "United States Steel Homestead Works," 89-91.

remove entrained particles. Typical of blast furnace practice at the time, the primary system would have been utilized for gas burned in boilers and hot blast stoves, while the secondary system would have cleaned gas to be used directly in the internal combustion engines.

To preheat 30,000 cubic feet of air per minute to an operating temperature of 1000 to 1200°F, Carrie 6 and 7 were equipped with eight 90' high x 21' wide Massicks & Crooke's hot blast stoves. The English-designed Massicks & Crooke stoves were first introduced into the United States in 1887 and later given an American patent after they were modified to meet the more demanding requirements of American practice. Significantly, in the early 1890s the Carrie Furnace Company was one of the first in the United States to adopt the Massicks & Crooke stoves. The stoves were three-pass stoves, meaning that after combustion in the bottom of the stove gas passed up through the central combustion chamber, down the side heating chambers, and back up through the chambers before exiting the stove at the top through their characteristic top chimney. Bricks laid in a checker-type formation in the heating chambers absorbed the heat of the gas, passing that heat to the incoming cold blast from the blowing engines. During the early twentieth century Massicks & Crooke's stove was considered to be the most efficient on the market and was among the most widely used stove in new furnace installations of the period.[80] Consistent with current Mesabi practice, the stoves utilized relatively large 9" checker openings that reduced the build-up of flue dust. Such build-up decreased the thermal efficiency of stoves over time. Pre-heated air was delivered to each furnace through twelve tuyeres spaced equally around the hearth. The hot blast main leading from the stoves, and the bustle pipe encircling the base of the furnace, were arranged to distribute the blast equally to the twelve tuyeres to insure more uniform combustion and gas distribution inside the furnace.[81] Common among large integrated blast furnace plants, the blowing engines and hot blast stoves for Carrie 6 and 7 were arranged so that they could operate either furnace independently of the other if a situation arose that necessitated an interchange of equipment.

The raw material handling and charging equipment at Carrie 6 and 7 was typical of northern integrated plants. A large capacity ore yard capable of stockpiling a winter's supply of ore and limestone ran parallel to the furnaces and hot blast stoves. Two 7.5-ton ore bridges manufactured by the American Bridge Company of Pittsburgh handled raw material transport functions in the ore yard, segregating materials by grade, mixing ores, and transporting the ores and limestone to transfer cars that operated on the stocking trestle. Ore and limestone from the ore yard were dumped into the stockhouse bins suspended below the stocking trestle, while coke was brought directly to the stockhouse by bottom drop transfer cars from the coke plants. Unlike the iron ore and limestone, coke could not be stored in the ore yard for long because it deteriorated quickly form exposure to the atmosphere, hampering its metallurgical functions in the blast furnace. Stockhouse ore bins were constructed with steep walls because of the tendency of Mesabi ores to stick to the walls, while coke bins were equipped with rather flat and shallow walls because coke flowed better over a flat surface, and would break if dropped at a high velocity into the skip cars. Carrie 6 and 7 were among the first furnaces in the country equipped with screening systems to remove the fine dust and insure a higher quality fuel was charged into the furnace. Each skip car was fitted with a deflector plate that threw the charge toward the center of the receiving hopper on the furnace top for better distribution, and the hopper had an extended neck so that it could take a complete charge. Although many furnaces were being equipped with revolving tops, the Carrie furnaces had stationary tops with steam-powered bells. Furnace superintendent Jacob Mohr was an ardent supporter of the simple stationary top, and the trouble-free operations of the distribution equipment at Carrie 6 and 7 supported many of his claims.[82]

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[80] American Iron and Steel Institute, *Directory of the Iron and Steel Works of the United States and Canada*, 20th ed. (New York: American Iron and Steel Institute, 1926), 88; Walter Crooke, "Massicks & Crooke's American Patent Fire-Brick Hot-Blast Stoves," *Transactions of the American Institute of Mining Engineers* 19 (May 1890-February 1891): 1036-1040; and "McClure & Amsler's Hot Blast Stove," *Iron Age* 49 (May 5, 1892): 864.

[81] Mohr, "Method of Charging Raw Materials," 232-235.

[82] Ibid., 239-256.

Coordination of these functions was critical for successful operations, especially considering that each furnace had to be filled with about 2500 pounds of solid material every minute to produce 500 tons of iron a day.

Carrie 6 and 7 was by all accounts a well-balanced furnace complex that combined the most modern technologies with more traditional technologies suited to smelting the troublesome Mesabi ores. Unlike smaller companies that had to grade their ore at the furnace plants, U.S. Steel pre-graded their ore at the docks so that furnace superintendents knew the quality of ore they were receiving. This greatly improved their efforts for ore could be quickly segregated by grade in the ore yard as it came into the plant facilitating the maintenance of uniform conditions. Because of the furnaces' primary function of supplying the open hearth furnaces with basic iron of a uniform grade, strict control over the quality of raw materials and the mixing of charges were central concerns. Consistent with the Mesabi practice discussed above, Mohr initiated stratified and volume charging at Carrie 6 and 7 to stabilize stock distribution and descent in the furnace. During tapping, iron was run directly to ladle cars that transported the hot metal over the hot metal bridge to the open hearth furnaces at the Homestead plant, while slag was run into granulating pits where it would solidify and later be utilized in cement-making, road ballast, or fill. By 1912, the Carrie furnace plant produced nearly 1 million tons of iron annually and was capable of generating 15,200 kw of power for the Homestead Steel Works. That same year the nation's total output of iron was just over 30 million tons.[83]

The construction of Carrie 6 and 7 was undertaken during an extremely active period of furnace building in the United States. During the first half of 1907, over 1.3 million tons were added to the nation's ironmaking capacity—the largest increase ever in American history up to that time. By the end of 1908, Pittsburgh had forty-eight blast furnaces with an annual capacity of nearly 7.3 million tons, or 30 percent of the nation's total ironmaking capacity. Thirty-two of these furnaces were owned by the Carnegie Steel Company, by then a subsidiary of U.S. Steel and emblematic of the high level of integration of iron and steelmaking operations in the Pittsburgh District - only two furnaces in the city sold iron on the open market. The growing demand for steel in America ensured a steady market for the nation's blast furnaces.

The engineering and metallurgical concerns that guided the construction of Carrie 6 and 7 had a direct impact on other U.S. Steel facilities, most notably the furnace plant at the new Gary Works, Gary, Indiana, considered to be the most modern, rationally-planned steel works in the world. Construction of the new Gary blast furnace plant commenced soon after construction of Carrie 6 and 7, and the Gary facility adopted the same furnace lines, hot blast plant, and blowing engines as those used at Carrie 6 and 7.[84] While steel production was moving westward to the lakefront facilities around Chicago, Illinois, and Gary, Indiana, with better access to ores and the fast-growing western markets, Pittsburgh was still the unquestioned world leader in iron and steel production. The concentration of the iron and steel industry in the Pittsburgh District, moreover, stimulated the development of ancillary metal consuming industries, as the region became the leading industrial district in the country. The shear volume of material passing through the city was staggering. At the time Carrie 6 and 7 were built, the total freight tonnage moving in and out of Pittsburgh reached more than 100 million tons annually, equal to the combined totals for London, New York, Antwerp, Hamburg and Hong Kong and three times as much freight as Chicago, widely considered America's preeminent rail distribution center.[85] At this time, the Homestead Works was not only the largest, most productive steel mill in the Monongahela Valley, but it was the largest steel works in the world. The Monongahela Valley increasingly took on the characteristic of

[83] Ibid.; "Method of Charging Raw Materials," 239-256; and Carnegie Steel Company, *General Statistics and Special Treatise on the Homestead Steel Works*, 16-21; Stoughton, *Metallurgy of Iron and Steel*, 5.

[84] For a thorough overview of the development of the Gary furnace plant see, "The Greatest Steel Plant in the World, I," *Iron Age* 83 (January 7, 1909): 3-11.

[85] "New Blast Furnace Capacity," *Iron Age* 80 (July 11, 1907): 104; "The Pre-eminence of Pittsburgh in Transportation," *Iron Age* 77 (March 22, 1906): 1022-1023; and Warren, *Triumphant Capitalism*, 313-324.

an integrated regional production system that extended from the coal patch towns to the south, to the massive iron and steel production complexes near Pittsburgh.

By the 1920s, developments in blast furnace practice nationwide and changes in the supply of fuel to Pittsburgh blast furnaces had a decided impact on operations at Carrie 6 and 7. Hearth diameters had been increasing steadily since the construction of the first modern furnaces in the Pittsburgh District in the 1870s. In the last thirty years of the nineteenth century, hearth diameters for the largest furnaces doubled from 7' to about 14'. Most furnace engineers were reluctant to construct hearths much larger than 14' or 15' out of fear that the blast could not penetrate the bed of fuel across such a large area to support complete combustion. In the years preceding World War I and in its immediate aftermath, however, the trend was to build much larger hearths and increase wind volume to maximize combustion. Emblematic of these developments was the construction of a new furnace at the South Works of Illinois Steel, another subsidiary of U.S. Steel, the first to have a 20' diameter hearth. Because of their large output and low fuel consumption when smelting Mesabi ores, the progressive enlargement of furnace hearths became the dominant technological concept of American blast furnace practice between the World Wars.[86] Another important development for Carrie 6 and 7 and the other blast furnaces of the Pittsburgh District, was the opening of U.S. Steel's by-product coke works in Clairton, Pennsylvania, located on the banks of the Monongahela River southeast of Homestead. The plant was designed to coke the high-volatile coals from the vicinity of Greene County, Pennsylvania, that could be transported to the facility by water at much cheaper rates than coal from the once dominant Connellsville Region. Although the coke produced at Clairton was a lower metallurgical grade, the economies of by-product coking for operations in the Pittsburgh District was all the inducement U.S. Steel needed to invest in the plant.[87] The use of Clairton coke had an important impact on furnace operations in the Pittsburgh District. For the first time Pittsburgh furnaces were forced to use inferior fuel compared with furnace operations in other districts such as Chicago. As the superintendent for the Carrie furnaces, James Lose, noted:

Much credit must be given to this plant (Clairton) for their marked success in producing the existing quality of metallurgical coke from an admittedly poor grade of raw material, nevertheless the coke is inferior to that produced by ovens using a mixture of high and low volatile coals. The features of cost, however, does not permit the use of low volatile coals at this plant and it becomes necessary for the furnace operator to use every means at his disposal to compensate for the deficiencies existing in coke quality.[88]

Consistent with the changes in furnace engineering, the hearth diameters of Carrie 6 and 7 were increased when new linings were installed in the furnaces in 1920. Relines were necessary operations due to the limited life of firebrick under the intense physical and chemical actions of the blast furnace, particularly under hard-driving conditions. Although some furnaces were producing more than 1 million tons on a single lining by the 1920s, it was more typical for furnaces to get around 700,000 tons per lining with existing refractory material.[89] As noted above, relines were good times to change the internal lines of the furnace to meet the most current engineering theories. By the spring of 1925, Carrie 6 and 7 could not be enlarged to any greater proportions because of the relatively small shells of their 1907 construction. In April of that year, U.S. Steel initiated a rebuilding campaign of both furnaces that included a remodeling of practically all the auxiliary equipment of the plant to serve the increased capacity of the furnaces.

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[86] For example see H. E. McDonnell, "Blast Furnace Progress in 1924," *Blast Furnace and Steel Plant* 13 (February 1925): 66-72; H. E. McDonnell, "Blast Furnace Progress in 1925," *Blast Furnace and Steel Plant* 14 (January 1926): 16-17; and Blast Furnace and Coke Association, *The Modern Blast Furnace and Auxiliaries* (Chicago: Blast Furnace and Coke Association, 1930), 2-62.

[87] Warren, *Triumphant Capitalism*, 324-329.

[88] Lose, "The Operation of Large Hearth Furnaces," 87.

[89] G. G. Coolidge, "Setting New Standards for Blast Furnace Runs," *Blast Furnace and Steel Plant* 25 (May 1937): 493-495. Later advances in brick making, including the development of power-pressed brick and carbon brick, greatly increased the life of furnace linings.

Perhaps the most significant change was the enlargement of the furnaces themselves, which were both built with 21'6" hearths, 24'9" boshes and 17'3" stocklines. These changes increased capacity from 500-tons per day to 700-tons per day. Increasing the productive capacity of the furnaces required more wind volume, greater blast heating capacity, and increased raw material handling capabilities. The original large checker 21' x 90' hot blast stoves were raised 20', relined with smaller checkers and fitted with pressure burners to improve combustion and heating capacity in proportion with increased wind volumes. Because of the smaller checkers, concerns of flue dust became more important, leading to the installation of Feld-type gas washers to improve the quality of gas burned in both the stoves and boilers. The blowing engines were rebuilt with larger gas and air cylinders, increasing their capacity from 30,000 cu. ft. per minute to 50,000 cubic feet per minute. Because of the increased material handling needs the stockhouse was enlarged and equipped with improved bins and larry cars that automatically recorded the weight of each charge. Larger, electrically-powered, high-speed skip cars were installed that were interfaced with the controls of the charging bells at the furnace top so that the operation of the bell was mechanically dependent upon the position of the skip cars. These changes to the stockhouse reduced labor requirements from five men per furnace to only one man per furnace. Sensitive to future needs, engineers designed the stockhouse to supply the demands of a 900 ton per day furnace. With Clairton coke and an ore mixture comprised of 90 percent Mesabi ores and 10 percent “old range” ores, both Carrie 6 and 7 began to average about 750 tons of hot metal a day with a coke consumption of less than one ton for every ton of iron produced.[90]

According to the *Directory of Iron and Steel Works in the United States and Canada* published by the American Iron and Steel Institute, Carrie 6 and 7 were both relined in 1928, at which time their hearths were further enlarged to 22'6" with bosh diameters 25'6". The late 1920s was a period of increased demand for steel in America, and most furnace plants and steel works were operating at full capacity. In the immediate years before the American Depression, the Carrie Furnace Plant had an annual capacity of over 1.5 million tons of iron.[91] Pittsburgh continued to lead the nation in iron and steel production, and the city’s industrial communities were home to fifty-nine blast furnaces, by far the highest concentration of stacks anywhere in the country.[92]

Depression, War, and Contraction

During the late 1920s there were movements toward even larger capacity blast furnaces, symbolized by the 1929 construction of a furnace with a 25' hearth in Youngstown, Ohio. Because of the economic conditions of the 1930s, however, few of these large stacks were built as the demand for iron and steel declined dramatically. Indicative of the period, active blast furnace capacity nationwide in 1932 dropped to below 20 percent, and production that year dipped below 10 million tons. For much of the 1930s, those furnaces that remained productive were driven much slower than during normal operations, and few furnaces required new linings between 1930 and 1936. During the Great Depression, Carrie 6 and 7 continued to produce iron at a greatly reduced rate, and Carrie 5 was shut down permanently and later dismantled. By 1937, the American steel industry began to recover and pig iron production reached a high mark for the decade at 41.5 million tons. Furnace engineers picked-up where they had left off in the late 1920s and began to build much larger furnaces, greatly increasing America’s ironmaking capacity while reducing the total number of furnaces nationwide. In the fifty years prior to 1938, the number of blast furnaces in America decreased by 60 percent, while the

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[90] Details of the rebuilding of Carrie 6 and 7 can be found in Lose, “The Operation of Large Hearth Furnaces,” 84-88; “Blast Furnace Development,” *Iron Age* 118 (September 30, 1926): 943; and James Lose, “Operation of Large Hearth Furnaces,” *Iron Age* 119 (May 26, 1927): 1517-1519.

[91] American Iron and Steel Institute, *Directory of Iron and Steel Works of the United States and Canada*, 22nd ed. (New York: American Iron and Steel Institute, 1935), 84.

[92] “Increase in Active Stacks,” *Iron Age* 115 (February 5, 1925): 424.

nation's ironmaking capacity rose over 300 percent.[93] Equally important for the future of Carrie 6 and 7 was the consolidation of production within a blast furnace plant to fewer units. Particularly after World War II, furnace plants that formerly had as many as eight or twelve blast furnaces reduced the number of operating units while at the same time increasing production through much larger units and improved techniques.

In 1936-1937 Carrie furnaces 6 and 7 were substantially rebuilt for the last time in their history. The furnaces were enlarged to their current working volume of 31,558 cu. ft., with 23'6" hearth diameters and 27' boshes, increasing their daily output to 900-1000 tons. New furnace shells were constructed with 2.5" thick steel plate supported by ten mantle columns spaced equally around the circumference of the stack. To better distribute the flow of gas from the furnace top, the original two uptakes were replaced by the current four uptakes, each fitted with a bleeder valve that released gas into the atmosphere whenever there was an overload of the gas cleaning system. Pneumatic-powered hoisting machinery manufactured by the Otis Company was installed to improve charging operations. This hoisting machinery provided much greater speed, regularity, and power to the mechanical charging system. The most significant alteration to the plant was the construction of a completely new hot blast plant with six 104' x 24' double-pass hot blast stoves with lateral combustion chambers. Consistent with contemporary trends in furnace engineering, the stoves' steel shells were welded rather than riveted, which improved their strength while reducing their weight and construction costs. A single stack was built adjacent to Carrie No. 7 to exhaust the combustion gases of the hot blast plant. Cast house operations were improved with the addition of a new electric mud gun and control house, cable-operated gates for the iron runners, and improved tap-hole drill.[94]

In the years before World War II, Carrie 6 and 7 were typical of the large, modern American blast furnaces of the period. In 1938, for instance, there were eighty-one furnaces, including Carrie 6 and 7, that had hearth diameters between 20' and 25', and only ten stacks that had hearths larger than 25'. By the end of World War II, however, there were about forty furnaces with hearth diameters larger than 25', including Carrie 3 and 4 which became the primary producers for the Homestead Works in the post-war years. These much larger furnaces produced well over 1000 tons per day, and required extensive changes to the auxiliary plant to better coordinate functions for much larger volumes of material. Investment in wartime production was geared toward maximizing output regardless of the costs, and according to William Hogan the majority of capital was put into facilities that would be used by the industry for years to come. Developments in furnace technology made during World War II shaped furnace construction during the post-war years. In 1946, the average large furnace had a cubical capacity of over 50,000 cu. ft., and produced 1300 tons of iron per day. New furnace construction declined in the years following World War II but the new furnaces that were built and those that were modernized were almost all built following the trend toward much larger production units—i.e. furnaces with hearth diameters well over 25'. At this time, Carrie 6 and 7 had working volumes under 32,000 cu. ft. and produced approximately 900 tons of iron per day.[95] Broader economic considerations of U.S. Steel, and the declining importance of Pittsburgh as a steel production district, removed the impetus for increasing capacity that shaped the evolution of Carrie 6 and 7 between 1907 and World War II.

Post-war developments in the Pittsburgh District were indicative of a larger restructuring of the American iron and steel industry. Between 1925 and 1946, the number of blast furnaces in the district declined from fifty-nine to forty-six, three of which were government-financed stacks built during the wartime expansion of iron and

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[93] Hogan, *Productivity in the Blast Furnace and Open-Hearth*, 38-40; "Summary by Years Showing When Blast Furnaces in the United States Were last Relined and Rebuilt," *Iron Age* 137 (January 30, 1936): 55-A; and "60 Percent Fewer Blast Furnaces than in 1889," *Iron Age* 142 (November 10, 1938): 55-A.

[94] Brown, "United States Steel Homestead Works," 89-91; *Directory of Iron and Steel Works in the United States and Canada*, 25th ed. (New York: American Iron and Steel Institute, 1948), 89; "News of the Plants," *Steel* 102 (January 3, 1938): 280.

[95] Hogan, *Productivity in the Blast Furnace and Open-Hearth*, 14-15, 39-40; and *Directory of Iron and Steel Works in the United States and Canada*, 25th ed. (New York: American Iron and Steel Institute, 1948), 89.

steel making capacity in the region.[96] Of the forty large-hearth furnaces in the country, only ten were located in the Pittsburgh District, including the three government-financed stacks and four new stacks built in Aliquippa by the Jones and Laughlin Steel Corporation. Despite this decline in the number of blast furnaces, total ironmaking capacity for the region increased to over 16.5 million tons in 1946, still nearly 25 percent of the nation's total. The largest concentration of blast furnaces (eighteen) with hearths larger than 25' in diameter in 1946 were located in the Great Lakes Region, where producers had easy access to low-cost, high-grade ores.[97] Despite the tremendous increases in iron and steel making capacity in the Pittsburgh District during the war years, through the 1950s and 1970s Pittsburgh's share of the nation's output continued to decline relative to its position since the American Civil War. Between 1947 and 1968, Pittsburgh's output of steel ingots increased from 22.3 million tons to 25.3 million tons, while the national output increased by more than 45 million tons.[98] Unlike the open flatlands along the Great Lakes, Pittsburgh's river front mills offered little room for expansion with the city's mills primarily geared toward the production of heavy steel products such as plate and structural shapes that dominated the market in the first half of the twentieth century. During the post-war economic boom, automobiles, appliances, and other consumer goods dominated an increasing share of the market. Production of these goods, moreover, was heavily concentrated in the Midwest closer to the fast-growing western markets. U.S. Steel and other integrated producers invested heavily in new sheet and tin mills to supply these new demands and looked toward the Great Lakes Region as the principle area of expansion. Despite its locational disadvantages and older stock of equipment, the highly-skilled labor in the Pittsburgh District and efforts to better consolidate and integrate operations among the region's production facilities, worked in its favor. In 1970, just a decade before the collapse of the steel industry in Pittsburgh, the city was still one of the eight largest steel producing districts in the world.[99] This, however, was a far drop from its prominence in the industry since the Civil War.

Post-War Blast Furnace Developments

In the twenty-five years following World War II, significant changes in American blast furnace construction and practice occurred that greatly improved their efficiency and productivity. Engineers continued to build much larger stacks, and by the 1960s, many furnaces were equipped with hearths larger than 30' in diameter producing more than 3000 tons of iron per day with the same furnace crews required in the 1000-ton furnaces of the World War II era. Increasing capacity, however, was not the only reason for improved productivity. Better raw materials, greater operating temperatures, increased blowing rates, higher furnace pressures, and improved instrumentation and material handling equipment all contributed to the gains in furnace output. During the 1950s and 1960s, great improvements were made in the beneficiation of iron ore that increased the iron content and lowered the percentage of impurities through a number of technologies, including concentration and agglomeration. In 1950, most of the ores used in American blast furnaces were charged directly from the mines, but by 1963 over 75 percent of the ores used in America were improved by some intermediary beneficiation process. Efforts were also made to improve the smelting capability of fine ores through pelletization technologies that agglomerated fine ores and dust into 1" to 2" diameter pellets that were roasted to drive-off moisture. These improvements in ore processing not only increased the iron content of the raw materials, but also improved furnace operations. Furnace gases were better able to permeate the descending stock column and less dust was produced because of the decrease in the use of crude ores. Better stock

[96] Two of the government-financed blast furnaces were constructed at U.S. Steel's Edgar Thomson Works, and another was built at the Monessen Works of the Pennsylvania Steel Company. After the war, the government sold these production units to the respective companies.

[97] Statistical information on the size of individual blast furnaces in the United States can be found in T. J. Ess, "The Modern Blast Furnace," *Yearly Proceedings of the Association of Iron and Steel Engineers* (Pittsburgh: Association of Iron and Steel Engineers, 1946), app., 238-241.

[98] Warren, *American Steel Industry*, 285.

[99] Warren gives a good overview of post-war conditions in the Pittsburgh District in *The American Steel Industry*, 285-291.

distribution and descent also allowed operators to greatly increase their blowing rates, often to levels greater than 100,000 cubic feet per minute, and increase their blast temperatures between 1500°F and 2000°F. These developments not only improved the physical output of blast furnaces but also improved their overall efficiency. Between 1955 and 1970, the average consumption of ore per ton of iron declined more than 10 percent, consumption of limestone decreased by 36 percent and coke consumption fell 28 percent.[100]

Consistent with the history of American blast furnaces, larger furnace units and changing raw materials that improved furnace output required alterations in their auxiliary equipment. In the post-war years, most new furnaces were equipped with high-pressure tops that reduced the velocity of the gas and increased the internal pressure to as much as 30 lbs. per sq. in. Combined with the increasing use of processed ores, high-top pressures forced a more intimate contact between the ascending gas and the descending stock column. Innovations were also made that improved the quality of the blast through oxygen enrichment and fuel injection (liquid, gaseous and powdered hydrocarbons) directly through the tuyeres into the furnace hearth to maximize combustion and minimize the duty of the coke charged into the furnace top. According to Kenneth Warren, by 1963 one-half of all blast furnaces in America were equipped for auxiliary fuel injection. Increased output necessitated changes to stocking and material handling operations at most post-war facilities. Automated conveyors that operated at much greater speeds and higher carrying capacity replaced the old stockhouse with its bins and larry cars. On many newer stacks, the skip hoist and charging bell were replaced by continuously operating conveyors and pressure-sealed charging funnels, such as the Paul-Wurth 3-lockhopper bell-less tops. These provided much greater control over the distribution of the stock in the furnace and their ability to handle large volumes of material greatly increased the potential for greater outputs. Technological advances not only improved the efficiency and productivity of American blast furnaces but also greatly increased the cost of new furnace plants. In 1948, two blast furnaces and their auxiliary equipment could be built for about $11 million, but by 1970 the cost of one modern blast furnace and its auxiliary equipment was well over $50 million.[101] In 1990, the cost of a 5,000-ton per day blast furnace and auxiliary plant reached $500 million. Such high capitalization costs have reduced the chances that any company will build a new blast furnace in the United States in the immediate future and the focus has been on maximizing output and extending the campaigns of existing stacks, many of which are large enough to supply an entire steel works with hot metal. Bethlehem's L furnace, for instance, can supply about a million more tons every year to the Sparrows Point Works, than the entire Carrie Furnace Plant could to the Homestead Works at the height of its production.[102] These single-unit furnace plants signify a marked departure from the economic and technological factors that led to the development of the Carrie Furnace Plant in the early twentieth century.

During the thirty-three years after World War II that Carrie 6 and 7 continued to produce iron for the Homestead Steel Works, they retained their 23'-6" hearths and their working volume of 31,558 cubic feet. Economic and technological considerations focused efforts increase ironmaking capacity at Carrie 3 and 4, which became the primary iron producers at Homestead during the post-War years. Reflective of this development, in 1957 Carrie No. 3 became the first blast furnace with a 28' hearth built by U.S. Steel in the Monongahela Valley. Carrie No. 4 was rebuilt along the same lines in 1959. These furnaces had working volumes over 51,000 cu. ft., and were blown by a turboblower capable of generating 135,000 cu. ft. of air per minute at a pressure of 42 pounds per square inch.[103] A number of improvements were initiated at Carrie 6 and 7 during the post-war years that improved their efficiency and productive capacity. Among the most significant

[100] Warren, *American Steel Industry*, 248-255; Hogan, *Economic History of the Iron and Steel Industry in the United States*, 4:1511-1519; and Bela Gold et al., *Technological Progress and Industrial Leadership: The Growth of the U.S. Steel Industry, 1900-1970* (Lexington, MA: DC Heath, 1984), 305-309.

[101] Hogan, *Economic History of the Iron and Steel Industry in the United States*, 4:1517.

[102] For a good overview of current blast furnace conditions see George W. Hess, "Is the Blast Furnace in its Twilight?" *Iron Age* 5 (November 1989): 16-26.

[103] Brown, "United States Steel Homestead Works," 89-91; *Directory of Iron and Steel Works*, 34th ed., 300.

change was the use of Ingersoll-Rand low pressure turboblowers that were originally installed to blow Carrie 1 and 2 in 1924. In the mid-1950s, these blowing engines, located in the No. 3 power house adjacent to Carrie 3 and 4, were switched to provide Carrie 6 and 7 with blast, and the original gas and steam-powered blowing engines were taken off line. The U.S. Steel Applied Research Laboratory conducted numerous studies of the Carrie 6 and 7 hot blast plant in the mid-1950s to improve the heat generating capacity of existing stoves. During this period, blast temperature requirements were increasing because of the more refractory sintered ores that were being used at U.S. Steel's Monongahela Valley blast furnaces. By changing the heating and cooling cycles of the stoves, and increasing the rate of gas flow into the combustion chamber, U.S. Steel was able to attain straight-line operating temperatures of 1600-1800°F.[104] To improve the quality of gas burned in the stoves, electrostatic precipitators manufactured by Research-Cottrell were added to the furnaces' gas cleaning system in 1956. These precipitators had a working capacity of 93,000 cubic feet per minute. In 1968, the Feld gas washers that were installed during the 1926 modernization of the furnaces were replaced by new gas washers manufactured by the S. P. Kinney Company that could handle 90,000 cubic feet of gas per minute.[105] The extant gas washers and electrostatic precipitators are the only primary equipment that were built after the period of significance.

In 1951, the ore yard for Carrie 6 and 7 was equipped with a new 15-ton ore bridge to replace the two original 7.5-ton bridges built in 1907. The new, steel-framed ore bridge, manufactured by the Pittsburgh-based Dravo Engineering Corporation, was composed of a 186' long warren truss span supported by two pier legs set on a motor-powered, eight-wheeled railroad truck that operated on rail lines on the northern and southern walls of the ore yard. The ore bridge was about 100' above the ore yard, and extended over the Harbor Line of the Monongahela River about 27' so that the hoisting trolley could operate over the railroad track nearest the river.[106] While the function of the bridge was the same as the original ore bridges, its greater handling capacity and operating speed improved the overall efficiency of the two blast furnaces. The existing bridge is an important resource in the proposed district. It shows how plant engineers integrated new technologies as they increased the efficiency and productive capacity of their ironmaking systems. Its construction after the district's period of significance, however, makes it a noncontributing resource to the proposed NHL.

ASSESSING POTENTIALLY COMPARABLE PROPERTIES

Carrie 6 and 7 are extremely rare examples of American industrial material culture. As an artifact of American technology and industry, the modern blast furnace is an endangered cultural resource. The consolidation of furnaces in areas where raw materials, capital, and labor could be assembled greatly increased the efficiency of modern production, but it also left these artifacts vulnerable in their post-production lives. Indicative of this, there are no extant blast furnaces from the late nineteenth century from which we can interpret the early development of modern iron smelting in America, while there are many extant nineteenth century stone furnaces in parts of the eastern United States. The rapid collapse of the steel industry in Pittsburgh and the complete dismantling of the region's largest production facilities has left the city with few remaining artifacts of its once dominant industry. This process of de-industrialization has also affected the physical landscape of the country's other iron and steel producing districts, including Youngstown and Cleveland, Ohio; Buffalo, New York; and Chicago, Illinois.

Brian Bliss, furnace engineer for American Iron and Steel Engineer (AISE), has noted that furnaces of Carrie's vintage were generally torn down completely, or picked of their component technologies after they were taken

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[104] Knepper and Campbell, "Temperature Distribution in the Blast Furnace Stove," 115-124.
[105] Brown, "United States Steel Homestead Works," 90.
[106] Ibid., 88; and "Harry Richter to the U.S. Army Corps of Engineers, February 9, 1950," in Permits for Structures in Navigable Waters, Permit No. 88076, Pittsburgh District, U.S. Army Corps of Engineers, Federal Building, Pittsburgh, Pennsylvania.

off-line to service blast furnaces still producing iron.[107] This point is reinforced by John Salo, former superintendent of the Edgar Thompson Works blast furnace plant and retired president of Blast Furnace Dynamics, an industry consulting company based in Pittsburgh. Salo notes that it is common practice in the industry to "cannibalize" older equipment to keep newer furnaces online.[108] Increasing tax liabilities and the rising cost of scrap metal, moreover, has led many companies to dismantle their obsolete equipment. The enormous expense of new furnace construction and the industry-wide movement toward mini-mills has reduced the possibility that new production units will be built in the United States in the near future. Companies are extending the life of their existing furnaces by upgrading processes and technologies, but some furnace engineers question whether there will be any active blast furnaces in the United States before long. A challenge for preservationists is determining the comparability of furnaces in different regions that have been frequently refitted and updated. Another key question is whether or not these industrial facilities continue to possess a level of historic integrity required for NHL eligibility. Based upon research into the development of blast furnace technology, there are certain key assumptions about the existing stock of mid-twentieth century furnaces that can be made:

1) Blast furnaces, like most industrial equipment, were continually upgraded and modernized during their productive lives to take advantage of new technologies, practices, and efficiencies. Consequently, all furnace plants have multiple layers of component technologies from different periods in their history. Many furnaces, moreover, have no components remaining from their original construction, except, perhaps, their foundations. This is an inherent characteristic of these resources, and it is important to understand since NHL standards demand a high degree of integrity.

2) Because of the complexity of these sites, it is almost impossible to determine the exact age of the different elements of these resources. A complete picture of their integrity can only be determined through a thorough documentation effort that is beyond the scope of this analysis. As is made clear elsewhere in the nomination, access to the Carrie site was severely limited by the previous owners.

3) Modern integrated iron production requires huge ancillary plants to provide raw material stocking and handling functions, continual hot blasts, waste gas collection and cleaning facilities, and hot metal and slag distribution systems. Increases in the productive capacity of furnaces requires changes to the auxiliary equipment to handle ever-increasing volumes of material going into the stacks, and iron, slag, and waste coming out. Older furnaces that are part of a more modern facility were often serviced by modern equipment. It is very rare to find furnace stacks, hot blast plants, engine houses, and material storage and stocking equipment of the same vintage as seen see at Carrie 6 and 7.

4) Blast furnaces built prior to World War II that were actively producing iron in the 1980s or 1990s were probably upgraded significantly. Such furnaces have little chance of NHL eligibility.

Potentially comparable resources to Carrie 6 and 7 were considered with these assumptions in mind. Therefore, any furnaces that may have been built originally during the period of significance for Carrie 6 and 7 (1906 to 1941) and continued to produce iron into the second half of the 1980s, the 1990s, or are currently producing iron, were not considered as a comparable resource to the proposed furnaces. The furnaces considered in this report were selected based upon a number of factors, including: chronology, production system, furnace practice, and regional connections.

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[107] Brian Bliss, American Iron and Steel engineer, phone conversation with author, April 27, 2002. "Off line" is a term that refers to a furnace's non-productive life.

[108] John Salo, former superintendent of the Edgar Thompson Works blast furnace plant and president of Blast Furnace Dynamics, phone conversation with author, March 22, 2003.

Chronology

Carrie 6 and 7 were under construction in 1906 and their period of significance extends from 1906 through 1941. The proposed district has a large percentage of resources dating to the 1920s and 1930s. Any comparable resource must represent pre-World War II technologies. While component technologies and practices have changed in the half-century since World War II, the basic process of making iron remains the same.

Production System

Typical of integrated iron and steel production systems, Carrie 6 and 7 were built as a pair and operated as a unit. The furnaces had two primary functions within the integrated steel works: the production of iron for the Homestead Works open-hearth steelmaking plant, and the production of gas for power generation. Comparable resources must have component technologies that reflect iron production in an integrated steel mill. For instance, the Sloss Furnaces NHL would not be considered a comparable resource to Carrie 6 and 7 since it operated under a different production system geared to the production of pig iron for sale on the open market. These were merchant furnaces, not integrated furnaces.

During the early twentieth century when Carrie 6 and 7 were built, the dominant approach to new furnace construction was to build paired units with shared raw material storage and handling equipment, hot blast plant, and blowing plant. Carrie 6 and 7 represent this approach to modern integrated iron production.

Furnace Practice

Furnace practice is a subtler issue. Carrie 6 and 7 were constructed during a period of rapid technological change in the smelting of Mesabi ores with Connellsville coke. In fact, as argued elsewhere in the nomination, Carrie 6 and 7 were built following new theories in the smelting of these ores and subsequently became a model for new furnace construction where these ores were primarily smelted. The importance of this point cannot be overestimated. During the furnaces’ period of significance, Mesabi ores were the most important commercial ores in the United States. Changes in practice are not readily apparent from exterior observations of these resources, but they are inherent in the history of the furnaces during their period of significance.

Regional Connections

Historic iron and steelmaking sites must be evaluated within their regional context. Current research into the development and evolution of blast furnace technology has highlighted the importance of regional markets, raw material use, and production style in furnace practice. Pittsburgh producers, for instance, operated their furnaces differently than Chicago or eastern producers, such as Bethlehem, because of differences in ore and fuel supply and different traditions of furnace practice. Geography mandated differences in layout and design of these sites. Moreover, regionalism is important to understanding national significance when we consider Pittsburgh’s role as a center for innovative technological change in blast furnace construction and operation.

These distinctions provide a framework to evaluate Carrie 6 and 7 in relation to potentially comparable blast furnaces still standing in the United States. It should be noted, however, that furnaces built in the 1950s and 1960s were not significantly different than furnaces built during World War II. There were no breakthrough technological changes that altered the way iron is produced. Each new generation of furnaces, however, included advances in monitoring and production technologies that allowed producers to increase the capacity and efficiency of their stacks. Changes in raw materials, moreover, necessitated changes to material handling and stocking equipment, as well as changes in furnace operations such as blowing rates and blast temperature.

The American steel industry is facing many problems and there is a good chance that over the next ten years many more blast furnaces from the 1950s and 1960s will be inactive. These furnaces will have to be evaluated separately to determine possible NHL eligibility.

Evaluation of Comparable Resources

There are ten facilities in United States that currently contain blast furnaces originally constructed prior to or during World War II. The following table provides basic information about these resources, including: company and plant information, furnace designation (name), original construction dates when known, current hearth diameters, and recent production history. An "X" in the field indicates that the furnace was producing iron in the corresponding year.[109]

Company/Works

Acme Steel Company Chicago Works	A Furnace			25'	X	X	X
	B Furnace	1909	1931/1970	19'8"			
AK Steel (Armco) Middletown Works, OH	Furnace No. 1	1908	1928/1938	18'6"	X		
Bethlehem Steel Company Bethlehem Works, PA	A Furnace	1903	1941				
	B Furnace	1954					
	C Furnace	1939	1943	27'11	X	X	
	D Furnace	1954		30'	X	X	
	E Furnace	1959					
Gulf State Steel Gadsden Works, AL	Furnace 2	1942	1966	26'	X	X	
Ispat Inland Inc. (Inland Steel) Indian Harbor Works, IN	Furnace 1	1907	1939/1940	20'9"	X		
	Furnace 2	1912	1927/1940	19'10	X		
	Furnace 5	1939	1974	26'6"	X		
National Steel Company Granite City Works, IL	A Furnace	1920		27'3"	X	X	X
	B Furnace	1926		27'3"	X	X	X
Rouge Steel Company Dearborn Works, MI	B Furnace	1922	1935	20'		X	X
USX/U. S. Steel Edgar Thompson Works, PA	Furnace 3			25'3"		X	X
Republic Technologies Int. (USX/Kobe Steel) Lorain Works, OH	Furnace 1	1899	1930	23'	X	X	
	Furnace2	1899	1937	23'			

[109] This furnace list was compiled from a variety of sources, including a 1996 survey of extant blast furnaces by J. Richard Rowlands, former president of the Jeanette Blast Furnace Preservation Association, Youngstown, Ohio, discussions with industry representatives associated with the American Iron and Steel Engineers and the Iron and Steel Society; and the annual "Blast Furnace Round-up," published in *Iron and Steelmaker*, a publication of the Iron and Steel Society.

Wheeling-Pitt Steel Company Steubenville Works, OH	1 North	1904	1929/1991	25’	X	X	X
	2 North	1904	1926	23’10			

Of these twenty furnaces, six were producing iron in 2002, ten were producing in 1992, and twelve were producing iron in 1988. Only four of these furnaces have not produced iron since 1988.[110] They include:

A Furnace, Bethlehem Steel Works, Bethlehem, Pennsylvania
B Furnace, ACME Steel Company, Chicago Works, Chicago, Illinois
Furnace 2, Republic Technologies, Int. (USX/Kobe), Lorain Works, Lorain, Ohio
2 North, Wheeling-Pitt Steel Company, Steubenville Works, Steubenville, Ohio

These four furnaces are single unit resources associated with larger blast furnace plants and steel works. There are also three furnaces that were producing iron into the late 1980s that are also potentially comparable to the proposed NHL furnace district. These furnaces are included despite assumption #4 above, because they retain a small size (20’ hearths or smaller) more reflective of the scale of World War II-era production. It is possible that these furnaces also retain much of their original equipment despite the fact that they continued to produce iron into the 1980s. To understand the relationship between hearth size and integrity, a furnace that was enlarged from a 20’ to a 28’ hearth would have required a complete rebuilding of the stack.[111] The three furnaces are:

Furnace 1, AK Steel, Middletown Works, Middletown, Ohio
Furnace 1, Ispat Inland, Inc., Indiana Harbor Works, East Chicago, Illinois
Furnace 2, Ispat Inland, Inc., Indiana Harbor Works, East Chicago, Illinois

Furnace A, Bethlehem Steel Works:

The Bethlehem Steel Works in Bethlehem, Pennsylvania is one of the oldest and most important steel mills in the world. Of all the facilities with potentially comparable resources, it is one of the few whose national significance in the social, cultural, and technological history of the United States is comparable to the Homestead Steel Works. The only other steel mill with the same historical significance as Homestead or Bethlehem is the Edgar Thompson Works in Braddock, Pennsylvania. The Edgar Thompson Works was Andrew Carnegie’s first integrated steel mill and is currently one of the few remaining steelmaking facilities in Pittsburgh. Its significance in the history of modern industrial production is well documented.

There are currently five extant blast furnaces on the Bethlehem site, two of which were originally constructed prior to World War II—Furnace A, built in 1903, and Furnace C, built in 1939. Both of these furnaces were significantly modernized since their original construction date. In 1941, Furnace A was rebuilt to its current dimensions, and in 1943, Furnace C was rebuilt with a 27’ hearth. Furnace C, moreover, continued to produce

[110] Although they were built in the 1950s, Bethlehem furnaces B, D, and E were included on the list because they represent a significant collection of blast furnaces associated with the Bethlehem Steel Works. Although they are not considered comparable to Carrie 6 and 7 for the basis of this analysis, they shared raw material stocking and handling equipment and blowing equipment with Bethlehem furnaces A and C that were built prior to World War II.

[111] Based upon the current “Blast Furnace Round-up,” the average hearth size for active furnaces in the United States is 29.5’. This includes the largest hearth of 45' for Furnace 7 of the Indiana Harbor Works of Ispat Inland and the smallest 20' hearth Furnace B of Rouge Steel in Dearborn, Michigan. Currently, the largest furnace in the United States is Bethlehem Steel’s L Furnace at Sparrow’s Point. This stack has a 44.25' hearth and a working volume of 132,857 cu. ft. In comparison, Carrie 6 and 7 both have working volumes of 31,588 cu. ft. See, “Iron and Steelmaker’s 2002 Blast Furnace Round-up,” *Iron & Steelmaker* 29 (August 2002): 88-91.

iron into the 1990s so it is unclear how much of the existing equipment is original to its 1943 rebuild. Based upon the criterion established for this study, only Furnace A is considered comparable to Carrie 6 and 7. Like Carrie 6 and 7, Furnace A represents 1940s-era smelting technology.

During a tour of the Bethlehem facility in September 2002, the author was not allowed to go onto the casting floor of Furnace A. We were told it was too dangerous, a good indication that the furnace has experienced some deterioration since it stopped producing iron. This was also evident in the other four more modern stacks that have also deteriorated since the plant shut down. Furnace A, however, is definitely comparable to Carrie 6 and 7, in age and in scale.

There are three unique elements that make the Bethlehem furnaces an intriguing historic resource:

1) The collection of three-pass hot blast stoves that generated heat for Furnace A. These are either Massick's & Crooks or McClure style three-pass stoves, and it is likely that they are the only remaining three-pass stoves in the country. Most producers, including U.S. Steel, moved to two-pass stoves during the 1920s and 1930s. These stoves are historically significant for their rarity and technological importance.

2) The collection of second and third generation gas-powered blowing engines. During the first half of the twentieth century, gas-powered blowing engines were a leading technology. While most plants, including Bethlehem, moved toward steam-powered turbo-blowers in the years after World War II, they retained the gas engines to supplement the turbo-blowers. And while the turbo-blowers and the building were torn down, the gas engines remain. Like the three-pass stoves, these may be the only significant collection of gas-powered blowing engines in the country.

3) Lastly, the Bethlehem plant still retains a large number of industrial buildings, some of which are empty and some of which still retain their original equipment. In this sense, Bethlehem retains much more integrity as an integrated steel works, providing a richer context to support NHL eligibility.

Like Carrie 6 and 7, local groups, along with state and federal agencies, are actively interpreting and preserving the Bethlehem furnaces and much of the remaining steel works. Both of these sites are worthy of preservation due to their profound national significance in the industrial history of the United States.

B Furnace, ACME Steel Company, Chicago Works:

As of 1996 the B Furnace was on standby status and its hot blast plant was being used by Furnace A to enhance blast temperatures and increase production. It is unlikely the B Furnace could be eligible for NHL status because of its recent production history.

Furnace 2, Republic Technologies, Int. (USX/Kobe), Lorain Works:

Republic Engineered Products was established in 2003 as a subsidiary of Republic Technologies International. Republic's primary product is Special Bar Quality steel (SBQ) for the automobile industry and industrial equipment producers. Headquartered in Akron, Ohio, the company employs over 2300 people in steelmaking and finishing facilities in Canton, Ohio; Lorain, Ohio; Massilion, Ohio; Lackawanna, New York; and Gary, Indiana. The company can trace its history back to the formation of the Republic Steel Company in 1930 by Cyrus Eaton. For much of the twentieth century, Republic was a leading producer of steel for America's automotive, agricultural, and aerospace industries. In 1984, Republic Steel merged with the Jones & Laughlin division of LTV Corporation, forming LTV Steel. Five years later the company's bar steel division was bought through an employee stock ownership plan and became Republic Engineered Steels, the predecessor of Republic Engineered Products. In 1999, the company purchased the bar steel facility of U.S. Steel (USS)/Kobe Steel in Lorain, Ohio.

The Lorain Works, located along the Black River in Lorain, Ohio, began its history as the Johnson Steel Street Rail Company in 1895. Between the 1890s and 1990s, the facility operated under various ownership and corporate names, including, Johnson Steel, Lorain Steel, National Tube Company of USS and the Lorain Steel Cuyahoga Works of USS. In 1989, the facility came under the joint ownership of USS/Kobe.

Ownership of the Lorain Works has changed numerous times over the past several years. As longtime resident Joe Tripolleti notes, "we do not know what is going on in there anymore."[112] Interviews with the current superintendent of the blast furnace plant, Dennis Lu, verifies that furnace No. 2 is still standing although much of its recent history is unknown by current management of the facility. Repeated requests for information have not been answered. Much of the plant has been dismantled for scrap and some equipment has been cannibalized to service the current operating furnace at the plant. Perhaps the most notable loss of resources includes the dismantling of the by-product coke ovens that served the facility.[113] Without a site visit it is difficult to determine whether or not this furnace is eligible for NHL status.

2 North, Wheeling-Pitt Steel Company, Steubenville Works:

Wheeling-Pitt Steel is an outgrowth of the Wheeling Steel Company, a completely integrated steel company founded in 1920. For much of its history Wheeling-Pitt was a primary producer of hot and cold rolled-sheet, galvanized-sheet steel and roofing, black plate, tin plate, continuous weld pipe, cut nails and other finished products. It operated plants along a 30-mile stretch of the Ohio River between Steubenville and Benwood, West Virginia. The Steubenville Works remains the company's primary steel-producing unit, and it is comprised of three plants designated the Steubenville North, South, and East works. The North Works is located in Steubenville, the South Works is in Mingo Junction, and the East Works is located in Follansbee. During its peak production period in the 1950s and 1960s, the North Works included two blast furnaces, eleven open-hearth furnaces, a blooming mill, a hot strip mill and a cold reduction mill. The primary products included both hot and cold rolled-sheet and plate.

Faced with growing debt and many needed upgrades to production technologies and pollution control measures, Wheeling-Pitt filed for bankruptcy in 2001. After three years of bankruptcy protection, the company was successfully reorganized and is currently investing in various components of their Steubenville works. Much of the blast furnace plant at the Steubenville North plant is still intact, including furnace Number 1 which was producing iron in 2003 and furnace Number 2 which has been inactive for nearly twenty years. Resources associated with material handling and storage, hot blast production, and waste-gas cleaning are still extant. Like Carrie 6 and 7, these furnaces were built as a pair in 1904 and share a similar history of modernization over the twentieth century. Like most plants, there are multiple layers of historic resources dating from the 1930s through the 1970s.

In late 2003, the company began to build a new 350-ton electric arc furnace to produce steel at its Mingo Junction Works. This furnace is the first continuously-fed electric arc furnace in the United States and will rely on a charge of about 40% hot metal and 60% scrap. With the construction of the new furnace, Wheeling-Pitt will phase-out operations at the Steubenville North blast furnace plant rather than invest the more than $100

[112] Phone conversation with Joe Tripolleti, Black River Historical Society, Lorain, Ohio, February 7, 2004.
[113] Phone interview with Dennis Lu, Superintendent of the blast furnace plant, Lorain Works, Republic Technologies Int., August 6, 2002.

million necessary to upgrade the plant. The decision to stop iron production at the North Works and the company's increasing need for scrap to feed their new electric arc furnace, will likely mean the plant will be dismantled and remelted.

Furnace No. 1, AK Steel Company, Middletown Works:

The Middletown Works of AK Steel is a fully integrated facility located in southwestern Ohio, between Cincinnati and Dayton. The plant's primary operations include carbon steel melting, casting, hot and cold rolling, and various finishing operations spread over a 2700-acre facility. The plant includes coke ovens, a blast furnace, basic oxygen steelmaking furnace, various casting and finishing mills, hot cast carbon, stainless, and galvanized steel lines and tempering mills.

Faced with growing debt and the need to invest heavily in plant modernization, AK Steel threatened bankruptcy numerous times over the past four years. As late as 2003, moreover, the company considered closing its Middletown Works. In early 2004, however, the company announced plans to invest in the steelmaking operations at the works that will include a rebuild of its only remaining operating blast furnace at the works originally built in 1953.

Numerous requests for information on Furnace No. 1 have gone unanswered. At this time, it is unclear whether or not Furnace No. 1 is still extant. It is also unclear what auxiliary equipment may still remain that serviced this furnace.

Furnaces No. 1 and 2, Ispat Inland, Inc., Indiana Harbor Works:

Ispat Inland, formerly the Inland Steel Company, was founded in 1895 and is the sixth largest integrated steel producer in the United States. The company's primary products include flat-rolled and bar steel. In 1901, Inland Steel was given fifty acres of free dune land near East Chicago, Indiana, by the Lake Michigan Land Company in exchange for a promise to construct a new steel mill on the site. East Chicago, which includes Indiana Harbor, became a leading railroad and steel manufacturing area and one of the most industrialized municipalities in the United States.

The Indiana Harbor Works sprawls over 1900 acres of primarily man-made fill. Its primary facilities include three blast furnaces, including its No. 7 furnace which is the largest in the Western Hemisphere; two basic oxygen furnaces; an 80-inch hot strip mill; a 56' and 80' cold reduction mill; annealing facilities; three temper-rolling mills; a 120-ton electric arc furnace; and a 12' bar mill. All steel at the plant is cast on a continuous basis.

Furnaces No. 1 and 2 were built in 1907 and 1912, respectively. Like Carrie 6 and 7, these furnaces were designed to smelt Mesabi ores for Inland Steel's open-hearth steelmaking plant. These were integrated furnaces operated as a pair. Following the pattern of many furnaces, including Carrie 6 and 7, the stacks were significantly rebuilt and modernized in the 1920s, 1930s, and 1940s during the World War II expansion programs. Referred to as the "war furnaces" because they were rebuilt during World War II, these stacks were very similar to Carrie 6 and 7 in technology and operational practice. To reduce their tax liability and provide scrap steel for their other melting operations, Ispat Inland began dismantling these stacks in the fall of 2003. Consequently, it is highly unlikely these furnaces are eligible for NHL status.[114]

[114] Phone conversation with Paul Meyer, Preservationist, Marktown Historic District, East Chicago, Indiana, September 30, 2003 and February 7, 2004.

CONCLUSION

Faced with rapidly changing conditions in the United States steel industry, all of these blast furnace complexes are in danger of being torn down. Once these furnaces are gone, an important physical link to American industrial and technological history will be gone. Among all the remaining blast furnaces nationwide, Carrie 6 and 7 have the greatest concentration of pre-World War II equipment. Although the dismantling of the Homestead Steel Works and blast furnace plant has removed much of the historic fabric once associated with the remaining furnaces, what is left is a unique and nationally significant collection of 1920s, 1930s, and 1940s-era ironmaking technology. Moreover, no other blast furnaces considered here have the historical associations with the city of Pittsburgh and the Homestead Steel Works. Carrie Blast Furnaces Number 6 and 7 cannot be assessed outside of their context as part of the largest steel production facility in America during the early twentieth century, in the largest iron and steel-producing region of the world. Currently, only one American blast furnace plant—the Sloss Furnaces in Birmingham, Alabama—has been designated an NHL by the Secretary of the Interior. These furnaces are wonderful examples of southern merchant foundry-iron production facilities and are important national landmarks of American industrial history. The furnaces represent significant technological changes in the southern foundry-iron industry, particularly during the 1920s when labor-intensive sand casting operations were superseded by mechanical casting. During the twentieth century, however, foundry iron production accounted for an increasingly minor share of the nation's total iron output, dropping from about 15 percent in 1919 to about 10 percent in 1929. In that same period, the amount of sand cast iron declined from 13 percent of the nation's total output to less than three percent, while the percentage of iron mechanically cast remained relatively stable at about 24 percent. During the 1920s and 1930s, moreover, the percentage of iron produced in merchant facilities, such as Sloss, that sold their product on the open market declined to less than 20 percent.[115] By far the greatest proportion of the nation's output of iron, roughly 70 percent, was produced in integrated blast furnace plants and delivered in a molten form to associated steel works. The large-scale, integrated, and highly mechanized operations exhibited at Carrie 6 and 7 represent the dominant technological and industrial changes associated with American iron production during the early twentieth century—a period during which America emerged as a leading world power. This fact does not negate the national importance of the Sloss Furnaces to the interpretation of regional variations in American furnace practice, but highlights the critical need for other landmark designations that provide a more comprehensive view of nationally significant iron and steel related resources.

There are many layers of significance that heighten the national importance of Carrie Blast Furnaces Number 6 and 7. Technologically, the furnaces represent an engineering response to changing raw materials and market demands that shaped much of American ironmaking operations during the first half of the twentieth century. There is a high-degree of integrity of the pre-World War II-era equipment and technologies from which to interpret these changes and illustrate a nationally significant aspect of American industrial production. The furnaces' association with the Homestead Steel Works is also important. When the furnaces were built, the Homestead Works was the largest and most productive steel mill in the world and its products helped shape the physical landscape of twentieth century America. As the last remaining early twentieth century blast furnaces in the Pittsburgh District, Carrie 6 and 7 are the only physical remains of the region's leadership in the development of American blast furnace practice. Few industrial artifacts have such an association with a particular area as the blast furnace has with the city of Pittsburgh. Carrie 6 and 7 can also illustrate the broader changes in American industrial production during the early twentieth century, when mechanization, consolidation and integration transformed how the nation manufactured products. This is particularly relevant

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[115] Department of Commerce, Bureau of Census, *Fourteenth Census of the United States*, vol. 10, *Manufacturers, 1919*, Prepared under the supervision of Eugene Hartley (Washington, DC: Government Printing Office, 1923), 315-319; and Department of Commerce, Bureau of Census, *Fifteenth Census of the United States*, vol. 2, *Manufacturers, 1929*, prepared under the supervision of LeVerne Beales (Washington, DC: Government Printing Office, 1933), 942-949.

to the iron and steel industry, arguably the most important industry in the United States during much of the nineteenth and twentieth centuries. As William Hogan observed in 1950, "the steel industry is at the base of the American economy in a literal as well as figurative sense . . . its importance to the daily life of the nation, both from the point of view of the individual citizen and that of the country as an economic unit, cannot be exaggerated."[116] All of these factors reinforce the national significance of Carrie Blast Furnaces Numbers 6 and 7 in American industry under NHL Criterion 1, and in American technology and engineering under Criterion 4.

[116] Hogan, *Productivity in the Blast Furnace and Open Hearth*, 1.

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Previous documentation on file (NPS):

__ Preliminary Determination of Individual Listing (36 CFR 67) has been requested.
__ Previously Listed in the National Register.
__ Previously Determined Eligible by the National Register.
__ Designated a National Historic Landmark.
__ Recorded by Historic American Buildings Survey: #
_X_ Recorded by Historic American Engineering Record: # PA-200-A

Primary Location of Additional Data:

__ State Historic Preservation Office
__ Other State Agency
__ Federal Agency
__ Local Government
__ University
_X_ Other: Steel Industry Heritage Corporation, 228 East Ninth Avenue, Homestead, PA 15120

10. GEOGRAPHICAL DATA

Acreage of Property: approximately 13.8 acres

UTM References:

	Zone	**Easting**	**Northing**
A	17	593810	4474360
B	17	594560	4474500
C	17	594840	4473530
D	17	594260	4473440

Verbal Boundary Description:

The boundary of the furnace site begins at the southern tip of the concrete structure that supported the former stationary car dumper. From that point, the boundary proceeds roughly northwest on the river side of that structure for a distance of approximately 930 feet. At that point, the boundary turns approximately 90 degrees and proceeds northeast for a distance of approximately 800 feet, passing within 95 feet to the west of the former stocking trestle and terminating approximately 120 feet south of the nearest remaining CSX railroad track. From this point, the boundary once again turns approximately 90 degrees and proceeds roughly southeast for a distance of 475 feet to a point approximately 45 feet northeast of the northeastern corner of the former AC power house. From this point, the boundary turns roughly south-southeast and proceeds approximately 1015 feet to meet its beginning point at the former stationary car dumper support structure. This southeastern edge of the boundary is nearly parallel to the southeastern side of the former AC power house, and approximately 30 feet to the southeast.

The boundary for the hot metal bridge over the Monongahela River encompasses the footprint of the bridge, a structure approximately 60 ft. wide and 2025 ft. long. The northernmost point of the boundary begins approximately 860 feet north of the north bank of the Monongahela River and extends south across the river. At a point approximately 80 ft. south of the south bank of the river, the boundary diverges along separate bridge approaches, one to the southeast and one to the northwest. The boundary extends roughly 250 ft. along the southeastern approach and 310 ft. along the northwestern approach, terminating where the approach structure ends. This boundary includes portions of the railroad tracks leading to the bridge on both the north and south sides of the river, four stone piers, 25 steel bents and the entire bridge span.

Boundary Justification:

The boundary for the proposed Carrie Blast Furnace includes furnaces 6 and 7, other buildings historically associated with the furnaces, and the hot metal bridge. The boundary excludes all other lands of the former blast furnace plant that no longer retain resources associated with the operation of these two furnaces.

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From M. W. Reed and Associates. "Summary of Lectures and Topic Outline for Steel Plant Design and Blast Furnaces." Unpublished work compiled by the Carnegie-Illinois Steel Company, 1944. Collection of Author.

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PHOTOGRAPHS:

Photographs were taken by Ron Baraff and Michael Bennett on June 23, 2000. Negatives are in the collection of the Rivers of Steel Archives, Homestead, Pennsylvania.

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