Coke Ovens: Industry Profile

Draft Report

Prepared for

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CONTENTS

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

Section | Page

LIST OF FIGURES

LIST OF TABLES

Number Page

CONTENTS

CONTENTS (CONTINUED)

CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF TABLES

SECTION 1
INTRODUCTION

The U.S. Environmental Protection Agency's (EPA's) Office of Air Quality Planning and Standards (OAQPS) is compiling information on coke manufacturing plants as part of its responsibility to develop National Emission Standards for Hazardous Air Pollutants (NESHAP) under Section 112 of the 1990 Clean Air Act. The NESHAP is scheduled to be proposed in 1999 and the Innovative Strategies and Economics Group is responsible for developing an economic impact analysis (EIA) in support of the evaluation of impacts associated with the regulatory options considered for this NESHAP. This industry profile of the coke manufacturing industry provides information to be used to support the EIA of the NESHAP.

Coke is metallurgical coal that has been baked into a charcoal-like substance. This substance burns more evenly than coal and also has more structural strength. The manufacture of coke is included under Standard Industrial Classification (SIC) code 3312—Blast Furnaces and Steel Mills; however, its production is a small fraction of this industry. In 1997, the U.S. produced 23.4 million short tons of coke. Coke is primarily used as an input for producing steel in blast furnaces at integrated iron and steel mills (i.e., furnace coke) and as an input for gray, ductile, and malleable iron castings in cupolas at iron foundries (i.e., foundry coke). Therefore, the demand for coke is a derived demand that is largely dependent on production of steel from blast furnaces and iron castings.

The information in this report will be used as background in developing the EIA methodology. This industry profile report is organized as follows.

- Section 2 includes a detailed description of the production of coke at U.S. manufacturing plants, with discussions of the production processes and inputs, types of coke products as well as by- and co-products, and the costs of production at these plants.
- Section 3 describes the characteristics, uses, and consumers of coke, historical and projected consumption by end-use, as well as substitution possibilities in consumption.

- Section 4 discusses the organization of the industry and provides information on market structure, manufacturing plants, and companies that own these potentially affected plants. At the company-level, special attention is given to data on small businesses for future use in evaluating the impact on these entities as required by the Small Business Regulatory Enforcement and Fairness Act (SBREFA).
- Section 5 provides historical and projected data on the volumes of U.S. production, foreign trade, and consumption of furnace and foundry coke, as well as market prices.

SECTION 2

THE SUPPLY OF COKE

This section provides an overview of coke production in the United States. The by-product coke production process has been the dominant technology used at U.S. coke manufacturing plants. The only other cokemaking technology currently employed in the United States is the nonrecovery cokemaking process, which is nonpolluting. Thus, the focus of this section is on by-product cokemaking because this technology is the only method of coke production subject to the proposed EPA regulations. This section describes this by-product coke production process, the major by-products and co-products associated with this process, and the final coke products. This section also discusses the costs of U.S. coke production and provides a discussion of alternative technologies for coke production.

2.1 By-Product Coke Production Process

Cokemaking involves heating coal in the absence of air resulting in the separation of the non-carbon elements of the coal from the product, i.e., coke. The process essentially bakes the coal into a charcoal-like substance for use as fuel in blast furnaces at integrated iron and steel mills and cupolas at iron foundries. Figure 2-1 summarizes the multi-step production process for by-product cokemaking. As shown, this production process includes the following steps:

- coal preparation and charging,
- coking and pushing,
- quenching, and
- by-product recovery.

In by-product cokemaking, the conversion of coal to coke is performed in long, narrow ovens (i.e., by-product coke ovens) that are constructed in groups with common side walls, called batteries (typically consisting of 10 to 100 coke ovens). Currently, there are 58 by-product coke batteries operating at 23 manufacturing plants across the United States.

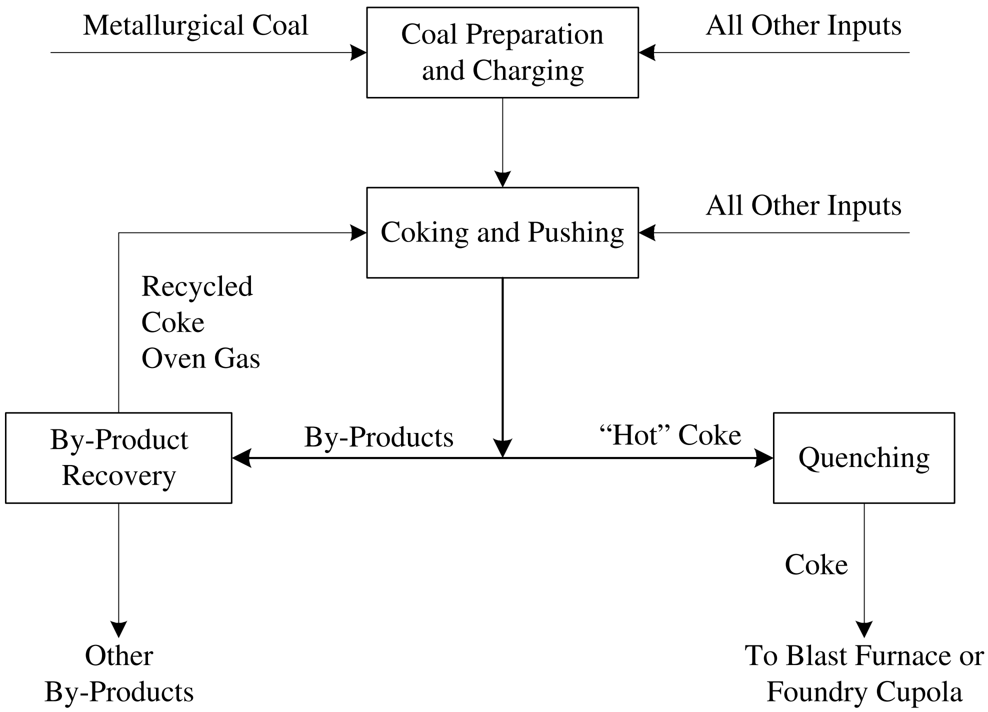


Figure 2-1. The By-Product Coke Production Process

Figure 2-2 provides a schematic of a by-product coke battery. In summary, the metallurgical coal is pulverized and fed into the oven (or charged) through ports at the top of the oven, which are then covered with lids. The coal undergoes destructive distillation in the oven at 1,650°F to 2,000°F for 15 to 30 hours. A slight positive back-pressure maintained on the oven prevents air from entering the oven during the coking process. After coking, the incandescent or "hot" coke is then pushed from the coke oven into a special railroad car and transported to a quench tower at the end of the battery where it is cooled with water and screened to a uniform size. During this process, raw coke oven gas is removed through an offtake system, by-products such as benzene, toluene, and xylene are recovered, and the cleaned gas is used to underfire the coke ovens and for fuel elsewhere in the plant.

As shown in Table 2-1, pollutants may be emitted into the atmosphere from several sources during by-product cokemaking. For the proposed MACT standards, the sources of environmental concern to EPA are the pushing of coke from the ovens, quenching of the incandescent coke, and by-product recovery. Coke pushing results in fugitive particulate

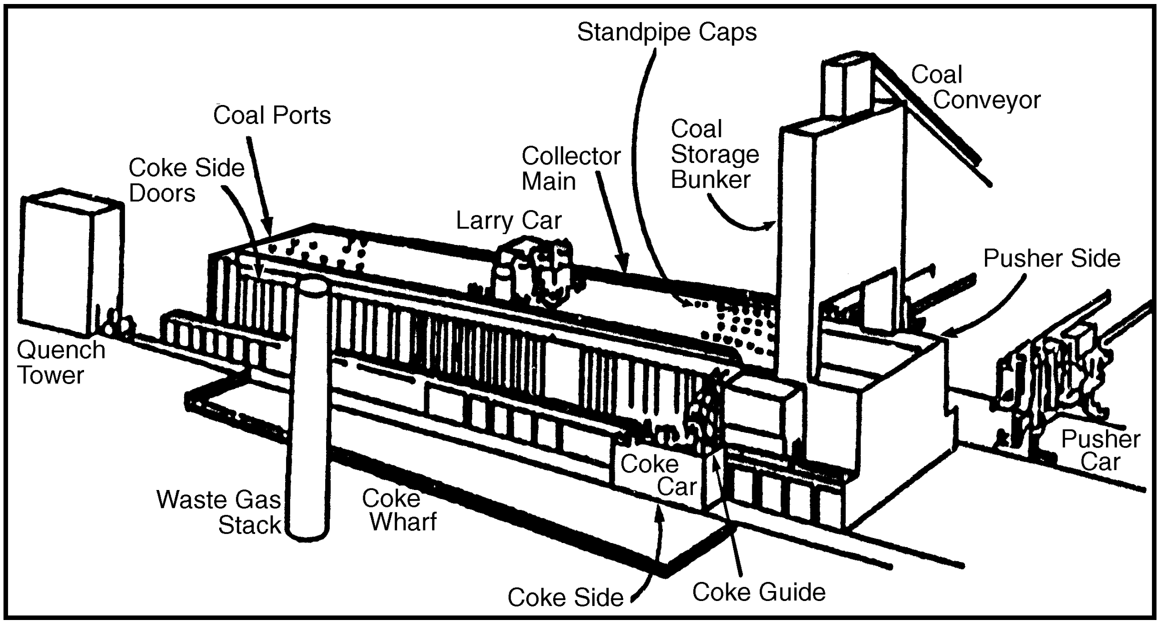


Figure 2-2. A Schematic of a By-Product Coke Battery

Source: U.S. International Trade Commission. 1994. *Metallurgical Coke: Baseline Analysis of the U.S. Industry and Imports.* Publication No. 2745. Washington, DC: U.S. International Trade Commission.

Table 2-1. Air Emissions from U.S. Coke Manufacturing Plants by Source

Process/Source	Pollutant
Oven charging	Fugitive particulates
Oven leaking during coking, coke pushing, and coke quenching	Particulates, organic compounds, acid gases
Oven underfiring	Particulates and acid gases
By-product recovery	Benzene, napthalene, and other HAPs

Source: Prabhu, D.U., and P.F. Cilione. 1992. "1990 Clean Air Act Amendments: Technical/Economic Impacts." *Iron and Steel Engineer* 69(1):33-44.

emissions, which may include volatile organic compounds (VOCs), while coke quenching results in particulate emissions with traces of organic compounds. In addition, the by-product recovery stacks may emit benzene, naphthalene and other HAPs. EPA will focus on these three areas of emissions as HAP-emitting source categories to be regulated. The following sections provide descriptions of each step in the by-product production process.

2.1.1 Coal Preparation and Charging

Metallurgical coal is delivered to coke manufacturing plants in railroad cars or barges. It is then transferred to mixing bins where the various types of coal are blended based on specific characteristics of the coal such as fluidity, ash, and sulfur content. Lankford et al. (1985) consider the selection of coals to be the single most important factor in establishing coke quality. The best coals are low in ash and sulfur content and produce a structurally strong coke. Coal blending results in improved and more consistent coke quality, which justifies the extra expense of mixing. The desired mix of coal is transferred from the mixing bins to the crusher where it is pulverized. The pulverized coal is then fed into the oven (or charged) through ports in the top of the oven by a device called a "larry" car. After the ovens have been charged the open ports are covered with lids. The by-product coking process typically yields between 1,200 and 1,400 pounds of coke per ton of coal charged into the oven.

2.1.2 Coking and Pushing

The coking step involves heating the pulverized coal in the coke oven at temperatures up to 2,000°F for 15 to 30 hours. The chemical compounds making up coal are unstable when subjected to such a high degree of heat. When heated to high temperatures, in the absence of air, the complex organic molecules break down to yield gases and a relatively nonvolatile carbonaceous residue, i.e., coke. The coking process takes place in retort ovens that are equipped with three main components constructed of refractory brick: the coking chambers, the heating flues, and the regenerative chambers. These ovens are configured as batteries, which consist of between 10 and 100 ovens. Coking chambers in a battery alternate with heating chambers, and the regenerative chambers are below the heating and coking chambers. During the coking period, the ends of the coking chamber are closed by refractory-lined doors, which are constructed to completely seal the ends of the ovens. Typical dimensions of a coke oven are 6 to 22 feet in height, 30 to 52 feet in length, and 12 to 22 inches in width. When blast-furnace gas or other lower calorie gases are used for oven heating, supplementary heating with gas of higher calorific value may be needed in order to maintain a high rate of coke production (Lankford et al., 1985).

At the end of the coking cycle, doors on each end of the oven are removed, and the incandescent coke is pushed from the oven. The pusher-side equipment is generally similar on all types of ovens and consists of three elements: a pusher, a leveler, and a door extractor. The pushing element is an electrically powered ram which pushes the coke from the oven. The leveling element is responsible for leveling the coal charge in the oven, leaving a free-gas space below the roof of the charged oven. The function of the door-extracting element is to remove and hold the pusher-side door during the pushing operation. Modern pusher equipment removes the carbon build-up from the doors and jambs so that the door seals tightly and thereby reduce emissions of gases during the coking cycle (Lankford et al., 1985).

2.1.3 Quenching

There are two methods for quenching the hot coke pushed from the ovens: wet quenching and dry quenching. Dry quenching is used primarily in Japan and Russia, while wet quenching is the primary method used in the United States. During the wet quenching process, the incandescent coke is carried to a quench tower where it is cooled to a temperature of 200 to 500°F by a system of stationary water sprays and air dried in preparation for sizing. This quenching prevents the coke from simply burning up in the air. The coke is then screened to a uniform size, which also results in some small coke fines (or breeze) that are recovered for use as a raw material input to blast furnaces. Roughly half of the water leaves the quenching tower as steam, while the remaining water that does not evaporate is drained to remove salable by-products before being returned to the quenching tank for recirculation.

Traditionally, U.S. coke plants have preferred wet quenching over dry quenching because of the high investment costs and technical problems associated with dry quenching. However, the dry quenching process recovers waste gases which can be utilized for steam cogeneration; thus, dry quenching is less polluting. As a result, there is a growing interest in dry quenching by U.S. coke manufacturers due to the more stringent regulations regarding pollution control (Lankford et al., 1985).

2.1.4 By-Product Recovery

Typically, roughly 75 percent of the output by weight of the by-product cokemaking process is coke, while the remaining share is composed of various by-products that are recovered at the plant (USITC, 1994). During coking, raw coke oven gas is removed through an offtake system composed of standpipes and other piping to a central collecting main. In the by-product recovery process, the first step is the recovery of the basic crude materials (coke-oven gas, ammonia liquor, tar and light oil). Between 20 to 35 percent of the coal charge becomes gases which are collected and processed to remove salable by-products such as coal tar, ammonia liquor, and light oil. The coke oven gas, net of these products, is then recycled to underfire the coke ovens, serve as a fuel source to other parts of the plant, or sold to outside utilities. The second step of the by-product recovery process involves processing these crude by-products to separate them into their components and produce secondary by-products such as anhydrous ammonia, phenol, ortho cresol, and toluene. The following section provides a detailed discussion of these by-products.

2.2 Major Co-Products and By-Products

There are many co-products and by-products of the by-product coke production process. There are two co-products: 1) coke breeze, the fine screenings that result from the crushing of coke; and 2) "other coke," the coke that does not meet size requirements of steel producers that is sold as a fuel source to non-steel producers. In addition, as described above, the by-product cokemaking process results in the recovery of some salable crude materials such as coke-oven gas, ammonia liquor, tar and light oil. The cleaned coke oven gas is used to underfire the coke ovens with excess gas used as fuel in other parts of the plant or sold. The remaining crude by-products may be further processed and separated into secondary products such as anhydrous ammonia, phenol, ortho cresol, and toluene. In the past, coke plants were a major source of these products (sometimes referred to as coal chemicals); however, today their output is overshadowed by chemicals produced from petroleum manufacturing (DOE, 1996a). These major co-products and by-products are discussed below.

2.2.1 Co-Products

Coke breeze is the fine particles of coke that result from the screening of coke after being quenched. Typically, these particles will pass through a 0.5 inch or 0.25 inch screen opening. Breeze may be reused in the by-product ovens for fuel or it may be utilized by integrated iron and steel producers as a fuel source in blast furnaces for the agglomeration of iron ore. Lankford et al. (1985) indicate that 100 to 200 pounds of coke breeze are recovered per ton of coal charged. In 1992, the market price for coke breeze was $41.29 per short ton (USITC, 1994).

Iron and steel producers require coke of a specific size for use in their blast furnaces or foundry cupolas. Coke which does not meet the required size specifications is sold as a fuel source to other industries and is referred to as "other coke." This other industrial coke is used as a fuel source in the processing of sugar beets in the sugar industry, in the reduction of lead in the primary and secondary lead smelting industry, in the mineral fiber industry, and in cement manufacturing (Sloss Industries, 1998). In 1992, the market price of other coke used by these industries was $105.36 per short ton (USITC, 1994).

2.2.2 Crude By-Products

The by-product cokemaking process results in the recovery of salable crude by-product materials including coke-oven gas, ammonia liquor, tar and light oil. Table 2-2 provides the typical recovery rate of these products per ton of coal charged, while Table 2-3 provides market prices for some these products as well as some associated secondary by-products. Coal tar can be burned for fuel or refined into tar-based products. About 93 percent of the coal tar produced in the United States is further refined into tar acid oil, which is distilled to produce various chemical derivatives, and pitch, which is used for waterproofing, roofing, and paving. Coal tar can also be further distilled to produce pyridine, napthalene, light oils, creosote oil, road tar, and other products. Light oils are composed of a mixture of aromatic hydrocarbons, which can be further separated to yield intermediate chemical products such as benzene, toluene, and xylenes for use as gasoline additives or in the production of cumene (Sloss Industries, 1998). The ammonia liquor reacts with sulfuric acid to produce ammonium sulfate, which is a primary source of ammonium in fertilizer production. Once these crude products have been removed, the residual is clean coke oven gas. This gas has approximately half the BTU value of natural gas with roughly half of the recovered gas being used to fire the coke ovens and the remainder being used as fuel elsewhere in the plant or sold (USITC, 1994).

2.2.3 Secondary By-Products

The crude by-products are removed and refined to produce many secondary by-products. These secondary by-products include the following:

- ***Anhydrous Ammonia***: a main source of nitrogen in fertilizer production. Ammonia has other end uses, such as those of special high-purity ammonia, which is used in chemical synthesis, in refrigeration, and in steel plants for generating reducing atmospheres.

Table 2-2. Typical By-Product Recovery Rate for U.S. Coke Production

By-Product	Recovery Rate (units/ton of coal charged)
Coke-oven gas	9,500 – 11,500 ft^3
Tar	8 – 12 gal
Ammonium sulphate	20– 28 lbs
Ammonia liquor	15 – 35 gal
Light oil	2.5 – 4 gal

Source: Lankford, William T., Norman L. Samways, Robert F. Craven, and Harold E. McGannon, eds. 1985. *The Making, Shaping and Treating of Steel*. Pittsburgh: United States Steel, Herbick & Held.

Table 2-3. Market Prices for By-Products of Coke Production

By-Product	Market Price
Crude by-products	
Crude coal tar[a]	$0.12/liter
Crude light oil[a]	$0.12/liter
Coke oven gas[a]	$0.88/thousand ft^3
Secondary by-products	
Anhydrous ammonia[b]	$225 to $230/ton
Phenol[b]	$0.43 to $0.45/lb
Ortho cresol[b]	$0.735/lb
Meta-para cresol[b]	$0.90/lb
Napthalenec[c]	$0.16/lb
Creosote[b]	$0.95 to $1.10/gal
Benzene[b]	$0.79 to $0.80/gal
Toluene[b]	$0.78 to $0.79/gal

[a] Values in 1992 dollars
[b] Values in 1998 dollars
[c] Values in 1995 dollars

Sources: *Chemical Market Reporter*. January 5, 1998.
U.S. International Trade Commission. 1994. *Metallurgical Coke: Baseline Analysis of the U.S. Industry and Imports.* Publication No. 2745. Washington, DC: U.S. International Trade Commission.
U.S. International Trade Commission. 1996. *Synthetic Organic Chemicals: U.S. Production and Sales, 1994*. Washington, DC: U.S. International Trade Commission.

- ***Phenol***: or carbolic acid, is recovered from both coal tar and ammonia liquor. The most important use of phenol is in the manufacture of resinous condensation products by reaction with formaldehyde. As a chemical intermediate, phenol is used in the preparation of synthetic tannins, dye intermediates, perfumes, plasticizers, picric acid, salicylic acid, and in the refining of lubricating oils.

- ***Ortho Cresol***: used in the production of synthetic resins to control the plasticity of the resin. It is nitrated to produce insecticides and weed killers, and is utilized in various organic syntheses as well as in the production of artificial flavors and perfumes.

- ***Meta-Para Cresol***: integral to the production of synthetic resins and the plasticizer tricresyl phosphate. This substance is also used in organic synthesis and in the production of insecticides, dyestuffs, pharmaceuticals and photographic compounds.

- ***Napthalene***: a large percent of this substance is converted to phthalic anhydride, whose principal use is in plasticizers and synthetic resins. Phthalic anhydride is also used in alkyd resins, which are important in the manufacture of coatings. Additional uses of phthalic anhydride include polyester resins, dyes, agricultural chemicals, pharmaceuticals, insect repellants, beta-naphthol, surface-active agents, tanning agents, and insecticides.

- ***Creosote***: an input for the pressure impregnation of wood products, such as piling, poles and railroad ties.

- ***Benzene***: used in the manufacture of styrene, which is used for the production of polystyrene resins and synthetic rubber. Benzene is also used for the manufacture of phenol, nylon, synthetic detergents, aniline, DDT, maleic anhydride, benzene hexachloride, mono- and dichloro-benzene, nitrobenzene, and diluent in various types of coatings.

- ***Toluene***: used in manufacture of synthetic organic chemicals, detergents, resins, plasticizers, explosives, solvents, dye intermediates and pharmaceuticals.

2.3 Coke Products

Coke is metallurgical coal that has been baked into a charcoal-like substance that burns more evenly than coal and serves as a fuel source in the U.S. iron and steel industry. The particular mix of high- and low-volatile coals used and the length of time the coal is heated (i.e., coking time) determine the type of coke produced. There are two types of coke: 1) furnace coke, which is used in blast furnaces as part of the traditional steelmaking process, and 2) foundry coke, which is used in the cupolas of foundries in making castings of gray, ductile, or malleable iron. Furnace coke is produced by baking a coal mix of 10 to

30 percent low-volatile coal for 16 to 18 hours at oven temperatures of 2,200°F. Most blast furnace operators prefer coke sized between 0.75 inches and 3 inches. Alternatively, foundry coke is produced by baking a mix of 50 percent or more low-volatile coal for 27 to 30 hours at oven temperatures of 1,800°F. Coke size requirements in foundry cupolas are a function of the cupola diameter (usually based on a 10:1 ratio of cupola diameter to coke size) with foundry coke ranging in size from 4 inches to 9 inches (Lankford et al., 1985). Furthermore, the longer coking times and lower temperatures required for foundry coke are more favorable for long-term production. As a result, foundry coke batteries typically remain in acceptable working condition longer than furnace coke batteries (Hogan and Koelble, 1996).

Figure 2-3 provides the distribution of U.S. coke production by furnace and foundry coke as of 1997. As shown, furnace coke accounts for the vast majority of coke produced in the United States. In 1997, furnace coke production was roughly 21.8 million short tons, or 93 percent of total U.S. coke production, while foundry coke production was only 1.6 million short tons. An additional distinction to be made is that between captive and merchant coke production. Integrated iron and steel producers that use furnace coke in their blast furnaces may either produce this coke on-site (i.e., captive coke producers) or purchase it on the market from merchant coke producers. As shown in Table 2-4, almost 90 percent of U.S. furnace coke capacity in 1995 was from captive operations at integrated steel producers (Hogan and Koelble, 1996). Alternatively, there are no captive coke operations at U.S. iron foundries so these producers purchase all foundry coke on the market from merchant coke producers. In summary, captive coke production occurs at large integrated iron and steel mills and accounts for the vast majority of domestic furnace coke production, while merchant coke production occurs at smaller merchant plants and accounts for a small share of furnace coke production and all of the foundry coke produced in the United States.

Table 2-4. Distribution of U.S. Coke Capacity by Product and Producer: 1995 (10^6 short tons)

	Integrated Producers		Merchant Producers		
Product Type	Capacity	Share	Capacity	Share	Total Capacity
Furnace coke	18.23	87.2%	2.67	12.8%	20.90
Foundry coke	0.0	0.0%	1.82	100.0%	1.82
Total	18.23	80.2%	4.49	19.8%	22.72

Source: Hogan, William T., and Frank T. Koelble. 1996. "Steel's Coke Deficit: 5.6 Million Tons and Growing." *New Steel* 12(12):50-59.

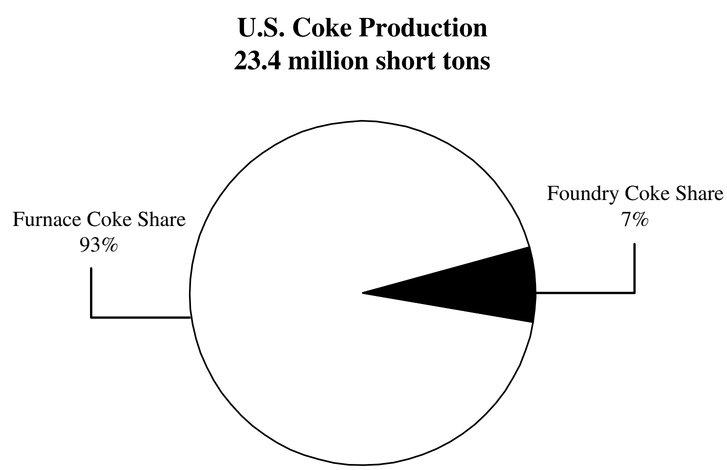


Figure 2-3. Distribution of U.S. Coke Production by Type: 1997

2.4 Costs of Production

Production of coke requires the combination of variable inputs such as raw materials, labor, and energy with fixed capital equipment (i.e., the coke oven batteries). There are also periodic costs related to repair and maintenance of the capital equipment and for pollution abatement. Table 2-5 provides estimates by the U.S. International Trade Commission (USITC) of furnace coke production costs at U.S. integrated and merchant manufacturing plants (USITC, 1994). These costs do not include credits for the sales of associated co- and by-products and, thus, reflect the realized production costs at these U.S. plants. As shown, the average total cost of producing furnace coke in the United States was $118.02 per short ton as of 1992. Raw materials account for slightly over 50 percent of these costs followed by other plant costs (e.g, annual depreciation, amortization, and other administrative costs) accounting for 22.4 percent and labor costs accounting for 13.3 percent. In addition, furnace coke production costs at integrated plants was 21.4 percent higher than at merchant plants in 1992. These cost differences are most noticeable for coal, energy, and other raw materials. However, the USITC (1994) reports that the large observed difference in energy costs may reflect the difficulty for integrated producers in allocating energy costs from coke production from steel production, while the higher "other costs" for integrated producers may reflect shut-down costs associated with closings of coke batteries during 1992.

2.4.1 Capital Costs

According to Agarwal et al. (1996), the U.S. steel industry has been reluctant to build new coke batteries or rebuild existing coke batteries because of the large capital outlays required for these projects. Typically, coke ovens must be rebuilt or refurbished after 30 to 40 years of operation (Schriefer, 1995). The capital investment cost of a new by-product cokemaking facility is estimated at $350 per annual short ton of capacity, while that of a rebuild is roughly $225 per annual short ton of capacity (Agarwal et al., 1996; USITC, 1994). In addition, capital improvements for the coke oven and auxiliary equipment also require large investments. For example, retrofitting coke oven doors can cost roughly $10,000 per door, while the costs for new door and jamb cleaners on both sides of a coke battery can cost up to $1.8 million (USITC, 1994). In addition, the coke industry projected capital expenditures for pollution abatement at $672 million from 1994 through 2003 to comply with existing and expected EPA regulations (USITC, 1994). Roughly 80 percent of these capital expenditures are to be undertaken by integrated producers. Faced with these costs, many integrated iron and steel producers have been shutting down their coke batteries and opting to purchase coke from merchant suppliers or other integrated iron and steel mills that have excess coke supplies.

Table 2-5. Summary of Cokemaking Production Cost for Furnace Coke by Type of Producer ($/short ton of coke)

	Integrated Producers			Merchant Producers			All Producers		
Cost Component	**1992$**	**1996$**	**Share**	**1992$**	**1996$**	**Share**	**1992$**	**1996$**	**Share**
Raw materials									
Metallurgical coal	$62.18	$67.71	51.4%	$55.89	$60.86	58.9%	$61.47	$66.94	52.1%
Other[a]	$8.25	$8.98	6.8%	$1.11	$1.23	1.1%	$7.44	$8.10	6.3%
Costs of good sold									
Direct labor	$15.73	$17.13	13.0%	$15.56	$16.94	16.4%	$15.71	$17.11	13.3%
Energy costs	$7.49	$8.16	6.2%	$2.74	$2.98	2.9%	$6.97	$7.59	5.9%
Other costs[b]	$27.27	$29.70	22.6%	$19.69	$21.44	20.7%	$26.43	$28.78	22.4%
Total costs	$120.92	$131.68	100.0%	$94.99	$103.45	100.0%	$118.02	$128.52	100.0%

[a] Other raw materials include process water, sulfuric acid, lime, and caustic soda.
[b] Includes depreciation, amortization, and other factory costs associated with metallurgical coke production not previously reported.

Note: The USITC reported production costs for 1992, which were converted to 1996 dollars using the producer price index for coke products (SIC product code 3312-111).

Source: U.S. International Trade Commission. 1994. *Metallurgical Coke: Baseline Analysis of the U.S. Industry and Imports.* Publication No. 2745. Washington, DC: U.S. International Trade Commission.

Although no major investments in new construction or expansion of by-product cokemaking facilities have been undertaken recently, U.S. steel producers have started to make investments in alternative cokemaking production technologies. These investments include the construction of a 1.33 million ton per year nonrecovery cokemaking and cogeneration facility at Inland Steel's Indiana Harbor Works that was scheduled for completion in June of 1998 (*Iron and Steel Engineer*, 1998). The cost of constructing this facility is estimated at $350 million, or roughly $263.15 per ton of coke. The total cost per ton of capacity of this new technology is almost 25 percent less than that of a new by-product cokemaking facility.

2.4.2 Variable Costs

There are four variable inputs in coke production—raw materials, labor, energy, and maintenance. Raw materials include metallurgical coal, process water, and other oven feed materials, labor is used in the raw material and final product transport and delivery, energy is largely consumed by the coke ovens and auxiliary equipment, and maintenance is required for periodic upkeep of the coke ovens. Coke production exhibits a fixed coefficient technology because the variable inputs are not substitutable. Accordingly, the total variable cost function is linear in the output and input prices or, in other words, the average variable cost function is independent of output. Thus, the average variable cost function (expressed in $ per ton of coke) may be written as:

$$AVC = AVCI \bullet Pc + AVLI \bullet w + AVEI \bullet Pe + AVMI \bullet Pm \quad (2.1)$$

where AVCI, AVLI, AVEI, and AVMI are the fixed requirements per ton of coke of metallurgical coal, labor, energy, and maintenance respectively, and Pc, w, Pe, and Pm are the prices of each variable input.

As shown in Eq. (2.1), the contribution of each variable input to the cost per ton of coke is equal to the average variable input (fixed requirement of the input per ton of coke) times the price of the input (per unit cost). For example, the contribution of energy to the cost per ton of coke is equal to the Btu requirement per ton of coke times the cost per Btu of energy. In fact, this fixed coefficient approach is similar to the method used by the EPA in estimating coke battery operating costs for its 1992 EIA in support of the MACT Standards on By-Product Coke Ovens. Table 2-6 provides prices for coal, labor, energy inputs. The use of each of these variable inputs in coke production is discussed below.

Table 2-6. Variable Input Prices for Metallurgical Coal, Labor, and Electricity by State

State	Metallurgical Coal[a] ($ per short ton)	Production Labor[b] ($ per hour)	Electricity ($ per MMBtu)[c]
AL	$49.37	$14.56	$11.88
IL	[d]	$15.14	$15.45
IN	$51.93	$18.17	$11.54
KY	[d]	$16.02	$8.58
MI	[d]	$16.48	$15.02
NY	[d]	$15.64	$16.97
OH	$44.98	$17.79	$12.21
PA	$45.16	$16.53	$17.35
UT	[d]	$17.66	$10.91
VA	[d]	$11.93	$12.20
WV	[d]	$17.31	$11.82
National average	$47.33	$15.22	$13.68

[a] Reflects for price of coal delivered to coke plants in 1996 dollars
[b] Reflects hourly wages for workers in Primary Metal Industries (SIC 32) in 1997 dollars.
[c] Reflects price for industrial section in 1995 dollars.
[d] State-level data withheld by Energy Information Administration to avoid disclosure of individual company data and, therefore, may be replaced by the national average.

Sources: U.S. Department of Energy. 1997. *Coal Industry Annual 1996*. Washington, DC: Energy Information Administration.
U.S. Department of Labor, Bureau of Labor Statistics. BLS LABSTAT Database: Employment and Earnings, SIC 33. <http://www.bls.gov>. Obtained in September 1998.
U.S. Department of Energy. 1998b. *State Energy Price and Expenditure Report 1995*. Washington, DC: Energy Information Administration.

2.4.2.1 Raw Materials

Based on responses to EPA's industry survey, U.S. coke producers require an average of 1.36 tons of coal to produce a ton of coke. This fixed input requirement varies slightly by type of producer (i.e., integrated iron and steel mills and merchant coke plants). Integrated, or captive, producers require an average of 1.38 tons of coal to produce a ton of coke, while merchant producers require an average of 1.31 tons of coal per ton of coke produced (EPA, 1998a). The quantity of metallurgical coal traded has declined over time as the quantity of coke produced and consumed has declined. Domestic consumption of metallurgical coal is now less than half of the 1980 level and currently accounts for only 3.2 percent of total U.S. coal consumption (U.S. Department of Energy, 1997).

2.4.2.2 Labor

The labor required to produce a ton of coke (AVLI) also varies by type of producer. Harry Kokkinis, an industry analyst with Locker Associates, and Monty Stuart, Supervisor of Environmental Affairs and Technical Programs for Bethlehem Steel, both provided estimates of the number of workers employed in coke production on a per-battery basis at integrated iron and steel mills (Kokkinis, 1992; Stuart, 1992). Because the coke battery capacities were different for each estimate, the average labor requirement at integrated plants was computed as a weighted average of these estimates at 1.09 man-hours per ton of coke produced. As expected, the larger capacity batteries required fewer man-hours per ton of coke.

The estimate of employment in coke production for the merchant sector relies on 1990 survey data gathered by the American Coke and Coal Chemicals Institute (ACCCI), a trade association of merchant coke producers (ACCCI, 1992). ACCCI represents merchant furnace coke producers as well as all U.S. foundry coke producers. According to the information supplied by ACCCI, the 27 coke batteries operating at 11 merchant plants during 1990 employed 2,530 production workers. These data result in an estimate of 1.442 man-hours per ton of coke produced in the merchant sector. The estimated labor requirement for merchant plants is higher than that for integrated plants. This disparity reflects economies of scale at the larger integrated producers relative to the smaller merchant producers.

2.4.2.3 Energy

Russell and Vaughn (1976) indicate that the fixed requirement of electricity per ton of coke produced (AVEI) was 37.8 kWh. This is most likely an underestimate because the by-product coke batteries are now older and currently require more electricity for pollution control than observed in the mid-1970s. In addition, Russell and Vaughn (1976) indicate that 2 MMBtu per ton of coal charged are required for underfiring the coke oven. The energy requirements at U.S. coke manufacturing plants are typically met by a combination of the recycled coke oven gas and cogeneration facilities at the coke manufacturing plant (i.e., boilers using either inplant by-product fuels or purchased fuel oil or natural gas).

2.4.2.4 Maintenance and Repair

Maintenance costs include the costs of periodic upkeep and repairs of the coke ovens and other equipment that are required to continue coke production, as well as the costs of pollution abatement. For example, the coke oven doors require periodic maintenance because they suffer extensive wear and tear during the production process. In fact, coke oven doors are a large contributor to total repairs and maintenance costs at these plants (Lankford et al., 1985). Actual estimates of these costs at coke plants are not available in the literature; however, a rule of thumb approach is typically used to approximate these costs.

2.4.3 Pollution Abatement

Pollution abatement has become an increasing component of production costs at U.S. coke manufacturing plants. New environmental regulations stemming from the 1990 Clean Air Act Amendments have raised the operating and capital costs for U.S. producers. Further cost increases are expected as additional regulations take effect over the next two decades. As shown in Table 2-7, the average pollution abatement costs per short ton of coke production in 1992 was $7.49 for integrated producers and $8.25 for merchant producers (USITC, 1994). These costs include controls designed to reduce air emissions, effluent releases, and solid waste generation. These pollution abatement costs would not be added directly into the cost function since much of the cost of abatement are likely embedded in the required labor and energy inputs.

2.5 Substitute Coke Production Technologies

Several substitute technologies for by-product cokemaking have been developed in the United States and abroad. These new coke producing technologies include nonrecovery cokemaking, formcoke, and jumbo coking ovens. Of these alternatives to by-product coke batteries, the nonrecovery method is the only substitute in terms of current market share in the United States.

2.5.1 Nonrecovery Cokemaking

As of 1997, 10 of the 68 coke batteries operating in the United States (or roughly 15 percent) employed the nonrecovery cokemaking technology. The significant difference between nonrecovery and by-product coke ovens occurs during the handling of the volatile gases released during coking. Nonrecovery coke ovens operate under negative pressure and

Table 2-7. Pollution Abatement Costs by Type of Producer ($ per short ton of coke)

Item	Integrated Producers		Merchant Producers	
	1992$	1996$	1992$	1996$
Air				
Depreciation	$1.82	$1.98	$2.22	$2.42
Salaries and wages	$1.03	$1.12	$0.82	$0.89
Fuel/electricity	$0.61	$0.66	$0.29	$0.32
Contract work	$0.15	$0.16	$0.23	$0.25
Materials, leasing and miscellaneous	$1.71	$1.86	$0.86	$0.94
Adjusted total[a]	$5.26	$5.73	$4.41	$4.80
Water				
Depreciation	$0.26	$0.29	$0.36	$0.40
Salaries and wages	$0.25	$0.28	$0.40	$0.44
Fuel/electricity	$0.29	$0.32	$0.34	$0.37
Contract work	$0.15	$0.17	$0.41	$0.45
Materials, leasing and miscellaneous	$0.98	$1.07	$1.40	$1.52
Adjusted total[a]	$1.98	$2.16	$2.94	$3.20
Solid/contained waste				
Depreciation	$0.00	$0.00	$0.05	$0.06
Salaries and wages	$0.01	$0.01	$0.03	$0.03
Fuel/electricity	$0.00	$0.00	$0.00	$0.00
Contract work	$0.10	$0.11	$0.08	$0.09
Materials, leasing and miscellaneous	$0.15	$0.16	$0.74	$0.80
Adjusted total[a]	$0.25	$0.27	$0.91	$0.99
Adjusted grand total[a]	$7.49	$8.16	$8.25	$8.99

[a] These abatement costs are total operating costs, plus payments to governments for services, minus pollution abatement costs offsets.

Note: The USITC reported production costs for 1992, which were converted to 1996 dollars using the producer price index for coke products (SIC product code 3312-111).

Source: U.S. International Trade Commission. 1994. *Metallurgical Coke: Baseline Analysis of the U.S. Industry and Imports.* Publication No. 2745. Washington, DC: U.S. International Trade Commission.

are designed to completely capture the volatile gases (Prabhu and Cilione, 1992). These volatile gases are oxidized in the oven chamber rather than recovered in a by-product plant. The oxidation of the gases above the coal bed provides the heat for the process and, thus, eliminates the need for external heat sources. The ovens are conveyor charged, rather than charged by a larry car, and the incandescent coke is conventionally pushed and quenched. Waste gases from these batteries may be captured and incorporated into a cogeneration facility for the production of electricity (USITC, 1994).

Benefits of the nonrecovery process relative to the by-product process include the following:

- lower initial capital costs,
- no expense associated with chemical recovery,
- reduced labor input (more reliance on computer monitoring),
- ease of maintenance,
- accommodates any coal blend, and
- exceeds standards for pollution abatement (*Engineering and Mining Journal*, 1997).

2.5.2 Formcoke

The formcoke production process begins with finely pulverized coking coal, which is dried and partially oxidized to prevent the coal from fusing together. This product is carbonized in two stages at successively higher temperatures to obtain a char. The char is formed into briquettes using roll presses, and these briquettes are then cured at low temperatures, carbonized at high temperatures, and finally air-cooled to produce coke (USITC, 1994). This technology has the benefits of lower raw material costs (due to the use of less expensive subbituminous coal) and lower dust releases to the environment. However, disadvantages of the formcoke process include lower productivity, higher fuel rates, and decreased stability of the coke product (USITC, 1994).

The Coal Technologies Corporation (CTC) used funding from the U.S. DOE to develop the CTC formcoke process (USITC, 1994). As of 1996, CTC was planning on building a formcoke plant in Princeton, West Virginia. CTC's formcoke process produces char through a gasification process. CTC currently operates a pilot facility which produces coke for testing purposes. The coke produced at this pilot plant closely mimic the characteristics of coke resulting from by-product cokemaking (*New Steel*, 1996).

2.5.3 Jumbo Coking Ovens

This technology was originally developed in Germany. There are no current plans for development of jumbo coking ovens in the United States. The jumbo oven production process is similar to the by-product process in that both coke and by-products are produced. These processes differ in the design of the ovens, however, with the jumbo ovens utilizing individually controlled single reactors as opposed to a multi-chamber system. Thus, these single reactors can be operated as independent coking units similar to coke batteries. The jumbo ovens are larger with fewer doors per oven, which results in reduced air emissions (USITC, 1994; Prabhu and Cilione, 1992). The jumbo ovens operate at costs roughly 25 percent less than by-product ovens, but have initial capital investment costs that are higher by 10 percent (USITC, 1994).

SECTION 3

THE DEMAND FOR COKE

This section characterizes the consumption of coke. It describes the characteristics of coke, its uses and consumers, the behavioral responses of consumers to price changes (i.e., the elasticity of demand), and the substitution possibilities in consumption.

3.1 Product Characteristics

Lancaster (1966) describes commodities as bundles of attributes that provide services. In other words, goods are of interest to the consumer because of the properties or characteristics the goods possess. Therefore, the demand for a commodity is not simply for the good itself but instead for a set of characteristics and properties that is satisfied by a particular commodity. Coke is a charcoal-like product made from metallurgical coal that burns more consistently and has more structural integrity than coal. It is used as a fuel and reducing agent in blast furnaces operations at integrated iron and steel mills to transform iron ore into pig iron and in the cupolas of iron foundries to producing gray, ductile, and malleable iron castings. The most significant attributes of coke are its stability, size, moisture content, and chemical composition (e.g., ash, sulfur, phosphorus content). Consistency across these attributes is extremely important; thus, blast furnace and cupola operators typically establish benchmark standards of quality that reflect their operational requirements. The USITC (1994) reports that common specifications by U.S. purchasers of coke include: 6 to 9 percent ash content; 0.6 to 0.8 percent sulfur content; 4 to 6 percent moisture content; and 57 to 60 CSR (coke strength after reactivity).

The attributes of coke depend mainly on the coking coal used and the temperature at which it is carbonized. The relative importance these attributes depends upon the requirements of the specific purchaser and end-use. Two of the most important properties of coke are its stability and size. Coke must be of high strength to withstand breakage and abrasion during handling and use. In addition, a uniform size of coke is desired by purchasers. Most blast furnace operators prefer coke sized between 0.75 and 3 inches. Porosity, density, and combustibility are controllable only to a small extent, and their importance in affecting blast-furnace operation has not been definitely established. Alternatively, foundry operators require low phosphorous, low reactivity coke of a larger size (Intertech, 1998). A blend of three to five coking coals is generally used in the production of foundry coke. Coke size requirements in foundry cupolas are a function of the cupola diameter, typically maintaining a 10:1 ratio of cupola diameter to coke size. Thus, foundry coke sizes range from 4 inches to 9 inches.

3.2 Uses and Consumers

Coke is a major input into blast furnaces in traditional steelmaking and into foundry cupolas in the production of iron castings. Because the physical properties required of coke used to produce steel differ from those required to produce iron castings, the market for coke comprises two primary markets: 1) the market for furnace coke, used to produce steel at integrated mills, and 2) the market for foundry coke, used to produce iron castings at foundry cupolas. Thus, conditions in the U.S. steel industry determine the demand for furnace coke, while conditions in the U.S. iron castings industry determine the demand for foundry coke. In addition, coke that is not suitable for furnace or foundry use is sold to other industries as a fuel input and referred to as “other coke.”

Figure 3-1 presents the distribution of U.S. coke consumption by end-user for 1997 (EPA, 1998a). As shown, integrated iron and steel mills accounted for over 90 percent of the 22.5 million short tons of coke shipped by U.S. producers during 1997. Iron foundries accounted for 7.2 percent of U.S. coke shipments, while other industrial users of coke accounted for the remaining 1.6 percent. Thus, the overall trends in coke consumption will be heavily influenced by the trends in consumption of furnace coke or conditions at integrated iron and steel mills.

Table 3-1 presents historical data on U.S. apparent consumption of coke from 1980 through 1997. Apparent consumption is computed as U.S. production minus exports plus imports plus or minus the change in inventory. The table presents aggregate figures across all types of coke because historical consumption data are not available by type of coke product (i.e., furnace, foundry, and other). As shown, U.S. consumption of coke has declined by 44.7 percent over this period from 41.3 million short tons in 1980 to 22.8 million short tons in 1997—an average reduction of 2.6 percent per year. Because the demand for coke is derived from the conditions in the U.S. iron and steel industry, much of the observed decline in U.S. coke consumption can be attributed to the reduction in production at integrated iron and steel mills. The large reduction in coke consumption from 44 million short tons in 1981 to 25.8 million short tons in 1982 accounts for the vast majority of the historical decline. This one-time reduction resulted from the restructuring of the U.S. iron and steel industry to reduce capacity, lower operating costs, and consolidate operations.

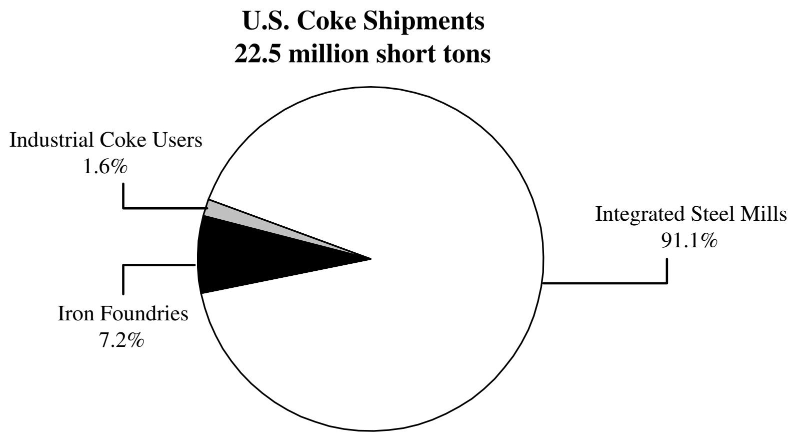


Figure 3-1. Distribution of U.S. Coke Shipments by Type of Consumer: 1997

Source: U.S. Environmental Protection Agency. 1998a. *Coke Industry Responses to Information Collection Request (ICR) Survey*. Database prepared for EPA's Office of Air Quality Planning and Standards. Research Triangle Park, NC.

These measures resulted in the closings of a wide variety of integrated mills, including some cokemaking plants (USITC, 1994).

3.2.1 Uses and Consumers of Furnace Coke

Furnace coke is used exclusively as an input into blast furnaces at integrated iron and steel mills. The demand for furnace coke, therefore, is derived from the demand for the steel products produced at these integrated mills. As shown in Figure 3-2, furnace coke is used in the initial step of the traditional steelmaking. Furnace coke is combined at the top of the blast furnace with ferrous material (e.g., iron ore) and a fluxing agent. Hot air is introduced lower down and blown up through the furnace to ignite the coke. The reduction occurs as the materials drop down through the tower and the molten iron is drawn off, or tapped, at the bottom. Then, the resulting pig iron is converted into molten steel by the steelmaking operations (i.e., basic oxygen furnace) and converted into final steel mill products by the forming and finishing operations at the mill.

Figure 3-3 provides the distribution of furnace coke consumption at U.S. integrated mills by source. The vast majority of furnace coke consumed is from coke manufacturing facilities that are located on-site or within close proximity of the mill. As shown, these

Table 3-1. U.S. Apparent Consumption of Coke: 1980-1997 (10^3 short tons)

Year	Apparent Consumption
1980	41,278
1981	44,046
1982	25,776
1983	29,850
1984	29,900
1985	29,270
1986	25,352
1987	27,650
1988	30,020
1989	28,940
1990	27,180
1991	24,216
1992	24,731
1993	24,303
1994	24,163
1995	24,449
1996	23,044
1997	22,845
Average Annual Growth Rates	
1980-1997	-2.6%
1980-1989	-3.3%
1989-1997	-2.6%

Source: U.S. Department of Energy. Various years. "Annual Coal Report." Washington, DC: Energy Information Administration.

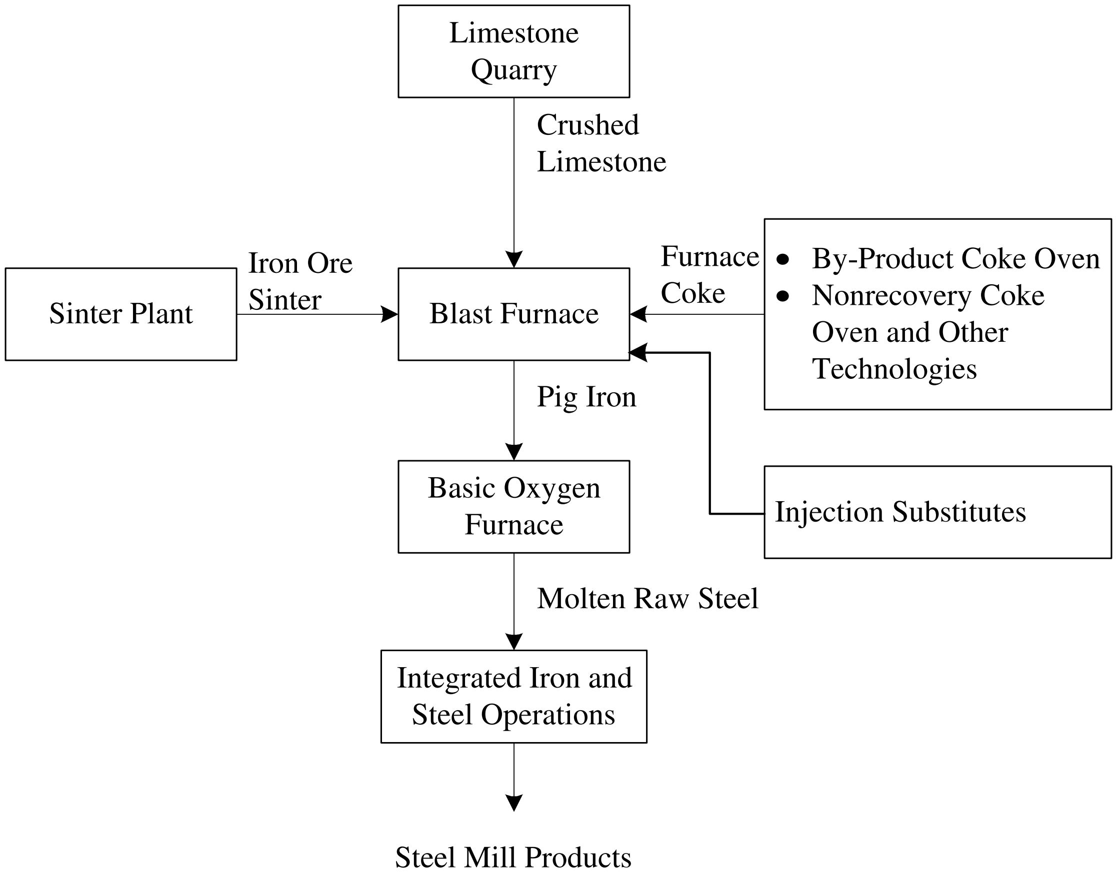


Figure 3-2. Use of Furnace Coke in Traditional Steelmaking Operations

captive operations accounted for 76.2 percent of coke consumed by integrated mills during 1997. Foreign imports of coke accounted for just over 14 percent of furnace coke consumption, while merchant coke plants accounted for the remaining 9.6 percent. As a result of recent closings of cokemaking operations at integrated mills, these producers are becoming more dependent upon U.S. merchant producers and foreign imports as a source of furnace coke.

Table 3-2 summarizes the furnace coke deficits and surpluses of U.S. integrated producers. As of 1995, captive coke production at these producers lagged the required coke consumption in their blast furnaces thereby resulting in a total coke deficit across all U.S. integrated producers of 5.6 million short tons. As shown, six of the fifteen U.S. integrated

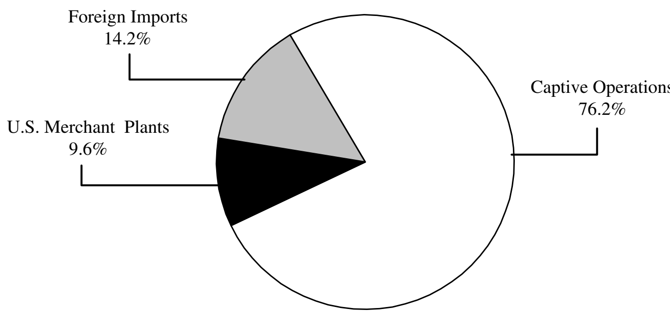


Figure 3-3. Distribution of Furnace Coke Consumption at Integrated Mills by Source: 1995

Source: Agarwal, Jay, Francis Brown, David Chin, Gregory Stevens, Richard Clark, and David Smith. 1996. "The Future Supply of Coke." *New Steel* 12(3):88.

steel companies had no captive coke capabilities and, thus, must purchase all of their furnace coke from outside sources (merchant producers, foreign imports or integrated producers with coke surplus). The total coke deficit for these six firms was 5.84 million short tons in 1995. Furthermore, four of the nine U.S. integrated steel companies with captive coke operations had a coke deficit, i.e., they had to supplement their captive production with additional purchases of furnace coke to operate their blast furnaces. The total coke deficit for these four firms was 2.27 million short tons in 1995. The five U.S. integrated steel companies whose captive operations produced an oversupply of coke had a total coke surplus of only 2.52 million short tons. As shown in Table 3-2, U.S. Steel accounted for three-fourths of this total coke surplus with 1.97 million short tons.

Table 3-3 provides historical data on U.S. consumption of furnace coke from 1975 to 1995. As shown, the U.S. consumption of furnace coke declined by almost 50 percent from 48.8 million short tons in 1975 to 24.5 million short tons in 1995—an average annual reduction of 2.5 percent. This downward trend is attributable to two factors. First, the overall reduction in U.S. steel output since the 1970s and the declining share of blast furnace steel production. As shown, U.S. steel production from blast furnaces declined by almost 30 percent from 79.9 million short tons in 1975 to 56.1 million short tons in 1995—an average reduction of 1.5 percent per year. Second, technical changes in steel manufacturing that have resulted in a decreased quantity of furnace coke required to produce a ton of blast furnace steel. As shown, the coke rate declined by 28.5 percent from 0.611 in 1975 to 0.437 in 1995. These two factors are discussed in more detail below.

Table 3-2. Furnace Coke Deficits and Surpluses at U.S. Integrated Steel Companies: 1995 (10^6 net short tons)

Company	Blast Furnace Steel Production[a]	Coke Rate	Coke Consumption	Coke Production[b]	Deficit/ Surplus
Acme	1.11	0.365	0.41	0.47	0.06
AK Steel	3.91	0.369	1.44	1.25	-0.19
Bethlehem	8.10	0.400	3.24	3.41	0.17
Geneva	2.33	0.451	1.05	0.68	-0.37
Gulf States	1.03	0.490	0.50	0.50	0.00
Inland	4.98	0.361	1.80	—	-1.80
LTV	7.30	0.411	3.00	2.48	-0.52
McLouth	1.18	0.475	0.56	—	-0.56
National	6.14	0.422	2.59	1.40	-1.19
Rouge	2.49	0.382	0.95	—	-0.95
U.S. Steel	11.40	0.375	4.28	6.25	1.97
USS/Kobe	2.19	0.397	0.87	—	-0.87
WCI	1.43	0.470	0.67	—	-0.67
Weirton	2.41	0.410	0.99	—	-0.99
Wheeling-Pittsburgh	2.19	0.418	0.92	1.24	0.32
Total	58.19	0.400	23.27	17.68	-5.59

[a] Represents 95 percent of potential maximum productive capability of U.S. blast furnaces; allows for scheduling, maintenance, and other operating delays.

[b] Represents 97 percent of potential maximum productive capability of coke ovens operated by companies with active blast furnaces; allows for limitations imposed by environmental and oven maintenance requirements.

Source: Hogan, William T., and Frank T. Koelble. 1996. "Steel's Coke Deficit: 5.6 Million Tons and Growing." *New Steel* 12(12):50-59.

Table 3-3. U.S. Blast Furnace Production, Furnace Coke Consumption, and Coke Rate

Year	U.S. Blast-Furnace Steel Production (million of net tons)	Furnace Coke Consumed (million of net tons)	Coke Rate
1975	79.9	48.8	0.611
1976	86.9	51.6	0.594
1977	81.3	48.5	0.597
1978	87.7	51.3	0.585
1979	87.0	50.0	0.575
1980	68.7	39.1	0.569
1981	73.6	40.5	0.550
1982	43.3	23.3	0.538
1983	48.7	26.3	0.540
1984	51.9	27.4	0.528
1985	50.4	25.6	0.508
1986	44.0	22.3	0.507
1987	48.4	25.5	0.527
1988	55.7	29.4	0.528
1989	55.9	29.2	0.522
1990	54.8	27.5	0.502
1991	48.6	24.8	0.510
1992	52.2	25.0	0.479
1993	53.1	23.7	0.446
1994	54.4	24.2	0.445
1995	56.1	24.5	0.437
Average Annual Growth Rates			
1975-1995	-1.5%	-2.5%	-1.4%
1975-1985	-3.7%	-4.8%	-1.7%
1985-1995	1.1%	-0.4%	-1.4%

Note: Coke rate is the tons of coke consumed per ton of blast-furnace iron produced.

Source: Hogan, William T., and Frank T. Koelble. 1996. "Steel's Coke Deficit: 5.6 Million Tons and Growing." *New Steel* 12(12):50-59.

Since the 1970s, there has been a decline in U.S. steel production and consumption due to reductions in the use of steel in U.S. manufactured goods. For example, steel use in automobile production has fallen because of substitution of other materials for steel and because of the general reduction in the size of American cars. Steel use in the typical U.S. domestic car declined by 33 percent from 2,081 pounds in 1972 to only 1,385 pounds in 1992—a total reduction of 696 pounds per vehicle (The World Bank, 1994). Similarly, other sectors of the U.S. economy have generally reduced their consumption levels of steel in their products in favor of substitute materials such as aluminum, paper, and plastic. In addition, there has also been a decline in the volume of steel produced from blast furnaces as a result of a shift in steelmaking technology towards the use of electric arc furnaces (EAFs). The EAF uses scrap steel and electricity as inputs in the steel production process and does not require coke, iron ore, or limestone. These furnaces also do not require the large capital investment that integrated plants do and have, therefore, given rise to "mini-mills." Although smaller in scale than integrated producers, the EAF share of domestic raw steel production increased from 15.3 percent in 1970 to 35.9 percent in 1989. As of 1996, EAFs accounted for 42.6 percent for U.S. raw steel production (AISI, 1997).

Figure 3-4 illustrates the historical decline of U.S. blast furnace steel production and the consequent decline in furnace coke consumption. As shown, the historical trends in these time-series are almost mirror reflections of each other with a correlation of 0.98 from 1975 through 1995. As of 1991, however, U.S. blast furnace steel production has increased each year at 3.9 percent while furnace coke consumption has slightly declined at 0.3 percent per year. From 1975 through 1991, the two time series are almost perfectly correlated at 0.995. Since that time, the two time series are negatively correlated with a measure of -0.39. This departure from the previously observed highly positive correlation is a result of the technical changes in blast furnace operations to reduce the coke rate through improved process efficiency and injection of pulverized coal in place of furnace coke. As shown in Table 3-3, the coke rate has been declining at a faster rate than furnace coke consumption since the mid-1980s. This disparity has been even more pronounced during the 1990s. From 1991 through 1995, the coke rate declined by 3.6 percent per year, while furnace coke consumption only declined by 0.3 percent per year.

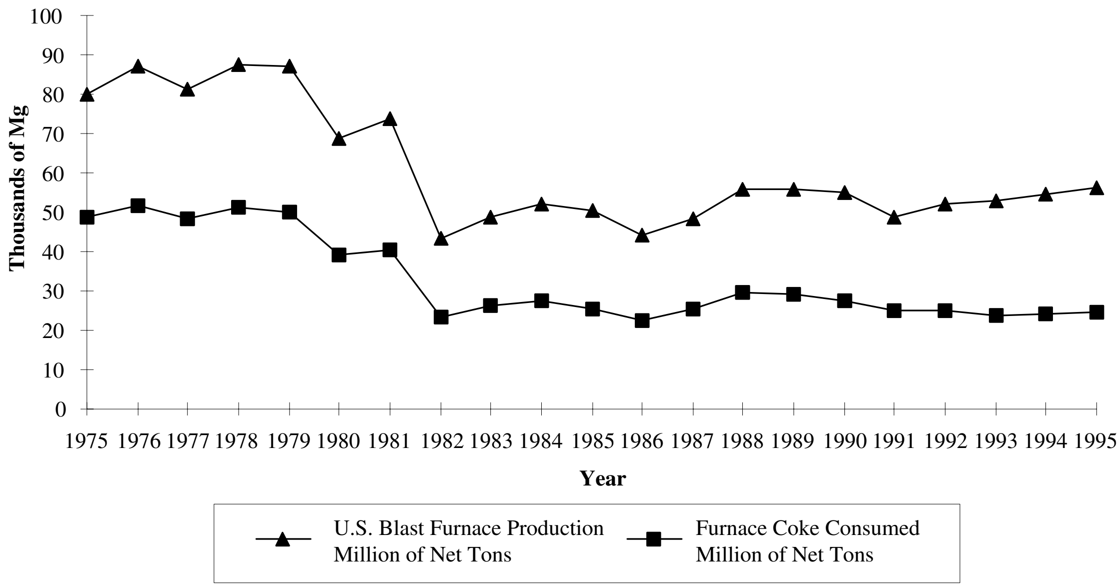


Figure 3-4. Blast Furnace Steel Production and Furnace Coke Consumption: 1975-1995

Source: Hogan, William T., and Frank T. Koelble. 1996. "Steel's Coke Deficit: 5.6 Million Tons and Growing." *New Steel* 12(12):50-59.

Most studies expect that U.S. furnace coke consumption will continue to decline into the next century. However, these declines will likely be exceeded by continued reductions in U.S. capacity resulting in increased reliance on foreign imports of coke (USITC, 1994). The McCloskey Coal Information Service projected U.S. furnace coke consumption to decline by a total of 10 percent from 25.7 million short tons in 1992 to 23 million short tons in 2000 (Bennett, 1993). As shown in Table 3-4, the Business Communications Company (1995) expects an even greater decline of almost 58 percent from 23.7 million short tons in 1994 to 10 million short tons in 2004—an average decline of 5.8 percent per year. These reductions are due in part to the projected decline in blast furnace steel production of 0.7 percent per year. However, the majority of the projected decline in U.S. furnace coke consumption results from the declining coke rate, i.e., the furnace coke required to produce a ton of blast furnace steel. Table 3-4 shows that the coke rate is projected to dramatically decline by 55 percent from 0.4 in 1994 to 0.18 in 2004—a 5.5 percent annual decline. This projection must incorporate technological changes in blast furnace operations as experts indicate that because coke serves as both a fuel and carbon source the coke rate cannot be reduced below 600 pounds per short ton of iron, or 0.3 (Schriefer, 1995).

Table 3-4. Projected U.S. Furnace Coke Consumption: 1994-2004

Years	Blast Furnace Steel Production (10^3 short tons)	Furnace Coke Consumption (10^3 short tons)	Coke Rate[a]
1994	59,360	23,703	0.40
1999	60,200	15,000	0.25
2004	55,500	10,000	0.18
	Average Annual Growth Rates		
1994-2004	-0.7%	-5.8%	-5.5%
1994-1999	0.3%	-7.3%	-7.5%
1999-2004	-1.6%	-6.7%	-5.6%

[a] Measure the tons of furnace coke input required to produce a ton of blast furnace steel.

Sources: Business Communications Company. October 1995. Selected excerpts from "The Future of the Steel Industry in the U.S." <http://www.profound.com>.

3.2.2 Uses and Consumers of Foundry Coke

Approximately 90 percent of all manufactured goods and almost all industrial machines currently produced in the United States contain some type of cast metal (Douglas, 1991). Examples of goods containing iron castings are automobiles and trucks, farm machinery, industrial machinery, boilers, pipes, and railroad equipment. The basic iron casting process is hardly different today than it was a thousand years ago. Metal is first melted, then refined by adding alloys, and then poured into prepared molds from a ladle. The castings are then cooled, taken out of their molds, and prepared for their final use (Douglas, 1991). Three types of furnaces are commonly used to melt the metals used to produce iron castings: cupolas, EAFs, and electric induction (EI) furnaces. Of these three furnace types, only cupolas, which resemble miniature blast furnaces, use foundry coke. Therefore, the demand for foundry coke is derived from the demand for iron castings produced using cupola melting. Cupola melting currently accounts for about 64 percent of all iron melted, with typical foundry coke demand ranging from 1.4 to 1.7 million tons per year (Stark, 1995).

As shown in Figure 3-5, foundry coke is used in the initial stage of casting production to melt scrap iron into a liquid that can be poured into prepared molds and allowed to cool and harden. Cupolas are charged at the top with alternating layers of foundry coke and scrap iron and/or steel and occasionally with small quantities of pig iron. Small amounts of ferro-alloys, such as nickel, silicon, chromium, molybdenum, titanium, and copper may be added to obtain a wide range of physical properties in castings. Enough limestone is added to the charge to remove ash from the coke to the slag, which is removed from the top of the melt prior to casting. Blasts of hot air that rise through the charge ignite the coke to provide the heat necessary to melt the metals (U.S. Steel, 1971). Foundry coke serves not only as the fuel in cupolas but also as the primary source of carbon for castings produced from scrap metals melted in cupolas (Eppich, 1992).

The quantity of foundry coke consumed each year in the United States is small relative to the quantity of furnace coke consumed. As shown previously in Figure 3-1, iron foundries accounted for only 7.2 percent of total U.S. coke shipments in 1997. Unlike the integrated iron and steel firms, U.S. iron foundries do not have captive operations and, thus, must purchase all of their coke inputs from merchant coke producers. Little, if any, of the foundry coke consumed in the United States is imported because of breakage during transportation and other quality concerns such as the higher sulphur content of foreign-made coke (Eppich, 1992). In addition, foundry coke is a specialized fuel so that substitution opportunities are severely limited for the cupola operators.

Historical data on foundry coke consumption is not available because publicly available sources only provide aggregate data for merchant coke producers, which produce both furnace and foundry coke. Table 3-5 provides reported U.S. shipments of foundry coke based on facility survey responses (USITC, 1994). The actual figures are expected to be between 30 and 35 percent higher than those reported since not all facilities responded to the USITC questionnaire. As shown, the U.S. consumption of foundry coke declined by

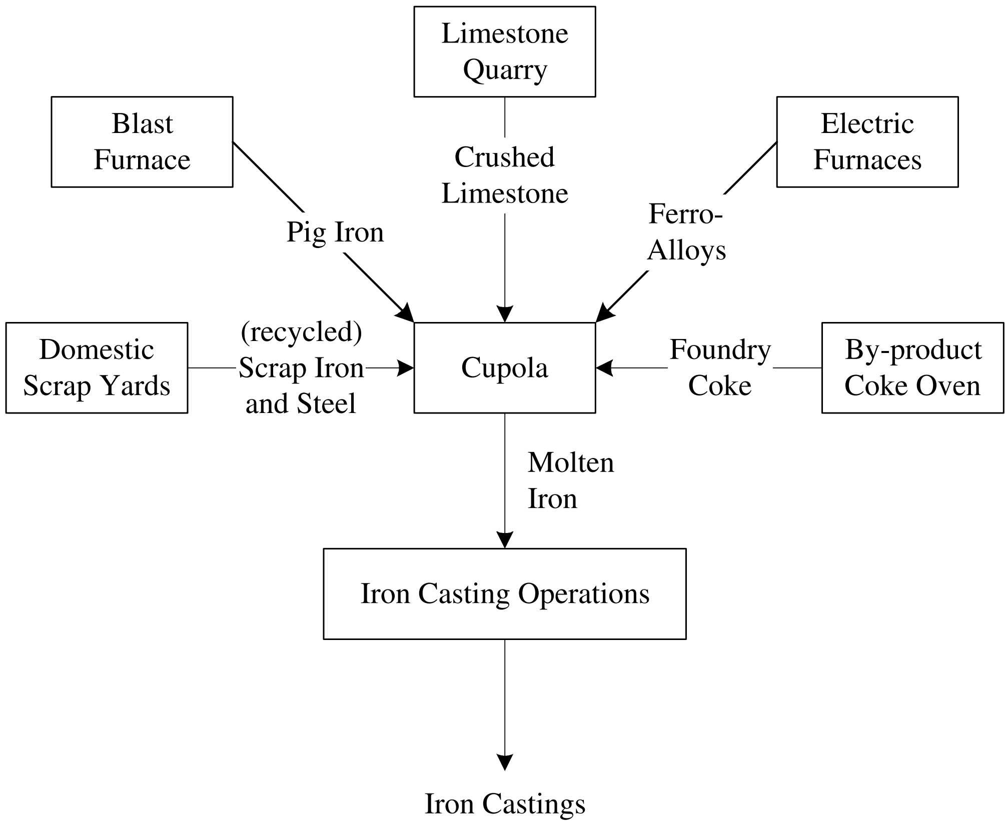


Figure 3-5. Use of Foundry Coke in Iron Castings Production

1.2 percent per year from 1990 through 1993. Based on the EPA industry database, U.S. foundry coke production totaled 1.6 million short tons in 1997 (EPA, 1998a).

Historically, the U.S. consumption of foundry coke is known to have declined because ferrous foundries experienced such huge declines in the 1970s and 1980s with over 1,000 metalcasting facilities closing (DOE, 1996b). These declines resulted from the combined effects of a slumping U.S. economy, fierce international competition, and higher costs of production resulting from stricter environmental regulations. Total production of ferrous castings in 1986 fell to about half the level recorded in 1978. Almost half of the foundries, representing over a third of U.S. production capacity operating in 1980, closed down during that period (Douglas, 1991).

Table 3-5. Reported U.S. Foundry Coke Shipments: 1990-1993[a]

Year	Volume (10^3 short tons)
1990	1,045
1991	940
1992	1,025
1993[b]	1,006
Average Annual Growth Rate	
1990-1993	-1.2%

[a] USITC indicates that the actual totals are expected to be 30 to 35 percent higher because data was not received from all foundry coke production facilities.

[b] Annual figure estimated by EPA based on data reported for January through June of 1993.

Source: U.S. International Trade Commission. 1994. *Metallurgical Coke: Baseline Analysis of the U.S. Industry and Imports.* Publication No. 2745. Washington, DC: USITC.

The metalcasting industry has recovered during the 1990s due to the improved U.S. economy and the corresponding increases in domestic demand for castings, particularly by automotive manufacturers (EPA, 1998b). U.S. shipments of iron castings have increased by 27 percent from 8.5 million short tons in 1990 to 10.8 million short tons in 1997—an average increase of 3.9 percent per year (DOC, 1991-1997). Despite these recent increases, ferrous castings have and will continue to face increasing competition from nonferrous castings (e.g., aluminum and copper) in several major markets including motor vehicles, industrial and transportation equipment, and construction materials. The American Foundrymen's Society projects iron casting demand to vary between 9 and 10.5 million tons through 2004 (Stark, 1995). Assuming casting yields of 55 percent, metal to coke ratios of 8 to 1, and cupola-melted iron at 64 percent of total iron melted, the projected U.S. foundry coke demand will range from 1.3 to 1.5 million tons per year (Stark, 1995). These projections reflect an overall decline of 7 percent from current levels of U.S. furnace coke consumption.

3.2.3 Uses and Consumers of Other Coke

Blast-furnace operators and iron castings producers require coke of a specific size. Coke that does not meet the required size specifications is sold to other industries and referred to as "other coke." Based on the EPA industry database, U.S. industrial coke production totaled 0.4 million short tons in 1997 (EPA, 1998a). These coke products are used as fuel inputs for other industrial processes. These processes include the processing of sugar beets in the sugar industry, the reduction of lead in the primary and secondary lead smelting industry, in the mineral fiber industry, and in the manufacture of cement (Sloss Industries, 1998).

3.3 Consumer Responses to Price Changes

The USITC (1994) reports that the domestic demand for furnace coke is generally considered to be price inelastic. This conclusion results from the derived demand nature of furnace coke, i.e., the consumption level is dependent upon steel output which should be relatively insensitive to changes in the coke price, especially in the short run. Ramachandran (1981) used time series data from 1950 through 1977 to compute ordinary least squares estimates of the derived demand elasticity for furnace coke and foundry coke. Based on a simple Cobb-Douglas production function for the steel industry, he estimated the derived demand elasticity for furnace coke to be -1.17. Applying this production function to the iron castings industry, he estimated the derived demand elasticity for foundry coke to be -1.03. These estimates apply to the short-run, where the capital stock is assumed to be fixed. In the long run, the demand elasticity is be expected to be even more elastic than the short run estimates as the capital stock is not fixed and the substitution possibilities are therefore greater. Ramachandran (1981) also estimates the short-run and long-run elasticities of import demand for furnace coke to be -1.88 and -26.86, respectively.

This study represents the only empirical estimates of demand elasticity for coke found in the economics literature. However, these estimates are limited by the assumed form of the production function. Based on the simplified Cobb-Douglas production function, the derived demand elasticity depends upon only the cost-share of coke for each industry and are restricted to be elastic, i.e., greater than one. Therefore, these are upper-bound estimates of the short-run demand elasticity because the ability for the industries to substitute for coke was not considered. The iron casting industry cannot substitute for foundry coke in foundry cupolas, which would lower the demand elasticity for foundry coke. Similarly, although substitutes do exist for furnace coke, these substitutes are only partial substitutes (i.e., the coke rate may be reduced, but the use of coke is still essential to the operation of blast furnaces). This heavy reliance on coke would translate into an less elastic (more inelastic) demand for furnace and foundry coke. Ramachandran (1981) did not provide estimates of the demand elasticity of other industrial coke, but this elasticity should be more elastic as the fuel substitution possibilities for these industrial users is much greater than for producers of blast-furnace steel and iron castings.

3.4 Substitutes for Coke

In recent years, several options for coke substitution have become available to blast furnace and cupola operators. This section focuses on the substitution possibilities for furnace and foundry coke in terms of material substitution and cokeless production technologies for both steel and iron casting producers.

3.4.1 Material Substitution

3.4.1.1 Furnace Coke

The coke rate, or the amount of furnace coke required per ton of blast furnace steel produced, has declined dramatically in the past twenty years. This decline is due mainly to the increase of supplemental fuel injection in blast furnaces so that operators are no longer depending solely on coke to fuel the production of pig iron. Natural gas and coal injection are being increasingly incorporated as fuel options. As shown previously in Table 3-4, the decrease in furnace coke consumption has continued to decline despite recent increases in U.S. blast furnace steel production. The reason behind this continued decrease is that the coke rate has been declining at an increasing rate and having a major impact on the amount of coke consumed.

Blast furnace operators have been using supplemental fuel injection for years, but the injection rates have been aggressively increased in recent years. These declines are a response to the increasing costs of coke and its decreasing availability. Environmental regulation and supply shortages have increased the cost of using coke. Coke capacity and production decreased due to the decline in blast furnace steel production and the closure of aging coke batteries. All of the currently operating blast furnaces inject either one or a combination of fuels including natural gas, pulverized coal, granular coal, oil, tar, and coke-oven gas (Hogan and Koelble, 1996).

The injection of natural gas is favored by many blast furnace operators because natural gas is readily available, relatively inexpensive, and can be adapted to blast furnace injection without major capital costs. Natural gas injection has been proven by some mills to be capable of displacing about 25 percent of coke requirements (USITC, 1994). Although some furnaces have reached injection rates of 250 pounds of natural gas per ton of pig iron produced, the average is rate is only 125 pounds per ton. Injection is typically limited to a range of 100 to 200 pounds per short ton because higher volumes lower flame temperatures and reduce furnace productivity (Hogan and Koelble, 1996).

Pulverized coal injection (PCI) does not affect flame temperatures in the same manner and, therefore, allows a greater opportunity for decreasing the amount of coke required. PCI can replace up to 40 percent of the coke requirement (USITC, 1994). The coal used in pulverized coal injection is lower-cost and lower-grade than the metallurgical coals required for cokemaking. USITC (1994) reports that some analysts predict PCI to displace up to 12 percent of the worldwide consumption of coke by 2000. However, PCI has the major disadvantage of high start-up costs of between $40 and $50 million to set-up coal preparation facilities and injection equipment. Alternatively, granular coal injection (GCI) is less costly than PCI because granulating requires less energy than pulverizing. A drawback of GCI, however, is that granular coal might plug the furnace at high injection levels. There is also the risk that granular coal will not fully burn in the furnace since it contains more moisture than pulverized coal (Ninneman, 1997).

3.4.1.2 Foundry Coke

In response to the increasing cost of metallurgical coke and costs of complying with environmental regulation, cupola operators have begun to use natural gas as a substitute for part of the foundry coke. Although no examples of its use at currently operating cupola were available, a Gas Research Institute (GRI) study evaluated the performance of a cupola using natural gas as a supplemental fuel (Molnar, 1993). This study indicated that natural gas could supply up to 20 percent of required thermal input and improve the thermal performance of the cupola, i.e., reducing the energy consumed per ton of iron. Furthermore, the operating costs were reduced by $2.60 per ton as a result of lower coke and limestone consumption with production gains of 20 percent. The use of natural gas also reduced air emissions because of the improved combustion of hydrocarbons and coke fines.

3.4.2 Cokeless Steelmaking Technologies

Another reason for the declining demand for furnace coke is that more steel is being produced without the input of blast furnace pig iron. The recent trend in U.S. steelmaking technology is towards cokeless steel production.

3.4.2.1 Electric Arc Furnaces

Steel has traditionally been made from iron that in turn was made in the blast furnace from furnace coke, iron ore, and flux. The resulting iron was made into steel using either the open hearth furnace (OHF) or the basic oxygen furnace (BOF). The OHF was the dominant furnace type for nearly a century, but it disappeared in 1992, replaced in integrated steel manufacturing by the BOF. Pig iron is melted and refined in these furnaces and transformed into steel. The molten steel is formed into ingots, which are in turn shaped in the primary mill into blooms, billets, or slabs, or put through a continuous casting process that forms them directly into these semi-finished forms. Finally, in the finishing mills, the steel is converted into final products such as sheets, wire, rods, or structural forms.

Electric arc furnaces offer an alternative steelmaking technology that uses scrap steel and electricity as inputs and does not require coke, iron ore, or limestone. Therefore, the steelmaker does not depend on these raw material supplies. This reduces the need for the traditional method of integrated steel production. Although EAFs have been in existence since the 1930s, rapid improvements in design during the 1960s increased their profitability. EAFs do not require the massive investment that integrated traditional plants do and have, therefore, given rise to “mini-mills,” which have much smaller average capacity than traditional steel mills.

Figure 3-6 shows the changing shares of total steel production over the last 20 years by steelmaking technologies: coke-using technologies (i.e., open hearth furnaces and basic oxygen furnaces) and EAFs. As shown, EAFs have accounted for a growing share of total U.S. steel production. The quantity of domestic raw steel produced using this technology

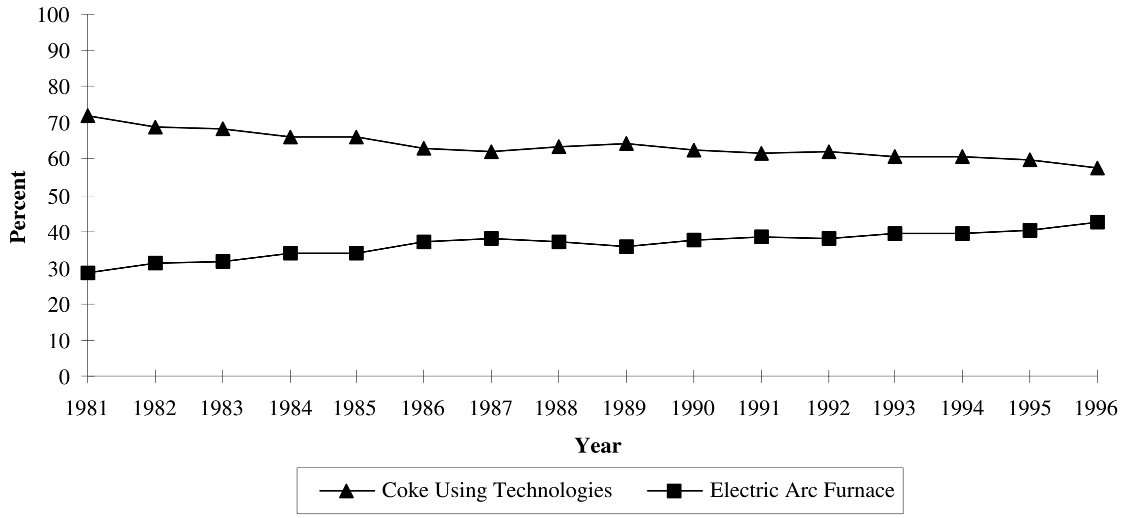


Figure 3-6. Share of U.S. Raw Steel Production Technology

Source: American Iron and Steel Institute (AISI). 1981-1996. *Annual Statistical Reports* Washington, DC: American Iron and Steel Institute.

increased steadily from 1970 to 1989. The EAFs share of U.S. raw steel production increased from 15.3 percent in 1970 to 35.9 percent in 1989—an average increase of 7 percent per year. As of 1996, EAFs accounted for 42.6 percent of U.S. raw steel production (AISI, 1997).

Because of continuing technological developments, the steelmaking technologies that do not require coke are expected to continue to increase their share of production. New EAF technologies are being developed that can produce a wider variety of steels at lower costs than conventional EAFs, and several new EAFs are under construction. Because this new process is less capital-intensive and more efficient than traditional methods, its development is expected to result in additional substitution of EAFs for traditional steelmaking methods.

3.4.2.2 Cokeless Ironmaking Processes

In an attempt to eliminate the traditional and increasingly expensive coke-oven/blast furnace ironmaking technology, several cokeless ironmaking processes have been developed in recent years. As opposed to material substitution that reduces the coke rate, these cokeless processes eliminate the use of coke altogether. These technologies are commonly referred to as direct ironmaking that produce directly reduced iron (DRI), which are iron-ore lumps, pellets, or fines that have had the oxygen removed from then by a reductant. DRI may be one of the following types:

- Hot-briquetted iron (HBI). Directly reduced iron that has been formed into briquettes for shipping (DRI that has not been briquetted can self-ignite during shipment).
- Sponge iron. DRI in various forms, but generally in lump or pellet form.
- Iron carbide. DRI in dull grey grains with a 6 percent carbon content (Ritt, 1996).

The composition of DRI typically includes 90 to 93 percent iron and 1 to 4 percent carbon.

The alternative ironmaking processes are based on either natural gas or coal. Natural gas processes are generally simpler than coal-based processes because they do not require additional steps to handle the coal and coal by-products. These processes are more attractive in areas where natural gas is relatively inexpensive, while coal-based processes are preferred where coal is more abundant and less expensive. However, coal-based processes produce DRI with more sulfur and generates more waste and environmental releases (Ritt, 1996).

Although the market shares of these technologies are not yet significant in the United States, the U.S. steel industry does appear to be investing in these technologies. In the United States, Geneva Steel currently uses a coal-based DRI process (i.e., Corex as described below) to lower costs and take advantage of low price for U.S. western coal. Some alternative processes are described in more detail below (Ritt, 1996; USITC, 1995):

- **AISI Direct Steelmaking.** This bath smelting process uses coal to smelt iron-ore pellets into molten iron, incorporating a shaft furnace and a smelting furnace. The iron oxide dissolves in a layer of slag. It was jointly funded by the U.S. Department of Energy and American Iron and Steel Institute.
- **Corex.** Development of this process started in 1981 by a German firm and is already employed commercially throughout the world. This process uses non-coking coal to produce molten iron. Iron ore in lump, pellet, or sintered form is reduced in a reduction shaft by gas formed in a melter or gasifier. After reduction, the iron burden travels by screw conveyor to the melter or gasifier to be melted.
- **DIOS (Direct iron-ore smelting).** This is a two-stage process developed in Japan that uses coal to smelt iron-ore fines into molten iron. The ore fines are pre-reduced in a fluidized bed reduction furnace by off-gas from the smelting reduction furnace, and are then charged in the smelting reduction furnace along

with coal and fluxes. Full commercialization of DIOS is expected by the year 2000 (USITC, 1995).

- **Fior (Fluid iron-ore reduction).** A natural gas-based process in which iron ore fines are reduced in a series of descending fluidized bed reactors. Counterflowing gas rich in hydrogen reduce the ore fines that are briquetted after leaving the reactor. The Finmet process is based on this technology.

- **HI-smelt.** This is a direct smelting process resulting from a joint venture between CRA Ltd., an Australian company, and Midrex Corporation, a U.S. company. It is particularly suited for Australian steel producers and uses coal to smelt iron-ore fines in a fluidized bed reactor to produce molten iron. The ore fines first are pre-reduced in a furnace by off-gas from a shaft furnace, and are then charged into a horizontal reduction furnace. Coal and natural gas are injected through the bottom of the furnace to reduce the iron ore.

- **Midrex.** A natural gas-based process in which lump ore or iron-oxide pellets are reduced in a vertical shaft furnace. The natural gas rises from the middle to the top of the furnace and reduces the feed stored in the upper half. The feed then falls to the bottom of the furnace where it is cooled.

- **Romelt.** This is a one-stage process that uses non-coking coal as a fuel and reductant to convert iron oxides into molten iron. The ferrous material to be reduced can be virgin iron ore or waste materials such as mill scale and iron dust. The iron-bearing material and coal are charged into a horizontal furnace, where the iron is reduced in a molten pool of swirling slag.

3.4.3 Cokeless Cupola Technology

Although not known to be currently employed in the United States, the cokeless cupola has existed for over 20 years (Taft, 1998). This technology is currently employed in the United Kingdom, Germany, Japan, and Korea. The cokeless cupola eliminates the need for foundry coke to melt iron by substituting natural gas, propane, diesel oil, powdered coal, or other suitable fuels (Cokeless Cupolas Limited, 1998). Advantages of cokeless technology are lower energy consumption (almost 50 percent less for ductile iron), better environmental performance through reduced formation of carbon dioxide and carbon monoxide, cleaner and better quality metal, less wear and tear on the refractory linings that may extend equipment lifetimes, and less generation of solids that reduce disposal problems (Cokeless Cupolas Limited, 1998). Existing cupolas may be converted; however, Taft (1998) indicates that some large hot-blast cupolas fitted with the proper environmental controls produce molten iron as cheaply and clean as cokeless cupolas and, thus, would likely not be economic to convert.

SECTION 4

INDUSTRY ORGANIZATION

This section describes the structure of the markets for furnace and foundry coke, the characteristics of the plants that manufacture coke, and the characteristics of the firms that own these manufacturing plants.

4.1 Market Structure

Market structure is important to understanding an industry because it determines the behavior of producers and consumers in the industry. If an industry is perfectly competitive, then individual producers are not able to influence the price of the output they sell or the inputs they purchase. This condition is most likely to hold if the industry has a large number of firms, the products sold are undifferentiated, and entry and exit of firms is unrestricted. Product differentiation can occur both from differences in product attributes and quality and from brand name recognition of products. Entry and exit of firms is unrestricted for most industries except, for example, in cases when government regulates who is able to produce, when one firm holds a patent on a product, when one firm owns the entire stock of a critical input, or when a single firm is able to supply the entire market.

When compared across industries, firms in industries with fewer firms, more product differentiation, and restricted entry are more likely to be able to influence the price they receive for a product by reducing output below perfectly competitive levels. This ability to influence price is referred to as exerting market power. At the extreme, a single monopolistic firm may supply the entire market and hence set the price of the output. On the input market side, firms may be able to influence the price they pay for an input if there are few firms, both from within and outside the industry, that use that input. At the extreme, a single monopsonist firm may purchase the entire supply of the input and hence set the price of the input.

To assess the competitiveness of a market, economists often estimate four-firm concentration ratios (CR4) and Herfindahl-Hirschman indexes (HHI) for the subject market or industry. The CR4s measure the percentage of sales accounted for by the top four firms in the industry, with higher (lower) percentages indicating more (less) concentrated markets and less (more) competition across firms. The HHIs are the sum of the squared market shares of firms in the industry, which provides a higher (lower) index when market shares are more (less) concentrated, indicating less (more) competitive markets. These measures of market concentration are typically computed by four-digit SIC codes based on U.S. Bureau of the Census data. However, coke producers are classified in SIC code 3312, Blast Furnaces and Steel Mills, which also contains integrated iron and steel mills. Because steel mill products are predominant in this SIC code, the Census Bureau measures of market concentration are not good approximations for evaluating the markets for coke.

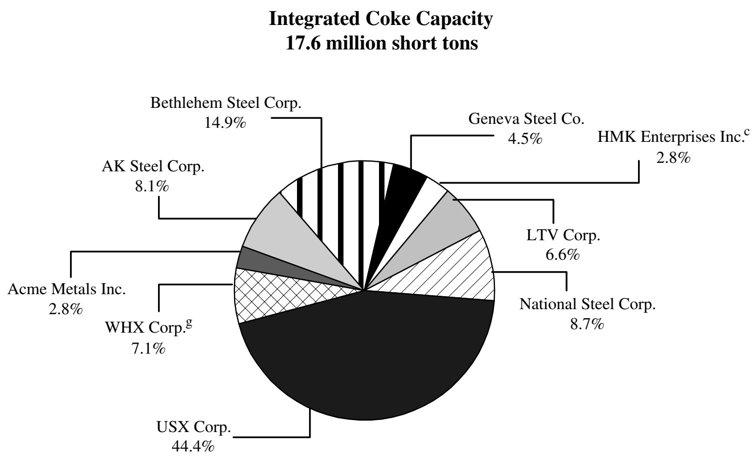
Thus, this examination of market structure for coke is based on data from EPA's facility survey and industry sources (EPA, 1998a; AISE, 1998; IISI, 1993). The U.S. coke industry has two primary product markets (i.e., furnace and foundry coke) that are supplied by two producing sectors—integrated producers and merchant producers. Integrated producers are part of integrated iron and steel mills and only produce furnace coke for captive use in blast furnaces. Therefore, much of the furnace coke is produced and consumed by the same integrated producer and never passes through a market. However, some integrated steel producers have closed their coke batteries over the past decade and must purchase their coke supply from merchant producers or foreign sources. In addition, a small number of integrated steelmakers produce more furnace coke than they need and sell their surplus to other integrated steelmakers. As of 1997, integrated producers accounted for roughly 76 percent of U.S. coke capacity with merchant producers accounting for the remaining 23 percent. These merchant producers sell furnace and foundry coke on the open market to integrated steel producers (i.e., furnace coke) and iron foundries (i.e, foundry coke). Some merchant producers sell both furnace and foundry coke, while others specialize on only one.

Figure 4-1 provides the distribution of U.S. integrated and merchant coke capacity by company. As shown, there were nine integrated companies with captive coke operations during 1997. USX Corporation was the largest integrated producer accounting for 44.4 percent of U.S. integrated coke capacity. Bethlehem Steel Corporation was the second largest producer with almost 15 percent of U.S. integrated coke capacity, followed by National Steel Corporation (8.7 percent) and AK Steel Corporation (8.1 percent). Alternatively, there were ten companies operating merchant coke operations during 1997. Sun Company Incorporated was the largest merchant producer by far accounting for 34.7 percent of U.S. merchant coke capacity. This company owns the non-recovery coke operations of Indiana Harbor Coke Company and Jewell Coke and Coal Company, which are not subject to the proposed regulations. Other larger merchant producers include Drummond

Company Incorporated (12.5 percent), Citizens Gas and Coke (11.3 percent), Aloe Holding Company (9.2 percent), and Walter Industries (8 percent).

Although captive consumption currently dominates the U.S. furnace coke market, open market sales of furnace coke are increasing (USITC, 1994). Because of higher production costs, U.S. integrated steel producers have been increasing their consumption of furnace coke from merchant coke producers, foreign imports, and other integrated steel producers with coke surpluses. Merchant coke producers accounted for only about 16 percent of U.S. furnace coke production in 1997. During that year, seven companies produced furnace coke in the United States. Figure 4-2 shows the distribution of furnace coke production across these companies. As shown, the U.S. furnace market appears to be slightly concentrated with a CR4 of 71.3 percent. However, the U.S. market for furnace coke is expected to be more competitive than this CR4 measure indicates after factoring in competition from foreign imports and integrated producers with coke surpluses.

Merchant coke producers account for a small share of U.S. furnace coke production; however, they account for 100 percent of U.S. foundry coke production. In 1997, six companies produced foundry coke in the United States. Figure 4-2 shows the distribution of foundry coke production across these companies. As shown, the U.S. foundry market appears to be fairly concentrated with two companies currently accounting for two-thirds of U.S. production—Drummond Company Incorporated with 45 percent and Citizens Gas and Coke with 22.6 percent. The remaining four merchant producers each account for between 7.5 and 8.8 percent of the market. Based on this data, the CR4 measure of concentration for this market is 84.5 percent. However, these producers do not produce a differentiated product and are limited to selling only to iron foundries, both of which would limit their ability to influence prices. In addition, the strategic location of these manufacturers would appear to promote competition within the southeastern and north-central United States and, perhaps, across regions given access to water transportation. Thus, the U.S. market for foundry coke is also expected to be more competitive than this CR4 measures implies.



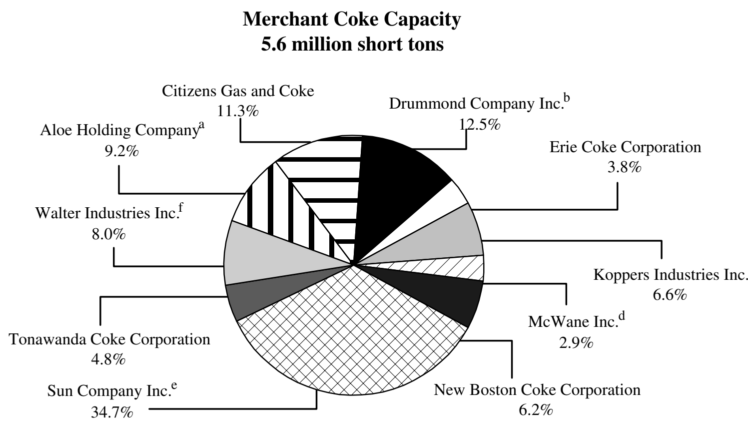
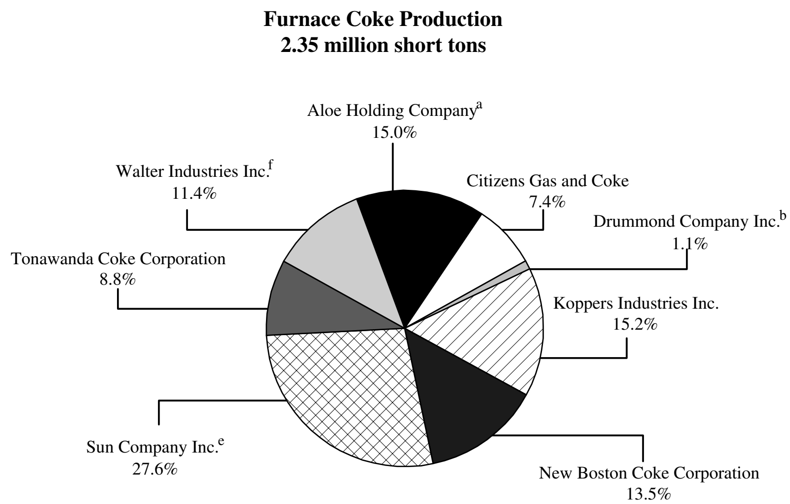


Figure 4-1. Distribution of Coke Capacity by Integrated and Merchant Companies: 1997

[a] Owns Shenango Inc.
[b] Owns ABC Coke.
[c] Owns Gulf States Steel, Inc.
[d] Owns Empire Coke.
[e] Owns Indiana Harbor Coke Co. and Jewell Coke and Coal Co., which are not subject to proposed regulations.
[f] Owns Sloss Industries Corporation.
[g] Owns Wheeling-Pittsburgh Corp.

Sources: U.S. Environmental Protection Agency. 1998a. *Coke Industry Responses to Information Collection Request (ICR) Survey*. Database prepared for EPA's Office of Air Quality Planning and Standards. Research Triangle Park, NC.
Association of Iron and Steel Engineers (AISE). 1998. "1998 Directory of Iron and Steel Plants: Volume 1 Plants and Facilities." Pittsburgh, PA: AISE.
International Iron and Steel Institute. 1993. *World Cokemaking Capacity*. Brussels, Belgium: IISI.



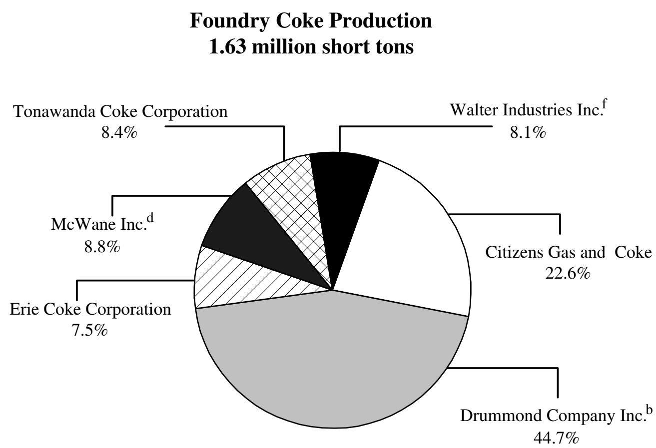


Figure 4-2. Distribution of Merchant Coke Production by Coke Type: 1997

[a] Owns Shenango Inc.
[b] Owns ABC Coke.
[c] Owns Gulf States Steel, Inc.
[d] Owns Empire Coke.
[e] Owns Indiana Harbor Coke Co. and Jewell Coke and Coal Co., which are not subject to proposed regulations.
[f] Owns Sloss Industries Corporation.
[g] Owns Wheeling-Pittsburgh Corp.

Source: U.S. Environmental Protection Agency. 1998a. *Coke Industry Responses to Information Collection Request (ICR) Survey*. Database prepared for EPA's Office of Air Quality Planning and Standards. Research Triangle Park, NC.

4.2 Coke Manufacturing Plants

Figure 4-3 identifies the location of U.S. coke manufacturing plants by type of producer (i.e., integrated and merchant). As shown, coke is currently manufactured at a total of 25 plants with 14 integrated plants and 11 merchant plants. These manufacturing plants are located near their end-users or customers and concentrated in the north-central United States and Alabama. The remainder of this section characterizes these integrated and merchant manufacturing plants in detail using facility responses to EPA's industry survey and industry data sources. Table 4-1 presents summary data for individual U.S. coke manufacturing plants, while Table 4-2 provides summary data by type of producer.

As of 1997, there were 14 integrated plants operating 40 coke batteries with 2,648 coke ovens. Total coke capacity at these plants was 17.6 million short tons with production devoted entirely to furnace coke. These integrated plants are owned and operated by large integrated steel companies and accounted for 80 percent of total U.S. coke production in 1997 (all furnace coke). The largest integrated producer is U.S. Steel, which operates two coke manufacturing plants in Clairton, Pennsylvania and Gary, Indiana. The Clairton facility is the largest single coke plant in the United States accounting for roughly 24 percent of U.S. cokemaking capacity. The two U.S. Steel plants together have a total of 16 coke batteries with 1,084 coke batteries accounting for roughly 40 percent of all coke batteries and ovens at integrated plants. As shown in Table 4-2, integrated coke plants had an average of 2.9 coke batteries, 189 coke ovens, and coke capacity of 1.26 million short tons per plant. These plants produced an average of 1.14 million short tons of furnace coke and accounted for 88 percent of the 18.2 million short tons of furnace coke produced in 1997. As of 1997, there were 11 merchant plants operating 26 coke batteries with 1,182 coke ovens. Total coke capacity at these plants was 5.6 million short tons with production split between furnace and foundry coke. Merchant coke plants are typically owned by smaller, independent companies that rely solely on the sale of coke and coke by-products to generate revenue. These plants accounted for 20 percent of total U.S. coke production in 1997. The largest merchant furnace producer is Sun Coal and Coke, which operates Jewell Coke and Coal in Vansant, Virginia and newly constructed operations at Indiana Harbor Coke in East Chicago, Illinois (both plants both employ the nonrecovery cokemaking processes). Although listed as a merchant producer, the Indiana Harbor Coke plant is co-located with Inland Steel's integrated plant in East Chicago, Illinois and has an agreement to supply

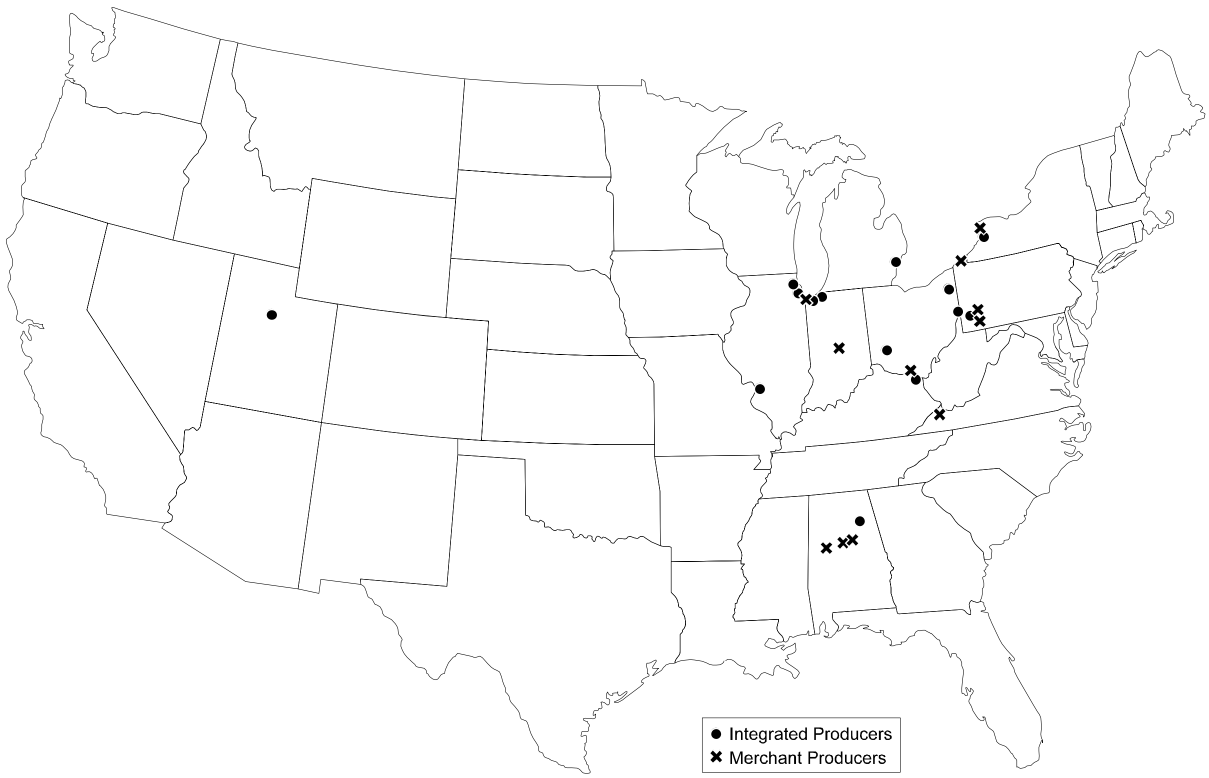


Figure 4-3. Location of Coke Manufacturing Plants by Type of Producer: 1997

Sources: U.S. Environmental Protection Agency. 1998a. *Coke Industry Responses to Information Collection Request (ICR) Survey*. Database prepared for EPA's Office of Air Quality Planning and Standards. Research Triangle Park, NC.

Table 4-1. Summary Data for Coke Manufacturing Plants: 1997

Plant Name	Location	Number of Batteries	Number of Coke Ovens	Total Coke Capacity (short tons/yr)	Coke Production by Type (short tons/yr)			
					Furnace	Foundry	Other	Total
Integrated Producers								
Acme Steel	Chicago, IL	2	100	500,000	493,552	0	19,988	513,538
AK Steel	Ashland, KY	2	146	1,000,000	942,986	0	0	942,986
AK Steel	Middletown, OH	1	76	429,901	410,000	0	0	410,000
Bethlehem Steel	Burns Harbor, IN	2	164	1,877,000	1,672,701	0	82,848	1,755,549
Bethlehem Steel	Lackawanna, NY	2	152	750,000	747,686	0	0	747,686
Geneva Steel	Provo, UT	4	252	800,000	700,002	0	16,320	716,322
Gulf States Steel	Gadsden, AL	2	130	500,000	521,000	0	0	521,000
LTV Steel	Chicago, IL	1	60	615,000	590,250	0	0	590,250
LTV Steel	Warren, OH	1	85	549,000	543,156	0	0	543,156
National Steel	Ecorse, MI	1	85	924,839	908,733	0	0	908,733
National Steel	Granite City, IL	2	90	601,862	570,654	0	0	570,654
U.S. Steel	Clairton, PA	12	816	5,573,185	4,854,111	0	0	4,854,111
U.S. Steel	Gary, IN	4	268	2,249,860	1,813,483	0	0	1,813,483
Wheeling-Pittsburgh	Follansbee, WV	4	224	1,247,000	1,249,501	0	36,247	1,285,748
Total, Integrated Producers		40	2,648	17,617,647	16,017,815	0	155,403	16,173,216

(continued)

Table 4-1. Summary Data for Coke Manufacturing Plants: 1997 (Continued)

Plant Name	Location	Number of Batteries	Number of Coke Ovens	Total Coke Capacity (short tons/yr)	Coke Production (short tons/yr)			
					Furnace	Foundry	Other	Total
Merchant Producers								
ABC Coke	Tarrant, AL	3	132	699,967	25,806	727,720	0	753,526
Citizens Gas	Indianapolis, IN	3	160	634,931	173,470	367,798	93,936	635,204
Empire Coke	Holt, AL	2	60	162,039	0	142,872	0	142,872
Erie Coke	Erie, PA	2	58	214,951	0	122,139	19,013	141,152
Indiana Harbor Coke[a,b]	East Chicago, IN	4	268	1,300,000	0	0	0	0
Jewell Coke and Coal[a]	Vansant, VA	4	142	649,000	649,000	0	0	649,000
Koppers	Monessen, PA	2	56	372,581	358,105	0	0	358,105
New Boston Coke	Portsmouth, OH	1	70	346,126	317,777	0	4,692	322,469
Shenango, Inc.	Pittsburgh, PA	1	56	514,779	354,137	0	0	354,137
Sloss Industries	Birmingham, AL	3	120	451,948	268,304	131,270	33,500	433,074
Tonawanda	Buffalo, NY	1	60	268,964	0	136,225	63,822	200,047
Total, Merchant Producers		26	1,182	5,615,286	2,146,599	1,628,024	214,963	3,989,586
Total, All Producers		66	3,830	23,232,933	18,164,414	1,628,024	370,366	20,162,802

[a] Operates nonrecovery coke batteries not subject to the regulations.
[b] Newly built coke operations coming on-line during 1998.

Sources: U.S. Environmental Protection Agency. 1998a. *Coke Industry Responses to Information Collection Request (ICR) Survey*. Database prepared for EPA's Office of Air Quality Planning and Standards. Research Triangle Park, NC.
Association of Iron and Steel Engineers (AISE). 1998. "1998 Directory of Iron and Steel Plants: Volume 1 Plants and Facilities." Pittsburgh, PA: AISE.
International Iron and Steel Institute. 1993. *World Cokemaking Capacity*. Brussels, Belgium: IISI.

Table 4-2. Coke Industry Summary Data by Type of Producer: 1997

Item	Integrated Producers		Merchant Producers		Total
	Total	Share	Total	Share	
Coke Plants (#)	14	56.0%	11	44.0%	25
Coke Batteries (#)					
Total number	40	60.6%	26	39.4%	66
Average per plant	2.86		2.36		2.64
Coke Ovens (#)					
Total number	2,648	69.1%	1,182	30.9%	3,830
Average per plant	189.1		107.5		153.2
Coke Capacity (short tons/yr)					
Total capacity	17,617,647	75.8%	5,615,286	24.2%	23,232,933
Average per plant	1,258,403		510,481		929,317
Coke Production (short tons/yr)					
Total production					
Furnace	16,017,815	88.2%	2,146,599	11.8%	18,164,414
Foundry	0	0.0%	1,628,024	100.0%	1,628,024
Other	155,403	42.0%	214,963	58.0%	370,366
Total	16,173,218	80.2%	3,989,586	19.8%	20,162,804
Average per Plant					
Furnace	1,144,130		195,145		726,577
Foundry	0		148,002		65,121
Other	11,100		19,542		14,815
Total	1,155,230		362,690		806,512

Sources: U.S. Environmental Protection Agency. 1998a. *Coke Industry Responses to Information Collection Request (ICR) Survey*. Database prepared for EPA's Office of Air Quality Planning and Standards. Research Triangle Park, NC.
Association of Iron and Steel Engineers (AISE). 1998. "1998 Directory of Iron and Steel Plants: Volume 1 Plants and Facilities." Pittsburgh, PA: AISE.
International Iron and Steel Institute. 1993. *World Cokemaking Capacity*. Brussels, Belgium: IISI.

1.2 million short tons of coke to Inland and sell the residual furnace coke production (Ninneman, 1997). As shown in Table 4-2, merchant coke plants are smaller than integrated plants with an average of 2.4 coke batteries, 108 coke ovens, and coke capacity of only 0.5 million short tons per plant. In 1997, these plants accounted for 12 percent of U.S. furnace coke produced and 100 percent of foundry coke production. They produced an average of 195 thousand short tons of furnace coke and 148 thousand short tons of foundry coke per plant.

Table 4-3 provides summary data for the 66 coke batteries currently operating at U.S. manufacturing plants. For each individual battery, this table provides information on the startup/rebuild date, number of coke ovens, height, manufacturer, coke rate, coke capacity, and coke production by type of product. As shown, integrated producers have a total of 40 coke batteries with 2,648 coke ovens for an average of 66 ovens per battery. The average startup or rebuild date for coke batteries at integrated producers was 1963, which corresponds to an average age of 34 years. In addition, these coke batteries averaged 0.73 tons of coke produced per ton of coal input. Alternatively, merchant producers have a total of 26 coke batteries with 1,18 coke ovens for an average of 45.5 ovens per battery. The average startup or rebuild date for coke batteries at merchant producers was 1967, which corresponds to an average age of 30 years. In addition, these coke batteries averaged 0.62 tons of coke produced per ton of coal input. In summary, integrated producers tend to have larger, older, and more efficient coke batteries than merchant producers.

As shown in Figure 4-4, the number of coke batteries operating in the U.S. coke industry has been declining over time. The number of coke batteries has declined by roughly 30 percent from 93 operating in 1989 to 66 operating in 1997. The majority of this decline is attributable to closings of coke plant and/or batteries at integrated steel producers. As shown, the number of coke batteries at integrated producers has declined by 39.4 percent from 66 operating in 1989 to 40 operating in 1997. The number of coke batteries at merchant producers has not declined as drastically as at integrated producers, falling from 28 in 1989 to 26 in 1997. As a result of these shutdowns, total U.S. coke capacity has declined by almost 20 percent from 28.6 million short tons in 1989 to 23.2 million short tons in 1997. Again, the majority of this capacity reduction is at integrated producers and, thus, has caused some difficulty for these producers to meet their demands for furnace coke. Consequently, the declining number of coke batteries and capacity at integrated producers has increased demand for merchant coke and allowed these producers to continue profitable operations and, in some cases, expand to meet the increasing demand.

Table 4-3. Summary Data for Operating Coke Batteries by Plant: 1997

Plant Name	Location	Battery ID	Startup or Rebuild Date	Number of Coke Ovens	Height (m)	Make[a]	Coke Rate[b]	Total Coke Capacity (short tons/yr)	Coke Production (short tons/yr) Furnace	Foundry	Other	Total
Integrated Producers												
Acme Steel	Chicago, IL	1	1980	50	4	W	0.63	250,000	246,776	0	9,994	256,769
		2	1979	50	4	W	0.63	250,000	246,776	0	9,994	256,769
AK Steel	Ashland, KY	3	1953	76	4	W	0.71	366,000	355,448	0	0	355,448
		4	1978	70	5	W	0.69	634,000	587,538	0	0	587,538
AK Steel	Middletown, OH	W	1994	76	4	W	0.72	429,901	410,000	0	0	410,000
Bethlehem Steel	Burns Harbor, IN	1	1983	82	6	O	0.75	929,000	814,354	0	40,390	854,744
		2	1994	82	6	K	0.76	948,000	858,347	0	42,458	900,805
Bethlehem Steel	Lackawanna, NY	7	1952	76	3.5	W	0.75	375,000	375,779	0	0	375,779
		8	1962	76	3.5	W	0.75	375,000	371,907	0	0	371,907
Geneva Steel	Provo, UT	1	1942	63	4	K	0.68	200,000	189,412	0	4,416	193,828
		2	1942	63	4	K	0.69	200,000	115,294	0	2,688	117,982
		3	1945	63	4	K	0.68	200,000	222,354	0	5,184	227,538
		4	1945	63	4	K	0.69	200,000	172,942	0	4,032	176,974
Gulf States Steel	Gadsden, AL	2	1943	65	4	W	0.69	250,000	208,400	0	0	208,400
		3	1965	65	4	W	0.69	250,000	312,600	0	0	312,600
LTV Steel	Chicago, IL	2	1981	60	6	D	0.76	615,000	590,250	0	0	590,250
LTV Steel	Warren, OH	4	1979	85	4	K	0.79	549,000	543,156	0	0	543,156
National Steel	Ecorse, MI	5	1994	85	6	O	0.68	924,839	908,733	0	0	908,733
National Steel	Granite City, IL	A	1980	45	4	O	0.72	300,931	285,287	0	0	285,287
		B	1982	45	4	O	0.72	300,931	285,367	0	0	285,367

(continued)

Table 4-3. Summary Data for Operating Coke Batteries by Plant: 1997 (Continued)

Plant Name	Location	Battery ID	Startup or Rebuild Date	Number of Coke Ovens	Height (m)	Make[a]	Coke Rate[b]	Total Coke Capacity (short tons/yr)	Coke Production (short tons/yr)			
									Furnace	Foundry	Other	Total
Integrated Producers (Continued)												
U.S. Steel	Clairton, PA	1	1955	64	3.6	W	0.74	378,505	315,000	0	0	315,000
		2	1955	64	3.6	W	0.74	378,505	315,000	0	0	315,000
		3	1955	64	3.6	W	0.74	378,505	315,000	0	0	315,000
		7	1954	64	3.6	K	0.72	378,505	320,000	0	0	320,000
		8	1954	64	3.6	K	0.72	378,505	320,000	0	0	320,000
		9	1954	64	3.6	K	0.72	378,505	320,000	0	0	320,000
		13	1989	61	3.6	S	0.76	373,395	332,275	0	0	332,275
		14	1989	61	3.6	S	0.76	373,395	332,275	0	0	332,275
		15	1979	61	3.6	S	0.76	373,395	332,275	0	0	332,275
		19	1976	87	4.3	K	0.75	668,680	537,005	0	0	537,005
		20	1978	87	4.3	K	0.75	668,680	537,005	0	0	537,005
		B	1982	75	6.1	S	0.73	844,610	878,276	0	0	878,276
U.S. Steel	Gary, IN	2	1975	57	6	S	0.73	827,820	640,045	0	0	640,045
		3	1976	57	6	S	0.73	827,820	618,970	0	0	618,970
		5	1952	77	3	W	0.75	297,110	269,549	0	0	269,549
		7	1952	77	3	W	0.75	297,110	284,919	0	0	284,919
Wheeling-Pittsburgh	Follansbee, WV	1	1955	47	3	K	0.74	151,000	137,445	0	3,986	141,431
		2	1956	47	3	K	0.74	151,000	137,445	0	3,986	141,431
		3	1963	51	3	K	0.74	163,000	137,445	0	3,986	141,431
		8	1976	79	6	K	0.75	782,000	837,166	0	24,289	861,455
Total/Average, Integrated Producers		40	1963	2,648	5	NA	0.73	17,617,647	16,017,815	0	155,403	16,173,216

(continued)

Table 4-3. Summary Data for Operating Coke Batteries by Plant: 1997 (Continued)

Plant Name	Location	Battery ID	Startup or Rebuild Date	Number of Coke Ovens	Height (m)	Make[a]	Coke Rate[b]	Total Coke Capacity (short tons/yr)	Coke Production (short tons/yr)			
									Furnace	Foundry	Other	Total
Merchant Producers												
ABC Coke	Tarrant, AL	1A	1967	78	5	W	0.78	490,528	0	536,258	0	536,258
		5/6	1951	54	4	K	0.80	209,439	25,806	191,462	0	217,268
Citizens Gas	Indianapolis, IN	E	1946	47	3.5	W	0.81	128,970	0	89,319	15,969	105,288
		H	1941	41	3.5	K	0.81	116,845	0	77,916	14,091	92,007
		1	1979	72	5	W	0.80	389,116	173,470	200,563	63,876	437,909
Empire Coke	Holt, AL	1	1941	40	2.49	S	0.80	108,026	0	95,248	0	95,248
		2	1941	20	2.49	S	0.80	54,013	0	47,624	0	47,624
Erie Coke	Erie, PA	A	1952	23	3.5	M	0.82	84,878	0	48,434	7,540	55,974
		B	1943	35	3.5	M	0.82	130,073	0	73,705	11,473	85,178
Indiana Harbor Coke[c]	East Chicago, IN	A	1998	67	16	T	0.63	325,000	0	0	0	0
		B	1998	67	16	T	0.63	325,000	0	0	0	0
		C	1998	67	16	T	0.63	325,000	0	0	0	0
		D	1998	67	16	T	0.63	325,000	0	0	0	0
Jewell Coke and Coal[c]	Vansant, VA	2	1976	43	15	T	NA	197,000	197,000	0	0	197,000
		3A	1983	36	15	T	NA	164,000	164,000	0	0	164,000
		3B	1989	27	15	T	NA	124,000	124,000	0	0	124,000
		3C	1990	36	15	T	NA	164,000	164,000	0	0	164,000
Koppers	Monessen, PA	1B	1981	37	4	K	0.69	245,815	236,605	0	0	236,605
		2	1980	19	4	K	0.69	126,766	121,500	0	0	121,500

(continued)

Table 4-3. Summary Data for Operating Coke Batteries by Plant: 1997 (Continued)

Plant Name	Location	Battery ID	Startup or Rebuild Date	Number of Coke Ovens	Height (m)	Make[a]	Coke Rate[b]	Total Coke Capacity (short tons/yr)	Coke Production (short tons/yr)			
									Furnace	Foundry	Other	Total
Merchant Producers (Continued)												
New Boston Coke	Portsmouth, OH	2	1964	70	4	K	0.67	346,126	317,777	0	4,692	322,469
Shenango, Inc.	Pittsburgh, PA	1	1983	56	4	O	0.73	514,779	354,137	0	0	354,137
Sloss Industries	Birmingham, AL	3	1952	30	3.7	K	0.72	133,931	126,520	0	0	126,520
		4	1956	30	3.7	K	0.72	133,931	126,520	0	0	126,520
		5	1958	60	3.7	K	0.75	184,086	15,264	131,270	33,500	180,034
Tonawanda	Buffalo, NY	2	1962	60	4	W	0.80	268,964	0	136,225	63,822	200,047
Total/Average, Merchant Producers		26	1967	1,182	8	NA	0.62	5,615,286	2,146,599	1,628,024	214,963	3,989,586

NA = not applicable

[a] Make of batteries: D = Didier, K = Koppers, O = Otto, S = Still, T = Thompson, and W = Wilputte.
[b] Coke rate is defined as average coke production (in short tons) per ton of coal input.
[c] Operates nonrecovery coke batteries not subject to the regulations.

Sources: U.S. Environmental Protection Agency. 1998a. *Coke Industry Responses to Information Collection Request (ICR) Survey*. Database prepared for EPA's Office of Air Quality Planning and Standards. Research Triangle Park, NC.
Association of Iron and Steel Engineers (AISE). 1998. "1998 Directory of Iron and Steel Plants: Volume 1 Plants and Facilities." Pittsburgh, PA: AISE.
International Iron and Steel Institute. 1993. *World Cokemaking Capacity*. Brussels, Belgium: IISI.

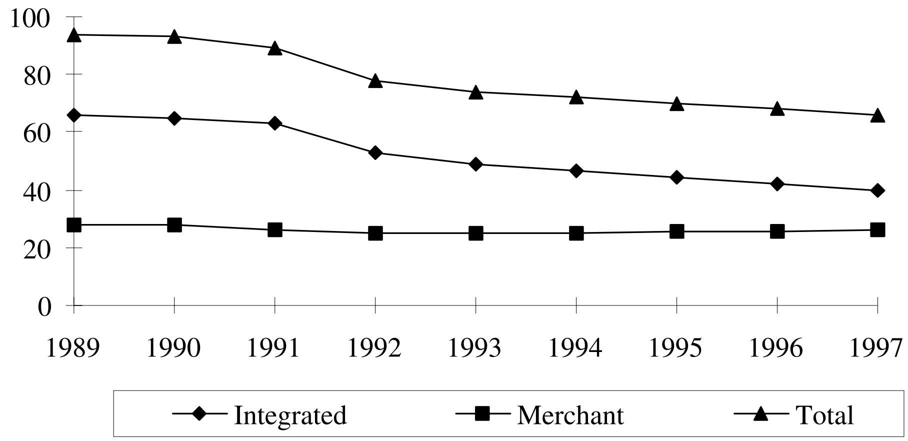


Figure 4-4. Operating Coke Batteries by Type of Producer: 1989-1997

Sources: U.S. Environmental Protection Agency. 1998a. *Coke Industry Responses to Information Collection Request (ICR) Survey*. Database prepared for EPA's Office of Air Quality Planning and Standards. Research Triangle Park, NC.

U.S. International Trade Commission. 1994. *Metallurgical Coke: Baseline Analysis of the U.S. Industry and Imports.* Publication No. 2745. Washington, DC: U.S. International Trade Commission.

4.3 Firm Characteristics

This section presents information on the parent companies that own the coke manufacturing plant identified in the previous section. The terms facility, establishment, and plant are synonymous and refer to the physical location where products are manufactured. Likewise, the terms company and firm are synonymous and refer to the legal business entity that owns one or more facilities. As seen in Figure 4-5, the chain of ownership may be as simple as one facility owned by one company (i.e., direct owner is parent company) or as complex as one facility owned by multiple companies (i.e., direct owner is subsidiary company or other legal entity).

4.3.1 Ownership

Table 4-4 lists parent companies that owned coke manufacturing plants as of 1997. Coke is currently manufactured by 19 companies operating 25 plants in the United States. These companies ranged from small, single-facility merchant coke producers to large

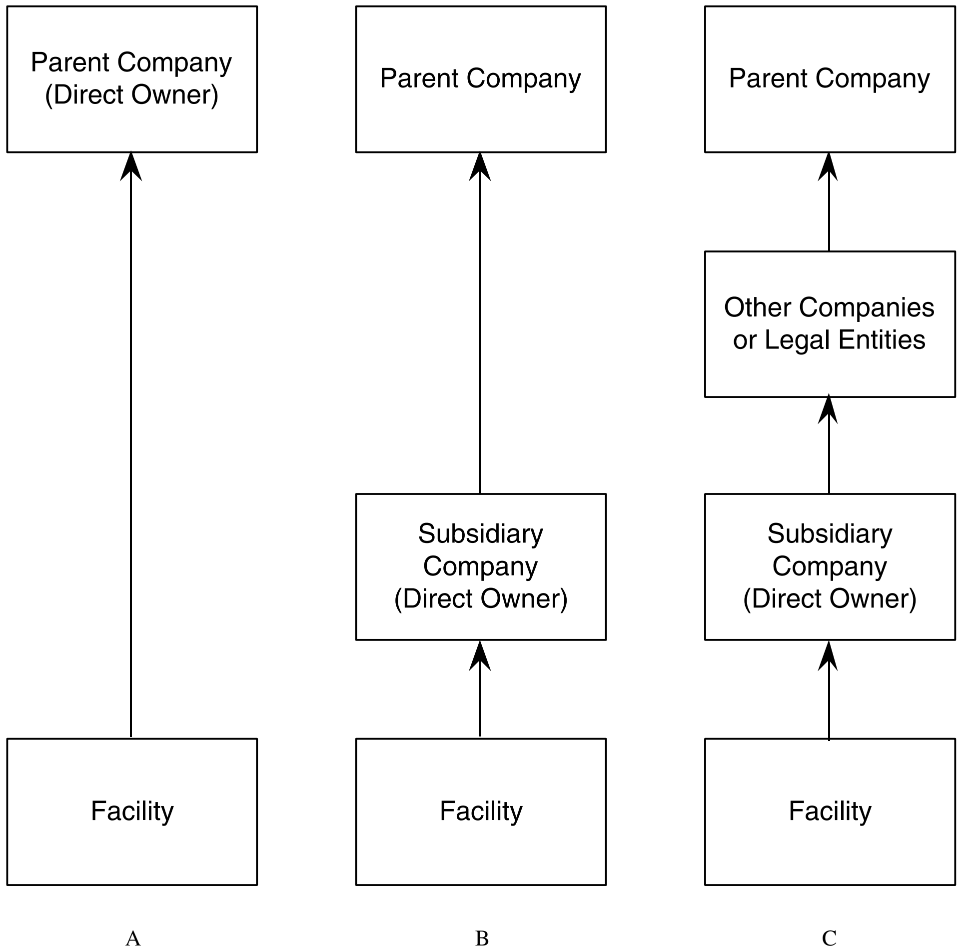


Figure 4-5. Possible Ownership Configurations in U.S. Coke Industry

integrated steel producers. Based on information from Dun & Bradstreet (1998), the majority of companies owning integrated operations were identified as publicly held (8 out of 9), while the majority of companies owning merchant operations were identified as private (4 out of 7 with known ownership). As shown, integrated producers are large, publicly owned integrated steel companies including USX Corporation, Bethlehem Steel Corporation, National Steel Corporation, LTV Corporation, and AK Steel Corporation. HMK Enterprises, which owns Gulf States Steel, is the only integrated producer that is privately owned. Alternatively, merchant producers are smaller companies that are typically privately owned and operated such as Koppers Industries, Drummond Company (owns ABC Coke), McWane

Table 4-4. Summary of Companies Owning Potentially Affected Coke Manufacturing Plants: 1997

Company Name	Legal Form of Organization	Producer Type	Total Sales ($\$10^6$)	Total Employment	Small Business
Acme Metals Inc.	Public	Integrated	488	2,471	No
AK Steel Corporation	Public	Integrated	2,441	5,800	No
Aloe Holding Company[a]	Holding company	Merchant	79	435	Yes
Bethlehem Steel Corporation	Public	Integrated	4,631	15,600	No
Citizens Gas and Coke	Private	Merchant	450	1,500	No
Drummond Company Inc.[b]	Private	Merchant	700	2,700	No
Erie Coke Corporation	NA	Merchant	24	130	Yes
Geneva Steel Company	Public	Integrated	727	2,600	No
HMK Enterprises Inc.[c]	Private	Integrated	530	3,000	No
Koppers Industries Inc.	Private	Merchant	465	1,800	No
LTV Corporation	Public	Integrated	4,446	15,500	No
McWane Inc.[d]	Private	Merchant	560	4,200	No
National Steel Corporation	Public subsidiary	Integrated	3,114	9,417	No
New Boston Coke Corporation	NA	Merchant	35	239	Yes
Sun Company Inc.[e]	Public	Merchant	10,464	10,900	No
Tonawanda Coke Corporation	NA	Merchant	23	130	Yes
USX Corporation	Public	Integrated	22,588	41,620	No
Walter Industries Inc.[f]	Public	Merchant	1,507	7,584	No
WHX Corporation[g]	Public	Integrated	642	5,706	No

[a] Owns Shenango Inc.
[b] Owns ABC Coke.
[c] Owns Gulf States Steel, Inc.
[d] Owns Empire Coke.
[e] Owns Indiana Harbor Coke Company and Jewell Coke and Coal Company, which are not subject to proposed regulations.
[f] Owns Sloss Industries Corporation.
[g] Owns Wheeling-Pittsburgh Corporation

Sources: Dun & Bradstreet. 1998. Dun's Market Identifier Electronic Database. Dialog Corporation.
Information Access Corporation. 1997. Business & Company Profile ASAP. [computer file] Foster City, CA: Information Access Corporation.

Table 4-5. Summary of Coke Operations at U.S. Companies: 1997

Company Name	Number of Coke Plants	Number of Batteries	Number of Coke Ovens	Total Coke Capacity (short tons/yr)	Coke Production by Type (short tons/yr)			
					Furnace	Foundry	Other	Total
Integrated Producers								
Acme Metals Inc.	1	2	100	500,000	493,552	0	19,988	513,540
AK Steel Corporation	2	3	222	1,429,901	1,352,986	0	0	1,352,986
Bethlehem Steel Corporation	2	4	316	2,627,000	2,420,387	0	82,848	2,503,235
Geneva Steel Company	1	4	252	800,000	700,002	0	16,320	716,322
HMK Enterprises Inc.[a]	1	2	130	500,000	521,000	0	0	521,000
LTV Corporation	2	2	145	1,164,000	1,133,406	0	0	1,133,406
National Steel Corporation	2	3	175	1,526,701	1,479,387	0	0	1,479,387
USX Corporation	2	16	1,084	7,823,045	6,667,594	0	0	6,667,594
WHX Corporation[b]	1	4	224	1,247,000	1,249,501	0	36,247	1,285,748
Total Integrated Producers	14	40	2,648	17,617,647	16,017,815	0	155,403	16,173,218

(continued)

Table 4-5. Summary of Coke Operations at U.S. Companies: 1997 (Continued)

Company Name	Number of Coke Plants	Number of Batteries	Number of Coke Ovens	Total Coke Capacity (short tons/yr)	Coke Production by Type (short tons/yr)			
					Furnace	Foundry	Other	Total
Merchant Producers								
Aloe Holding Company[c]	1	1	56	514,779	354,137	0	0	354,137
Citizens Gas and Coke	1	3	160	634,931	173,470	367,798	93,936	635,204
Drummond Company Inc.[d]	1	3	132	699,967	25,806	727,720	0	753,526
Erie Coke Corporation	1	2	58	214,951	0	122,139	19,013	141,152
Koppers Industries Inc.	1	2	56	372,581	358,105	0	0	358,105
McWane Inc.[e]	1	2	60	162,039	0	142,872	0	142,872
New Boston Coke Corporation	1	1	70	346,126	317,777	0	0	317,777
Sun Company Inc.[f]	2	8	410	1,949,000	649,000	0	0	649,000
Tonawanda Coke Corporation	1	1	60	268,964	207,234	136,225	63,822	407,281
Walter Industries[g]	1	3	120	451,948	268,304	131,270	33,500	433,074
Total Merchant Producers	11	26	1,182	5,615,286	2,353,833	1,628,024	210,271	4,192,128
Total	25	66	3,830	23,232,933	18,371,648	1,628,024	365,674	20,365,346

[a] Owns Gulf States Steel, Inc.
[b] Owns Wheeling-Pittsburgh Corporation
[c] Owns Shenango Inc.
[d] Owns ABC Coke.
[e] Owns Empire Coke.
[f] Owns Indiana Harbor Coke Company and Jewell Coke and Coal Company, which are not subject to proposed regulations.
[g] Owns Sloss Industries Corporation

Sources: U.S. Environmental Protection Agency. 1998a. *Coke Industry Responses to Information Collection Request (ICR) Survey*. Database prepared for EPA's Office of Air Quality Planning and Standards. Research Triangle Park, NC.
Association of Iron and Steel Engineers (AISE). 1998. "1998 Directory of Iron and Steel Plants: Volume 1 Plants and Facilities." Pittsburgh, PA: AISE.

Incorporated (owns Empire Coke), and Citizens Gas and Coke. As shown, one merchant producer is a holding company (Aloe Holding Company) and two merchant producers are publicly held companies (Walter Industries, which owns Sloss Industries Corporation, and Sun Company, which owns Jewell Coke and Coal and Indiana Harbor Coke Company). The corporate ownership of the remaining 3 merchant producers could not be identified based on available information.

Table 4-5 provides summary data of coke operations at U.S. companies by type of producer. As shown, USX Corporation is the largest of the nine companies owning integrated producers. As of 1997, this company owned 2 manufacturing plants, 16 coke batteries with 1,084 ovens, and accounted for 44.4 percent of U.S. integrated coke capacity with 7.8 million short tons per year. Alternatively, the Sun Company is the largest of the 10 companies owning merchant producers. As of 1997, this company owned 2 manufacturing plants, 8 coke batteries with 410 ovens, and accounted for 35 percent of U.S. merchant coke capacity with 1.95 million short tons per year.

4.3.2 Size

Company size is likely to be a factor in the distribution of the impacts of the proposed regulation across companies. Grouping the companies by size facilitates the analysis of small business impacts as required by the Regulatory Flexibility Act (RFA) of 1982 as amended by the Small Business Regulatory Enforcement Fairness Act of 1996 (SBREFA). Companies are grouped into small and large categories using Small Business Administration (SBA) general size standard definitions for SIC codes. These size standards are presented either by number of employees or by annual receipt levels, depending on SIC code. The manufacture of coke is covered under SIC code 3312, Blast Furnaces and Steel Mills. Thus, according to SBA size standards, companies owning coke manufacturing facilities and other SIC 3312 plants are small if the total number of employees at the company is less than 1,000; otherwise the company is classified as large.

Potentially affected companies range in size from 130 to over 22,000 employees. Figure 4-6 illustrates the distribution of affected U.S. companies by size based on employment data from Table 4-4. As shown, a total of four companies, or 22.2 percent, are categorized as small, while 15 companies, or 77.8 percent, are in the large category. As expected, the companies owning integrated coke plants are generally larger than the companies owning merchant coke plants. None of the nine companies owning integrated operations have fewer than 1,000 employees or are classified as small businesses. Alternatively, four of the ten companies owning merchant operations have fewer than

1,000 employees. Thus, the four companies that are classified as small businesses according to the SBA size criteria are all merchant producers. It should be noted, however, that not all companies owning merchant coke plants are small. For example, the Sun Company is one of the largest companies shown in Table 4-4 with over 10,000 employees.

Firms may differ in size for on or both of the following reasons:

- Coke manufacturing plants vary widely in size. All else being held equal, firms with large plants are larger than firms with small plants.
- Firms vary in the number of coke plants they own. All else being held equal, firms with more plants are larger than those with fewer plants.

Table 4-6 shows the average size of coke manufacturing plants by company size category. As shown, plants owned by large companies tend to be larger than those owned by small companies. Coke plants owned by small companies averaged 1.25 coke batteries, 61 coke ovens, and 169 employees, while plants owned by large companies averaged 2.9 coke batteries, 180 coke ovens, and 1,619 employees. Table 4-7 shows the distribution of firms by the number of coke manufacturing plants owned. As shown, a correlation seems to exist between the number of plants owned and company size. The average number of coke plants owned by small companies is 1 (i.e., 4 plants owned by 4 companies) as compared to an average of 2.33 (i.e., 35 plants owned by 15 companies). Manufacturing plants owned by these companies that do not produce coke are not reflected in this distribution.

4.3.3 Vertical and Horizontal Integration

Parent companies within the U.S. coke industry may be vertically and/or horizontally integrated. Vertical aspects of the firm’s structure reflect the extent to which inputs are purchased from outside the company to be manufactured into products in-house. Firms may own several plants, each of which handles different stages in the production process of the final product. This is the case for integrated producers, but not typical for merchant producers. Integrated producers are owned and operated by large integrated iron and steel companies that are involved with each and every stage of production for steel mill products.

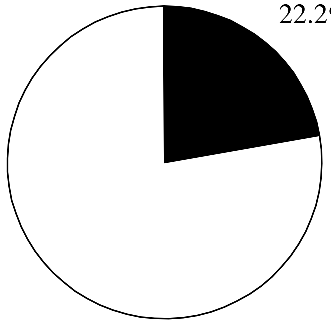


Figure 4-6. Distribution of Affected U.S. Companies by Size: 1997

Table 4-6. Average Size of Coke Operations by Firm Size Category: 1997

	Average Size of Coke Plant (# per plant)		
Company Size Category	**Batteries**	**Coke Ovens**	**Employment**
Small	1.25	61.0	168.5
Large	2.91	179.5	1,619.2
All companies	2.64	153.2	1,355.4

Table 4-7. Distribution of Companies by Number of Coke Plants: 1997

	Number of Coke Plants Owned per Company			
Company Size Category	**1**	**2 to 3**	**Over 3**	**Total**
Small	4	0	0	4
Large	9	6	0	15
All companies	13	6	0	19

This vertical integration may extend from ownership of the basic inputs such as coal and ore mines to the transport and distribution of the final steel mill products. Vertical integration is important because a regulation that increases the cost of manufacturing coke will also affect the cost of the final products that use coke in the production process.

Horizontal aspects of the firm's structure refer to the scale of production in a single-product firm or to the scope of production of all products (related and unrelated) in a multi-product firm. Some of the firms in the U.S. coke industry are horizontally integrated. This diversification goes beyond the coke by-products such as breeze, light oil, coal tar, other coal chemicals. This is particularly true for merchant producers, which are typically owned by diversified companies involved in chemicals, coal, or energy-related industries. Sloss Industries Corporation, which is owned by Walter Industries, has a diversified product-line including specialty chemicals for the rubber, automotive, and agriculture industries and slag wool for primarily thermal and acoustical insulation products (Sloss Industries, 1998). In addition, Koppers also supplies carbon materials and specialty chemicals, refined tars, pressure treated wood products, and commercial grade roofing products (Koppers Industries, 1998).

4.3.4 Financial Status

Based on 1992 data from USITC (1994), Table 4-8 provides a summary of the financial status of U.S. coke companies by type of producer. As shown, integrated producers relied solely on the net sales of furnace coke, while merchant producers relied on sales of furnace, foundry, and industrial coke. Net sales of coke at integrated producers totaled $1.9 million during 1992 , which dwarfed the net sales of coke at merchant producers of $430 thousand during that year. Profits and profitability measures were not available for integrated producers because profits are typically defined for their final product making it

Table 4-8. Financial Summary of U.S. Coke Industry by Type of Producer: 1992

	Integrated Producers	Merchant Producers
Net Sales ($\$10^3$)		
Furnace coke	\$1,910,213	\$245,004
Foundry coke	\$0	\$142,606
Industrial coke	\$0	\$42,642
Total	\$1,910,213	\$430,252
Net Profit[a]		
Absolute ($\$10^3$)		
Furnace coke	NA	\$10,442
Foundry coke	NA	\$23,395
Total	NA	\$33,837
Per unit (\$/short ton of coke production)		
Furnace coke	NA	\$3.72
Foundry coke	NA	\$22.90
Total	NA	\$8.84
Profitability (return on sales)		
Furnace coke	NA	4.3%
Foundry coke	NA	12.6%
Total	NA	7.9%

NA = not available

[a] Profits from the sale of industrial coke are included with profits reported for foundry coke.

Source: U.S. International Trade Commission. 1994. *Metallurgical Coke: Baseline Analysis of the U.S. Industry and Imports.* Publication No. 2745. Washington, DC: U.S. International Trade Commission.

difficult to properly allocate costs to the level of coke production. Merchant producers reported profits and profitability measures as they do not have this problem. Reported profits margins were higher for foundry and industrial coke relative to furnace coke. As shown, merchant producers earned a net profit of $3.72 per short ton of furnace coke and $22.90 per short ton of foundry and industrial coke (combined profits were reported only). Thus, their return on sales was 4.3 percent for furnace coke and 12.6 percent for foundry coke.

4.4 Industry Trends

During the 1970s and 1980s, integrated steelmakers shut down blast furnaces in response to reduced demand for steel thereby reducing the demand for furnace coke. During this time, many coke batteries were shut down thereby reducing the supply of coke. During the 1990s, the improved U.S. economy has produced strong demand for steel and now domestic coke consumption exceeds production. This deficit may increase because many domestic furnace coke batteries are approaching their life expectancies and may be shut down rather than rebuilt. However, no new coke batteries have been built and only 2 coke oven batteries have been rebuilt since 1990—National Steel in Ecorse, Michigan and Bethlehem Steel in Burns Harbor, Indiana (Agarwal et al., 1996). Most recent investments in new cokemaking have been made in non-recovery coke batteries as opposed to by-product recovery coke batteries. In fact, LTV Steel Corporation and the U.S. Steelworkers Union are reportedly exploring the possibility of locating a non-recovery coke facility on the site of the steelmaker’s current coke plant in Pittsburgh (American Metal Market, 1998). LTV closed this coke plant at the end of 1997 because its operating and environmental performance deteriorated to the point it was unable to meet CAA requirements without prohibitive investments of between $400 and $50 million (*New Steel*, 1997a).

Faced with the prospect of spending hundreds of millions of dollars to rebuild aging coke batteries, many integrated steelmakers have totally abandoned their captive cokemaking operations and now rely on outside suppliers. As of 1997, there were five integrated steel companies that did not produce their own coke and had to purchase this input from merchant plants, foreign sources, or other integrated producers with coke surpluses. These integrated steel companies include Inland Steel, Rouge Steel, USS/Kobe Steel, WCI Steel, and Weirton Steel with an estimated aggregate coke demand of 5.8 million short tons (Hogan and Koelble, 1996). In addition, there are four other integrated producers that currently have coke deficits. However, there are few integrated producers with coke surpluses to take up the slack. Hogan and Koelble (1996) reported that only 4 integrated steelmakers had coke surpluses as of 1995. This number is now down to 3 with the March 1998 closing of Bethlehem Steel’s coke operations in Bethlehem, Pennsylvania (*New Steel*, 1998b). These recent closures by LTV and Bethlehem removed 2.4 million short tons, or 10.5 percent, of U.S. coke capacity (*New Steel*, 1998b).

Furthermore, several integrated firms have sold some or all of their coke batteries to merchant companies, which then sell the majority of the coke they produce to the steel company at which the battery is located. Some of these are existing coke batteries, and others are newly rebuilt batteries, including some that use the non-recovery cokemaking process. An example is the Indiana Harbor Coke Company's coke batteries located at Inland Steel's Indiana Harbor Works in East Chicago, Indiana. Both National Steel and Bethlehem Steel have recently sold coke batteries to DTE Energy Company (*New Steel*, 1998a; *New Steel*, 1997b). Both steel companies will continue to operate the batteries and will buy the majority of the coke produced by the batteries from DTE at market value (National Steel, 1998).

These recent trends should have the following future impacts on the U.S. coke industry:

- Reduce the share of furnace coke produced by integrated producers thereby increasing reliance on merchant producers and foreign sources.
- Increase the furnace coke share of merchant production as these producers respond to expected increases in market prices for furnace coke, which also has lower production cost than foundry coke.
- Increase the volume of foreign imports of furnace and foundry coke as domestic demand continues to exceed domestic supply.

SECTION 5

MARKET DATA

This section presents historical and projected market data for coke products. Historical market data include the volumes of U.S. production, apparent consumption, and foreign trade, as well as market prices. In addition to historical market data, this section provides future projections of U.S. production and consumption of coke.

5.1 Market Volumes

Table 5-1 provides the historical volumes of U.S. production, foreign trade, changes in inventories, and apparent consumption of coke. Historical domestic data for 1980 through 1997 were obtained from the U.S. Department of Energy's Energy Information Administration (EIA) and supplemented by USITC (1994) and Hogan and Koelble (1996). Historical data for U.S. exports and imports of coke were obtained from the U.S. International Trade Commission's Trade Database (USITC, 1998).

5.1.1 Production

As shown in Table 5-1, U.S. coke production has declined by 52 percent from 46.1 million short tons in 1980 to 22.1 million short tons in 1997. During this period, coke production declined at an average annual rate of 3.1 percent, with growth from year to year varying slightly throughout the period. The largest decline occurred between 1981 and 1982 as U.S. coke production fell from 42.8 to 28.1 million short tons. This reduction was caused by the large-scale restructuring of the U.S. steel industry during which a large number of integrated mills and their associated cokemaking plants were shutdown. As shown in Table 5-1, the production volume of coke remained relatively stable during the remainder of the 1980s. U.S. coke production was almost unchanged from 28.1 million short tons in 1982 to 28 million short tons in 1989. However, during the 1990s, it has steadily declined by an average of 2.6 percent per year. This steady reduction is associated with the closings of aging cokemaking operations by a number of integrated U.S. steel producers.

Table 5-2 provides U.S. coke production by type of producer for 1980 through 1997. As shown, both integrated and merchant coke production have declined over this period. Integrated coke production has declined by 54 percent from 41.9 million short tons in 1980

Table 5-1. U.S. Production, Foreign Trade, and Apparent Consumption of Coke: 1980-1997 (10^3 short tons)

Year	U.S. Production	Exports	Imports	Changes in Inventories	Apparent Consumption[a]
1980	46,132	2,071	659	3,442	41,278
1981	42,786	1,170	527	-1,903	44,046
1982	28,115	993	120	1,466	25,776
1983	25,808	665	35	-4,672	29,850
1984	30,561	1,045	582	198	29,900
1985	28,651	1,122	578	-1,163	29,270
1986	25,540	1,004	329	-487	25,352
1987	26,304	574	922	-1,012	27,664
1988	28,945	1,093	2,688	529	30,011
1989	28,045	1,085	2,311	336	28,935
1990	27,617	572	1,078	-1	28,124
1991	24,046	740	1,185	189	24,302
1992	23,410	642	2,098	-224	25,090
1993	23,182	835	2,155	-422	25,924
1994	22,686	660	3,338	-525	25,889
1995	23,749	750	3,820	366	26,453
1996	23,075	1,121	2,543	21	24,476
1997	22,115	832	3,185	3	24,465
Average Annual Growth Rates					
1980-1997	-3.1%	-3.5%	22.5%	-5.9%	-2.4%
1980-1989	-4.4%	-5.3%	27.9%	-10.0%	-3.3%
1989-1997	-2.6%	-2.9%	4.7%	-12.4%	-1.9%

[a] Apparent consumption is equal to U.S. production minus exports plus imports minus changes in inventories.

Sources: U.S. Department of Energy. "AER Database: Coke Overview, 1949-1997." <http://tonto.eia.doe.gov/aer/aer-toc-d.cfm>. Washington, DC: Energy Information Administration. As obtained on September 14, 1998a.
Hogan, William T., and Frank T. Koelble. 1996. "Steel's Coke Deficit: 5.6 Million Tons and Growing." *New Steel* 12(12):50-59.
U.S. International Trade Commission. Trade Database: Version 1.7.1. <http://205.197.120.17/scripts/user_set.asp> As obtained in September 1998.

Table 5-2. U.S. Coke Production by Type of Producer: 1980-1997 (10^3 short tons)

	Integrated Producers		Merchant Producers		
Year	Volume	Share	Volume	Share	Total Volume
1980	41,899	90.8%	4,233	9.2%	46,132
1981	38,903	90.9%	3,884	9.1%	42,787
1982	25,374	90.3%	2,741	9.7%	28,115
1983	22,556	87.4%	3,253	12.6%	25,808
1984	26,791	87.7%	3,770	12.3%	30,561
1985	25,175	87.9%	3,476	12.1%	28,651
1986	22,251	87.1%	3,289	12.9%	25,540
1987	22,973	87.3%	3,331	12.7%	26,304
1988	25,490	88.1%	3,455	11.9%	28,945
1989	24,808	88.5%	3,237	11.5%	28,045
1990	23,892	86.5%	3,724	13.5%	27,616
1991	20,796	86.5%	3,252	13.5%	24,046
1992	20,162	86.1%	3,248	13.9%	23,410
1993	19,973	86.2%	3,209	13.8%	23,183
1994	19,444	85.7%	3,244	14.3%	22,686
1995	20,510	86.4%	3,240	13.6%	23,749
1996	19,969	86.5%	3,105	13.5%	23,075
1997	19,213	86.9%	2,903	13.1%	22,116
Average Annual Growth Rates					
1980-1997	-3.2%	-0.3%	-1.8%	2.5%	-3.1%
1980-1989	-4.5%	-0.3%	-2.6%	2.9%	-4.4%
1989-1997	-2.8%	-0.2%	-1.3%	1.7%	-2.6%

Source: U.S. Department of Energy. Various years. "Quarterly Coal Report." Washington, DC: Energy Information Administration.

to 19.2 million short tons in 1997—an average annual decline of 3.2 percent. Merchant coke production has declined by 31.5 percent from 4.2 million short tons in 1980 to 2.9 million short tons in 1997—an average annual decline of 1.8 percent. These declines follow the general trends for total U.S. coke production discussed above. Furthermore, integrated production dominates the U.S. coke industry. As shown in Table 5-2, integrated producers accounted for 91 percent of U.S. coke production in 1980 and continued strong with 87 percent in 1997. Merchant producer's share slightly increased from 9.2 percent in 1980 to 13.1 percent in 1997. Integrated production includes only furnace coke, while merchant production includes both furnace and foundry coke. However, available sources do not provide a breakdown of merchant production by type of coke.

Thus, to provide U.S. production by type of coke, the Agency generated historical estimates of the furnace coke share of merchant production. Based on limited time-series data from Hogan and Koelble (1996) on the furnace coke share of merchant coke production, regression analysis was employed to estimate an equation to project this share from 1980 through 1997.[1] The following time trend equation was estimated using ordinary least squares (with t-statistics shown in parentheses below coefficients):

$$\text{Furnace Coke Share} = \underset{(-39.0)}{-47.04} + \underset{(-39.3)}{.0238}\ \text{Year} \tag{5.1}$$

This equation appears to be highly predictive with an adjusted R-Square value of 0.9987. The Agency estimated U.S. furnace coke production from merchant producers by multiply the projected shares from Eq. (5.1) by total merchant coke production for each year from 1980 through 1997. U.S. foundry coke production was then derived as the residual volume.

Table 5-3 provides historical data on U.S. furnace coke production by producer type. As shown, U.S. production of furnace coke has declined by 51 percent from 42.8 million short tons in 1980 to 21 million short tons in 1997—an average annual reduction of 3 percent. Integrated producers have been predominant and accounted for 98 percent of U.S. furnace coke production in 1980. This share has declined by 6.5 percent over time to 91.5 percent as of 1997. This decline is attributable to reductions in U.S. cokemaking capacity due to plant closings at integrated producers. As a result, merchant producer's share has increased by four-fold from 2.1 percent in 1980 to 8.5 percent in 1997. This increase is not only due to declines at integrated producers but also steady increases in production by

[1]The time-series data consisted of only 3 annual observations for 1979 (19 percent), 1988 (39.6 percent), and 1996 (59.6 percent).

Table 5-3. U.S. Production of Furnace Coke by Producer Type: 1980-1997 (10^3 short tons)

	Integrated Producers		Merchant Producers		
Year	Volume	Share	Volume	Share	Total Production
1980	41,899	97.9%	893	2.1%	42,792
1981	38,903	97.7%	912	2.3%	39,815
1982	25,374	97.3%	709	2.7%	26,083
1983	22,556	96.1%	919	3.9%	23,475
1984	26,791	95.9%	1,156	4.1%	27,947
1985	25,175	95.6%	1,148	4.4%	26,323
1986	22,251	95.0%	1,165	5.0%	23,416
1987	22,973	94.8%	1,259	5.2%	24,232
1988	25,490	94.8%	1,389	5.2%	26,879
1989	24,808	94.7%	1,378	5.3%	26,186
1990	23,892	93.7%	1,675	6.3%	25,567
1991	20,796	93.1%	1,540	6.9%	22,336
1992	20,162	92.6%	1,616	7.4%	21,778
1993	19,973	92.3%	1,673	7.7%	21,646
1994	19,444	91.7%	1,768	8.3%	21,212
1995	20,510	91.8%	1,844	8.2%	22,354
1996	19,969	91.6%	1,841	8.4%	21,810
1997	19,213	91.5%	1,790	8.5%	21,003
Average Annual Growth Rates					
1980-1997	-3.2%	-0.4%	5.9%	18.1%	-3.0%
1980-1989	-4.5%	-0.4%	6.0%	16.9%	-4.3%
1989-1997	-2.8%	-0.4%	3.7%	7.7%	-2.5%

Sources: U.S. Department of Energy. Various years. "Annual Coal Report." Washington, DC: Energy Information Administration.
EPA estimates.

Table 5-4. U.S. Production of Foundry Coke by Producer Type: 1980-1997[a] (10^3 short tons)

	Integrated Producers		Merchant Producers		
Year	Volume	Share	Volume	Share	Total Production
1980	0	0.0%	3,340	100.0%	3,340
1981	0	0.0%	2,972	100.0%	2,972
1982	0	0.0%	2,032	100.0%	2,032
1983	0	0.0%	2,334	100.0%	2,334
1984	0	0.0%	2,614	100.0%	2,614
1985	0	0.0%	2,328	100.0%	2,328
1986	0	0.0%	2,124	100.0%	2,124
1987	0	0.0%	2,072	100.0%	2,072
1988	0	0.0%	2,066	100.0%	2,066
1989	0	0.0%	1,859	100.0%	1,859
1990	0	0.0%	2,049	100.0%	2,049
1991	0	0.0%	1,712	100.0%	1,712
1992	0	0.0%	1,632	100.0%	1,632
1993	0	0.0%	1,536	100.0%	1,536
1994	0	0.0%	1,476	100.0%	1,476
1995	0	0.0%	1,396	100.0%	1,396
1996	0	0.0%	1,264	100.0%	1,264
1997	0	0.0%	1,113	100.0%	1,113
Average Annual Growth Rates					
1980-1997	0.0%	0.0%	-3.9%	0.0%	-3.9%
1980-1989	0.0%	0.0%	-4.9%	0.0%	-4.9%
1989-1997	0.0%	0.0%	-5.9%	0.0%	-5.9%

[a] May include some coke screenings or industrial coke.

Source: EPA estimates.

merchant producers. As shown in Table 5-3, merchant production of furnace coke has doubled over this period from an estimated 0.9 million short tons in 1980 to 1.8 million short tons in 1997—an average increase of almost 6 percent per year.

Table 5-4 provides historical data on U.S. foundry coke production. As discussed previously, all foundry coke is manufactured at merchant plants. Although merchant production of furnace coke has increased over time, their production of foundry coke has steadily declined. As shown, U.S. production of foundry coke has declined by two-thirds from an estimated 3.34 million short tons in 1980 to 1.11 million short tons in 1997—an average annual reduction of 3 percent. These reductions are attributable to two factors: 1) declining demand by iron foundries, and 2) increasing incentive to shift production toward furnace coke. During the 1980s, the demand for iron castings declined because of the poor performance of the U.S. economy and changes in the automotive industry (i.e., reduced demand and material substitution). As a result, one-third of the U.S. foundries shut down operations (USITC, 1994). Reductions in demand have continued throughout the 1990s as foundries have made technological improvements, similar to those at blast furnaces, to reduce the amount of coke required to produce castings. In addition, merchant producers now face increasing incentives of expected higher prices and lower costs of producing furnace coke to meet the ver increasing domestic demand by integrated steelmakers.

5.1.2 Foreign Trade

International trade has historically comprised a small portion of the U.S. coke industry because of limitations associated with transport costs and breakage during transport. However, trade has become increasingly important during the 1990s. Table 5-1 provides the volume of U.S. exports and imports for coke from 1980 through 1997. As shown, the United States has become a net importer of coke. In 1980, the volume of coke exports was 2.1 million short tons, while the volume of coke imports was only 0.7 million short tons. By 1997, the coke exports had declined by almost 60 percent to 0.8 million short tons, and the coke imports were almost 5 times the level in 1980 at 3.2 million short tons. The decline in coke exports resulted from reductions in coke production associated with the declining U.S. steel industry during the 1980s. Despite the U.S. steel industry's turnaround during the 1990s, coke exports have continued to decline as they are crowded out by increasing domestic demand. The dramatic increase in imports has resulted from the improved U.S. economy and increasing demand for U.S. steel products since the late 1980s. These factors combined with previous and continued closings of U.S. coke plants have caused an aggregate

Table 5-5. Foreign Trade Concentration Ratios for Coke: 1980-1997

	Export Concentration Ratio[a] (%)	Import Concentration Ratio[b] (%)
1980	4.5	1.6
1981	2.7	1.2
1982	3.5	0.5
1983	2.6	0.1
1984	3.4	1.9
1985	3.9	2.0
1986	3.9	1.3
1987	2.2	3.3
1988	3.8	9.0
1989	3.9	8.0
1990	2.1	3.8
1991	3.1	4.9
1992	2.7	8.4
1993	3.6	8.6
1994	2.9	12.9
1995	3.2	14.4
1996	4.9	10.4
1997	3.8	13.0

[a] Measured as export share of U.S. production.
[b] Measured as import share of U.S. apparent consumption.

coke deficit at integrated iron and steel mills during the 1990s as domestic supply is not able to keep pace with demand for coke.

Table 5-5 provides foreign trade concentration ratios from 1980 through 1997. These ratios measure the export share of U.S. production and the import share of U.S. consumption. Thus, these measures demonstrate the importance of foreign trade to the U.S. coke industry. As shown, the U.S. export share of domestic production has been relatively stable over this

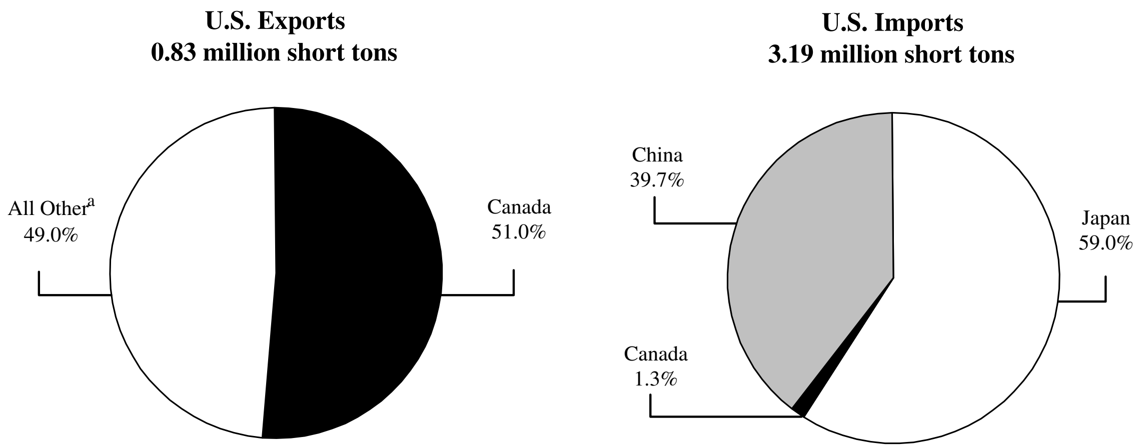


Figure 5-1. Distribution of U.S. Foreign Trade for Coke by Country: 1997

[a] Includes India, Japan, Mexico, Venezuela, and Thailand.

Source: U.S. International Trade Commission. "Trade Database: Version 1.7.1." <http://205.197.120.17/scripts/user_set.asp>. As obtained in September 1998.

period, decreasing slightly from 4.5 percent in 1980 to 3.8 percent in 1997. Alternatively, the U.S. import share of apparent consumption has dramatically increased over this period from 1.6 percent in 1980 to 13 percent in 1997. As shown, foreign imports have become and are expected to continue to be a significant factor in the U.S. coke industry.

Figure 5-1 provides the distribution of U.S. foreign trade for coke by country of origin/destination. Canada, Japan, and China were the United States' largest trading partners during 1997. Canada has been and continues to be the largest consumer of U.S. exports of coke because of proximity. In 1997, Canada accounted for 51 percent of the volume of U.S. coke exports with India, Mexico, Venezuela, and Thailand accounting for the remaining 49 percent. During that same year, Japan accounted for 59 percent of the volume of U.S. coke imports, followed by China with 39.7 percent and Canada with 1.3 percent. Since 1990, China has greatly increased its share of U.S. imports, i.e., from 2 percent in 1989 to 40 percent in 1997 (USITC, 1994; 1998). Alternatively, Australia's share of U.S. imports has totally been displaced, i.e., from 22 percent in 1989 to zero percent in 1997 (USITC, 1994; 1998).

5.1.3 Apparent Consumption

U.S. consumption of coke is measured by what is termed “apparent consumption,” which is computed as U.S. production minus exports plus imports minus changes in inventories. Table 5-1 provides historical data for the apparent U.S. consumption of total coke—the sum of furnace and foundry coke. As shown, apparent U.S. consumption of coke has decreased by 41 percent from 41.28 million short tons in 1980 to 24.47 million short tons in 1997—an average decline of 2. 4 percent per year. From 1980 to 1989, apparent consumption of coke declined by 3.3 percent per year, reflecting the decline in the U.S. economy and steel industry during this period. However, this decline has slowed during the 1990s as the U.S. economy has improved and the U.S. steel industry has rebounded. However, these positive effects have not been able to offset the shifts within the U.S. steel industry toward reduced coke consumption through improved efficiency of operations, substitution to alternative sources of fuel, and substitution toward “cokeless” technologies for iron and steel making. In addition, as shown in Table 5-5, the foreign import share of apparent U.S. consumption of coke has increased from 1.6 percent in 1980 to 13 percent in 1997. This increase in import dependence is a result of the increasing coke deficit at U.S. integrated iron and steel mills during the 1990s as domestic supply is not able to keep pace with demand for coke.

5.2 Market Prices

Historical data on market prices for coke are not directly available from public source nor can they be derived from the sources providing market volumes. Based on discussions with DOE’s Energy Information Administration, the USITC (1994) is the only known source of recent market prices for coke. These market prices are reported as net f.o.b. at plant and are based on industry responses to the USITC questionnaire. According to the USITC (1994), a vast majority of coke is sold under long-term contracts ranging from 1 to 6 years. These contracts typically provide for semiannual or annual renegotiation so that contract prices are closely related to open market prices. Thus, because a large share of coke is purchased through contracts, the USITC provides prices for both contract sales and spot market sales.

Table 5-6 provides market prices by type of coke product for 1990 through 1993. As shown, the spot market price is generally higher than the contract sales price and both seem positively correlated over time. The table also provides a weighted average price based on the volumes sold through contracts and the spot market for each year. As shown, the weighted average market price for furnace coke was roughly $100 per short ton in 1993 and has declined since 1990. The market price for foundry coke is typically 50 percent higher than for furnace coke. In 1993, the weighted average market price for foundry coke was $154 per short ton and has slightly increased since 1990. Table 5-6 also provides the market prices for other industrial coke and coke breeze. Industrial coke had a weighted average market price of $113 per short ton in 1993, while coke breeze was priced at $44 per short ton.

5.3 Future Projections

Future projections for the U.S. coke industry depend on a number of factors that are uncertain and interdependent. These factors include trends in integrated steelmaking and iron casting, compliance with environmental regulation, investments in or closures of domestic coke capacity, quality and availability of imports, and economic performance of domestic producers. For furnace coke, most analysts agree that U.S. capacity and production will decline faster than consumption and result in continued coke shortfalls to be meet by foreign imports. Based on a survey of studies, the USITC (1994) reports that U.S. furnace coke capacity is expected to decline by between 10 to 37 percent from 1990 through 2000, while U.S. consumption is forecast to decline between 10 and 23 percent. During the 1990s, furnace coke capacity at U.S. integrated producers has already declined by 27 percent from 24.2 million short tons in 1990 to 17.6 million short tons per year in 1997 (USITC, 1994; EPA, 1998a). This decline in capacity at integrated producers has been partially offset by increases in furnace coke capacity at merchant producers from 2.7 million short tons in 1990 to roughly 4 million short tons in 1997 (USITC, 1994; EPA, 1998a).

Assuming current rates of investment in existing coke batteries at integrated producers, furnace coke production in the United States is not expected to exceed 16 million short tons per year through 2000 (Agarwal et al., 1996). Alternatively, assuming integrated steelmakers demand between 52 to 59 million tons per year of molten iron, furnace coke consumption is estimated at between 18 to 22 million tons per year in 2000 (Agarwal et al., 1996). Included in this projected consumption level is the assumption that injection of natural gas and coal will continue to increase thereby reducing coke rates and decreasing demand for coke by an additional 1.2 to 2 million short tons per year. If steel demand is low (i.e., 52 to 54 million tons per year), then coke demand will be satisfied at the current import level of 3 million tons per year. However, if this demand is high (i.e., 56 to 59 million tons per year), then coke imports would likely increase to 6 million tons per year. Agarwal et al. (1996) predict that this increase in foreign imports may lead to future increases in coke prices and trigger a scramble for coke.

Table 5-6. Market Prices of Coke by Type: 1990-1993[a] ($ per short ton)

Product/Year	Contract Sales Price	Spot Market Sales Price	Weighted Average Price
Furnace coke			
1990	$106.62	$113.87	$107.06
1991	$103.99	$111.26	$105.00
1992	$103.05	$81.55	$102.50
1993[b]	$101.18	$71.12	$100.69
Foundry coke			
1990	$149.06	$151.86	$149.82
1991	$153.55	$147.60	$151.83
1992	$152.26	$153.60	$152.58
1993[b]	$152.90	$156.35	$153.75
Other industrial coke			
1990	$119.98	$117.53	$119.21
1991	$117.07	$118.06	$117.41
1992	$115.13	$117.46	$115.25
1993[b]	$112.08	$115.89	$112.29
Coke breeze			
1990	$42.83	$69.01	$43.31
1991	$44.42	$70.67	$44.94
1992	$45.42	$59.78	$45.88
1993[b]	$43.35	$70.38	$43.91

[a] Market prices are reported as net f.o.b. at plant.
[b] Reflects prices observed for January through June of 1993.

Source: U.S. International Trade Commission. 1994. *Metallurgical Coke: Baseline Analysis of the U.S. Industry and Imports.* Publication No. 2745. Washington, DC: USITC.

For foundry coke, most analysts agree that U.S. capacity will be stable and sufficient to meet future demands by iron foundries. The American Foundryman's Society has projected the demand for iron castings to be between 9 and 10.5 million short tons through 2004 (Stark, 1995). Based on casting yields of 55 percent, metal to coke ratios of 8 to 1, and a cupola-melting share at 64 percent of total, Stark (1995) projects foundry coke demand to range from 1.3 to 1.5 million short tons per year through 2004. As of 1997, total merchant plant capacity was 5.6 million short tons per year with roughly 2.1 million tons for foundry coke. Therefore, existing foundry coke capacity will exceed the projected demand and likely cause merchant producers to increasingly rely on furnace coke to fill this excess capacity (Stark, 1995).

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