Economic Impact Analysis of Final Iron and Steel Foundries NESHAP

Final Report

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Economic Impact Analysis of Final Iron and Steel Foundries NESHAP

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- industry-level impacts (e.g., changes in revenue, costs, and employment), and
- societal-level impacts (e.g., estimates of the consumer burden as a result of higher prices and reduced consumption levels and changes in domestic and foreign profitability).

1.2 Overview of Coke, Iron and Steel, and Foundry Industries

Iron and steel foundries produce castings that are either used internally (i.e., captive foundries vertically integrated into firms such as automobile manufacturers) or sold on the open market (i.e., merchant foundries). Although most steel foundries use electric arc or electric induction processes to melt metal, some foundries employ cupola furnaces that use foundry coke as a fuel to melt metal. Figure 1-1 summarizes these interactions between source categories and markets within the broader iron and steel industry.

The EIA models the specific links between these product markets. The analysis to support the iron and steel foundry EIA focuses on three specific markets:

- iron and steel castings and
- foundry coke.

Changes in price and quantity in these markets are used to estimate the market, industry, and social impacts of the iron and steel foundry MACT regulation.

1.3 Summary of EIA Results

The rule requires some iron and steel foundries to implement pollution control methods that will increase the costs of producing iron and steel foundries at affected facilities. The increased production costs primarily affect iron foundries and will lead to economic impacts in the form of very small increases in market prices and decreases in domestic iron castings production. The impacts of these price increases will be borne largely by affected iron foundries that use cupola furnaces as well as consumers of iron foundry products. Unaffected domestic foundries and foreign producers of coke will earn slightly higher profits. Key results of the EIA for the iron and steel foundry MACT are as follows:

- *Engineering Costs*: The engineering analysis estimates annual costs for existing sources of $21.23 million.

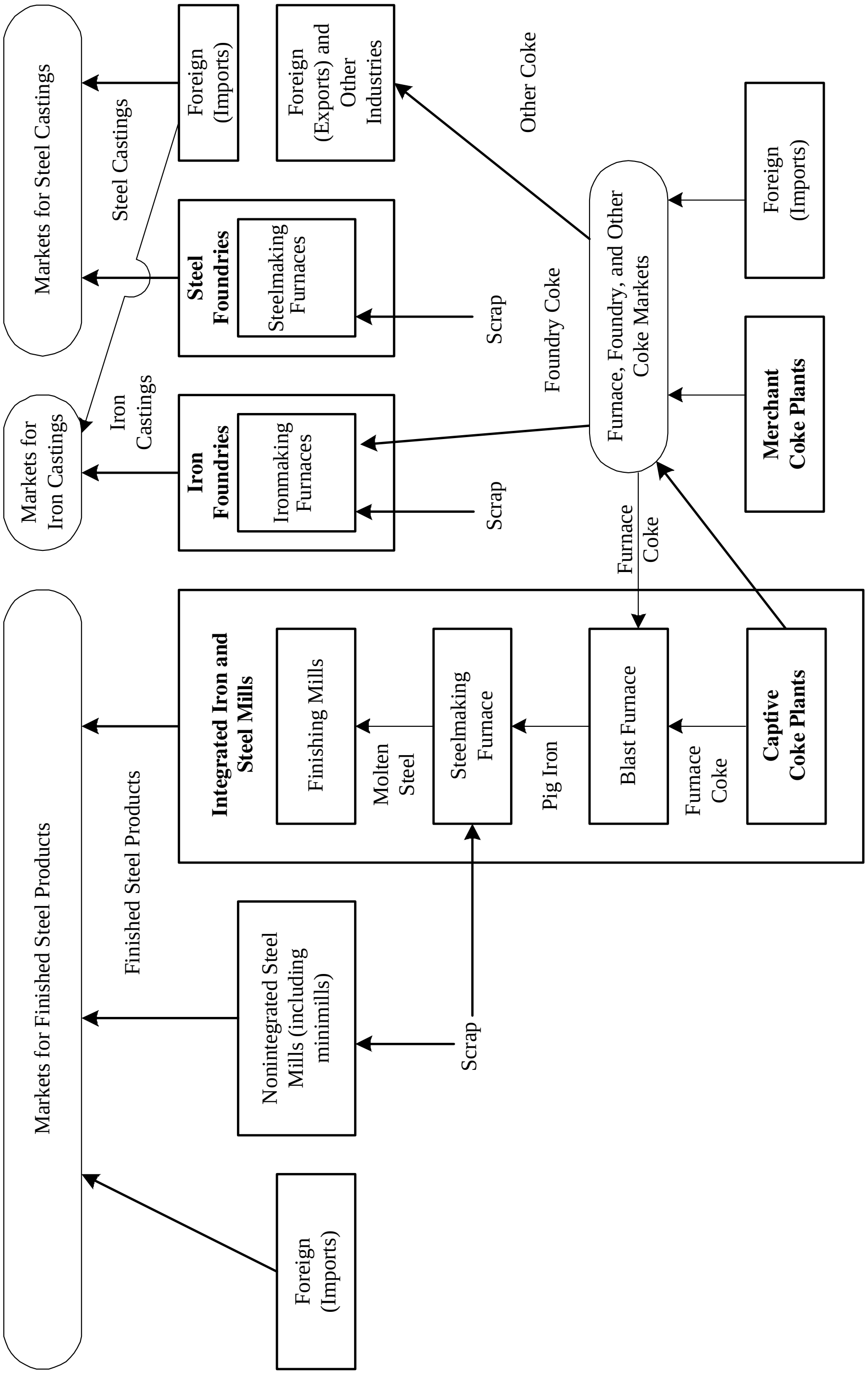

Figure 1-1. Interactions between Source Categories and Markets

- *Price and Quantity Impacts*: The EIA model predicts the following:
  - — The market price for iron castings is projected to increase by 0.1 percent ($1.12/short ton), and domestic iron castings production is projected to decrease by 0.08 percent (8,400 tons/year).
  - — The market price for steel castings is projected to increase by less than 0.05 percent ($0.45/short ton).
  - — The market price for foundry coke is projected to remain unchanged, and domestic foundry coke production is projected to decrease by less than 0.1 percent.
- *Small Businesses*: The Agency has determined that 20 small businesses within this source category would be subject to this rule. The average cost-to-sales ratio (CSR) for these firms is 0.40 percent. One small company is projected to have a CSR between 1 and 3 percent. However, no small firms are projected to have CSRs greater than 3 percent.
- *Social Costs*: The annual social costs are projected to be approximately $21.22 million.
  - — The consumer burden as a result of higher prices and reduced consumption levels is $13.2 million annually.
  - — The aggregate producer profits are expected to decrease by $8.0 million.

    The profit losses are $12.1 million annually for affected domestic iron and steel foundries.

    The profit increases are $3.1 million annually for unaffected domestic iron and steel foundries.

    Foreign producer profits increase by $1.0 million due to higher prices.

1.4 Organization of this Report

The remainder of this report supports and details the methodology and the results of the EIA of the iron and steel foundry MACT.

- Section 2 presents a profile of the iron and steel foundry industry.
- Section 3 describes the regulatory controls and presents engineering cost estimates for the regulation.
- Section 4 reports market-, industry-, and societal-level impacts.

- Section 5 presents the small business screening analysis.
- Appendix A describes the EIA methodology.
- Appendix B describes the development of the coke battery cost functions.
- Appendix C includes the econometric estimation of the demand elasticity for iron and steel casting products.

SECTION 2

INDUSTRY PROFILE

This section provides a summary profile of the iron and steel castings industry in the United States. The profile provides background on the technical and economic aspects of the industry used to support the EIA. The manufacture of iron and steel castings is included under Standard Industrial Classification (SIC) codes 3321—Gray and Ductile Iron Foundries; 3322—Malleable Iron Foundries; 3324—Steel Investment Foundries; and 3325—Steel Foundries, Not Elsewhere Classified.[1] Iron and steel castings are used in the production of over 90 percent of all manufactured durable goods and almost all industrial equipment (DOE, 1996). Therefore, the demand for iron and steel castings is a derived demand that depends on a diverse base of consumer products. In 1997, the United States produced 12 million short tons of iron and steel castings.

Section 2.1 provides an overview of the production processes and the resulting types of castings. Section 2.2 summarizes the organization of the U.S. iron and steel castings industry, including a description of the U.S. iron and steel foundries, the companies that own these facilities, and the markets for foundry products. Lastly, Section 2.3 presents historical data and future projections of the iron and steel foundry industry, including U.S. production and shipments.

2.1 Overview of Production Process

A casting is a "metal object obtained by allowing molten metal to solidify in a mold" (SFSA, 1998). Foundries manufacture castings by pouring metal melted in a furnace into a mold of a desired, and potentially intricate, shape. Achieving the same detail of form as a casting would require extensive tooling and shaping of metal from a mill. Creating some very small and precise castings is impossible by other means than casting.

The production of castings at foundries involves four distinct processes (see Figure 2-1). The first process is to make the molds and cores that will shape the casting.

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[1] These SICs correspond to the following North American Industrial Classification System (NAICS) codes: 331511–Iron Foundries; 331512–Steel Investment Foundries; and 331513–Steel Foundries, except Investment.

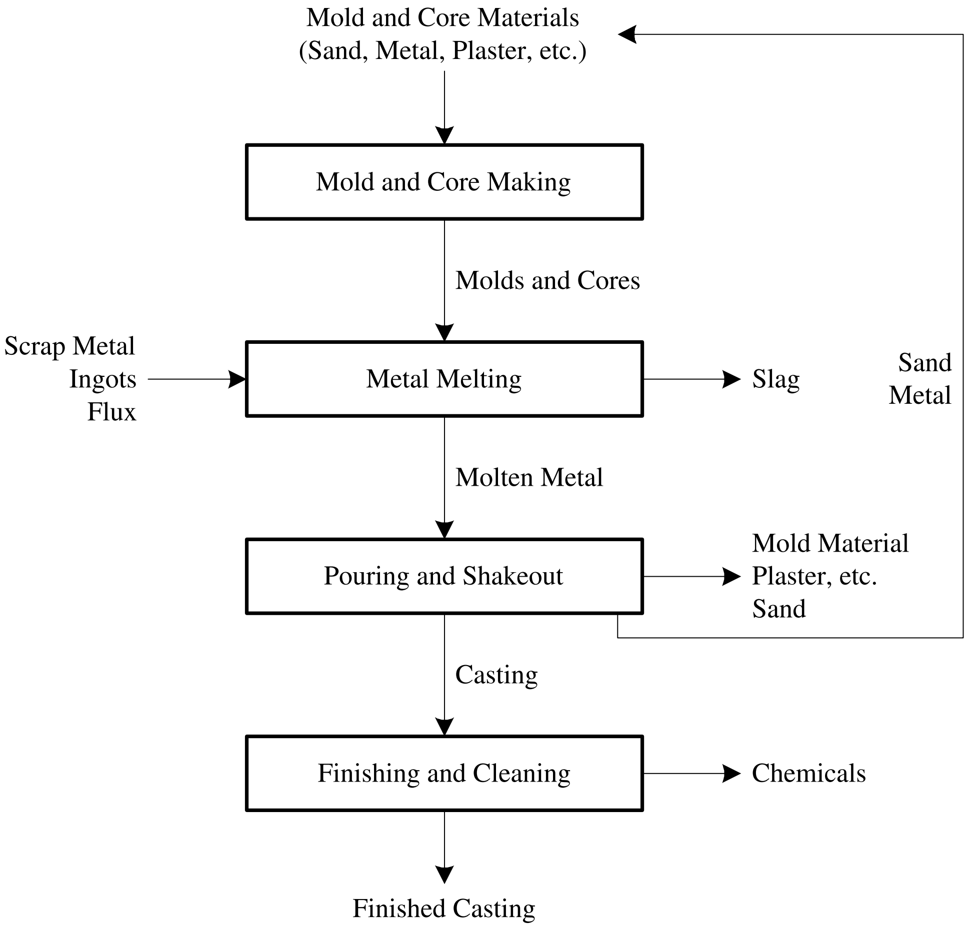


Figure 2-1. Overview of the Foundry Casting Processes

Foundries use many types of molds, depending on the type, quality, and quantity of castings required. The two most common mold types are the sand mold and the permanent mold. Once the mold has been made, the second process involves melting the iron or steel, which is done almost exclusively by cupolas, electric arc furnaces, and electric induction furnaces. Once the steel is melted, the third process is pouring the steel into the mold. After sufficient cooling time, the casting and mold are separated. The fourth process is finishing the casting, which requires smoothing, mechanical cleaning, and, in some cases, coating with a protective material such as paint or varnish.

2.1.1 Mold and Core Making

Iron and steel castings can range in size from ounces to tons, but all molds possess a few important features. All molds have a vertical channel, called a sprue, through which the molten metal is poured. Molten metal might flow to many sprues if the mold is designed to make multiple castings at a time. From the bottom of the sprue, channels direct the metal into points at the bottom of the mold so that the mold is filled from the bottom up. At the top of the mold, vertical channels called risers collect excess metal, gases that do not escape through the mold, and loose sand and other debris that is picked by the molten metal (SFSA, 1998). As the metal cools, it shrinks somewhat. For every foot, aluminum alloys shrink 5/32 inch, cast iron shrinks 4/32 inch, and stainless steel shrinks 8/32 inch (LaRue, 1989). Mold makers must take this shrinkage into account and make the mold slightly oversized. The risers also serve to compensate for shrinkage by serving as reservoirs of extra molten metal that can flow back into the mold when the metal begins to shrink.

2.1.1.1 Sand Casting Process

Most iron foundries pour metal into molds that are made primarily out of sand. The outer shapes of sand molds are typically made by forming sand into two halves that are subsequently joined together. The inner shapes of the mold that cannot be directly configured into the mold halves are created by inserting separately made components called cores, which are also made of sand. Sand cores are also required in many permanent mold and centrifugal casting operations.

Silica sand is the most commonly used granular refractory material in sand molding. Other more expensive granular refractory materials are used for specialized applications. Some of these materials are zircon, olivine, chromite, mullite, and carbon sands (Schleg and Kanicki, 1998). Olivine, for example, is more resistant to fracture than silica sand and exhibits less thermal expansion than silica sand (LaRue, 1989). Sand can be molded to very precise specifications, and, after solidification by compaction or chemical reaction, sand molds have sufficient strength to contain a significant volume of molten metal.

Ninety percent of all castings are done with green sand (EPA, 1998a). Green sand is a combination of roughly 85 to 95 percent sand, 4 to 10 percent bentonite clay, 2 to 10 percent carbonaceous materials, and 2 to 5 percent water. The composition of green sand is chosen so that the sand will form a stable shape when compacted under pressure, maintain that shape when heated by the molten metal poured, and separate easily from the solidified metal casting. The clay and water bind the sand together. The carbonaceous materials partially volatilize when molten metal is poured into the mold, which serves to create a reducing atmosphere that prevents the surface of the casting from oxidizing while it solidifies. Addition of these materials also helps to control expansion of the mold. Commonly used materials are powdered coal (commonly called sea coal), petroleum products, corn starch, wood flour, and cereal (LaRue, 1989; EPA, 1998a).

Once the green sand is formed around the pattern, the pattern can either be removed, or additional steps can be taken to improve the quality of the mold. In the skin drying technique, the outer layer of the mold is dried and coated with a fine layer of crushed refractory material such as silica, zircon, chromite, or mullite. This coating provides resistance to the high temperatures of the hot metal and easier separation of the casting from the mold. In dry sand molding, foundries bake the green sand mold. A petroleum binder may be added to the mold before baking to increase the strength of the baked mold. Baked molds are stronger than standard green sand molds, and they also produce a smoother finish.

Chemical binder systems are used when the shape of the mold or core cannot be made from green sand or when strength and dimensional stability requirements are too stringent for green sand to provide. Chemically bonded sand moldings are stronger than green sand moldings. The traditional method is to mix sand with a resin or oil and then to bake the mold. In the shell process, foundry workers coat sand with a plastic resin and then blow the sand onto a metal pattern that has been heated to at least 450°F. The shell process can be time intensive because the mold or core sometimes must be slowly heated progressively from one end to the other. After curing, the chemically bonded molds are often coated with a finely ground refractory material to provide a smoother surface finish on the casting.

Other less often used methods include forming molds by combining sand with expendable polystyrene (EPS) beads, and vacuum molding by shaping unbonded sand around a pattern with a vacuum, which holds the mold in the desired shape.

2.1.1.2 Permanent Mold Casting Process

Permanent molds must themselves be cast, tooled, and machined, but once the initial time and expense are invested, foundries can use the mold thousands of times. The most common metal fashioned into permanent molds is gray iron. Other materials, such as steel, copper, and aluminum, can also be used. Permanent molds can be made out of graphite, which has a chilling effect that enhances particular characteristics of the casting. Molds are typically hinged to open. Permanent molds may also have water cooling channels and ejector pins. The molds do wear out over time and must eventually be replaced. Permanent molds are most appropriate for large quantities of uniform castings as well as smooth surface finish and intricate details.

2.1.1.3 Investment Casting Process

A third, less common casting process is investment casting. In this process, workers dip wax or plastic molds into a vat of liquid ceramic. Foundries use wax or plastic so that the entire pattern can be melted away from the finished mold. The plaster that workers use is typically gypsum (calcium sulfate) mixed with fibrous talcs, finely ground silica, pumice stone, clay, and/or graphite. Plaster can be 50 percent sand (EPA, 1998a). Foundries cover the coated pattern with a layer of refractory material. Workers may repeat this process several times to achieve a mold of desired thickness. The foundry then heats the mold to about 1,800°F to harden the mold and burn out the pattern. These molds are best suited for metals containing titanium and other super-alloys that do not react well with green sand.

2.1.2 Metal Melting

The primary source of iron and steel for foundries is scrap. Workers must sort scrap, cut it to fit the furnaces, and clean it. Scrap cannot have any rust and is cleaned by using solvents or a precombustion step to burn off residues (EPA, 1998a). Metal ingot is a secondary source of iron and steel for foundries. Foundry returns consisting of sprues, runners, and risers separated from previous castings may contribute a significant share of input metal. Foundries can also purchase directly reduced iron (DRI) to employ as an iron source. Pig iron and DRI dilute the alloy content of the scrap metal. Foundries add flux material, typically chloride or fluoride salts, to the furnace to combine with the impurities in molten metal in the furnace, forming a dross or slag. This dross or slag separates from the molten metal and is removed from the metal before workers tap the furnace.

Foundries use various alloy metals, such as aluminum, magnesium, nickel, chromium, zinc, and lead, to alter the metallurgical properties of the resulting product. Foundries add graphite for carbon content in the production of ductile iron. Twenty percent of the carbon in ductile iron must come from graphite (Ductile Iron Society, 1998). These materials may then be melted in furnaces ranging from cupolas to electric induction.

Table 2-1 provides the number and share of the primary furnaces used by iron and steel foundries in 1997. As shown, over 80 percent of furnaces in the industry are electric induction. Electric arc and electric induction furnaces use electrical energy to create heat that melts the metal. Cupola furnaces use foundry coke as fuel to melt the metal. Coke is

Table 2-1. Distribution of Iron and Steel Foundry Furnaces by Type: 1997

Furnace Type	Number	Share (%)
Cupola	155	9.8%
Electric arc	131	8.2%
Electric induction	1,292	81.3%
Other	12	0.8%
Total	1,590	100.0%

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

made from metallurgical coal and is purchased by the foundries from merchant coke producers. The burning coke removes some contaminants and also raises the carbon content of the metal. Other furnaces include reverbertory and crucible types that represent less than 1 percent of furnaces in use during 1997.

2.1.2.1 Cupola Furnace

As Figure 2-2 illustrates, the cupola furnace is a hollow vertical cylinder that is lined with refractory material and has doors at the bottom. The charging process begins by laying sand in the bottom of the furnace and topping the sand with coke, which is ignited. Next, workers add carefully measured alternating layers of metal, flux, and coke until the furnace is full to the charging door. Air is forced through tuyeres, which are the holes at the base of the furnace. The metal melts and drips to the base of the furnace. A tap hole near the top of the sand layer allows workers to remove the molten metal. Foundries remove slag either through a slightly higher slag spout or through the tap spout with the metal and separated by a specially designed spout (LaRue, 1989). As the metal and slag are removed, additional layers of charge can be added to the furnace to maintain continuous production. When the furnace needs to be cleaned and emptied, the doors at the bottom swing open and drop the contents on a bed of sand.

2.1.2.2 Electric Arc Furnace (EAF)

EAFs have a rounded, shorter shape than cupola furnaces. Workers charge the furnace with metal, and carbon electrodes create an arc of electric current. If the arc passes through the metal, it is considered a direct arc furnace. If the arc passes above the metal, it is

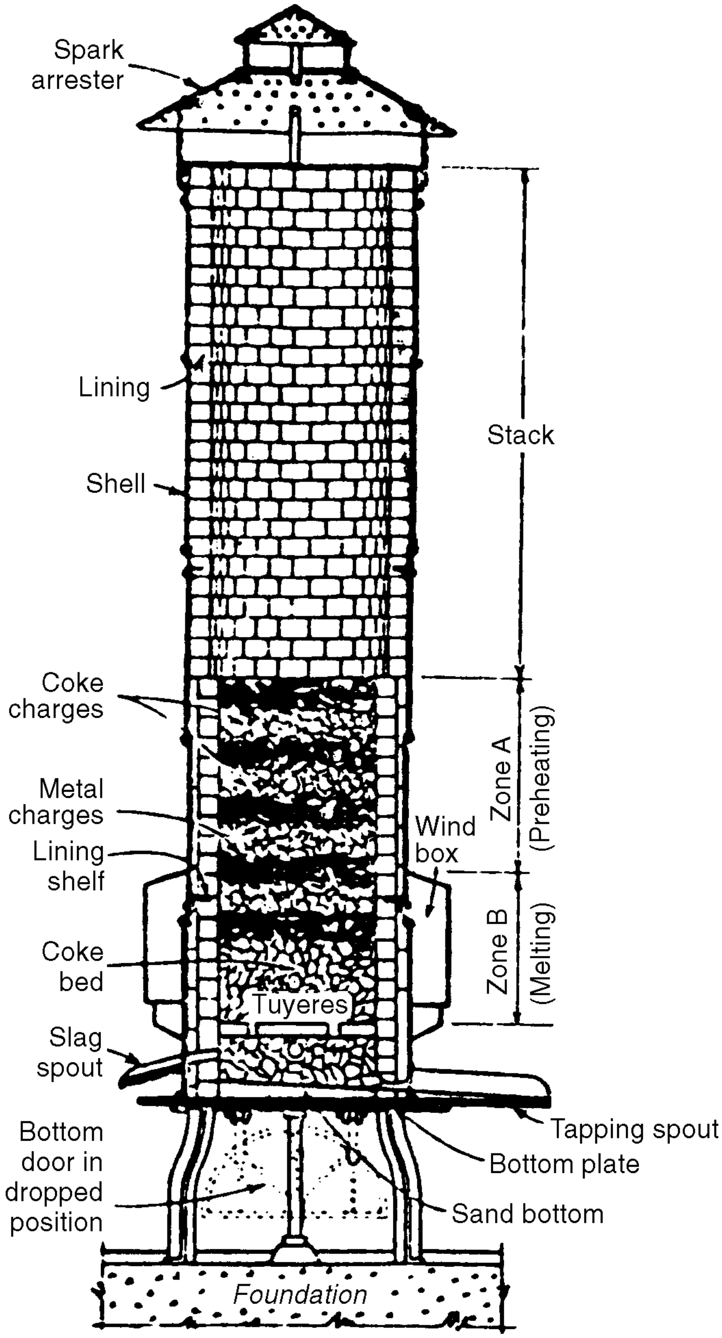
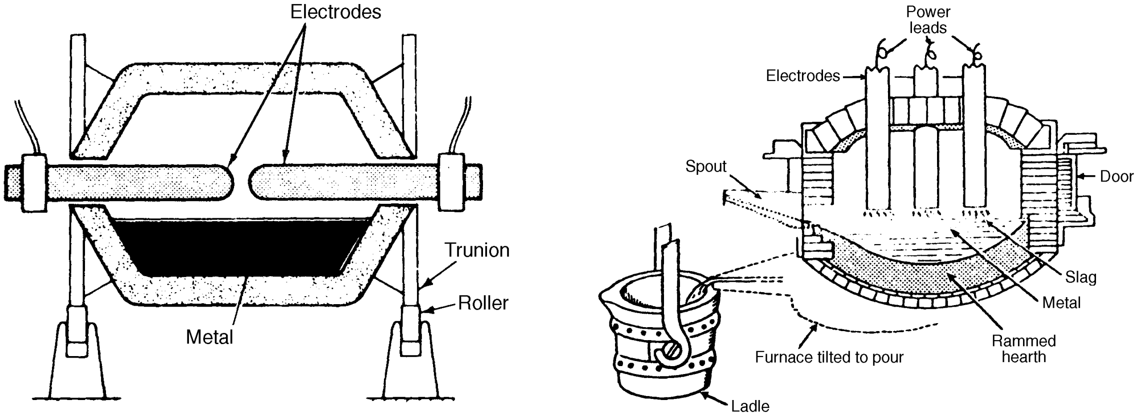


Figure 2-2. The Cupola Furnace

Source: LaRue, James P. 1989. *Basic Metalcasting*. Des Plaines, IL: American Foundrymen's Society.

considered an indirect arc furnace. The two models are shown in Figure 2-3. The electric arc creates heat, which melts the metal. As the metal melts, workers adjust the electrodes to maintain their relative position to the top of the charge. Once the metal has melted, workers insert flux to combine with the impurities, and the metal can be supplemented with alloy materials. Doors opposite the spout where the metal is poured out allow workers to remove the slag. Workers remove the metal by tipping the furnace to pour the liquid.



Indirect **Direct**

Figure 2-3. Indirect and Direct Electric Arc Furnaces

Source: LaRue, James P. 1989. *Basic Metalcasting*. Des Plaines, IL: American Foundrymen's Society.

2.1.2.3 Induction Furnace

Induction furnaces, or electric induction furnaces as they are sometimes called, generate heat by passing an electric current through a coil either around or below the hearth. Furnaces with the coil around the hearth are called coreless induction furnaces, and those with the coil below the hearth are called channel induction furnaces. Both types are shown in Figure 2-4. The electric current generates a magnetic field. The magnetic field creates voltage, which moves across the hearth and through the charged metal. As the electric current attempts to pass through the metal, it meets resistance, which produces heat to melt the metal. Typically, the coils carrying the electric current are cooled with water. Induction furnaces are designed in various shapes and sizes so the tapping and slag removal varies.

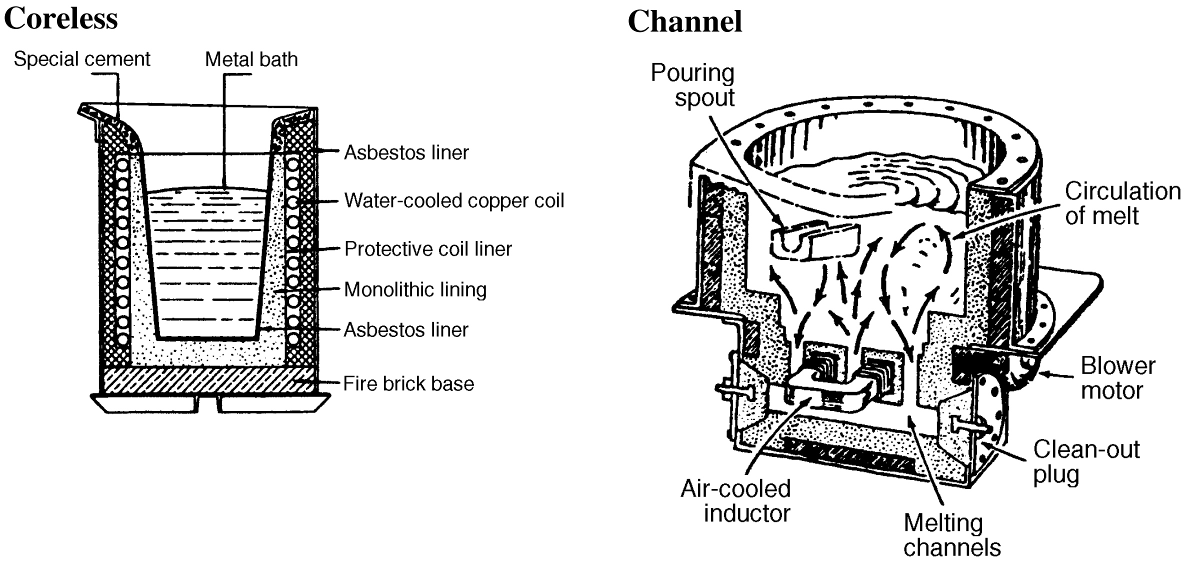


Figure 2-4. Coreless and Channel Electric Induction Furnaces

Source: LaRue, James P. 1989. *Basic Metalcasting*. Des Plaines, IL: American Foundrymen's Society.

Induction furnaces require cleaner scrap input than EAFs, but induction furnaces make possible more precise adjustments to the metallurgical properties of the metal (EPA, 1998a).

2.1.3 Pouring and Shakeout

Workers transport liquid iron and steel directly from the foundry furnaces to the molds to maintain the liquid state. Some molds, particularly green sand and vacuum molds, cannot be stored long before they are used. Typically, foundries start the process of melting before the molds are finished. Permanent molds and chemical molds with strong binders can be stored for a considerable period without losing their shape. Carbonaceous material in the mold burns, creating a reducing atmosphere and prevents the oxidation of the hot metal. In the vacuum process, a vacuum inside the mold sucks the molten metal up into the mold. The vacuum pressure is maintained until the casting has solidified. In the lost foam process, the foam pattern is still inside the mold. As the metal is poured into the mold, the foam vaporizes and leaves the mold. Certain molds, particularly intricate designs, require pressure to force the molten metal into all areas of the mold. Some techniques used with permanent molds require centrifugal casting machines to spin the mold at high speeds. The pressure holds refractory material on the walls of the mold and forces the metal into the mold to eliminate empty spaces.

Spills of molten metal are called runouts. Workers must be ready to cover runouts with sand and to use sand to block the flow of metal if the mold begins to overflow, because fires can result. No molten metal should be allowed to solidify in the crucible or ladle, so a standby container such as ingot molds must be ready to receive any excess metal. The crucible must be quickly cleaned to prevent build-up.

After pouring, castings are allowed to cool within the mold. Rapid cooling increases casting hardness. Workers can manually separate castings from the mold, although some large foundries have vibrating grids to shake the sand off the casting. Certain permanent molds have ejector pins to push the casting out of the mold.

2.1.4 Finishing and Cleaning

When castings emerge from the mold, they are typically hard and brittle. To improve the metallurgical properties of castings, they are frequently put through heat treatment. Heat treatment refines the grain of the metal and relieves internal stresses in addition to improving the metal's properties (Lankford et al., 1985). Heat treatment must be done with care, because it can potentially warp or crack the casting. The standard heat treatment is annealing. For annealing, foundries place the casting in a furnace and raise the temperature slowly, with the target temperature depending on the metal type. For carbon steel, the temperature is about 1,650°F. Operators can manipulate the properties of a particular area or part of a casting by directly applying a flame to the casting.

New castings require processing after removal from the mold; sometimes the processing is extensive and is used to modify the basic shape. Workers remove unwanted structures with hammers, saws, flame devices such as oxyacetylene torches, and grinders. Workers can also add structures to the casting at this point, typically by welding. In any case, the surface may be rough and contain unwanted substances such as rust, oxides, oil, grease, and dust. Foundries typically clean and smooth the casting surface by sand or steel shot blasting.

Workers cool and rinse castings with water. The water may contain chemical additives to prevent oxidation of the casting. Chemical cleaning of the casting can be done with organic solvents such as chlorinated solvents, naphtha, methanol, and toluene. Emulsifiers, pressurized water, abrasives, and alkaline agents such as caustic soda, soda ash, alkaline silicates, and phosphates are also used for cleaning. Castings may also undergo acid pickling using hydrochloric, sulfuric, or nitric acid (EPA, 1998a).

Coatings are used to inhibit oxidation and corrosion, to alter mechanical and metallurgical properties, and to improve surface finish and appearance. Some coating processes include painting, electroplating, electroless nickel plating, hard facing, hot dipping, thermal spraying, diffusion, conversion, porcelain enameling, and organic or fused dry-resin coating (EPA, 1998a).

Foundries can typically reuse sand from molds numerous times, although a portion must be disposed of each time to eliminate the sand that has been worn very fine. Some sand can be used in construction as filler and for the production of portland cement, concrete, and asphalt. Much sand from foundries contains chemical binders, and about 2 percent of foundry waste sand is considered hazardous waste, which requires expensive disposal (EPA, 1998a). Core sand is the most likely sand to be disposed of because it requires the strongest binders. To reuse sand, it must be cleaned. Metal particulates must be separated from the sand. Various machines are used to break apart sand clumps and grind the binder off the sand. Heat can also be used to break down the resins on sand.

2.1.5 Residuals and By-products

Resins and binders are left in spills, containers, and outdated materials. Other residuals include gaseous emissions such as carbon monoxide, volatile organic compounds (VOCs), and other HAPs. HAP emissions can occur during mold and core making, melting, pouring, cooling, and shakeout (PCS) (EPA, 1998a). Foundries scrub offgases from core-making processes that use triethylamine gas as a catalyst with acidic solution. Scrubbing gases generate sludges or liquors, which must be adjusted for pH so that they can be released as nonhazardous waste. Sulfur dioxide can be controlled with amine scrubbers that convert the sulfur dioxide to hydrogen sulfide. Cleaning solvents such as methanol, trichloroethylene, and xylenes are also toxic residuals (EPA, 1998a). The making of expendable polystyrene patterns leaves chemicals, and the use of lost foam casting generates organic vapors that may contain HAPs.

All furnaces emit hydrocarbons, while cupolas and EAFs also emit sulfur dioxide, nitrogen oxides, chlorides, and fluorides, and cupolas emit carbon monoxide (EPA, 1998a). Melting furnaces also emit metallic fumes. The composition of fumes emitted depends on the type of scrap used as input. Galvanized steel leads to high zinc emissions, and stainless steel produces greater nickel and chromium emissions than standard carbon steel. Whenever the furnace is open, such as for tapping or charging, emissions are highest. Hoods over the doors and spouts of the furnaces and near pouring areas capture emissions.

The water used to cool and rinse the castings picks up lubricants, cleansers, mill scale, mold coatings, and acids. Water used to cool chemically bonded molds can pick up chemicals. A sludge may form that contains metals such as cadmium, chromium, and lead. Foundries are able to recover acids to be used again. Iron chloride, when removed from the acids, is a saleable product. The water in the acids is recovered by evaporation and condensation to be re-used for rinsing and cooling. This procedure is less expensive than transporting and disposing of the acid. Some foundries are also recovering fluoride from spent pickling acids in the form of calcium fluoride, which can be used as a flux material that is more effective than purchased fluorspar (EPA, 1998a).

2.1.5.1 Particulate Matter

Particulates are emitted by cupolas and EAFs and to a lesser extent by induction furnaces. The emissions of foundry furnaces typically are cleaned with fabric filters (baghouses), which collect particulates, or wet scrubbers, which produce waste water and sludge.

EAFs release 1 to 2 percent of their charge as dust or fumes. Lead and cadmium can be reclaimed if their contents are significantly high. Some techniques send the dust back through the furnace after the metal has melted so that the dust captures more metal particulates such as zinc to increase the zinc content above 15 percent. On site, foundries can pelletize EAF dust to be reused in the furnace. This method is not frequently cost-effective at the foundry and may be more efficient off site. Some techniques recycle EAF dust directly back into the furnace, but this approach requires low impurity content for the dust.

The vigorous shakeout operations generate metal and other types of dust. In addition, as permanent molds gradually wear out they produce metallic particles. The dust requires air filtering by using electrostatic precipitators, baghouses, or wet scrubbers. Dust from sand systems can be used by cement companies and can potentially supply 5 to 10 percent of the raw material used by cement manufacturers (EPA, 1998a).

2.1.5.2 Slag

Slag can have a complex composition at foundries. Foundry slag may contain metal oxides, melted refractory materials, sand, coke ash, and other impurities. If the slag contains enough toxic metals such as lead, cadmium, or chromium, the slag will be classified as a hazardous material. Some foundries making ductile iron use calcium carbide as a flux for desulfurization, resulting in slag that is classified as a reactive waste because it is potentially explosive (EPA, 1998a). Metal can be reclaimed by allowing the slag to solidify and then crushing it. Metal can be extracted from crushed slag by hand or with magnets. Reusing slag in different iron production lines can sometimes reduce the hazardous content of the slag.

2.1.6 Production Costs

Table 2-2 shows production costs for foundries by type. Total costs are greatest for gray and ductile iron foundries across all categories due to higher production volume. Table 2-2 also shows the average variable cost and average total cost by type of foundry. Gray and ductile iron foundries have the lowest costs per short ton, while the per-ton cost of steel castings is more than three times that of gray and ductile iron.

Table 2-2. Summary of Production Costs by Foundry Type (1996)

Cost Element	Gray and Ductile Iron Foundries	Malleable Foundries	Steel Foundries
Variable inputs ($$10^6$)	$7,857.8	$230.6	$2,911.2
Production labor	$2,261.1	$92.2	$956.2
Materials	$5,040.6	$115.3	$1,757.1
Fuels and electricity	$556.1	$23.1	$197.9
General and administrative costs ($$10^6$)	$1,677.1	$65.7	$789.3
Capital expenditures ($$10^6$)	$515.7	$15.8	$151.4
Total costs ($$10^6$)	$10,050.6	$312.1	$3,851.9
AVC ($/short ton)	$747.65	$876.81	$2,290.48
ATC ($/short ton)	$956.29	$1,186.69	$3,030.61

AVC = average variable cost
ATC = average total cost
Source: U.S. Department of Commerce. February 1998. *1996 Annual Survey of Manufactures: Statistics for Industry Groups and Industries*. M96(AS)-1. Washington, DC: U.S. Government Printing Office.

Table 2-3 displays costs of materials and their shares by type of casting. Gray and ductile iron foundries use scrap as a greater share of their input costs compared to malleable iron and steel. The ability to use large amounts of low-cost scrap contributes to the low price of gray and ductile iron castings.

Table 2-4 shows employees and earnings for iron and steel foundries. The number of employees and production workers decreased until the early 1990s as shipments decreased. The number of employees, including production workers, has increased from the lows of the 1980s, but not to the highs of the early 1980s. Hourly earnings have consistently increased every year since 1980.

2.1.7 Metal Types

The most basic variation in castings stems from manipulating the charge material. Four basic types of metal are melted in foundry furnaces: gray iron, ductile iron, malleable iron, and steel. Each type of iron and steel has a general range of characteristics. Further variation in mechanical properties of the casting can be achieved during cooling and finishing operations. Table 2-5 shows the volume of the iron and steel castings in 1997 by casting type. The majority of all ferrous castings in 1997 was gray iron, followed by ductile iron.

Because gray iron was the first cast iron, some people use the term cast iron to refer to gray iron. Gray iron received its name from the color of the graphite flakes dispersed throughout the silicon iron matrix of the metal. The graphite flakes do not contribute strength or hardness, but they can have some positive benefits such as dimensional stability under differential heating and high vibration damping. Gray iron has the greatest damping capacity, followed by ductile iron, then malleable, and finally steel (Foti et al., 1998). Foundries can add alloys to gray iron to increase the hardness and employ heat treatments to soften gray iron, making it easier to form but decreasing its strength.

Ductile iron was invented in the 1940s. It is similar to gray iron, although the graphite is in spheroids or spherulites rather than flakes. Because of the spheres, ductile iron is sometimes called nodular iron. The spheroids are created by adding a controlled amount of magnesium to the molten iron, which alters the way the graphite is formed. The formation of graphite prevents ductile iron from shrinking when it solidifies, as occurs in malleable iron and cast steel. Ductile iron is known for being capable of a wide range of yield strengths, high ductility, and ease of being shaped.

Table 2-3. Distribution of Material Costs by Foundry Type (1992)

Material	Gray and Ductile Iron Foundries		Malleable Foundries		Steel Foundries	
	Delivered Cost ($\$10^6$)	Share (%)	Delivered Cost ($\$10^6$)	Share (%)	Delivered Cost ($\$10^6$)	Share (%)
Ferrous and nonferrous shapes and forms	$314.7	11.9	$2.2	3.0	$260.9	24.6
Purchased scrap	$785.1	29.8	$13.9	19.1	$137.0	12.9
Steel, clay, glass, and concrete products	$86.7	3.3	$0.3	0.4	$71.0	6.7
Industrial patterns, dies, molds, and other machinery and equipment	$76.2	2.9	NA	NA	$37.4	3.5
Sand	$110.2	4.2	$0.5	0.7	$34.3	3.2
All other materials	$1,258.5	47.7	$53.1	73.1	$521.6	49.1
Total[a]	$2,637.4	100.0	$72.6	100.0	$1,062.4	100.0

NA = not available

[a] Totals may not sum due to undisclosed costs for some categories.

Source: U.S. Department of Commerce. 1995. *1992 Census of Manufactures: Industry Series—Blast Furnaces, Steel Works, and Rolling and Finishing Mills Industry*. Washington, DC: U.S. Government Printing Office.

Table 2-4. Summary of Labor Statistics for SIC Code 332, Iron and Steel Foundries: 1980-1997

			Production Workers		
Year	**All Employees (10^3)**	**Production Workers (10^3)**	**Average Weekly Earnings**	**Average Weekly Hours**	**Average Hourly Earnings ($)**
1980	208.8	167.3	328.00	40.00	8.20
1981	200.8	159.9	354.99	39.4	9.01
1982	158.6	121.8	353.98	37.3	9.49
1983	139.0	106.3	397.79	40.1	9.92
1984	148.6	117.5	421.45	41.4	10.18
1985	141.4	111.6	427.76	40.7	10.51
1986	130.9	102.9	438.01	41.4	10.58
1987	129.8	102.4	460.53	42.8	10.76
1988	136.4	109.4	477.86	43.6	10.96
1989	137.3	109.7	475.42	42.6	11.16
1990	132.4	105.3	486.26	42.1	11.55
1991	125.8	99.5	491.71	41.6	11.82
1992	120.2	96.1	522.09	42.9	12.17
1993	119.0	94.8	555.89	44.4	12.52
1994	125.1	101.4	608.72	45.7	13.32
1995	131.1	107.1	597.19	44.5	13.42
1996	128.5	105.2	604.78	44.6	13.56
1997	130.0	106.7	636.64	46.1	13.81

Source: U.S. Department of Labor, Bureau of Labor Statistics. BLS LABSTAT Database: Employment and Earnings, SIC 33. <http://www.bls.gov>. Obtained in March 2002.

Malleable iron is the result of heat treating iron over an extended period. Similar to ductile iron, the majority of the carbon content in malleable iron is in nodules. As suggested by the name, malleable iron is soft and can be bent without immediately breaking.

Table 2-5. Shipments of Iron and Steel Castings by Type (1997)

	Volume (10^3 short tons)	Share (%)
Iron	10,790	89.9%
Ductile iron	4,333	36.1%
Gray iron	6,186	51.5%
Malleable iron	271	2.3%
Steel	1,217	10.1%
Total	12,007	100.0%

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

Steel products made by casting processes have mechanical properties inferior to those of steel products manufactured by steel mills. The advantage of using the casting process to make steel products is that casting is the most direct method for making products of a specific shape.

2.2 Industry Organization

This section presents information on the manufacturing plants within this source category and the companies that own and operate these foundries.

2.2.1 Manufacturing Plants

Figure 2-5 identifies the number of U.S. iron and steel foundries by state. Iron and steel foundries are located in nearly every state, and Ohio has the most for a single state, with 79 iron and steel foundries. The remainder of this section characterizes these foundries using facility responses to EPA's industry survey and industry data sources.

Tables 2-6 and 2-7 present summary data by type of producer, merchant or captive. Merchant producers are foundries that purchase their inputs and sell their products on the open market. Captive foundries are vertically integrated with iron and steel and/or coke producers. As of 1997, the United States had 860 reported iron-making furnaces and 730 reported steel-making furnaces. In U.S. foundries, iron melting capacity is nearly ten times the steel melting capacity. Most furnaces for iron and steel making are electric induction. For the 545 iron and steel foundries that reported the relevant information of the total 798

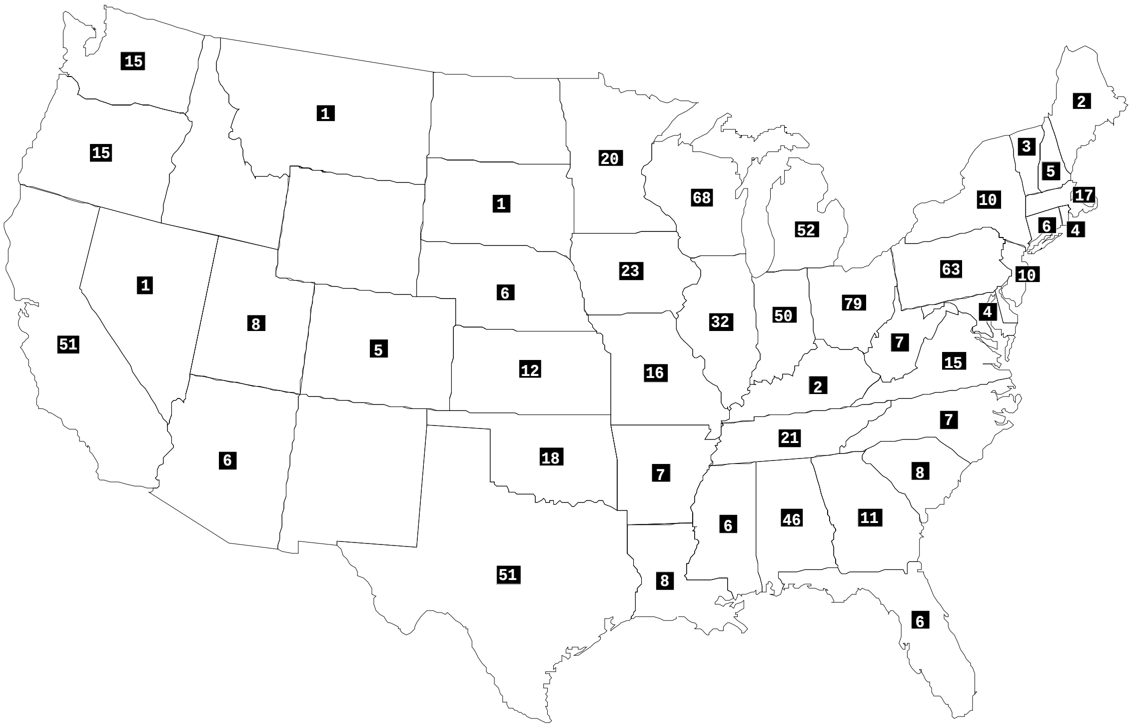


Figure 2-5. Number of U.S. Iron and Steel Foundries by State: 1997

affected iron and steel foundries, total hourly capacity in 1997 for iron melting was 41,298 tons and for steel melting was 4,737 tons.

2.2.2 Companies

The National Emission Standard for Hazardous Air Pollutants (NESHAP) will potentially affect business entities that own iron and steel foundry facilities. Facilities comprise a site of land with plant and equipment that combine inputs (raw materials, energy, labor) to produce outputs (castings). Companies that own these facilities are legal business entities that have capacity to conduct business transactions and make business decisions that affect the facility. The terms facility, establishment, plant, and mill are synonymous in this analysis 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. Figure 2-6 shows the possible chains of foundry ownership.

Table 2-6. Iron and Steel Foundry Data by Type of Producer: Iron-Making Furnaces (1997)

	Merchant Foundries	Captive Foundries	All[a] Foundries
Iron-making furnaces			
Number (#)			
Cupola	35	107	155
Electric arc	0	2	2
Electric induction	170	493	698
Other	0	5	5
Total	205	607	860
Capacity (short tons/hour)			
Cupola	1,139	10,132	11,307
Electric arc	0	48	48
Electric induction	2,154	27,433	29,737
Other	0	206	206
Total	3,293	37,819	41,298

[a] Not all survey respondents identified their production by type. Therefore, merchant and captive foundries data do add to totals shown for all foundries.

Table 2-7. Iron and Steel Foundry Data by Type of Producer: Steel-Making Furnaces (1997)

	Merchant Foundries	Captive Foundries	All[a] Foundries
Steel-making furnaces			
Number (#)			
Electric arc	69	31	129
Electric induction	341	176	594
Other	5	2	7
Total	415	209	730
Capacity (short tons/hour)			
Electric arc	772	269	1,342
Electric induction	1,078	1,830	3,390
Other	4	1	5
Total	1,854	2,100	4,737

[a] Not all survey respondents identified their production by type. Therefore, merchant and captive foundries data do add to totals shown for all foundries.

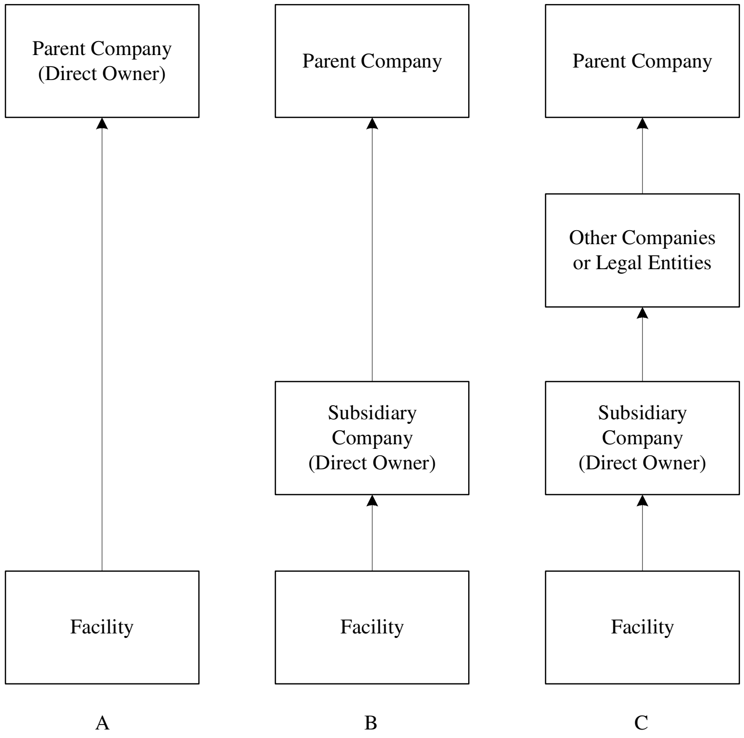


Figure 2-6. Possible Ownership Configurations for U.S. Iron and Steel Foundries

The Small Business Administration (SBA) defines small businesses based on size standards developed for North American Industrial Classification System (NAICS). The SBA defines firms owning iron and/or steel foundries as small if they have 500 or fewer employees. As shown in Figure 2-7, 78 percent of affected U.S. companies with available data meet the small business definition. Table 2-8 shows the distribution of companies by the number of foundries owned: 6 percent of small companies own more than one foundry, while 34 percent of large companies own more than one foundry. Table 2-9 summarizes foundry operations by firm size. Even though there are nearly three times as many reporting small companies as there are large companies, the number of iron-making and steel-making furnaces is near the number owned by small companies. The mean number of furnaces for large companies versus small reflects the distribution of furnaces between the two groups.

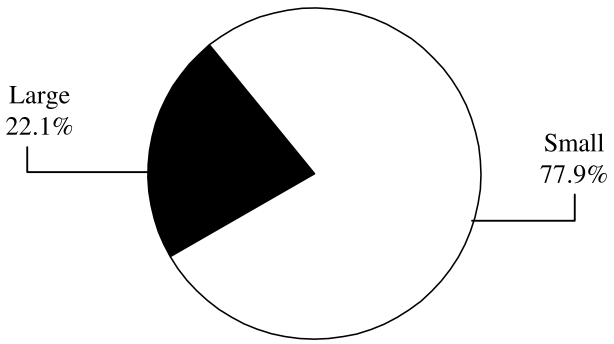


Figure 2-7. Distribution of Affected U.S. Companies by Size: 1997[a]

[a] Reflects distribution for only those 584 companies owning U.S. iron and steel foundries with data allowing identification as small or large business.

Table 2-8. Distribution of Companies by Number of Foundries: 1997[a]

Company Size Category	Number of Foundries Owned per Company					
	1	2	3	4	5 or more	Total
Small	299	17	3	0	0	319
Large	74	19	7	4	8	112
All companies	373	36	10	4	8	431

[a] Data reported for only those foundries with complete responses to EPA industry survey.

Table 2-9. Summary of Iron and Steel Foundry Operations by Firm Size Category: 1997[a]

		Foundries (#)[b]			Iron-Making Furnaces			Steel-Making Furnaces		
Company Size Category	Number of Companies	Total	Iron Making	Steel Making	Number	Capacity (short tons/hour)	Annual Production (10^3 short tons)	Number	Capacity (short tons/hour)	Annual Production (10^3 short tons)
					Sample Totals					
Small	319	342	245	152	447	31,132	2,268.4	399	1,794	380.7
Large	112	215	146	79	408	10,163	12,351.6	329	2,924	1,371.2
Total	431	557	391	231	855	41,295	14,620.0	728	4,718	1,751.9
					Sample Means					
Small	319	1.05	0.54	0.33	0.98	68.42	5.0	0.88	3.94	0.8
Large	112	1.81	1.13	0.61	3.16	78.78	95.7	2.55	22.67	10.6
Total	431	1.20	0.59	0.35	1.29	62.10	22.0	1.10	7.12	2.7

[a] Data reported for only those foundries with complete responses to U.S. EPA industry survey.

[b] Foundries that produce iron and steel shown once in each column.

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

2.2.3 Industry Trends

The number of metal casting foundries in the United States has dropped by nearly half since 1955 (Heil and Peck, 1998). During the 1970s, orders for foundry castings exceeded annual capacity. Profit margins were high, and shipments were often late due to the excess demand. In the presence of excess demand, the foundry industry did not experience pressure to improve casting quality. Foreign producers gained a foothold during the recession of the 1980s and 1990s. In addition to lower prices, foreign producers had more modern equipment than U.S. producers, which allowed foreign producers to have higher quality castings. The number of U.S. foundries steadily dropped and capacity utilization was below 50 percent in the mid-1980s. Even though the number of foundries has not increased to the highs of the 1970s and 1980s, output per producer has risen (Heil and Peck, 1998).

U.S. iron and steel foundry production has increased since the lows at the beginning of the 1990s. Gray iron castings production has increased with the health of the economy, while ductile iron saw greater gains because in some applications it replaced steel castings and forgings, as well as malleable iron castings. Malleable iron castings production has decreased, because more than one-third of malleable iron foundries in the United States have closed since the 1980s; this trend is expected to continue. Malleable iron castings production has declined to mostly small custom orders and captive operations (Heil and Peck, 1998).

Similar to gray and ductile iron, steel castings production has increased since the lows of the early 1990s. The primary issue of concern in the 1990s for steel castings has been the cleanliness of the steel (Tardiff, 1998). Steel with low impurities has superior mechanical properties, improving the position of steel against possible substitutes such as aluminum and reinforced plastics. A general trend among ferrous castings is demand for low-weight parts, particularly among the transportation industry as it seeks greater fuel efficiency. New casting techniques allow metals to be cast with thinner dimensions, reducing overall weight.

2.2.4 Markets

The markets for the various types of iron and steel castings overlap but are not identical, because the properties and costs of each type vary. During the 1970s and 1980s, many iron and steel foundries were captively owned. As end product production dropped, many captive foundries were left with excess capacity. To avoid the fixed costs of idle foundries, companies shut down captive foundries or sold them to produce for sale directly to the market. Of those foundries that are still captive, the majority are iron-producing. Nineteen percent of 1997 iron casting shipments were captive, while only 3.5 percent of 1997 steel castings were captive (DOC, 1997). Table 2-10 shows the market and captive shares for iron and steel castings.

Table 2-10. U.S. Shipments of Iron and Steel Castings by Market and Captive: 1997 (10^3 short tons)

	Market		Captive		
Casting	Volume	Share (%)	Volume	Share (%)	Total Volume
Gray	4,693	75.9%	1,493	24.1%	6,186
Ductile	3,925	90.6%	408	9.4%	4,333
Malleable	121	44.6%	150	55.4%	271
Steel	1,174	96.5%	43	3.5%	1,217

Sources: U.S. Department of Commerce, Bureau of the Census. 1988-1997. *Current Industrial Reports*. Washington, DC: U.S. Government Printing Office.
U.S. Department of Energy. 1996. "Trends Effecting [sic] R&D in the Metalcasting Industry." Prepared by BCS Incorporated for Office of Industrial Technologies, Washington, DC.

Automotive and aerospace have traditionally been the largest consumers of gray and ductile iron castings. Substitutes such as composites and aluminum have gained share in these markets due to reduced weight and corrosion resistance. Pipes and pipe fittings are another major market for gray and ductile iron castings. Improvements in ductile iron that increased strength and durability have allowed it to be a reduced-cost substitute for forged and cast steel in some applications.

Appliances, hardware, aerospace, and automotive components have been the major uses for malleable iron castings. Plastics, nonferrous metals, as well as other types of iron and steel castings have displaced malleable iron from many applications (Heil and Peck, 1998). Ductile iron castings are responsible for the majority of malleable iron castings displacement, particularly in plumbing and electrical.

Steel castings are used in many of the same markets as iron castings, including automotive, aerospace, and construction. Steel castings are also extensively used in the railroad industry (BTA, 1996). In addition, steel investment castings are used in a diverse range of industries employing small or very thin castings, including jewelry.

2.3 Historical Industry Data

This section presents domestic production, imports, exports, and apparent consumption. We also present historic market price. Finally, this section shows past iron and steel castings shipments by end-user market and discusses various projections for the future of the shipments in the next decade.

2.3.1 Domestic Production

Table 2-11 shows iron and steel castings shipments. Shipments were at their lowest over the 10-year period in 1991 for all types except malleable iron. Shipments for gray and ductile iron, as well as steel castings, have increased over 25 percent since the lows of 1991. Malleable iron castings shipments were lowest in 1992, and although shipments increased in the mid-1990s along with the other types of iron and steel castings, malleable iron castings shipments have declined. Gray iron castings shipments have also declined slightly, while ductile iron castings shipments have consistently increased every year since 1991.

2.3.2 Foreign Trade and Apparent Consumption

The only year for which import and export data are available for iron and steel castings is 1994. We used the import and export data to derive apparent consumption by subtracting exports and adding imports to production. Table 2-12 presents these data. Table 2-13 provides the export and import concentration ratios for the types of iron and steel castings. Export and import concentration ratios represent the share of U.S. production expected and the share of apparent consumption imported. Concentration ratios for iron and steel castings are typically around 7 percent. Foreign producers of iron and steel castings gained a foothold in the 1980s and early 1990s when foreign prices were lower than those of U.S. castings, and foreign quality was equal or better (Heil and Peck, 1998).

2.3.3 Market Prices

We derived prices for iron and steel castings by dividing the quantity of shipments by the value of shipments, generating an average price. Table 2-14 shows the prices from 1987 through 1997. Gray iron castings are consistently the lowest priced, which explains the steady share of castings maintained by gray iron. Ductile iron castings are consistently lower priced than malleable iron castings. Ductile iron castings are displacing malleable iron castings for many applications because of their lower price, strength, and durability.

Table 2-11. U.S. Shipments of Iron and Steel Castings: 1987-1997 (10^3 short tons)

Year	Iron Castings				Steel Castings	Total
	Ductile	Gray	Malleable	Total		
1987	3,044	5,701	321	9,066	1,013	10,079
1988	3,210	5,941	323	9,474	1,187	10,661
1989	3,321	5,638	299	9,258	1,184	10,442
1990	3,186	5,073	290	8,549	1,133	9,682
1991	2,789	4,609	262	7,660	957	8,617
1992	3,051	4,800	253	8,104	986	9,090
1993	3,267	5,215	278	8,760	1,021	9,781
1994	3,709	6,401	300	10,410	1,039	11,449
1995	4,304	6,260	293	10,857	1,160	12,017
1996	4,312	6,198	263	10,773	1,271	12,044
1997	4,333	6,186	271	10,790	1,217	12,007
Average Annual Growth Rates						
1987-1997	4.2%	0.9%	–1.6%	1.9%	2.0%	1.9%
1987-1992	0.0%	–3.2%	–4.2%	–2.1%	–0.5%	–2.0%
1992-1997	8.4%	5.8%	1.4%	6.6%	4.7%	6.4%

Source: U.S. Department of Commerce, Bureau of the Census. 1988-1997. *Current Industrial Reports*. Washington, DC: U.S. Government Printing Office.

2.4 Market Shipments and Future Projections

Future projections for iron and steel castings take into account the strength of the economy, the strength of the U.S. dollar, interest rates, end-user product markets, input supply, and development of substitutes. The American Foundrymen's Society (AFS) projects that the metal casting industry in general will experience declines until 2002 and then increases until 2004, which AFS expects could possibly be the strongest year for castings in the past two decades (AFS, 1998). AFS expects gray and ductile iron castings shipments to do well early in the next decade because it will be the peak period for baby boomers to purchase vehicles, although the share of gray iron per vehicle will continue to drop. A short-term downturn in the strength of the economy, followed by an expansion from 2002 through 2008, should maintain gray and ductile iron castings shipments for farm and construction equipment and tools. AFS projects that malleable iron castings shipments will continue a rapid decline.

Table 2-12. U.S. Production, Foreign Trade, and Apparent Consumption of Iron and Steel Castings: 1994 (10^3 short tons)

Type	U.S. Production	Exports	Imports	Apparent Consumption[a]
Iron castings	10,411	741	831	10,501
Ductile iron	3,710	276	213	3,647
Gray iron	6,401	442	579	6,538
Malleable iron	300	23	39	314
Steel castings	1,129	96	113	1,146
Steel investment	91	NA	NA	NA
Steel castings, n.e.c.	1,038	NA	NA	NA
Iron and steel castings	11,540	837	944	11,647

NA = not available

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

Sources: U.S. Department of Commerce, Bureau of the Census. 1988-1997. *Current Industrial Reports*. Washington, DC: U.S. Government Printing Office.
U.S. Department of Energy. 1996. "Trends Effecting [sic] R&D in the Metalcasting Industry." Prepared by BCS Incorporated for Office of Industrial Technologies, Washington, DC.

Table 2-13. Foreign Trade Concentration Ratios for Iron and Steel Castings by Type: 1994

Type	Export Concentration Ratio[a] (%)	Import Concentration Ratio[b] (%)
Iron castings	7.1%	7.9%
Ductile iron	7.4%	5.8%
Gray iron	6.9%	8.9%
Malleable iron	7.7%	12.3%
Steel castings	8.5%	9.9%
Iron and steel castings (combined)	7.3%	8.1%

NA = not available

[a] Measured as export share of U.S. production.

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

Source: U.S. Department of Energy. 1996. "Trends Effecting [sic] R&D in the Metalcasting Industry." Prepared by BCS Incorporated for Office of Industrial Technologies, Washington, DC.

Table 2-14. Market Prices for Iron and Steel Castings by Type: 1987-1997

	Iron Castings				
Year	**Ductile**	**Gray**	**Malleable**	**Steel**	**All Castings**
			Prices ($/short ton)		
1987	$624.05	$529.92	$885.05	$5,311.45	$1,050.23
1988	$640.22	$567.26	$1,040.56	$5,192.42	$1,118.53
1989	$681.51	$602.31	$947.16	$2,793.67	$885.85
1990	$725.46	$641.59	$1,057.59	$2,863.64	$941.68
1991	$751.31	$641.96	$1,062.21	$3,125.71	$965.97
1992	$700.26	$662.77	$869.96	$2,780.22	$910.80
1993	$777.39	$669.35	$923.81	$3,990.01	$1,033.73
1994	$800.22	$600.00	$923.42	$5,816.15	$1,146.70
1995	$851.43	$719.33	$924.59	$5,472.04	$1,230.43
1996	$921.04	$720.06	$1,011.72	$5,253.90	$1,276.84
1997	$957.81	$759.87	$1,006.33	$5,159.39	$1,282.79
			Quantities (10^3 short tons)		
1987	3,044	5,701	321	1,013	10,079
1988	3,210	5,941	323	1,187	10,661
1989	3,321	5,638	299	1,184	10,442
1990	3,186	5,073	290	1,133	9,682
1991	2,789	4,609	262	957	8,617
1992	3,051	4,800	253	986	9,090
1993	3,749	9,128	292	1,461	14,630
1994	3,709	6,401	300	1,039	11,449
1995	4,304	6,260	293	1,160	12,017
1996	4,312	6,198	263	1,271	12,044
1997	4,333	6,186	271	1,217	12,007

Source: U.S. Department of Commerce, Bureau of the Census. 1988-1997. *Current Industrial Reports*. Washington, DC: U.S. Government Printing Office.

Table 2-15 provides projections for castings shipments from a different group, Business Trend Analysts (BTA). BTA expects shipments to increase consistently until 2005 for all types except malleable iron.

Table 2-15. Projected U.S. Shipments of Iron and Steel Castings by Type: 1997, 2000, and 2005 (10^3 short tons)

	Iron Castings				Steel Castings		
Year	Ductile	Gray	Malleable	Total	Investment	All Other	Total
1997	3,289.6	5,420.5	203.5	8,913.6	40.3	1,557.8	1,598.1
2000	3,395.6	5,577.7	232.4	9,205.7	41.6	1,784.9	1,826.5
2005	3,505.6	5,614.6	194.0	9,314.2	45.2	1,945.0	1,990.2
Average Annual Growth Rates							
1997-2005	0.8%	0.4%	–0.6%	0.6%	1.5%	3.1%	3.1%
1997-2000	1.1%	1.0%	4.7%	1.1%	1.1%	4.9%	4.8%
2000-2005	0.6%	0.1%	–3.3%	0.2%	1.7%	1.8%	1.8%

Source: Business Trend Analysts. 1996. “Foundry Products and Markets in the U.S.—Company Profiles and Ferrous Castings.”

BTA separates projected castings shipments by market, as displayed for iron in Table 2-16. The greatest decreases in shipments have been for soil pipe (shown on continued page), and BTA expects these decreases to accelerate as iron pipe is replaced by PVC pipe. Displacement by PVC will reduce the annual growth rate for iron pressure pipe, but the growth rate is expected to stay positive. From 1987 to 1997, machinery was a strong and growing area for iron castings, and BTA expects this trend to continue. BTA projects that the relatively small market of railroad equipment will have the strongest growth rate as ductile iron replaces some steel castings.

Table 2-17 shows historical shipments and BTA projections for steel castings. BTA expects growth rates for nearly all markets to decrease over the next decade from the growth rates of the 1990s. Motor vehicles, defense, and aerospace are exceptions, which BTA projects will climb back to positive growth rates. Railroad equipment has been and will continue to be the largest and fastest growing market for steel castings, although BTA projects the growth rate to decrease, as ductile iron replaces steel castings.

Table 2-16. Iron Castings Shipments by Market: 1987-2005 (10^3 short tons)

Year	Motor Vehicles	Valves and Fittings	Construction Machinery	Railroad Equipment	Engines	Mining Equipment	Hardware	Pressure Pipe	Farm Machinery and Equipment
1987	2,623.8	337.8	425.0	14.0	542.4	8.0	9.0	1,200.0	546.8
1990	2,323.7	402.4	479.7	21.8	464.1	8.3	9.4	1,565.0	695.0
1992	2,180.8	403.6	418.9	22.6	516.4	6.9	8.9	1,449.1	801.1
1995	2,629.2	452.7	534.4	27.2	584.3	8.2	9.4	1,487.0	815.5
1996	2,381.5	458.9	582.8	23.3	484.7	8.4	9.5	1,516.7	774.8
1997[a]	2,325.5	460.2	568.5	24.9	504.2	8.7	9.7	1,586.0	783.2
2000[a]	2,386.1	511.7	607.8	29.6	533.9	9.6	9.9	1,606.9	855.1
2005[a]	2,294.0	536.1	625.0	32.0	557.0	9.9	10.0	1,650.6	917.4
Average Annual Growth Rates									
1987-2005	–0.7%	3.3%	2.6%	7.1%	0.1%	1.3%	0.6%	2.1%	3.8%
1987-1997	–1.1%	3.6%	3.4%	7.8%	–0.7%	0.9%	0.8%	3.2%	4.3%
1997-2005	–0.2%	2.1%	1.2%	3.6%	1.3%	1.7%	0.4%	0.5%	2.1%

(continued)

Table 2-16. Iron Castings Shipments by Market: 1987-2005 (10^3 short tons) (Continued)

Year	Metalworking and Industrial Machinery	Ingot Mold	Soil Pipe	Municipal	HVAC	Compressors	Power Transmission	Other	Total
1987	485.4	476.0	378.0	550.0	142.0	192.0	108.0	427.0	8,465.2
1990	575.9	330.0	325.7	552.2	154.9	228.7	109.6	441.6	8,688.0
1992	533.7	310.0	273.4	523.2	138.3	230.2	115.2	421.0	8,353.3
1995	618.0	219.4	234.4	553.8	137.0	245.7	115.8	430.0	9,102.0
1996	647.6	172.9	222.7	560.5	133.7	250.3	117.5	431.5	8,777.3
1997[a]	668.4	151.0	211.6	567.6	134.0	251.6	119.3	437.8	8,812.2
2000[a]	716.1	147.0	145.6	570.0	145.5	258.2	121.1	436.8	9,090.9
2005[a]	774.9	139.4	106.9	575.0	146.8	265.3	122.9	435.8	9,199.0
Average Annual Growth Rates									
1987-2005	3.3%	–3.9%	–4.0%	0.3%	0.2%	2.1%	0.8%	0.1%	0.5%
1987-1997	3.8%	–6.8%	–4.4%	0.3%	–0.6%	3.1%	1.0%	0.3%	0.4%
1997-2005	2.0%	–1.0%	–6.2%	0.2%	1.2%	0.7%	0.4%	–0.1%	0.5%

[a] Forecasts

Source: Business Trend Analysts. 1996. “Foundry Products and Markets in the U.S.—Company Profiles and Ferrous Castings.”

Table 2-17. Steel Castings Shipments by Market: 1987-2005 (10^3 short tons)

Year	Railroad Equipment	Construction Equipment	Mining Machinery	Motor Vehicles	Valves and Fittings	General and Special Industrial Machinery	Metalworking Machinery	Defense and Aerospace	Other	Total
1987	630.0	59.2	149.0	88.8	72.6	64.0	34.0	20.7	68.1	1,186.4
1990	956.0	69.6	154.2	91.9	86.5	76.2	44.3	25.0	71.8	1,575.5
1992	811.0	58.4	128.9	76.8	87.1	76.7	41.1	15.0	68.4	1,363.4
1995	1,102.5	91.2	152.3	90.8	100.4	88.5	42.1	12.9	71.2	1,751.9
1996	1,050.0	85.4	157.2	72.6	102.2	90.1	43.4	13.0	72.4	1,686.3
1997[a]	952.0	83.7	162.2	75.7	102.7	90.5	44.3	13.2	73.8	1,598.1
2000[a]	1,130.5	99.1	178.3	86.2	105.1	92.7	46.3	14.2	74.1	1,826.5
2005[a]	1,260.0	106.6	184.0	89.6	111.7	98.5	48.6	16.7	74.5	1,990.2
Average Annual Growth Rates										
1987-2005	5.6%	4.4%	1.3%	0.1%	3.0%	3.0%	2.4%	–1.1%	0.5%	3.8%
1987-1997	5.1%	4.1%	0.9%	–1.5%	4.1%	4.1%	3.0%	–3.6%	0.8%	3.5%
1997-2005	4.0%	3.4%	1.7%	2.3%	1.1%	1.1%	1.2%	3.3%	0.1%	3.1%

[a] Forecasts

Source: Business Trend Analysts. 1996. “Foundry Products and Markets in the U.S.—Company Profiles and Ferrous Castings.”

SECTION 3

ENGINEERING COST ANALYSIS

Control measures implemented to comply with the MACT standard will impose regulatory costs on iron and steel foundries. This section presents compliance costs for affected foundries and the national estimate of compliance costs associated with the rule. These engineering costs are defined as the annual capital and operating and maintenance costs, assuming no behavioral market adjustment by producers or consumers. For input to the EIA, engineering costs are expressed per unit of iron casting production and used to shift the individual supply functions in the market model.

The MACT standard covers the iron foundry and steel foundry source categories. The processes covered by the regulation include the melting furnace; scrap preheating; pouring, cooling, and shakeout (PCS); mold and core coating; and mold and core making. EPA estimates that approximately 100 iron and steel foundries are major sources of HAP emissions. For the purposes of developing an estimate of the environmental and economic impacts, EPA identified 98 specific foundries that are projected to be major sources of HAP emissions. Consequently, the economic impacts of the MACT standard are based on the compliance costs projected for these 98 foundries. Capital, operating, and maintenance and monitoring costs were estimated for each plant. New or upgraded control equipment will be required at 52 of the foundries, while all 98 foundries will be required to install additional monitoring equipment.

3.1 Overview of Emissions from Iron Foundries

A variety of metal HAPs are contained in the particulate matter (PM) emitted from iron foundries, primarily from the furnace melting operations. The primary metal HAPs emitted from iron and steel foundries are manganese and lead, with concentrations typically ranging from 1 to 5 percent of PM. Trace quantities (generally less than 0.1 percent of PM) of antimony, arsenic, beryllium, cadmium, chromium, cobalt, mercury, nickel, and selenium are also present. Some iron and steel foundries produce iron alloys that increase the concentration of certain metal HAPs in the emitted PM, most commonly chromium and/or nickel. By controlling PM emissions, the foundry effectively controls its metal HAP emissions. The PM control devices most commonly used at foundries are baghouses and venturi scrubbers.

Organic HAP compounds are released from a variety of sources. The organic HAP emission source common to nearly all foundries is the PCS lines, where organic material in the mold or core is vaporized or partially combusted after the hot metal is poured into the mold. The organic HAPs from PCS lines include benzene, toluene, formaldehyde, acetaldehyde, and polycyclic organic matter (POM); the primary POM is naphthalene. Organic HAP emission controls, such as incineration and carbon adsorption, are used for a few selected PCS lines, comprising roughly 1 percent of the total number of PCS lines operated by iron and steel foundries.

Chemical additives (or "binders") are commonly added to the sand cores and occasionally added to the sand molds to increase the strength of the cores and molds. Depending on the composition of the binder systems employed, significant quantities of organic HAPs may be released during the mold- and core-making processes. The organic HAPs released are specific to the type of binder system employed, but important organic HAPs for mold- and core-making operations include cumene, formaldehyde, methanol, naphthalene (a POM), phenol, and triethylamine (TEA). Binder systems using TEA gas are commonly controlled by acid/wet scrubbing. Except for the TEA gas binder systems, the only available organic HAP emission control technique appears to be binder reformulations with non-HAP or reduced-HAP binder systems.

Melting furnaces, primarily cupolas and scrap preheaters, have a potential to emit trace amounts of organic HAPs including POM (such as polynuclear aromatic hydrocarbons and chlorinated dibenzodioxins and furans), and volatile organics such as benzene, carbon disulfide, toluene, and xylene. Organic HAP emissions for these sources typically are controlled through afterburning or direct-flame incineration.

Overall, the iron and steel foundries MACT standard is expected to reduce metal HAP emissions by 102 tons per year (tpy) and organic HAP emissions by 720 tpy. The standard is also expected to reduce PM emissions by 1,780 tpy and volatile organic compound (VOC) emissions by 770 tpy. The emission reductions will result from replacing existing venturi scrubbers with new baghouse control systems on cupolas; installing afterburners in cupolas that do not currently use afterburning; installing PM control systems for currently uncontrolled electric induction furnaces (EIFs) and pouring stations; installing new acid/wet scrubbers at foundries that currently have uncontrolled TEA gas binder systems; and setting binder and coating formulation limitations for mold- and core-making lines.

3.2 General Approach for Estimating Compliance Costs

EPA conducted a detailed survey of the iron and steel industries in 1998 to gather information regarding the types of processes and control devices currently used by each foundry. This survey information was used to identify the specific processes within each foundry that would need to be upgraded or to have new control equipment added. The control costs were estimated using the cost algorithms described in the *OAQPS Control Cost Manual* (EPA, 1991c) and the *Handbook: Control Technologies for Hazardous Air Pollutants* (EPA, 1991b). The control costs were estimated in fourth-quarter 1998 dollars.[1] Costs of the control systems are driven primarily by the flow rate of the exhaust gas requiring treatment. Typical vent stream characteristics (e.g., flow rates per unit capacity or throughput, temperature) were developed from data reported in response to the detailed questionnaires. Costs also were included for monitoring devices associated with the control equipment, such as temperature monitors, pressure monitors, flow rate monitors, and bag leak detection systems. Finally, costs were included for recordkeeping and reporting requirements. More details regarding the control costs estimated for specific processes are provided in the following sections.

3.3 Cupola Melting Furnace Control Systems

The MACT standard establishes PM emission limits (as a surrogate for metal HAP) for cupola melting furnaces based on baghouse control systems. Venturi scrubbers are not expected to be able to meet the PM limits when used to control cupola emissions. Consequently, foundries whose cupolas currently are controlled using venturi scrubbers are expected to have to replace their existing venturi scrubbing control systems with baghouses. To estimate the costs of replacing venturi scrubbers with baghouses, essentially two cost estimates were made. First, the capital investment costs and the annual operating and maintenance costs (AOCs) of a new baghouse system were estimated. Second, the AOCs of a venturi wet scrubber system were estimated because these costs were already being incurred by the foundries and offset the operating cost of the baghouse. Additionally, the MACT standard establishes organic HAP emission limits for cupolas. Therefore, costs were also developed for installing an afterburner to cupola furnace exhaust streams that currently do not use afterburning.

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[1] Cost estimates were calculated in 1998 dollars because the detailed industry survey provided a snapshot of the industry in 1998.

3.3.1 Baghouse Control Costs for Cupola Melting Furnaces

Baghouse or fabric filter control costs were estimated using the CostAir program (EPA, 1991c). The fabric filters were designed as pulse-jet modular systems with an air-to-cloth ratio of 2.37 ft per minute using Nomex bags. Auxiliary equipment included the cost of a new fan, motor, two dampers, 300 ft of ductwork, and new stack. The additional damper and ductwork (300 ft versus a typical value of 100 ft) and an additional system pressure drop of 8 in of water were included in the cost analyses to roughly simulate the added capital and operating costs associated with cooling the cupola exhaust stream prior to the baghouse by using the hot exhaust gases to preheat the cupola blast air. These costs would be incurred because a baghouse control system cannot operate at as high an inlet gas temperature as a venturi scrubber control system. A retrofit cost factor of 2.2 was applied to the total capital investment cost estimate to capture costs of removing existing control equipment and to include additional costs associated with the exhaust stream cooling system and site-specific difficulties anticipated with a system retrofit of this nature. All cost values were calculated in fourth-quarter 1998 dollars (Vatavuk Air Pollution Control Cost Index = 110.9).

Control costs for six different sizes of baghouses were calculated based on the anticipated range of vent stream flow rates. The baghouse flow rates considered ranged from 20,000 to 280,000 actual cubic feet per minute (acfm), which approximately covers a range of cupola melting furnace capacities from 10 to 140 tons per hour (tph). The total capital investment and the annual operating and maintenance costs for these model baghouse systems are summarized in Table 3-1. The calculated control costs for these systems were essentially linear over the flow rates investigated; a linear regression analysis of the capital and the operating and maintenance control costs had R^2 values of 0.999 and 0.993, respectively. Consequently, a simple linear expression was derived to estimate the total capital investment (TCI) and the AOC based on the system exhaust flow rate as follows:

$$TCI_{BH} = 510{,}100 + 32.90\ Q_{BH} \tag{3.1}$$

$$AOC_{BH} = 95{,}820 + 4.703\ Q_{BH} \tag{3.2}$$

where

TCI_{BH} = total capital investment for a baghouse, \$ (fourth quarter 1998);

AOC_{BH} = annual operating and maintenance cost for a baghouse, 1998 \$/yr; and

Q_{BH} = design exhaust vent flow rate based on cupola-baghouse, acfm.

Table 3-1. Summary of Control Costs for Baghouses and Wet Scrubbers: 1998

Flow Rate Through Control Device—Baghouse (Wet Scrubber), acfm	Baghouse Total Capital ($$10^3$)	Baghouse Annual Capital ($$10^3$)[a]	Baghouse Annual Operating ($$10^3$/yr)	Baghouse Total Annual ($$10^3$/yr)	Wet Scrubber Annual Operating ($$10^3$/yr)
20,000 (15,400)	$1,064	$100	$167	$267	$217
40,000 (30,800)	$1,814	$171	$259	$430	$343
80,000 (61,500)	$3,208	$303	$509	$812	$599
120,000 (92,300)	$4,542	$429	$687	$1,116	$855
200,000 (154,000)	$7,126	$673	$1,041	$1,714	$1,365
280,000 (215,000)	$9,648	$911	$1,392	$2,303	$1,867

[a] Reflects capital recovery based on a 20-year life and 7 percent interest rate.

The TCI and AOC for each cupola baghouse were calculated using these equations and the maximum anticipated flow rate based on the cupola melt capacity and the cupola exhaust system design (above or below gas takeoff). Table 3-2 provides the flow rate factors used to estimate the exhaust stream flow rate based on the cupola melting capacity and exhaust system design.

Table 3-2. Estimating Exhaust Air Flow Rates for Control Costs Estimates

Cupola Charge Position and Type of Air Pollution Control Device	Flow Rate Factor (acfm/tph)[a]
Above-Charge Takeoff // Fabric Filter	3,000
Above-Charge Takeoff // Wet Scrubber	2,200
Below-Charge Takeoff // Fabric Filter	2,500
Below-Charge Takeoff // Wet Scrubber	1,800

[a] Adjusted for typical operating temperatures of approximately 500 °F.

A capital recovery factor (CRF) of 0.0944 was used for baghouses to annualize the capital investment on the basis of a 20-year equipment life and an annual interest rate of 7 percent. The total annualized cost (TAC) was calculated as the sum of the annualized capital investment cost and the annual operating and maintenance cost (e.g., TCI × CRF + AOC).

3.3.2 Venturi Scrubber Control Costs for Cupola Melting Furnaces

The costs of operating a venturi scrubber with a pressure drop of 40 in of water were estimated using the cost algorithms described in the *Handbook: Control Technologies for Hazardous Air Pollutants* (EPA, 1991b). The cost of wastewater disposal was assumed to be approximately the same as the water consumption cost, an assumption that likely understates the operating cost of the venturi scrubber. The control costs were converted from 1989 to 1998 dollars using the Chemical Engineering Plant Cost Index (from 355 for base year to 389.5). As with baghouses, the operating costs for venturi scrubbers were calculated for six different exhaust vent flow rates, and a linear regression analysis was performed. Because the operating and maintenance costs for venturi scrubbers are driven by the fan electrical usage, the water consumption, and the wastewater treatment costs, the AOC for venturi scrubbers is linear with exhaust stream flow rate ($R^2 = 0.99999$). The resulting AOC equation for venturi scrubbers is

$$AOC_{VS} = 90{,}250 + 8.262\ Q_{VS} \tag{3.3}$$

where

AOC_{VS} = annual operating and maintenance cost for a venturi scrubber, 1998 $/yr, and

Q_{VS} = design exhaust vent flow rate based on cupola-venturi scrubber, acfm.

As shown in Table 3-2, the average flow rate per furnace capacity is approximately 30 percent higher when baghouse systems are employed than when venturi scrubbers are used. This is thought to be caused primarily by additional air sucked into the exhaust system (the vent is at a negative pressure with respect to atmospheric) when the exhaust stream is cooled prior to the baghouse. Consequently, the operating and maintenance costs for venturi scrubbers are provided in Table 3-1 for flow rates ranging from 15,400 to 215,000 acfm, because these costs are more comparable to the baghouse costs reported in Table 3-1 on the basis of cupola melting capacity.

3.3.3 Net Metal HAP Control Cost for Cupola Melting Furnaces

The net control costs for replacing a venturi scrubber with a baghouse control system were calculated using the following equations:

$$TCI_{VS\rightarrow BH} = TCI_{BH} \tag{3.4}$$

$$AOC_{VS\rightarrow BH} = AOC_{BH} - AOC_{VS} \tag{3.5}$$

$$TAC_{VS\rightarrow BH} = CRF \times TCI_{VS\rightarrow BH} + AOC_{VS\rightarrow BH} \tag{3.6}$$

where

$TCI_{VS \rightarrow BH}$ = total capital investment for replacing a venturi scrubber with a baghouse, 1998 $;

$AOC_{VS \rightarrow BH}$ = net annual operating and maintenance cost for replacing a venturi scrubber with a baghouse, 1998 $/yr;

$TAC_{VS \rightarrow BH}$ = total annualized cost for replacing a venturi scrubber with a baghouse, 1998 $/yr; and

CRF = capital recovery factor = 0.0944 (20 years; 7 percent interest).

3.3.4 Sample Calculation of Metal HAP Control Cost for Cupola Melting Furnaces

The annual operating and maintenance cost of an existing venturi scrubber system was first calculated based on the melting capacity of the furnace. For example, given an above-charge takeoff cupola with a melting capacity of 50 tph, the design vent stream flow rate for a cupola-venturi scrubber system was calculated to be Q_{VS} = 50 tph × 2,200 acfm/tph (flow rate factor from Table 3-2) = 110,000 acfm. The annual operating and maintenance cost of the existing venturi scrubber system was then calculated using Eq. (3.3) to yield an AOC_{VS} = $999,000/yr.

The design exhaust flow rate of the new fabric filter system was then calculated as Q_{BH} = 50 tph × 3,000 acfm/tph (factor from Table 3-2) = 150,000 acfm. The control costs for the new fabric filter system were then calculated using this revised design exhaust flow rate as shown in Eqs. (3.1) and (3.2), yielding TCI_{BH} = $5,445,000 and AOC_{BH} = $801,000/yr.

The net control costs were then calculated using Eqs. (3.4) and (3.5) to yield $TCI_{VS \rightarrow BH}$ = $5,445,000; $AOC_{VS \rightarrow BH}$ = ($198,000/yr); and $TAC_{VS \rightarrow BH}$ = $316,000/yr.

3.3.5 Afterburning Control Cost for Cupola Melting Furnaces

Afterburning control costs were estimated using the CostAir program for incinerator systems (EPA, 1991c). The incinerators were designed to operate at a minimum of 1,300 °F. From data collected during EPA source tests, it was assumed that the temperature of the cupola exhaust stream entering the incinerator/afterburner was 500 °F. This inlet gas stream was assumed to contain adequate oxygen, coming from air entering the cupola exhaust stream through the charge door opening. The CO concentration after dilution with the charge door ventilation air was assumed to be 5 percent. The incinerator/afterburner was assumed to operate without heat recovery, and a retrofit cost factor of 1.2 was applied to the total capital investment cost estimate.

Control costs for 10 different sizes of incinerators were calculated based on the anticipated range of vent stream flow rates because of a shift in the cost curves identified for gas flows less than 40,000 acfm. The shift in the cost curve function can be seen in Figure 3-1. Subsequently, two control cost equations were developed for each cost parameter (total capital investment and the annual operating and maintenance cost): one for systems of less than 40,000 acfm and one for systems of 40,000 acfm or more. A log-log correlation was used for the total capital investment cost curves. The calculated control cost equations are:

For systems $Q_{AB} < 40,000$ acfm

$$TCI_{AB} = 1{,}000 \times \exp[2.997 + 0.2355 \ln(Q_{AB})] \tag{3.7}$$

$$AOC_{AB} = 36{,}360 + 2.113\ Q_{AB} \tag{3.8}$$

For systems $Q_{AB} \geq 40,000$ acfm

$$TCI_{AB} = 1{,}000 \times \exp[3.339 + 0.2355 \ln(Q_{AB})] \tag{3.9}$$

$$AOC_{AB} = 60{,}430 + 2.040\ Q_{AB} \tag{3.10}$$

where

TCI_{AB} = total capital investment for an afterburner, \$ (fourth quarter 1998);

AOC_{AB} = annual operating and maintenance cost for an afterburner, 1998 \$/yr; and

Q_{AB} = design exhaust vent flow rate at afterburner inlet, acfm.

A linear regression analysis of these control cost equations had R^2 values of 0.9999 or greater.

The cupola inlet gas flow rate was estimated using the flow rate factors presented in Table 3-2. These flow rate factors were developed from systems that had afterburners, but the flow rate measurements were made downstream of the cupola afterburner. As such, use of the flow rate factors in Table 3-2 is expected to yield cost estimates that are biased high. Nonetheless, because cupola afterburners generally operate with a minimum of auxiliary fuel (CO in the exhaust stream being the primary fuel), applying the flow rate factors in Table 3-2 should result in a reasonable estimate of the flow rate at the inlet to the afterburner.

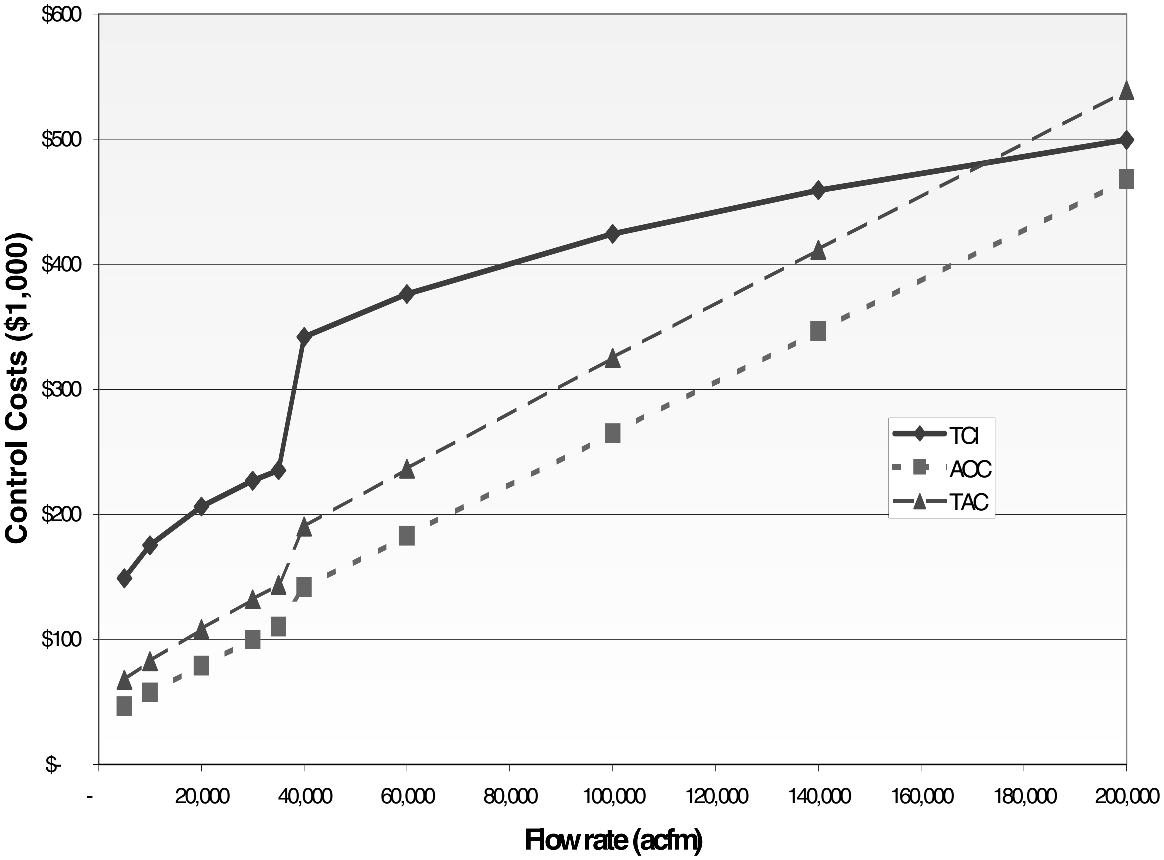

Figure 3-1. Control Cost Curves for Cupola Afterburners

A capital recovery factor of 0.1424 was used for baghouses to annualize the capital investment on the basis of a 10-year equipment life and an annual interest rate of 7 percent. The total annualized cost was calculated as the sum of the annualized capital investment cost and the annual operating and maintenance cost (e.g., TCI × CRF + AOC).

3.3.6 Sample Calculation of Organic HAP Control Cost for Cupola Melting Furnaces

Continuing the example of an above-charge takeoff cupola with a melting capacity of 50 tph, the design exhaust flow rate was estimated as Q_{AB} = 50 tph × 3,000 acfm/tph (factor from Table 3-2) = 150,000 acfm. The control costs for the new afterburner system were then calculated using Eqs. (3.9) and (3.10), yielding TCI_{AB} = $467,000 and AOC_{BH} = $366,000/yr. Using the capital recovery factor of 0.1424, TAC_{AB} = $433,000/yr.

3.4 Electric Induction, Scrap Preheater, and Pouring Station Control Systems

The MACT standard also establishes PM emission limits (as a surrogate for metal HAP) for other types of melting furnaces commonly used at foundries (i.e., electric induction furnaces and electric arc furnaces [EAFs]), as well as scrap preheaters and pouring stations. These emission limits are again based primarily on baghouse control systems. All EAFs at the 98 foundries expected to be major sources of HAP emissions were controlled using baghouses. Some EIFs, scrap preheaters, and pouring stations employed venturi wet scrubbers. However, these emission sources do not have the same level of uncontrolled emissions as cupolas or EAFs, and well-operated and maintained venturi scrubbers should be able to meet the PM limits for existing EIFs, scrap preheaters, and pouring stations. As such, costs were only estimated for adding new PM control systems (assumed to be baghouses for costing purposes) for sources that currently do not operate a control system.

Additionally, the MACT standard establishes requirements for scrap preheaters. All scrap preheaters must either use direct-gas flame scrap preheating or meet an organic HAP emission limit. The existing scrap preheaters, as operated at the 98 foundries projected to be major sources of HAP emissions, are expected to meet the MACT requirements without additional control costs. Consequently, this section summarizes control costs for baghouses for EIFs, scrap preheaters, and pouring stations.

3.4.1 Baghouse Control Costs for EIFs and Scrap Preheaters

As with the baghouse costs developed for cupolas, baghouse control costs for the control of EIFs and scrap preheater PM emissions were estimated using the CostAir program (EPA, 1991c). However, the fabric filters in service for these emission sources, based on the information in the detailed industry survey, generally operate at much lower temperatures and at significantly higher air-to-cloth ratios than cupola baghouses. The EIF/scrap preheater fabric filters were designed as pulse-jet modular systems with an air-to-cloth ratio of 5.1 acfm/ft^2 using polyester bags. Auxiliary equipment included the cost of a new fan, motor, one damper, 40 ft of ductwork, and new stack. A retrofit cost factor of 1.2 was applied to the total capital investment cost to estimate the retrofit costs for all baghouse systems installed to control emissions from scrap preheaters and from EIFs that already have a capture system (but no control device).[2] As before, all cost values were calculated in fourth quarter 1998 dollars (Vatavuk Air Pollution Control Cost Index = 110.9).

Control costs for 10 different sizes of baghouses were calculated based on the anticipated range of vent stream flow rates. There is a noticeable shift in the operating cost

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[2] EIFs with no capture systems were assumed to elect to meet the opacity limit for the foundry rather than install a capture and control system for their EIF.

curve for gas flows between 40,000 and 50,000 acfm (see Figure 3-2). Subsequently, two control cost equations were developed for each cost parameter (total capital investment and the annual operating and maintenance cost): one for systems of less than 50,000 acfm and one for systems of 50,000 acfm or more. Overall, the baghouse flow rates considered ranged from 5,000 to 180,000 acfm. A linear regression analysis of the capital and the operating and maintenance control costs resulted in R^2 values exceeding 0.999 for each size range for each cost parameter.

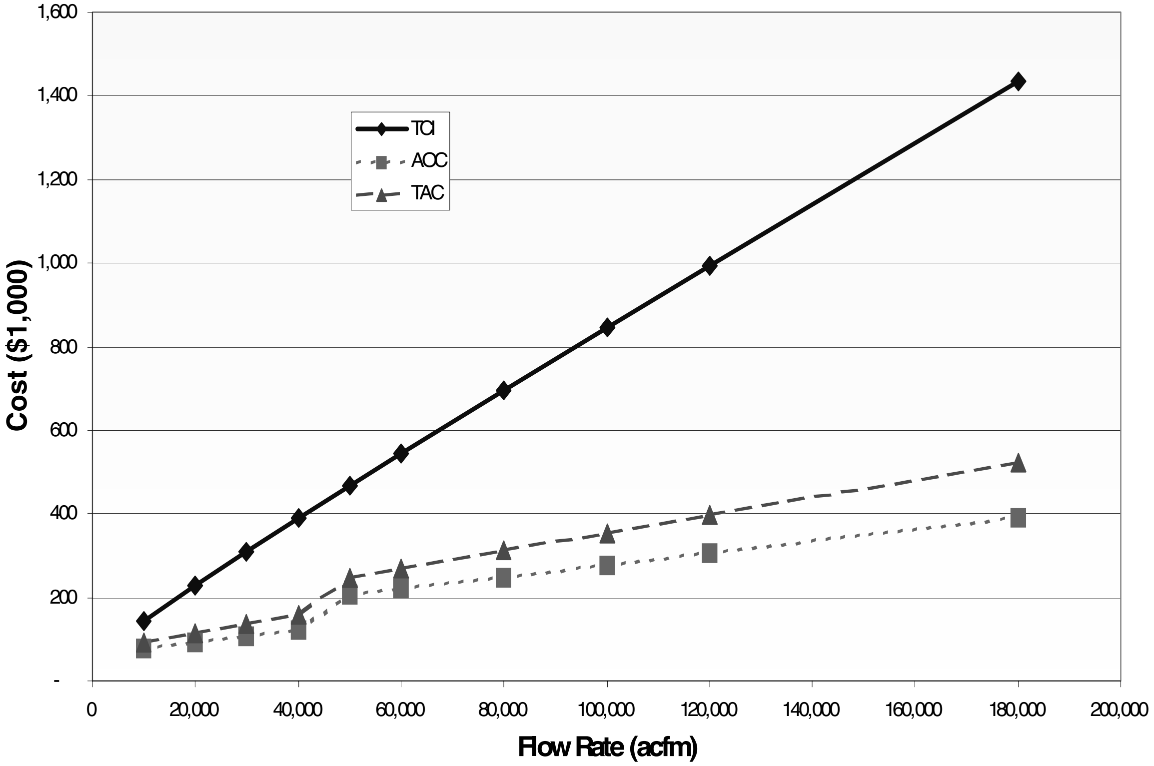

Figure 3-2. Control Cost Curves for EIF/Scrap Preheater Baghouses

From the linear regression analysis, the following control cost equations were developed:

For systems $Q_{EIF/SPH} < 50,000$ acfm

$$TCI_{EIF/SPH} = 63,840 + 8.162\ Q_{EIF/SPH} \qquad (3.11)$$

$$AOC_{EIF/SPH} = 63,870 + 1.458\ Q_{EIF/SPH} \qquad (3.12)$$

For systems $Q_{EIF/SPH} \geq 50{,}000$ acfm

$$TCI_{EIF/SPH} = 99{,}230 + 7.437\ Q_{EIF/SPH} \qquad (3.13)$$

$$AOC_{EIF/SPH} = 133{,}900 + 1.429\ Q_{EIF/SPH} \qquad (3.14)$$

where

$TCI_{EIF/SPH}$ = total capital investment for an EIF/scrap preheater baghouse, 1998 \$;

$AOC_{EIF/SPH}$ = annual operating and maintenance costs for an EIF/scrap preheater baghouse, 1998 \$/yr; and

$Q_{EIF/SPH}$ = design exhaust vent flow rate based on EIF/scrap preheater, acfm.

Again, a capital recovery factor of 0.0944 was used for baghouses to annualize the capital investment on the basis of a 20-year equipment life and an annual interest rate of 7 percent.

The design exhaust flow rate of the EIF control system was estimated based on the melting capacity of the EIF. The design exhaust flow rate for a scrap preheater control system was estimated based on the number of scrap preheaters requiring control. If a foundry needed to add controls for both its EIFs and its scrap preheaters, then a single baghouse would need to be designed to control the combined system flow rate. Therefore, the EIF/scrap preheater control system flow rate was calculated as

$$Q_{EIF/SPH} = Q_{EIF} + Q_{SPH} \qquad (3.15)$$

where

Q_{EIF} = design exhaust vent flow rate based on EIF capacity, acfm and

Q_{SPH} = design exhaust vent flow rate based on number of scrap preheaters, acfm.

The EIF control system flow rate was calculated from EIF melting rate capacity. Additionally, if pouring station emission controls were also required at the foundry, then the EIF control system would need to be designed to include the flow rate from the pouring station capture system, as well. Specifically, the EIF exhaust flow rate was estimated as

$$Q_{EIF} = 5{,}000 \times NumEIF \times (MeltCap_{EIF})^{0.667} + Q_{PourSt} \qquad (3.16)$$

where

NumEIF = number of EIF of given melting rate capacity;

$MeltCap_{EIF}$ = melting rate capacity of the EIF, tons/hr; and

Q_{PourSt} = design exhaust vent flow rate based on number of pouring stations, acfm (see Section 3.4.2).

The factor of 5,000 was assigned based on a 5 ft × 5 ft canopy hood with an entrance design velocity of 200 ft/min for a 1 tph EIF. The capture system exhaust flow rate from other EIF melting furnaces was assumed to be proportional to the cross-sectional area of the furnace (or to the 2/3 power of the capacity of the furnace). If pouring stations also required control at the foundry, the exhaust from the pouring station capture systems was assumed to be added to the EIF exhaust stream prior to the control device.

The flow rate of a scrap preheater control system was calculated as a simple function of the number of scrap preheaters requiring PM controls, as follows:

Number of Scrap Preheaters Requiring Control:	**Exhaust Flow Rate**:
1	Q_{SPH} = 20,000 acfm
2, 3, or 4	Q_{SPH} = 60,000 acfm
5 or more	Q_{SPH} = 100,000 acfm

These scrap preheater exhaust flow rates were used directly as the control system flow rates in Eqs. (3.11) through (3.14) if the EIFs at a given foundry did not need control. That is, pouring station exhaust flows were only combined with EIF/scrap preheater control systems when the EIFs required control. Otherwise, costs for separate control systems were developed when a foundry required control of a scrap preheater and a pouring station but not an EIF.

3.4.2 Baghouse Control Costs for Pouring Stations

Baghouse control costs for the controlling PM emissions from pouring stations were again estimated using the CostAir program (EPA, 1991c). The design used for pouring station control systems was based on baghouses used to control PM emissions from pouring, cooling, and shakeout lines. As such, the cost curves presented in this section can be used to estimate baghouse costs for controlling pouring, cooling, or shakeout PM emissions. However, these equations were employed only for pouring station emission control and then only when no additional EIF emission control was required at the foundry. The pouring station baghouses were designed as pulse-jet modular systems with an air-to-cloth ratio of 6.8 acfm/ft^2. Auxiliary equipment included the cost of a new fan, motor, one damper, 40 ft of ductwork, and new stack. A retrofit cost factor of 1.2 was applied to the total capital investment cost estimate. Control system costs were only estimated for pouring stations with existing capture systems but no additional PM control system. Pouring stations with no capture systems reported were assumed to elect to meet the opacity limit for the foundry rather than install a capture and control system for their pouring station. Again, all cost values were calculated in fourth-quarter 1998 dollars (Vatavuk Air Pollution Control Cost Index = 110.9).

Control costs for nine different sizes of baghouses were calculated based on the anticipated range of vent stream flow rates. As with the EIF/scrap preheater operating cost curve, there is a noticeable shift in the operating cost curve for gas flows between 40,000 and 50,000 acfm (see Figure 3-3). Subsequently, two control cost equations were developed for each cost parameter (total capital investment and the annual operating and maintenance cost): one for systems less than 50,000 acfm and one for systems of 50,000 acfm or more. Overall, the baghouse flow rates for which direct cost estimates were developed ranged from 5,000 to 180,000 acfm. A linear regression analysis of the capital and the operating and maintenance control costs resulted in R^2 values exceeding 0.999 for both size ranges and for each cost parameter evaluated. The resulting control cost equations follow.

For systems $Q_{PourSt} < 50{,}000$ acfm

$$TCI_{PourSt} = 63{,}360 + 6.732\ Q_{PourSt} \tag{3.17}$$

$$AOC_{PourSt} = 63{,}720 + 1.412\ Q_{PourSt} \tag{3.18}$$

For systems $Q_{EIF/SPH} \geq 50{,}000$ acfm

$$TCI_{PourSt} = 99{,}100 + 5.892\ Q_{PourSt} \tag{3.19}$$

$$AOC_{PourSt} = 133{,}900 + 1.378\ Q_{PourSt} \tag{3.20}$$

where

TCI_{PourSt} = total capital investment for pouring station baghouse, 1998 $;

AOC_{PourSt} = annual operating and maintenance cost for pouring station baghouse, 1998 $/yr; and

Q_{PourSt} = design exhaust vent flow rate based on number of pouring stations requiring additional control, acfm.

Again, a capital recovery factor of 0.0944 was used for baghouses to annualize the capital investment on the basis of a 20-year equipment life and an annual interest rate of 7 percent.

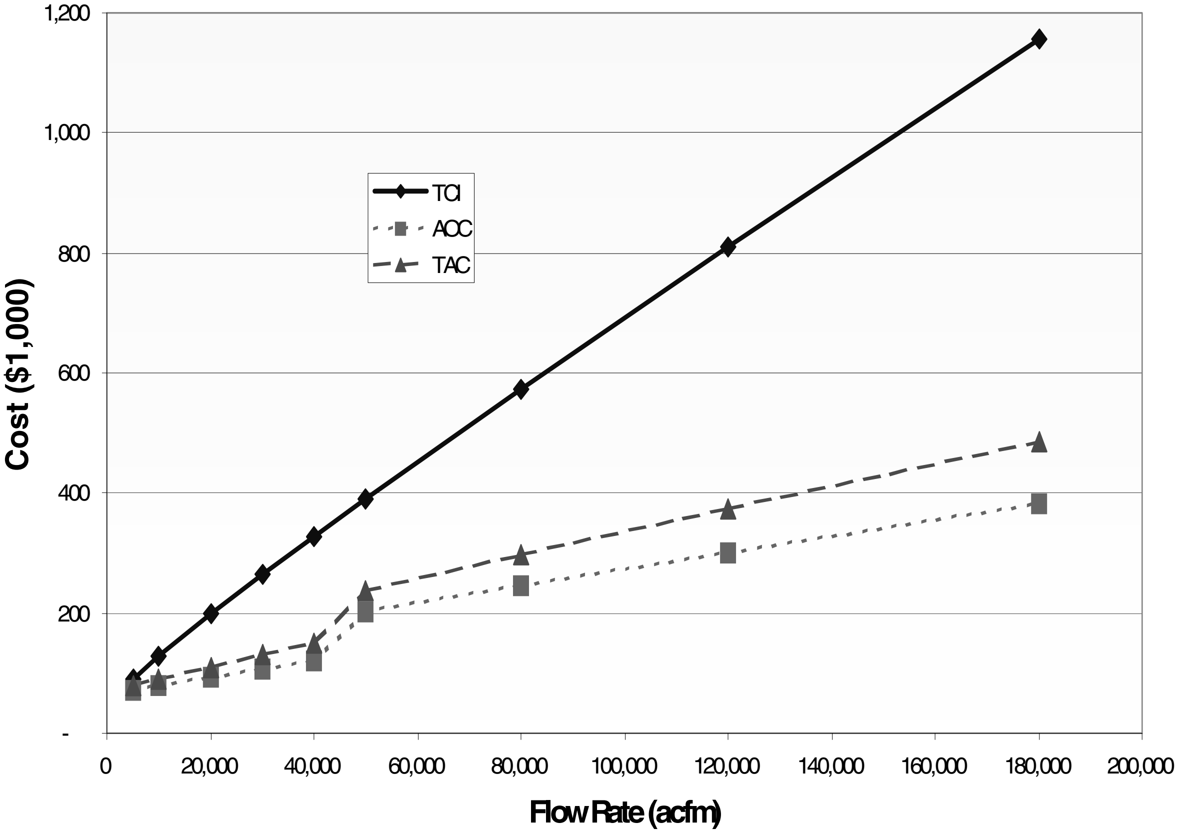

Figure 3-3. Control Cost Curves for Pouring Station Baghouses

The flow rates for the pouring station control systems were calculated assuming each pouring station capture system was a 5 ft × 4 ft canopy hood with an entrance design velocity of 200 ft/min, so that each pouring station requiring control contributed 4,000 acfm to the pouring station control system. However, if only one pouring station control system required control at a foundry, the pouring station baghouse was designed for a flow rate of 6,000 acfm (essentially a 6 ft × 5 ft canopy hood with an entrance design velocity of 200 ft/min).

Number of Pouring Stations Requiring Control:	**Exhaust Flow Rate:**
1	Q_{PourSt} = 6,000 acfm
2 or more	Q_{PourSt} = 4,000 acfm × # Pouring Stations

As discussed in Section 3.4.1, the pouring station emissions were assumed to be combined with the EIF emissions if the foundry was required to add a control system for the EIFs. Even though the cost of an EIF/SPH baghouse at any given flow rate is higher than the cost of a similar-sized pouring station baghouse (because of the different air-to-cloth ratios assumed for these systems), it is still more cost-effective to install a single control system at the lower air-to-cloth ratio than to install two separate control systems. It is also likely that foundries that have to control both scrap preheater and pouring station emissions will install a single control system for both of these emission sources to save on costs. However, based on the logic used in the control cost model, separate control systems were designed for these emission sources if no additional control was required for the EIFs.

3.5 Mold- and Core-Making Control Systems

The MACT standard establishes two emission reduction measures for mold- and core-making lines. For binder systems that employ a triethylamine gas catalyst, the emission reduction method is the installation of an acid/wet (absorptive) scrubber. Five of the 96 foundries had uncontrolled TEA emissions from their mold- and core-making TEA gas binder systems. The costs associated with the acid/wet scrubber for TEA emissions controls are described in this section. For furan warm-box systems, there are also restrictions on the methanol content of the catalyst portion of the binder system. Alternative water-based catalyst formulations, however, appear to be available that can meet the restrictions pertaining to methanol in the furan warm-box catalyst formulation with no further costs associated with the adaptation.

Costs associated with the installation and operation of acid/wet scrubbers to control emissions of TEA were calculated using the cost algorithms reported in the *OAQPS Control Cost Manual*, 5th Edition (EPA, 1991c). Based on the TEA usage rates at the five foundries with uncontrolled TEA mold- and core-making lines, three scrubber control systems were sized based on removing 10 tpy, 25 tpy and 125 tpy. These model acid/wet scrubber systems were then assigned to each of the uncontrolled TEA mold- and core-making lines based on the current TEA usage rates. The model scrubbers generally had a 25 to 50 percent excess capacity compared to the projected usage rates for any given uncontrolled TEA mold- and core-making line for which it was assigned. From the available source test data, TEA inlet (uncontrolled) concentrations ranged from 10 to 130 ppm. However, the systems with the highest flow rates also had the highest TEA concentrations. Therefore, the small- and medium-sized scrubbers (10 and 25 tpy of TEA systems) were assumed to operate 4,000 hrs/yr with an inlet TEA concentration of 50 parts per million by volume (ppmv; median value from the test data). The larger scrubber, capable of removing 125 tpy of TEA, was assumed to operate 4,000 hrs/yr and at an inlet TEA concentration of 100 ppmv.

The cost functions presented in the *OAQPS Control Cost Manual* are provided in third-quarter 1991 dollars. These costs were scaled to 1998 dollars by using the Chemical Engineering Plant Cost Index (using 361 for 1991 and 389.5 for 1998). The calculated control costs for the three acid/wet scrubbers are as provided in Table 3-3.

Table 3-3. Summary of Control Costs for Acid/Wet Scrubbing Systems: 1998

Model Scrubber	Total Capital ($\$10^3$)	Annual Capital[a]	Annual Operating ($\$10^3$/yr)	Total Annual ($\$10^3$/yr)
Scrubber 1 (10 tpy)	$87	$12.3	$25.0	$37.3
Scrubber 2 (25 tpy)	$157	$22.3	$31.6	$53.9
Scrubber 3 (125 tpy)	$309	$44.1	$50.8	$94.9

[a] Reflects capital recovery factor of 0.1424 based on a 10-year life and a 7 percent interest rate.

3.6 Monitoring, Reporting, and Recordkeeping

Most of the monitoring requirements in the iron and steel foundries MACT standard are continuous parameter monitoring requirements. The standard requires each baghouse to be equipped with a bag leak detection system. Foundries with TEA scrubber systems are also required to install and operate a pH monitoring system and gas and liquid flow rate monitors. For venturi wet scrubbers used to meet a PM emission limit, the monitored parameters include the pressure drop and gas and liquid flow rates. Finally, some recordkeeping and reporting costs were estimated for implementing a scrap selection and inspection program; conducting performance tests; preparing a start-up, shut-down, and malfunction plan; preparing operating and maintenance records; and maintaining records of HAP usage rates associated with coatings and chemical binders used for mold- and core-making. These costs are described in the following sections. All capital costs for monitoring and recordkeeping equipment were annualized using a capital recovery factor of 0.1424 based on 10-year equipment life and 7 percent interest rate.

3.6.1 Bag Leak Detection Systems

Each baghouse will need to be equipped with a bag leak detection system. These systems will have an installed capital cost of $9,000 each, with an annual operating cost of $500/yr (EPA, 1998a). There are a total of 288 baghouses, either existing or required to be installed, at the 98 major source iron and steel foundries. Consequently, the total capital cost for bag leak detectors was calculated as $2.59 million, with an annual operating cost of $144,000/yr, resulting in a total annualized cost for bag leak detectors of $513,000/yr.

3.6.2 Parameter Monitoring Systems

The costs for parameter monitoring systems were estimated using a generic parameter monitoring system. Monitoring system costs were evaluated from control equipment supply company catalogues for pH, pressure, and flow measurement systems and associated electronic recording systems. These costs ranged from \$1,500 to \$3,000 per monitoring and data recording system (in 1998 dollars). Therefore, the general cost of equipment for any parameter monitoring system was estimated to be \$2,500. It was estimated that the installation, calibration, troubleshooting, training, and quality assurance procedure development costs for a new monitoring system would be \$5,000, so that the total installed cost per new monitoring system would be \$7,500.

The annual operating costs were estimated to be \$2,000/yr. These costs are largely for calibration and maintenance of the equipment, but they also include summarizing and annual reporting of the data.

Costs were not separately included for temperature monitoring systems on thermal destruction devices. These monitoring devices are integral to the control device and must be properly maintained for proper control device performance. Thus, costs for temperature monitors are included in the operating and maintenance costs of the new afterburners, and foundries currently operating thermal combustion systems are assumed to already have and maintain the required temperature monitors.

3.6.2.1 Parameter Monitoring Systems for Venturi (PM) Wet Scrubbers

Existing venturi wet scrubbing systems are expected to be able to meet PM emission limits from EIFs, scrap preheaters, and pouring stations. If a venturi scrubbing system is employed, both the pressure drop and scrubbing liquid flow rate must be monitored. Both of these monitoring systems were assumed to be in place at each venturi scrubber control device. Annual operating costs for both parameter monitoring systems were assumed to be \$4,000/yr (\$2,000 × 2). Eighteen existing venturi wet scrubbing systems were associated with EIFs, scrap preheaters, and pouring stations at the major source foundries, so the total annualized monitoring costs for these systems would be \$72,000.

3.6.2.2 Parameter Monitoring Systems for Acid/Wet Scrubbing Systems

The acid/wet scrubbing systems used to control TEA emissions from mold- and core-making operations are required to monitor flow rate and pH of the scrubbing liquor. Because the equipment costs for new scrubbers typically includes these monitors, it was assumed that all acid/wet scrubbing systems have flow monitors already in place, and it was assumed that all systems would have to have a pH monitor installed. Consequently, the monitoring costs per scrubbing system would be $7,500 capital costs and $4,000 annual operating and maintenance costs. These costs were projected for 46 TEA acid/wet scrubbing systems.

3.6.3 Foundry Recordkeeping, Reporting, and Compliance Costs

Several work practices in the MACT standard require foundries to prepare plans and maintain records of certain emissions-reducing activities. It was assumed that all foundries routinely provided an ignition source to mold vents after pouring if these vents did not auto-ignite. Therefore, no control costs were attributed to these activities; however, costs were attributed to performing an initial assessment of which mold vents were required to be ignited under the regulation. Costs were also estimated for developing a scrap selection and inspection plan, conducting performance tests, and maintaining records of HAP usage rates in coating materials and binder formulations. These costs were calculated primarily based on an estimate of the technical person-hours required to complete each activity and the frequency of occurrence. Additionally, the increased cost of certain scrap material based on the requirements of the scrap selection and inspection program was also estimated.

Labor rates and associated costs were based on Bureau of Labor Statistics (BLS) data. Technical, management, and clerical average hourly rates for civilian workers were taken from the March 2002 Employment Cost Trends (http://stats.bls.gov). Wages for civilian workers (white-collar occupations) were used as the basis for the labor rates with a total compensation of $28.49/hr for technical, $42.20/hr for managerial, and $18.41/hr for clerical. These rates represent salaries plus fringe benefits and do not include the cost of overhead. An overhead rate of 110 percent was used to account for these costs. The fully burdened wage rates used to represent respondent labor costs were technical at $59.83, management at $88.62, and clerical at $38.66.

The number of technical hours needed for each compliance activity was first estimated. For each technical hour needed, 0.05 managerial hours and 0.10 clerical hours were also assumed to be required. Consequently, the total labor cost, including technical, managerial, and clerical labor, for a compliance activity would be $68.125 per technical hour expended.[3] The 2002 labor costs were multiplied by 0.8837 (139.8/158.2) to estimate the compliance costs in fourth-quarter 1998 dollars. Therefore, the compliance costs were calculated using $60.20 per technical hour expended.

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[3] As stated, these labor rates are based on March 2002 statistics. According to BLS data, the Employment Cost Index (ECI) for civilian workers in March 2002 was 158.2, while the ECI for civilian workers in December 1998 was 139.8.

3.6.3.1 Performance Tests

A total of 70 technical hours was estimated for each performance test. This included time to prepare a site-specific QA test plan, conduct the performance test, and prepare the final source test report. The total number of stacks requiring performance testing was estimated to be 377.

The performance tests are required once every 5 years. The compliance period is 3 years. Therefore, the required performance tests can be fairly evenly distributed across the compliance period. The average annual compliance cost associated with conducting performance tests at a given foundry was calculated as the total costs for conducting all required performance tests at that foundry and distributing those costs evenly over 5 years. Thus, 5,278 technical hrs/yr were estimated for conducting performance tests, for a total annual cost of $318,000/yr.

3.6.3.2 Scrap Selection and Inspection

Most of the 98 foundries had a scrap selection and inspection program; however, it is anticipated that many foundries will have increased the number of technical hours spent on scrap selection and inspection to comply with requirements in the MACT standard. It was assumed that the scrap inspection requirements would increase a typical foundry's inspection process by 0.5 hr/day or 175 hrs/yr (assuming 350 operating days/yr). A one-time scrap selection plan must be prepared and communicated within the foundry. Because most foundries do not operate 350 days per year, this activity was assumed to be included in the 175 technical hrs/yr per foundry labor estimate. Of the 98 facilities considered to be major sources of HAP emissions, two of these foundries each operate two adjacent plants. Although they are considered a single facility under the Clean Air Act, these adjacent plants have separate scrap-receiving areas that would require inspection. Thus, the scrap selection and inspection costs were estimated based on 100 scrap-receiving areas. The total nationwide cost for the scrap selection and inspection program was estimated to be $1.05 million/yr.

The scrap selection and inspection program also includes restrictions on the use of scrap metal known to contain mercury switches or lead components, which is primarily contained in automotive body scrap. The MACT standard will require foundries to purchase only automotive body scrap that has had the mercury switches and lead components removed. It is estimated that this will increase the cost of automotive body scrap by $1.60/ton of scrap. It is estimated that automotive scrap is approximately 10 percent of the total nationwide scrap supply. Based on the estimated production capacity of major source iron and steel foundries of 16.1 million tons/yr, the scrap selection and inspection program is estimated to cost foundries an additional $2.58 million/yr in increased scrap costs. Together with the inspections, the total cost of the scrap selection and inspection program is estimated to be $3.63 million/yr.

3.6.3.3 Start-up, Shutdown, and Malfunction Plan

Each foundry is required to develop a start-up, shutdown, and malfunction (SSM) plan. Eighty technical hours were estimated for preparing the SSM plan. This plan is predominately a one-time requirement, but it is likely that the plan will be reviewed and updated once per Title V permit period (i.e., once every 5 years). Assuming re-evaluations are performed once every 5 years, the average annual technical hours required to complete these evaluations would be 16 hrs/yr per foundry. Based on 98 major source iron and steel foundries, the total nationwide annualized cost for preparing the SSM plan was estimated to be $94,400/yr.

3.6.3.4 Operating and Maintenance Plan

Each foundry is required to develop an operating and maintenance (O&M) plan. This plan includes an assessment of ignitability for mold vents and operating and maintenance requirements for capture systems and emission control devices. One hundred and twenty technical hours were estimated for preparing the O&M plan and performing the mold vent ignitability determination. Again, the development of the O&M plan is predominately a one-time requirement, but it is likely that the plan will be reviewed and updated once per Title V permit period (i.e., once every 5 years). Therefore, the annualized costs for the preparation of the O&M plan were estimated based on 24 hrs/yr per foundry, resulting in a total nationwide annualized cost for the 98 major source iron and steel foundries of $142,000/yr.

3.6.3.5 Miscellaneous Recordkeeping and Reporting Costs

Each foundry is required to maintain certain records of its monitored parameters. Costs for data logging instruments were included in the cost of the monitoring equipment. Additionally, the scrap inspection cost estimate included the effort to complete an inspection record. Costs associated with maintaining these types of records at the foundry level were estimated based on two filing cabinets (for capital equipment costs of $400, which were annualized over 10 years) and a pack of 10 writeable CDs (for annual operating costs of $32). In addition, each foundry is required to maintain records of the annual HAP usage rates associated with the foundry’s coating materials and chemical binder formulations. Compiling and filing these records were estimated to require 8 hrs/yr per foundry or $47,000/yr nationwide.

Each foundry is also required to submit a semiannual report to document compliance with the MACT standard. Each report was estimated to require 20 technical hours to prepare, so that the annual labor estimate for this requirement is 40 hrs/yr per foundry.

These reports are required for 98 major source iron and steel foundries so that the total nationwide costs for reporting were estimated to be $236,000/yr.

3.7 Total Nationwide Costs

The total nationwide costs for each of the major control or monitoring systems are provided in Table 3-4. Table 3-4 also summarizes the estimated recordkeeping and reporting costs. The total annual nationwide cost of the MACT standard for iron and steel foundries is projected to be $21.0 million/yr.

Table 3-4. Nationwide Cost Estimates for Iron Foundry MACT: 1998$

Source	Total Capital ($1,000)	Annual Capital[a]	Annual Operating ($1,000/yr)	Total Annual ($1,000/yr)
Baghouse replacement of cupola venturi scrubbers	175,217	16,540	(6,134)	10,406
Cupola afterburners	555	79	228	307
Baghouses on EIF and scrap preheaters	5,721	540	2,126	2,666
Baghouses on pouring stations	2,882	272	1,715	1,987
Acid/wet scrubber systems for TEA control	949	135	183	318
Total Emission Control Costs	185,324	17,567	(1,882)	15,685
Bag leak detection systems	2,592	369	144	513
Venturi scrubber monitoring systems	0	0	72	72
Acid/wet scrubber parameter monitoring systems	345	49	184	233
Performance tests	0	0	318	318
Scrap selection and inspection	0	0	3,630	3,630
Start-up, shutdown, and malfunction plan	0	0	94	94
Operating and maintenance plan	0	0	142	142
Other recordkeeping and reporting costs	39	6	286	292
Total Monitoring, Recordkeeping and Reporting Costs	2,976	176	4,870	5,294
Total Engineering Control Costs	**188,300**	**17,743**	**2,988**	**20,979**

[a] Reflects capital recovery based on a 20-year life and 7 percent interest rate for baghouse emission controls and a 10-year life and 7 percent interest rate for cupola afterburners, TEA scrubbers, and all monitoring equipment.

SECTION 4

ECONOMIC IMPACT ANALYSIS

The rule to control the release of HAPs from iron and steel foundry operations will directly (through imposition of compliance costs) or indirectly (through changes in market prices) affect the entire U.S. iron and steel industry. The response by these producers to these additional costs will determine the economic impacts of the regulation. Specifically, the impacts will be distributed across producers and consumers of iron castings and foundry coke through changes in prices and quantities in the affected markets. This section presents estimates of the economic impacts of the iron and steel foundry MACT using an economic model that captures the linkages between the iron castings and foundry coke markets.

This section describes the data and approach used to estimate the economic impacts of this rule for the baseline year of 2000. Section 4.1 presents the inputs for the economic analysis, including characterization of producers, markets, and the costs of compliance. Section 4.2 summarizes the conceptual approach to estimating the economic impacts on the affected industries. A fully detailed description of the economic impact methodology is provided in Appendix A. Lastly, Section 4.3 provides the results of the economic impact analysis.

4.1 Market Characterization

EPA estimated changes in the equilibrium price and quantity due to control costs on iron and steel foundries using the following three linked markets:

- market for iron castings,
- market for steel castings, and
- market for foundry coke.

EPA collected data for the castings market using the Current Industrial Reports series (U.S. Bureau of the Census, 2001). Data on the foundry market were obtained from the economic impact analysis of the final Coke Ovens NESHAP (EPA, 2002). Table 4-1 reports the baseline data used in the market model.

Table 4-1. Baseline Market Data Set: 2000

Market	Value
Iron Castings	
Market price ($/short ton)	$1,029
Market output (10^3 tpy)	11,345.7
Domestic	10,507.0
Affected	7,985.3
Unaffected	2,521.7
Imports	838.7
Steel Castings	
Market price ($/short ton)	$3,761
Market output (10^3 tpy)	1,144.1
Domestic	1,040.0
Affected	436.8
Unaffected	603.2
Imports	104.1
Foundry Coke	
Market price ($/short ton)	$161
Market output (10^3 tpy)	1,385
Domestic	1,238
Imports	147

4.1.1 Regulatory Control Costs

As shown in Section 3, the Agency developed compliance cost estimates for model plants that can be mapped to each supply segment affected by the rule. These estimates reflect the "most reasonable" scenario for this industry. These cost estimates serve as inputs to the economic analysis and affect the supply decisions of casting producers (see Figure 4-1). The total annual nationwide cost of the MACT for iron and steel foundries is projected to be $21.23 million as expressed in 2000 dollars.[1]

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[1] The baseline year of the economic analysis is 2000. Therefore, engineering compliance cost estimates (as presented in Section 3) were adjusted using the Chemical Engineering plant cost index (394.1/389.5 = 1.012).

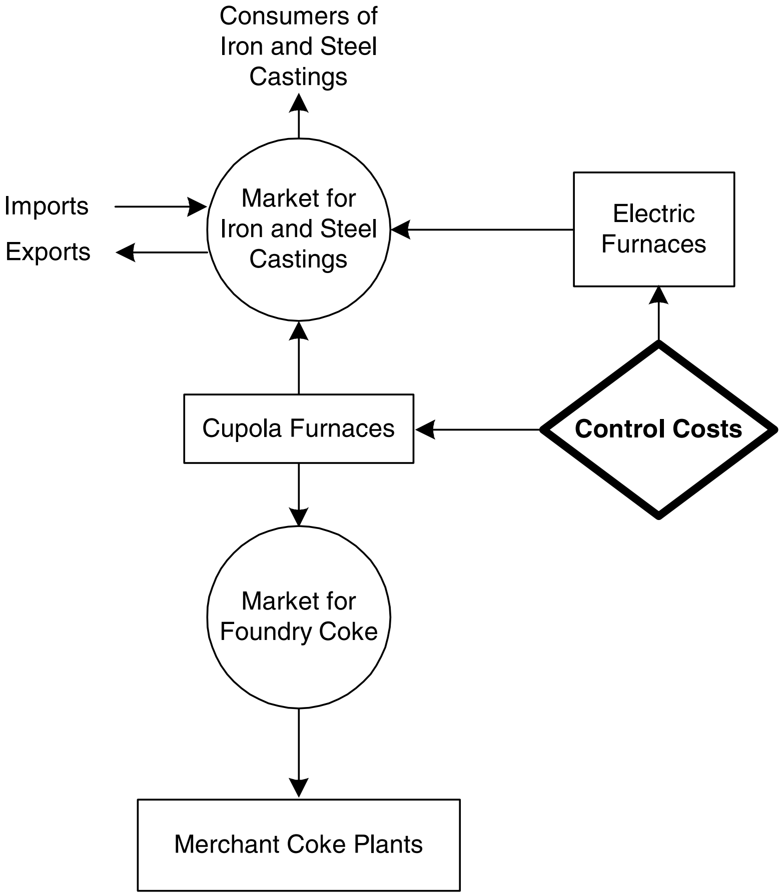


Figure 4-1. Market Linkages Modeled in the Economic Impact Analysis

EPA compared each individual plant's total annual compliance costs with an estimate of baseline plant-level revenue (cost-to-sales ratio [CSR]). The results (see Figure 4-2) show the following:

- No affected plant is projected to have a CSR exceeding 2 percent.
- Over 90 percent of the affected plants have CSRs below 0.5 percent.

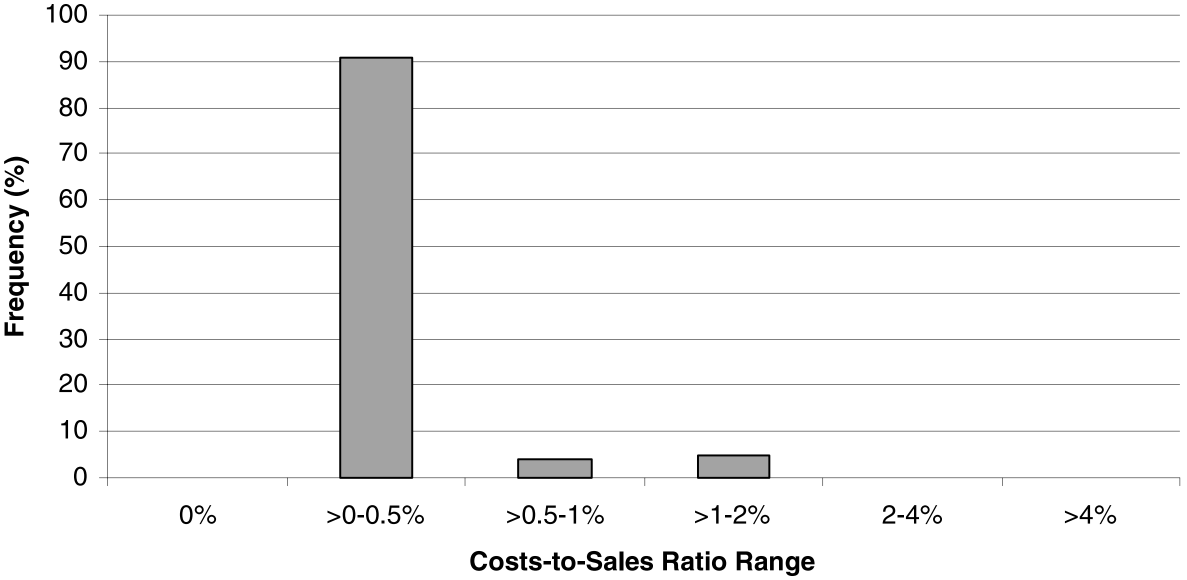


Figure 4-2. Distribution of Plant-level Compliance Costs-to-Sales Ratios: 2000

4.2 EIA Methodology Summary

In general, the EIA methodology needs to allow EPA to consider the effect of the different regulatory alternatives. Several types of economic impact modeling approaches have been developed to support regulatory development. These approaches can be viewed as varying along two modeling dimensions:

- the scope of economic decision making accounted for in the model, and
- the scope of interaction between different segments of the economy.

Each of these dimensions was considered in selecting the approach used to model the economic impact of the coke regulation.

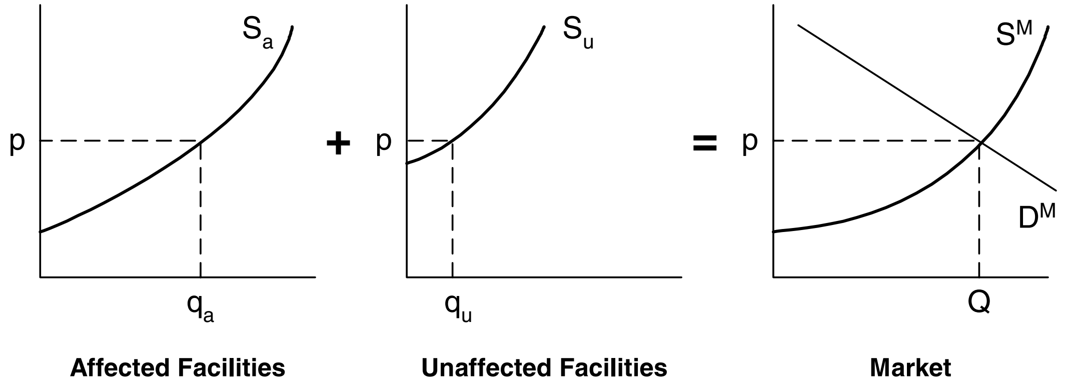
To conduct the analysis for the iron and steel foundry MACT, the Agency used a market modeling approach that incorporates behavioral responses in a multiple-market partial equilibrium model. Multiple-market partial equilibrium analysis provides a manageable approach to incorporate interactions between the foundry coke and iron castings markets into the EIA to better estimate the regulation's impact. The multiple-market partial equilibrium approach represents an intermediate step between a simple, single-market partial equilibrium approach and a full general equilibrium approach. The modeling technique is to link a series of standard partial equilibrium models by specifying the interactions between the supply and demand for products and then solving for changes in prices and quantities across all markets simultaneously. The EIA methodology is fully detailed in Appendix A.

The Agency's methodology is soundly based on standard microeconomic theory relying heavily on previous economic analyses, employs a comparative static approach, and assumes certainty in relevant markets. For this analysis, prices and quantities are determined in perfectly competitive markets for iron castings and foundry coke. The competitive model of price formation, as shown in Figure 4-3 (a), posits that market prices and quantities are determined by the intersection of market supply and demand curves. Under the baseline scenario, a market price and quantity (P, Q) are determined by the downward-sloping market demand curve (D^M) and the upward-sloping market supply curve (S^M) that reflects the horizontal summation of the individual supply curves of directly affected and indirectly affected facilities that produce a given product.

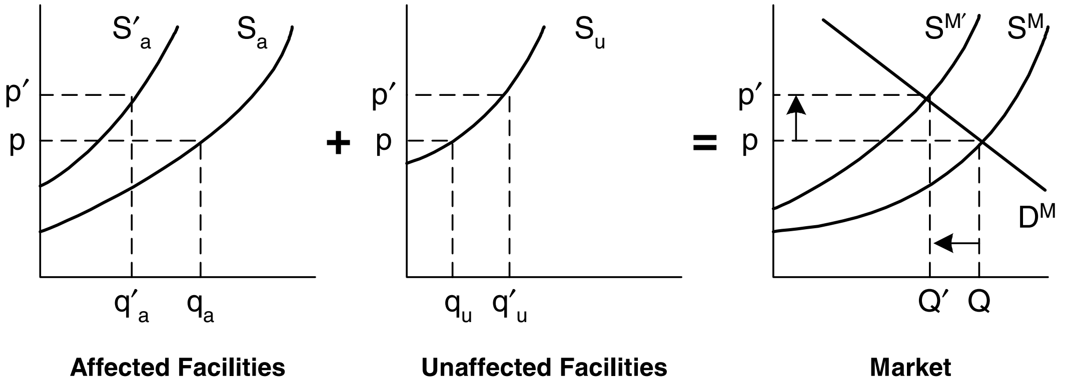
With the regulation, the cost of production increases for directly affected producers. The imposition of the compliance costs is represented as an upward shift in the supply curve for each affected facility from S_a to $S_a{}'$. As a result, the market supply curve shifts upward to S^M, as shown in Figure 4-3(b), reflecting the increased costs of production at these facilities. In the baseline scenario without the standards, the industry would produce total output, Q, at the price, P, with affected facilities producing the amount q_a and unaffected facilities accounting for Q minus q_a, or q_u. At the new equilibrium with the regulation, the market price increases from P to P′ and market output (as determined from the market demand curve, D^M) declines from Q to Q′. This reduction in market output is the net result from reductions at affected facilities and increases at unaffected facilities.

4.3 Economic Impact Results

Based on the simple analytics presented above, when faced with higher costs of production, producers will attempt to mitigate the impacts by making adjustments to shift as much of the burden on other economic agents as market conditions allow. We would expect upward pressure on prices as producers reduce output rates in response to higher costs. Higher prices reduce quantity demanded and output for each market product, leading to changes in profitability of foundries, batteries, and firms. These market and industry



a) Baseline Equilibrium



b) With-Regulation Equilibrium

Figure 4-3. Market Equilibrium without and with Regulation

adjustments determine the social costs of the regulation and the distribution of costs across stakeholders (producers and consumers).

To estimate these impacts, the economic modeling approach described in Appendix A was operationalized in a multiple spreadsheet model. This model characterizes those producers and consumers identified in Figure 4-1 and their behavioral responses to the imposition of the regulatory compliance costs. These costs are expressed per ton of casting product and serve as the input to the economic model, or "cost-shifters" of the baseline supply curves at affected facilities.

In addition to the "cost-shifters" the other major factors that influence behavior adjustments in the model are the supply and demand elasticities of producers and consumers. Table 4-2 presents the key elasticity parameters used in the model. Specific functional forms are presented in Appendix A.

Table 4-2. Supply and Demand Elasticities Used in Analysis

Market	Supply Elasticity	Demand Elasticity
Iron Castings		
Domestic	1.0[a]	–0.58[b]
Foreign	1.0[a]	–1.0[a]
Steel Castings		
Domestic	1.0[a]	–0.59[b]
Foreign	1.0[a]	–1.0[a]
Foundry Coke		
Domestic	1.1[c]	Derived demand
Foreign	3.0[d]	–0.3[d]

[a] Assumed value.
[b] Weighted average of product demand elasticities estimated in econometric analysis (see Appendix C).
[c] Estimate based on individual battery production costs and output.
[d] Graham, Paul, Sally Thorpe, and Lindsay Hogan. 1999. "Non-competitive Market Behavior in the International Coking Coal Market." *Energy Economics* 21:195-212.

Given these costs and supply and demand elasticities, the model determines a new equilibrium solution in a comparative static approach. The following sections provide the Agency's estimates of the resulting economic impacts for the rule.

4.3.1 Market-Level Impacts

The increased cost of production due to the regulation is expected to slightly increase the price of castings products and reduce their production and consumption from 2000 baseline levels. As shown in Table 4-3, the regulation is projected to increase the price of iron casting by less than 0.2 percent, or $1.12 per short ton. Similarly, we project the price of steel casting will increase by less than 0.1 percent, or $0.45 per short ton. The regulation results in output declines of less than 0.1 percent in both castings markets. Iron castings output declines by 7,500 short tons per year, and steel castings decline by less than 500 short

Table 4-3. Market-Level Impacts of the Iron and Steel Foundries MACT: 2000

		Changes from Baseline	
Market	**Baseline**	**Absolute**	**Percent**
Iron Castings			
Market price ($/short ton)	$1,029	$1.12	0.109%
Market output (10^3 tpy)	11,345.7	–7.5	–0.066%
Domestic	10,507.0	–8.4	–0.080%
Affected	7,985.3	–11.1	–0.140%
Unaffected	2,521.7	2.7	0.109%
Imports	838.7	0.9	0.109%
Steel Castings			
Market price ($/short ton)	$3,761	$0.45	0.012%
Market output (10^3 tpy)	1,144.1	–0.1	–0.007%
Domestic	1,040.0	–0.1	–0.009%
Affected	436.8	–0.2	–0.038%
Unaffected	603.2	0.1	0.012%
Imports	104.1	0.0	0.012%
Foundry Coke			
Market price ($/short ton)	$161	$0.00	0.00%
Market output (10^3 tpy)	1,385	<0.01	–0.01%
Domestic	1,238	<0.01	–0.01%
Imports	147	0	0.00%

tons per year. Market output declines are the net effect of directly affected castings output declines across affected producers (11,200 tpy) and small increases in supply (3,700 tpy) from unaffected domestic and foreign producers not subject to the regulation.

Given that the change in casting output is so small and the change in demand for foundry coke is also very small (less than 10,000 tpy), the entire market impact can be absorbed by a single foundry battery that is assumed to have a constant marginal cost. As a result, the market price is unchanged.[2] This in turn leads to no change in the level of imports (or exports) of foundry coke.

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[2] See Appendix B for a detailed description of the step-wise supply function for the foundry coke market.

4.3.2 Industry-Level Impacts

Industry profitability changes as prices and production levels adjust to increased production costs. As shown in Table 4-4, the economic model projects that profits for affected foundries will decrease by $12.1. In addition, the Agency projects no change in profits for furnace coke plants because the small reduction in output comes from the marginal coke battery, which by assumption has zero profit in baseline. Those domestic suppliers not subject to the regulation experience small gains ($3.1 million); profits for foreign foundries increase by $0.9 million.

Table 4-4. National-Level Industry Impacts of the Iron and Steel Foundries MACT: 2000

Market	Value
Iron Castings	
Change in operating profit ($$10^6$/yr)	–$7.7
Domestic	–$8.6
Affected	–$11.5
Unaffected	$2.8
Imports	$0.9
Steel Castings	
Change in operating profit (10^6/yr)	–$0.3
Domestic	–$0.4
Affected	–$0.6
Unaffected	$0.3
Imports	$0.0
Foundry Coke	
Change in operating profit (10^6/yr)	$0
Domestic	$0
Imports	$0

4.3.3 Social Cost

The social impact of a regulatory action is traditionally measured by the change in economic welfare that it generates. The social costs of the rule will be distributed across consumers and producers alike. Consumers experience welfare impacts due to changes in market prices and consumption levels associated with the rule. Producers experience welfare impacts resulting from changes in profits corresponding with the changes in production levels and market prices. However, it is important to emphasize that this measure does not include benefits that occur outside the market, that is, the value of reduced levels of air pollution with the regulation.

The national compliance cost estimates are often used as an approximation of the social cost of the rule. The engineering analysis estimated annual costs of $21.23 million. In this case, the burden of the regulation falls solely on the affected facilities that experience a profit loss exactly equal to these cost estimates. Thus, the entire loss is a change in producer surplus with no change (by assumption) in consumer surplus. This is typically referred to as a “full-cost absorption” scenario in which all factors of production are assumed to be fixed and firms are unable to adjust their output levels when faced with additional costs.

In contrast, the economic analysis accounts for behavioral responses by producers and consumers to the regulation (i.e., shifting costs to other economic agents). This approach may result in a social cost estimate that differs from the engineering estimate and also provides insights on how the regulatory burden is distributed across stakeholders. As shown in Table 4-5, the economic model estimates the total social cost of the rule to be $21.22 million. Although society reallocates resources as a result of the increased cost of iron castings production, the social cost estimate is only slightly smaller than the engineering cost estimate (approximately $10,000).

In the castings markets, higher market prices lead to consumer losses of $13.2 million. A significant share of these losses occurs in the iron castings market (90 percent, or $11.9 million). Although foundries are able to pass on a limited amount of cost increases to their final consumers (e.g., automotive manufacturers, appliance and hardware producers, and the construction industry), the increased costs result in a net decline in producer profits of $8.0 million. The model projects affected foundries experience $12.1 million in losses, while unaffected domestic and foreign producers experience gains ($3.1 million and $0.9 million). These producers benefit from higher market prices for castings without additional control costs. In the coke industry, foundry coke profits at merchant plants are projected to remain unchanged, because reductions in output come from the marginal merchant furnace coke battery.

Table 4-5. Distribution of the Social Costs of the Iron and Steel Foundry MACT: 2000

Market	Value
Change in Consumer Surplus ($\$10^6$/yr)	**–\$13.2**
Iron castings consumers	
Domestic	–\$11.9
Foreign	–\$0.8
Steel castings consumers	
Domestic	–\$0.5
Foreign	–\$0.0
Change in Producer Surplus ($\$10^6$/yr)	**–\$8.0**
Iron casting producers	
Domestic	–\$8.6
Affected	–\$11.5
Unaffected	\$2.8
Foreign	\$0.9
Steel casting producers	
Domestic	–\$0.4
Affected	–\$0.6
Unaffected	\$0.3
Foreign	\$0.0
Change in Total Surplus ($\$10^6$/yr)	**–\$21.22**[a]

[a] The negative change in total surplus indicates the social cost of the regulation is $21.22 million.

SECTION 5

SMALL BUSINESS IMPACTS

This regulatory action will potentially affect the economic welfare of owners of iron and steel foundries. These individuals may be owners/operators who directly conduct the business of the firm or, more commonly, investors or stockholders who employ others to conduct the business of the firm on their behalf through privately held or publicly traded corporations. The legal and financial responsibility for compliance with a regulatory action ultimately rests with plant managers, but the owners must bear the financial consequences of the decisions. Although environmental regulations can affect all businesses, small businesses may have special problems complying with such regulations.

The Regulatory Flexibility Act (RFA) of 1980 requires that special consideration be given to small entities affected by federal regulations. The RFA was amended in 1996 by the Small Business Regulatory Enforcement Fairness Act (SBREFA) to strengthen its analytical and procedural requirements. Under SBREFA, the Agency must perform a regulatory flexibility analysis for rules that will have a significant impact on a substantial number of small entities.

This section focuses on the compliance burden of small businesses within the iron and steel foundry industry and provides a screening analysis to determine whether this rule is likely to impose a significant impact on a substantial number of the small entities (SISNOSE) within this industry. The screening analysis employed here is a “sales test” that computes the annualized compliance costs as a share of sales for each company. In addition, it provides information about the impacts on small businesses after accounting for producer responses to the rule and the resulting changes in market prices and output.

5.1 Identifying Small Businesses

For purposes of assessing the impacts of the rule on small entities, a small entity is defined as (1) a small business according to SBA size standards for NAICS code 331511 (Iron Foundries), 331512 (Steel Investment Foundries), or 331513 (Steel Foundries, Except Investment) of 500 or fewer employees; (2) a small governmental jurisdiction that is a government of a city, county, town, school district, or special district with a population of less than 50,000; and (3) a small organization that is any not-for-profit enterprise that is independently owned and operated and is not dominant in its field. Based on these SBA size definitions for the affected industries and reported sales and employment data, the Agency has identified 20 small businesses directly affected by the rule.[1]

5.2 Screening-Level Analysis

To assess the potential impact of this rule on small businesses, the Agency calculated the share of annual compliance costs relative to baseline sales for each company. When a company owns more than one affected facility, EPA combined the costs for each facility for the numerator of the test ratio. Annual compliance costs include annualized capital costs and operating and maintenance costs imposed on these companies. They do not include changes in production or market adjustments.

Small businesses within the source category are expected to incur approximately 15 percent of the total industry compliance cost of $21.23 million (see Table 5-1). The average total annual compliance cost is projected to be $163,000 for small companies, while the average for large companies is projected to be approximately $418,000 per company. The average CSR for small firms is 0.40 percent. One small company is projected to have a CSR between 1 and 3 percent. No small firms are projected to have CSRs greater than 3 percent.

5.3 Assessment

The Agency's analysis indicates no significant impacts on small firms' ability to continue operations and remain profitable. The screening analysis shows all small firms' cost-to-sales ratios are below the average return to sales for all reporting companies reported by statistical publications. The *Quarterly Financial Report* (*QFR*) from the U.S. Bureau of the Census reports that the average return on sales for the iron and steel industry ranged from 3.2 to 4.6 percent (U.S. Bureau of the Census, 1998).[2] In addition, Dun & Bradstreet reports

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[1] EPA updated sales and employment data for affected companies reported in Section 2 to reflect more recent financial data (2002).

[2] Furthermore, the *QFR* reports that companies within the iron and steel industry with less than $25 million in assets reported an average return to sales ranging from 6.8 to 9.8 percent.

Table 5-1. Summary Statistics for SBREFA Screening Analysis: 2000

	Small		**Large**		**All Companies**	
Total Number of Affected Companies	20		43		63	
Total Annual Compliance Costs (TACC) ($\$10^3$/yr)	\$3,269		\$17,961		\$21,230	
Average TACC per company ($\$10^3$/yr)	\$163		\$418		\$337	
Compliance Cost-to-Sales Ratios						
Average	0.40%		0.13%		0.22%	
Median	0.26%		0.07%		0.09%	
Maximum	1.04%		1.92%		1.92%	
Minimum	0.04%		0.00%		0.00%	
	Number	Share	Number	Share	Number	Share
Compliance costs are < 1% of sales	19	95%	42	98%	61	97%
Compliance costs are ≥1 to 3% of sales	1	5%	1	2%	2	3%
Compliance costs are ≥3% of sales	0	0%	0	0%	0	0%

Note: Assumes no market responses (i.e., price and output adjustments) by regulated entities.

the median return on sales as 3.4 percent for SIC 3321—Gray and Ductile Foundries; 4.3 percent for SIC 3324—Steel Investment Foundries; and 4.8 percent for SIC 3325—Steel Foundries, NEC (Dun & Bradstreet, 1997).

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APPENDIX A

ECONOMIC IMPACT ANALYSIS METHODOLOGY

This appendix provides the methodology for analyzing the economic impacts of the coke ovens, integrated iron and steel, and iron and steel foundries MACT standards to ensure consistency across the EIAs. Implementation of this methodology provided the economic data and supporting information that EPA requires to support its regulatory determination. This approach is firmly rooted in microeconomic theory and the methods developed for earlier EPA studies to operationalize this theory. The Agency employed a computerized market model of the coke, steel mill products, and iron and steel castings industries to estimate the behavioral responses to the imposition of regulatory costs and, thus, the economic impacts of the standard. The market model captures the linkages between these industries through changes in equilibrium prices and quantities.

This methodology section describes the conceptual approach selected for this EIA. For each product market included in the analysis, EPA derived facility-level supply functions and demand functions that are able to account for the behavioral responses of producers and consumers and market implications of the regulatory costs. Finally, this appendix presents an overview of the specific functional forms that constitute the Agency's computerized market model.

A.1 Overview of Economic Modeling Approach

In general, the EIA methodology needs to allow EPA to consider the effect of the different regulatory alternatives. Several types of economic impact modeling approaches have been developed to support regulatory development. These approaches can be viewed as varying along two modeling dimensions:

- the scope of economic decision making accounted for in the model, and
- the scope of interaction between different segments of the economy.

Each of these dimensions was considered in selecting the approach used to model the economic impact of the regulation. Bingham and Fox (1999) provide a useful summary of these dimensions as they relate to modeling the outcomes of environmental regulations.

For this analysis, prices and quantities are determined in perfectly competitive markets for furnace coke, foundry coke, steel mill products, and iron castings. The Agency analyzed the impact of the regulation using a market modeling approach that incorporates behavioral responses in a multiple-market partial equilibrium model. Multiple-market partial equilibrium analysis accounts for the interactions between coke, steel mill product, and iron and steel castings markets into the EIA to better estimate the regulation's impact. The modeling technique is to link a series of standard partial equilibrium models by specifying the interactions between the supply and demand for products and then solving for changes in prices and quantities across all markets simultaneously.

Figure A-1 summarizes the market interactions included in the Agency's EIA modeling approach. Changes in the equilibrium price and quantity due to control costs associated with individual MACTs were estimated simultaneously in four linked markets:

- market for furnace coke,
- market for foundry coke,
- market for steel mill products, and
- markets for iron and steel castings.

As described in Section 2 of this EIA report, many captive coke plants supply their excess furnace coke to the market. Merchant coke plants and foreign imports account for the remaining supply to the furnace coke market. Furnace coke produced at captive coke plants and shipped directly to integrated iron and steel mills owned by their parent companies does not directly enter the market for furnace coke. However, compliance costs incurred by these captive, or "in-house," furnace coke batteries indirectly affect the furnace coke market through price and output changes in the steel mill products market.

The market demand for furnace coke is derived from integrated mills producing steel mill products. Integrated iron and steel mills that need more coke than their captive batteries can produce will purchase furnace coke from the market. Integrated mills' market demand for furnace coke depends on their production levels as influenced by the market for steel mill products. Steel mill products are supplied by three sources: integrated iron and steel mills, nonintegrated steel mills (primarily minimills), and imports. Domestic consumers of steel mill products and exports account for the market demand.

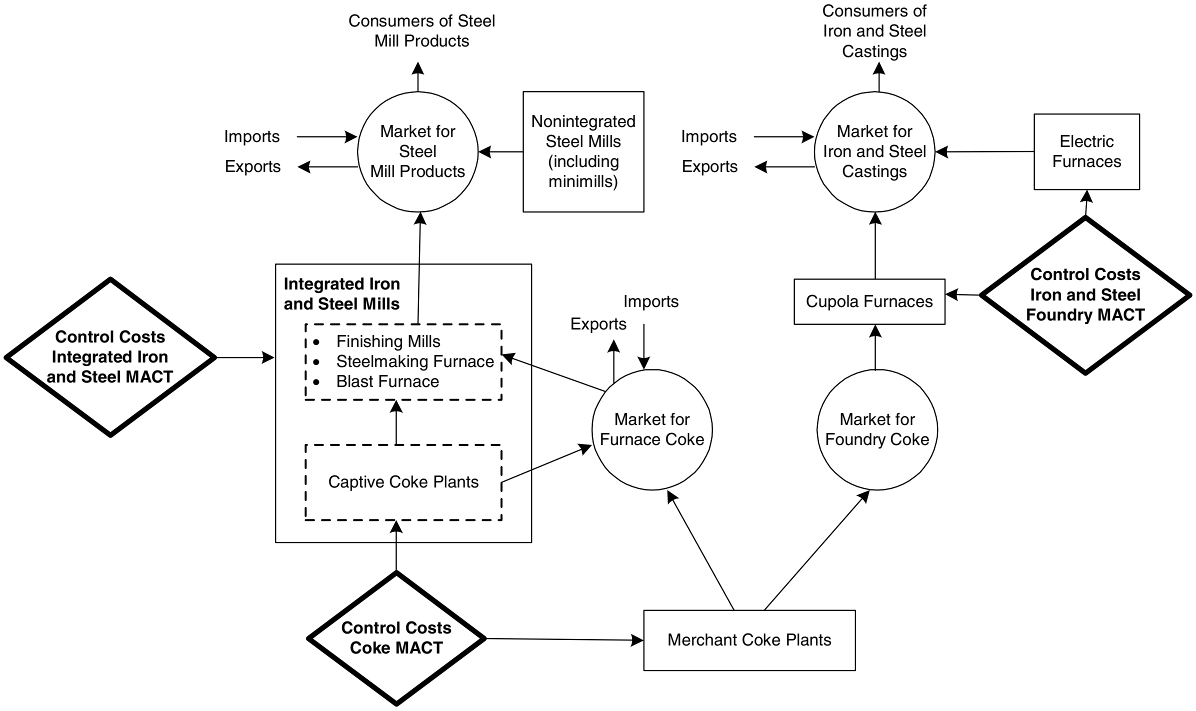


Figure A-1. Market Linkages Modeled in the Economic Impact Analysis

Domestic merchant plants are the primary suppliers of foundry coke to the market. However, the U.S. International Trade Commission (2000) has documented an increasing trend in foreign imports of foundry coke from China. Therefore, we have included a single import supply curve to characterize this supply segment.

In addition to furnace and foundry coke, merchant and captive coke plants sell a by-product referred to as "other coke" that is purchased as a fuel input by cement plants, chemical plants, and nonferrous smelters. Because "other coke" is a by-product and represented only 2 percent of U.S. coke production in 1997, it is not formally characterized by supply and demand in the market model. Revenues from this product are accounted for by assuming its volume is a constant proportion of the total amount of coke produced by a battery and sold at a constant price.

A.2 Conceptual Market Modeling Approach

This section examines the impact of the regulations on the production costs for affected facilities, both merchant and captive. It provides an overview of the basic economic theory of the effect of regulations on facility production decisions and the concomitant effect on market outcomes. Following the *OAQPS Economic Analysis Resource Document* (EPA, 1999), we employed standard concepts in microeconomics to model the supply of affected products and the impacts of the regulations on production costs and the operating decisions. The approach relies heavily on previous economic analyses, employs a comparative static approach, and assumes certainty in relevant markets. The three main elements of the analysis are regulatory effects on the manufacturing facility, market responses, and facility–market interactions. The remainder of this section describes each of these main elements.

A.2.1 Facility-level Responses to Control Costs

Individual plant-level production decisions were modeled to develop the market supply and demand for key industry segments in the analysis. Production decisions were modeled as intermediate-run decisions, assuming that the plant size, equipment, and technologies are fixed. For example, the production decision typically involves (1) whether a firm with plant and equipment already in place purchases inputs to produce output and (2) at what capacity utilization the plant should operate. A profit-maximizing firm will operate existing capital as long as the market price for its output exceeds its per-unit variable production costs, since the facility will cover not only the cost of its variable inputs but also part of its capital costs. Thus, in the short run, a profit-maximizing firm will not pass up an opportunity to recover even part of its fixed investment in plant and equipment.

The existence of fixed production factors gives rise to diminishing returns to those fixed factors and, along with the terms under which variable inputs are purchased, defines the upward-sloping form of the marginal cost (supply) curve employed for this analysis. Figure A-2 illustrates this derivation of the supply function at an individual mill based on the classical U-shaped cost structure. The MC curve is the marginal cost of production, which intersects the facility's average variable (avoidable) cost curve (AVC) and its average total cost curve (ATC) at their respective minimum points. The supply function is that portion of the marginal cost curve bounded by the minimum economically feasible production rate (q^m) and the technical capacity (q^M). A profit-maximizing producer will select the output rate where marginal revenue equals price, that is, at [P*, q*]. If market price falls below ATC,

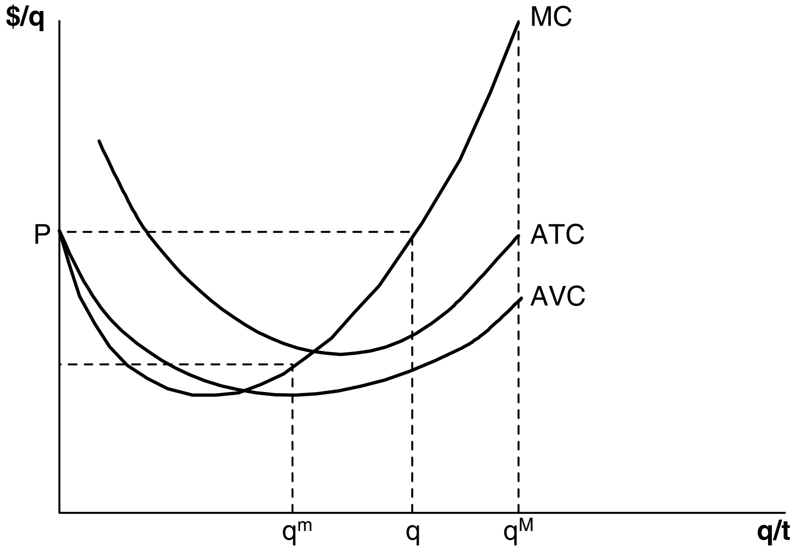


Figure A-2. Product Supply Function at Facility

then the firm's best response is to cease production because total revenue does not cover total costs of production.

Now consider the effect of the regulation and the associated compliance costs. These fall into one of two categories: avoidable variable and avoidable nonvariable. These final costs are characterized as avoidable because a firm can choose to cease operation of the facility and, thus, avoid incurring the costs of compliance. The variable control costs include the operating and maintenance costs of the controls, while the nonvariable costs include compliance capital equipment. Figure A-3 illustrates the effect of these additional costs on the facility supply function. The facility's AVC and MC curves shift upward (to AVC′ and MC′) by the per-unit variable compliance costs. In addition, the nonvariable compliance costs increase total avoidable costs and, thus, the vertical distance between ATC′ and AVC′. The facility's supply curve shifts upward with marginal costs, and the new (higher) minimum operating level (q) is determined by a new (higher) ps.

Next consider the effect of compliance costs on the derived demand for inputs at the regulated facility. Integrated iron and steel mills are market demanders of furnace coke, while foundries with cupola furnaces are market demanders of foundry coke. We employ similar neoclassical analysis to that above to demonstrate the effect of the regulation on the

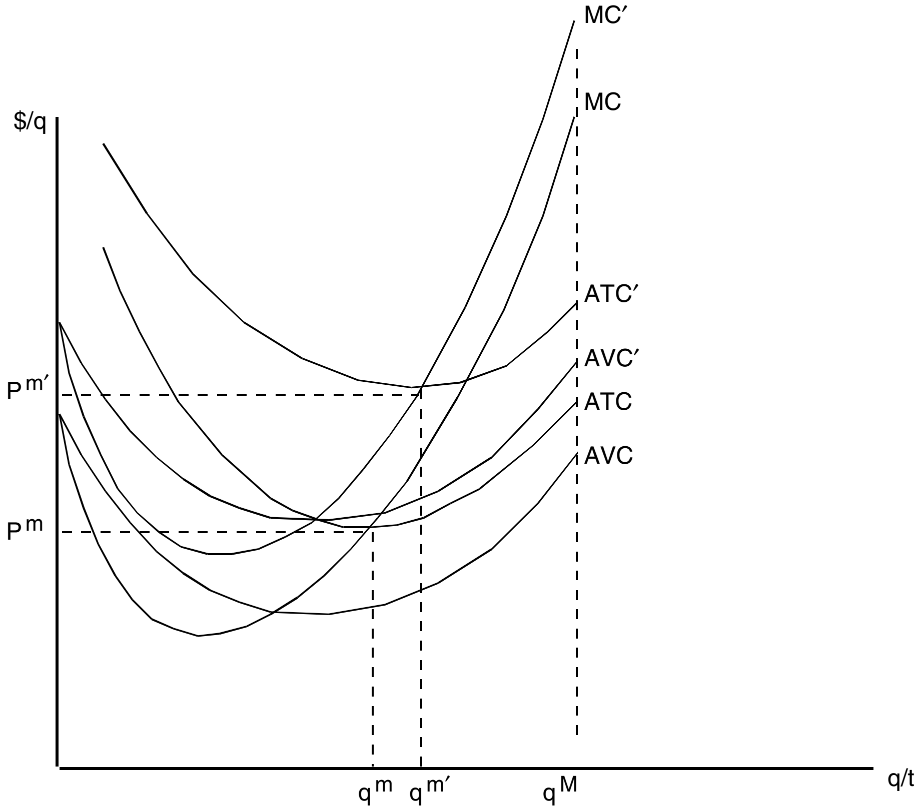


Figure A-3. Effect of Compliance Costs on Product Supply Function at Facility

demand for market coke inputs, both furnace and foundry. Figure A-4 illustrates the derived demand curve for coke inputs. Each point on the derived demand curve equals the willingness to pay for the corresponding marginal input. This is typically referred to as the input's value of marginal product (VMP), which is equal to the price of the output (P) less the per-unit compliance cost (c) times the input's "marginal physical product" (MPP), which is the incremental output attributable to the incremental inputs. If, as assumed in this analysis, the input-output relationship between the market coke input and the final product (steel mill products or iron castings) is strictly fixed, then the VMP of the market coke is constant and the derived demand curve is horizontal with the constant VMP as the vertical intercept, as shown in Figure A-4. Ignoring any effect on the output price for now, an increase in regulatory costs will lower the VMP of all inputs leading to a downward shift in the derived demand in Figure A-4 from D_y to D_y^1.

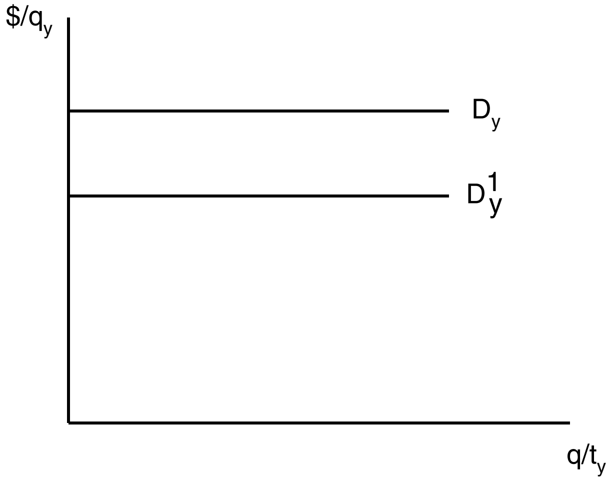
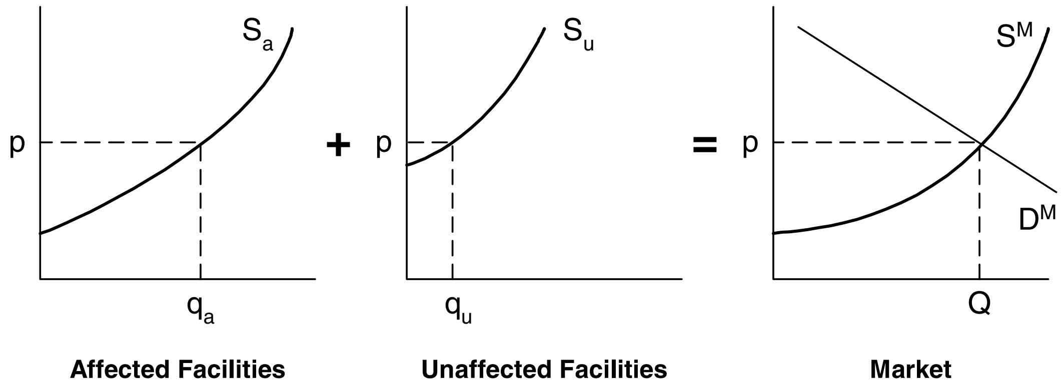


Figure A-4. Derived Demand Curve for Coke Inputs

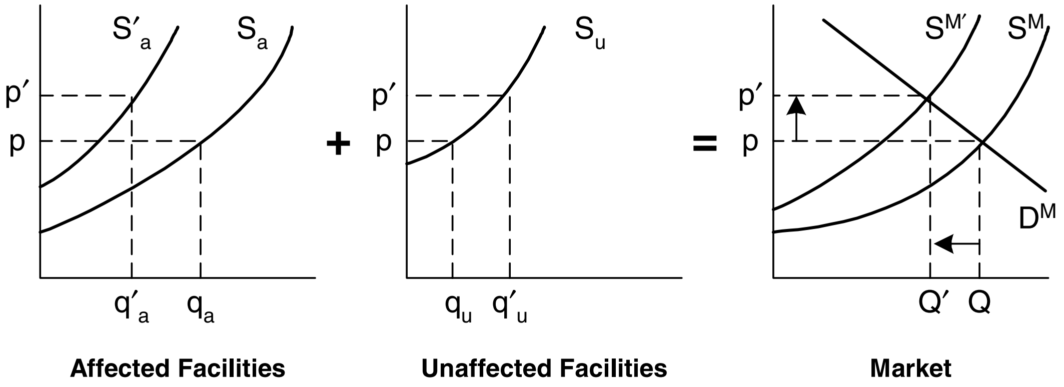
A.2.2 Market Effects

To evaluate the market impacts, the economic analysis assumes that prices and quantities are determined in a competitive market (i.e., individual facilities have negligible power over the market price and thus take the price as “given” by the market). As shown in Figure A-5(a), under perfect competition, market prices and quantities are determined by the intersection of market supply and demand curves. The initial baseline scenario consists of a market price and quantity (P, Q) that is determined by the downward-sloping market demand curve (D^M) and the upward-sloping market supply curve (S^M) that reflects the horizontal summation of the individual producers’ supply curves.

Now consider the effect of the regulation on the baseline scenario as shown in Figure A-5(b). In the baseline scenario without the standards, at the projected price, P, the industry would produce total output, Q, with affected facilities producing the amount q_a and unaffected facilities accounting for Q minus q_a, or q_u. The regulation raises the production costs at affected facilities, causing their supply curves to shift upward from S_a to S_a' and the market supply curve to shift upward to $S^{M\prime}$. At the new with-regulation equilibrium, the market price increases from P to P′ and market output (as determined from the market demand curve, D^M) declines from Q to Q′. This reduction in market output is the net result from reductions at affected facilities and increases at unaffected facilities.



a) Baseline Equilibrium



b) With-Regulation Equilibrium

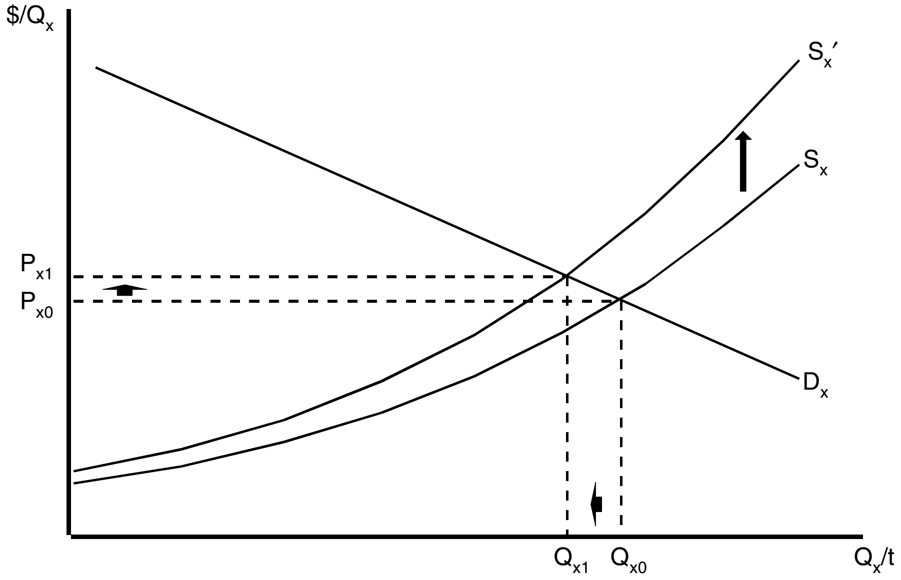
Figure A-5. Market Equilibrium without and with Regulation

Unaffected facilities do not incur the increased costs due to regulation so their response to higher product prices is to increase production. Foreign suppliers (i.e., imports), which also do not face higher costs, will respond in the same manner as these unaffected producers.

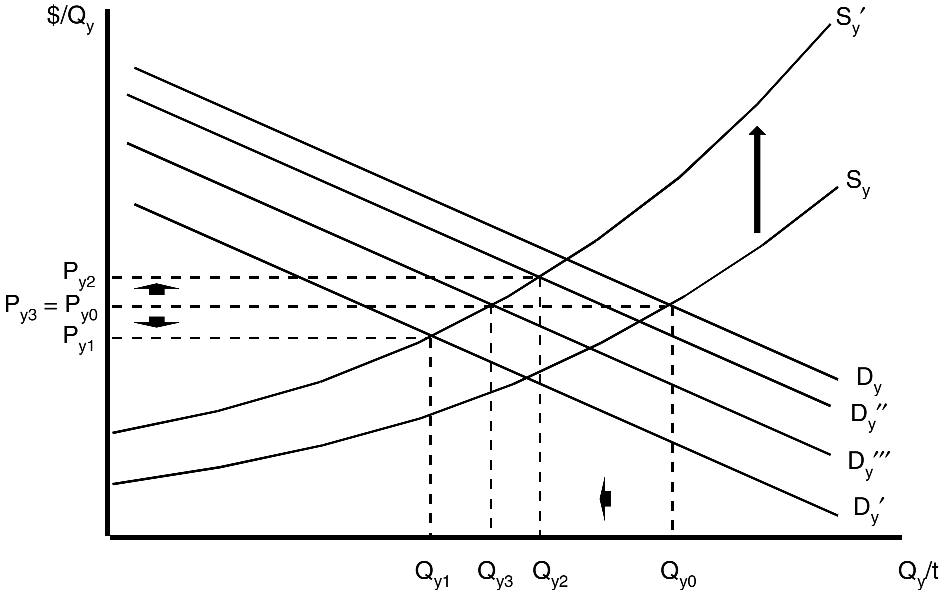
The above description is typical of the expected market effects for final product markets. The regulations would potentially affect the costs of producing steel mill products through additional control costs and increases in the market price of furnace coke and the cost of producing captive furnace coke. The increase in control costs, the market price, and captive production costs for furnace coke result in an upward shift in the supply functions of integrated iron and steel mills, while nonintegrated and foreign suppliers are unaffected. Additionally, the regulations would potentially affect the costs of producing iron castings through additional control costs and changes in the market price of foundry coke. This results in an upward shift in supply functions of foundries operating cupola furnaces, while foundries operating electric furnaces are only affected to the extent they are subject to additional control costs.

However, there are additional impacts on the furnace and foundry coke markets related to their derived demand as inputs to either the production of steel mill products or iron castings. Figure A-6 illustrates, under perfect competition, the baseline scenario where the market quantity and price of the final steel mill product or iron and steel casting, $Q_x(Q_{x0}, P_{x0})$, are determined by the intersection of the market demand curve (D_x) and the market supply curve (S_x), and the market quantity and price of furnace or foundry coke, $Q_y(Q_{y0}, P_{y0})$, are determined by the intersection of the market demand curve (D_y) and market supply curve (S_y). Given the derived demand for coke, the demanders of coke, Q_y, are the individual facilities that purchase coke for producing their final products (i.e., integrated steel mills in the case of furnace coke or foundries with cupola furnaces in the case of foundry coke).

Imposing the regulations increases the costs of producing coke and, thus, the final product, shifting the market supply functions for both commodities upward to S_x' and S_y', respectively. The supply shift in the final product market causes the market quantity to fall to Q_{x1} and the market price to rise to P_{x1} in the new equilibrium. In the market for coke, the reduced production of the final product causes a downward shift in the demand curve (D_y) with an unambiguous reduction in coke production, but the direction of the change in market price is determined by the relative magnitude of the demand and supply shift. If the downward demand effect dominates, the price will fall (e.g., P_{y1}); however, if the upward supply effect dominates, the price will rise (e.g., P_{y2}). Otherwise, if the effects just offset each other, the price remains unchanged (e.g., $P_{y3} = P_{y0}$).



(a) Market for single steel mill product or iron and steel casting, Q_x



(b) Market for coke input, Q_y

Figure A-6. Market Equilibria With and Without Compliance Costs

A.2.3 Facility-Level Responses to Compliance Costs and New Market Prices

In evaluating the market effects, we must distinguish between the initial effect of the regulations and the net effect after all markets have adjusted. The profit-maximizing behavior of firms, as described above, may lead to changes in output that, when aggregated across all producers, lead to changes in the market-clearing price and feedback on the firms to alter their decisions. These adjustments are characterized as a simultaneous interaction of producers, consumers, and markets. Thus, to evaluate the facility-market outcomes, the analysis must go beyond the initial effect of the regulation and estimate the net effect after markets have fully adjusted.

Given changes in the market prices and costs, each facility will elect to either

- continue to operate, adjusting production and input use based on new revenues and costs, or
- cease production at the facility if total revenues do not exceed total costs.

This decision can be extended to those facilities with multiple product lines or operations (e.g., coke batteries, blast furnaces, cupolas). If product revenues are less than product-specific costs, then these product lines or operations may be closed.

Therefore, after accounting for the facility-market interaction, the operating decisions at each individual facility can be derived. These operating decisions include whether to continue to operate the facility (i.e., closure) and, if so, the optimal production level based on compliance costs and new market prices. The approach to modeling the facility closure decision is based on conventional microeconomic theory. This approach compares the ATC—which includes all cost components that fall to zero when production discontinues—to the expected post-regulatory price. Figure A-3 illustrates this comparison. If price falls below the ATC, total revenue would be less than the total costs. In this situation, the owner’s cost-minimizing response is to close the facility. Therefore, as long as there is some return to the fixed factors of production—that is, some positive level of profits—the firm is expected to continue to operate the facility.

If the firm decides to continue operations, then the facility’s decision turns to the optimal output rate. Facility and product-line closures, of course, directly translate into reductions in output. However, the output of facilities that continue to operate will also change depending on the relative impact of compliance costs and higher market prices. Increases in costs will tend to reduce producers’ output rates; however, some of this effect is mitigated when prices are increased. If the market price increase more than offsets the increase in unit costs, then even some affected facilities could respond by increasing their production. Similarly, supply from unaffected domestic producers and foreign sources will respond positively to changes in market prices.

A.3 Operational Economic Model

Implementation of the MACT standards will affect the costs of production for plants across the United States subject to the rule. Responses at the facility level to these additional costs will collectively determine the market impacts of the rule. Specifically, the cost of the regulation may induce some facilities to alter their current level of production or to cease operations. These choices affect and, in turn are affected by, the market price of each product. As described above, the Agency has employed standard microeconomic concepts to model the supply and demand of each product and the impacts of the regulation on production costs and the output decisions of facilities. The main elements of the analysis are to

- characterize production of each product at the individual supplier and market levels,
- characterize the demand for each product, and
- develop the solution algorithm to determine the new with-regulation equilibrium.

The following sections provide the supply and demand specifications for each product market as implemented in the EIA model and summarize the model's solution algorithm. Supply and demand elasticities used in the model are presented in Table A-1.

A.3.1 Furnace Coke Market

The market for furnace coke consists of supply from domestic coke plants, both merchant and captive, and foreign imports and of demand from integrated steel mills and foreign exports. The domestic supply for furnace coke is modeled as a step-wise supply function developed from the marginal cost of production at individual furnace coke batteries. The domestic demand is derived from iron and steel production at integrated mills as determined through the market for steel mill products and coking rates for individual batteries. The following section details the market supply and demand components for this analysis.

Table A-1. Supply and Demand Elasticities Used in Analysis

Market	Supply Elasticity	Demand Elasticity
Furnace Coke		
Domestic	2.1[a]	Derived demand
Foreign	3.0[b]	–0.3[b]
Foundry Coke		
Domestic	1.1[a]	Derived demand
Foreign	3.0[b]	–0.3[b]
Steel Mill Products		
Domestic	3.5[c]	–0.59[d]
Foreign	1.5[c]	–1.25[e]
Iron Castings		
Domestic	1.0[f]	–0.58[d]
Foreign	1.0[f]	–1.0[f]
Steel Castings		
Domestic	1.0[f]	–0.59[d]
Foreign	1.0[f]	–1.0[f]

[a] Estimate based on individual battery production costs and output.

[b] Graham, Paul, Sally Thorpe, and Lindsay Hogan. 1999. "Non-competitive Market Behaviour in the International Coking Coal Market." *Energy Economics* 21:195-212.

[c] U.S. International Trade Commission (USITC). 2001a. Memorandum to the Commission from Craig Thomsen, John Giamalua, John Benedetto, and Joshua Level, International Economists. Investigation No. TA-201-73: STEEL—Remedy Memorandum. November 21, 2001.

[d] Econometric analysis (see Appendix C for details).

[e] Ho, M., and D. Jorgenson. 1998. "Modeling Trade Policies and U.S. Growth: Some Methodological Issues." Presented at USITC Conference on Evaluating APEC Trade Liberalization: Tariff and Nontariff Barriers. September 11-12, 1997.

[f] Assumed value.

A.3.1.1 Market Supply of Furnace Coke

The market supply for furnace coke, Q^{Sc}, is the sum of coke production from merchant facilities, excess production from captive facilities (coke produced at captive batteries less coke consumed for internal production on steel mill products), and foreign imports, i.e.,

$$Q^{Sc} = q_M^{Sc} + q_I^{Sc} + q_F^{Sc} \tag{A.1}$$

where

q_M^{Sc} = furnace coke supply from merchant plants,

q_I^{Sc} = furnace coke supply from integrated steel mills, and

q_F^{Sc} = furnace coke supply from foreign sources (imports).

Supply from Merchant and Captive Coke Plants. The domestic supply of furnace coke is composed of the supply from merchant and captive coke plants reflecting plant-level production decisions for individual coke batteries. For merchant coke plants the supply is characterized as

$$q_M^{Sc} = \sum_l \sum_j q_{M(l,j)}^{Sc} \qquad \text{(A.2)}$$

where

q_M^{Sc} = supply of foundry coke from coke battery (j) at merchant plant (l).

Alternatively, for captive coke plants the supply is characterized as the furnace coke production remaining after internal coke requirements are satisfied for production of final steel mill products, i.e,

$$q_I^{SE} = \text{MAX}\left[\sum_l \left(\sum_j q_{I(l,j)}^{Sc} - r_{I(1)}^{S}\, q_{I(1)}^{Ss}\right),\ 0\right] \qquad \text{(A.3)}$$

where

$q_{I(l,j)}^{Sc}$ = the furnace coke production from captive battery (j) at integrated steel mill (l);

$r_{I(l)}^{S}$ = the coke rate for integrated steel mill (l), which specifies the amount of furnace coke input per unit of final steel mill product;[1] and

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[1] The furnace coke rate for each integrated steel mill is taken from Hogan and Koelble (1996). The coke rate is assumed to be constant with respect to the quantity of finished steel products produced at a given mill. A constant coke rate at each integrated mill implies a constant efficiency of use at all output levels and substitution possibilities do not exist given the technology in place at integrated mills. Furthermore, the initial captive share of each integrated mill's coke requirement is based on the baseline data from the EPA estimates.

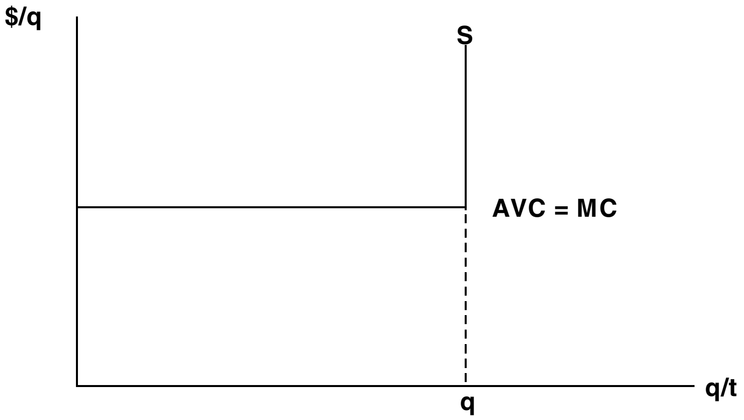
$q^{Ss}_{I(l)}$ = supply of steel mill product from integrated mill (l).

The MAX function in Eq. (A.3) indicates that if the total captive production of furnace coke at an integrated mill is greater than the amount of furnace coke consumption required to produce steel mill products, then supply to the furnace coke market will equal the difference; otherwise, the mill's supply to the furnace coke market will be zero (i.e., it only satisfies internal requirements from its captive operations).

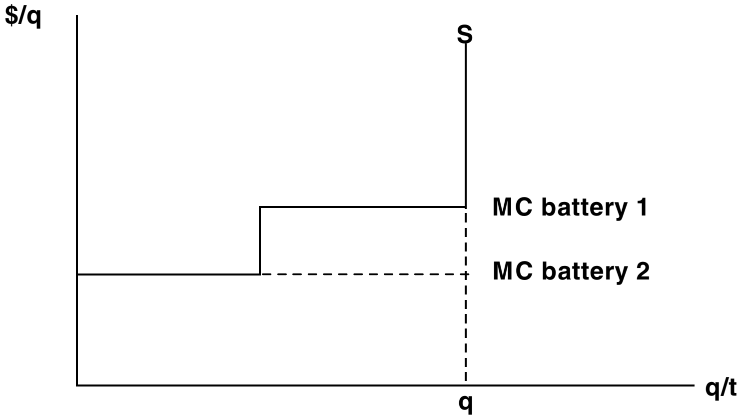
As stated above, the domestic supply of furnace coke is developed from plant-level production decisions for individual coke batteries. For an individual coke battery the marginal cost was assumed to be constant. Thus, merchant batteries supply 100 percent of a battery's capacity to the market if the battery's marginal cost (MC) is below the market price for furnace coke (p_c), or zero if MC exceeds p_c. Captive batteries first supply the furnace coke demanded by their internal steel-making requirements. Any excess capacity will then supply the furnace coke market if the remaining captive battery's MC is below the market price.

Marginal cost curves were developed for all furnace coke batteries at merchant and captive plants in the United States as detailed in Appendix B. Production costs for a single battery are characterized by constant marginal cost throughout the capacity range of the battery. This yields the inverted L-shaped supply function shown in Figure A-7(a). In this case, marginal cost (MC) equals average variable cost (AVC) and is constant up to the production capacity given by q. The supply function becomes vertical at q because increasing production beyond this point is not possible. The minimum economically achievable price level is equal to p*. Below this price level, p* is less than AVC, and the supplier would choose to shut down rather than to continue to produce coke.

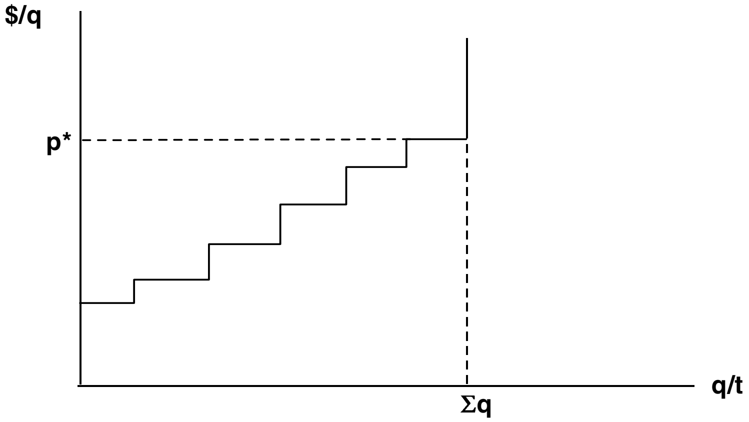
A step-wise supply function can be created for each facility with multiple batteries by ordering production from least to highest MC batteries (see Figure A-7[b]). For captive coke plants, the lowest cost batteries are assumed to supply internal demand, leaving the higher cost battery(ies) to supply the market if MC<P for the appropriate battery(ies). Similarly, a step-wise aggregate domestic supply function can be created by ordering production from least to highest MC batteries (see Figure A-7[c]). Based on this characterization of domestic supply, a decrease in demand for furnace coke would then sequentially close batteries beginning with the highest MC battery.



(a) Inverted L-Shaped Supply Function at Single-Battery Plant



(b) Inverted L-Shaped Supply Functions at Multibattery Plant



(c) Step-wise Aggregate Supply Curve

Figure A-7. Facility-Level Supply Functions for Coke

Foreign Supply of Furnace Coke. Foreign supply of furnace coke (q_F^{Sc}) is expressed as

$$q_F^{Sc} = A_F^c \, (p^c)^{\xi_F^c} \tag{A.4}$$

where

A_F^c = multiplicative parameter for the foreign furnace coke supply equation and

ξ_F^c = foreign supply elasticity for furnace coke.

The multiplicative parameter (A_F^c) calibrates the foreign coke supply equation to replicate the observed 2000 level of furnace coke imports based on the market price and the foreign supply elasticity.

A.3.1.2 Market Demand for Furnace Coke

Market demand for furnace coke (Q^{Dc}) is the sum of domestic demand from integrated steel mills and foreign demand (exports), i.e.,

$$Q^{Dc} = q_I^{Dc} + q_F^{Dc} \tag{A.5}$$

where

q_I^{Dc} = derived demand of furnace coke from integrated steel mills and

q_F^{Dc} = foreign demand of furnace coke (exports).

Domestic Demand for Furnace Coke. Integrated steel mills use furnace coke as an input to the production of finished steel products. Furnace coke demand is derived from the final product supply decisions at the integrated steel mills. Once these final production decisions of integrated producers have been made, the mill-specific coke input rate will determine their individual coke requirements. Integrated steel mills satisfy their internal requirements first through captive operations and second through market purchases. Thus, the derived demand for furnace coke is the difference between total furnace coke required and the captive capacity at integrated plants, i.e.,

$$q_I^{Dc} = \mathrm{MAX}\left[\sum_l \left(r_{I(l)}^{s}\, q_{I(l)}^{Ss} - \sum_j q_{I(l,j)}^{Sc} \right),\ 0\right] \tag{A.6}$$

$r_{I(l)}^{s}$ = the coke rate for integrated steel mill (l), which specifies the amount of furnace coke input per unit of final steel mill product;

$q_{I(l)}^{Ss}$ = supply of steel mill product from integrated mill (l); and

$q_{I(l,j)}^{Sc}$ = the furnace coke production from captive battery (j) at integrated steel mill (l).

The MAX function in Eq. (A.3) indicates that if the amount of furnace coke consumption required by an integrated mill to produce steel mill products is greater than its total captive production, then demand from the furnace coke market will equal the difference; otherwise, the mill's demand from the furnace coke market will be zero (i.e., it fully satisfies internal requirements from its captive operations).

Increases in the price for furnace coke will increase the per-unit costs of final steel products and thereby shift upward the integrated mill's supply curve for steel mill products. The shift in the supply curve decreases the market quantity of finished steel products produced, which subsequently reduces the quantity of furnace coke consumed at integrated mills and shifts their demand curve downward in the furnace coke market.

Foreign Demand for Furnace Coke (Exports). Foreign demand for furnace coke is expressed as

$$q_F^{Dc} = B_F^{c}\,(p^{c})^{\eta_F^{c}} \tag{A.7}$$

where

B_F^{c} = multiplicative demand parameter for the foreign furnace coke demand equation and

η_F^{c} = foreign demand elasticity for furnace coke.

The multiplicative demand parameter, B_F^{c}, calibrates the foreign coke demand equation to replicate the observed 2000 level of foreign exports based on the market price and the foreign demand elasticity.

A.3.2 Market for Steel Mill Products

The market for steel mill products consists of supply from domestic mills and foreign imports and of demand from domestic and foreign consumers. Steel mill products are modeled as a single commodity market. The domestic supply for steel mill products includes production from integrated mills operating blast furnaces that require furnace coke and from nonintegrated mills that operate electric arc furnaces that do not. The coke oven NESHAP is expected to increase the cost of furnace coke inputs. In addition, the integrated iron and steel NESHAP will also increase the costs of production leading to similar impacts. This will increase the cost of production at integrated mills and thereby shift their supply curves upward and increase the price of steel mill products.

A.3.2.1 Market Supply of Steel Mill Products

The market supply for steel mill products (Q^{Ss}) is defined as the sum of the supply from integrated iron and steel mills, nonintegrated mills, and foreign imports, i.e.,

$$Q^{Ss} = q_I^{Ss} + q_{NI}^{Ss} + q_F^{Ss} \tag{A.8}$$

where

q_I^{Ss} = supply of steel mill products from integrated mills;

q_{NI}^{Ss} = supply of steel mill products from the nonintegrated steel mills; and

q_F^{Ss} = supply of steel mill products from foreign suppliers (imports).

Supply from Integrated Mills. Supply of steel mill products from integrated iron and steel mills is the sum of individual mill production, i.e.,

$$q_I^{Ss} = \sum_{l} q_{I(1)}^{Ss} \tag{A.9}$$

where

$q_{I(l)}^{Ss}$ = quantity of steel mill products produced at an individual integrated mill (l).

Integrated producers of steel mill products vary output as production costs change. As described above, upward-sloping supply curves were used to model integrated mills' responses. For this analysis, the generalized Leontief technology is assumed to characterize the production of steel mill products at each facility. This technology is appropriate, given the fixed-proportion material input of coke and the variable-proportion inputs of labor, energy, and raw materials. The generalized Leontief supply function is

$$q^{Ss}_{I(1)} = \gamma_l + \frac{B}{2}\left(\frac{1}{p_s}\right)^{\frac{1}{2}} \tag{A.10}$$

where p_s is the market price for the steel product, γ_l and β are model parameters, and l indexes affected integrated mills. The theoretical restrictions on the model parameters that ensure upward-sloping supply curves are $\gamma_l > 0$ and $\beta < 0$.

Figure A-8 illustrates the theoretical supply function of Eq. (A.10). As shown, the upward-sloping supply curve is specified over a productive range with a lower bound of zero that corresponds with a shutdown price equal to $\frac{\beta^2}{4\gamma_l^2}$ and an upper bound given by the productive capacity of q_l^M that is approximated by the supply parameter γ_l. The curvature of the supply function is determined by the β parameter.

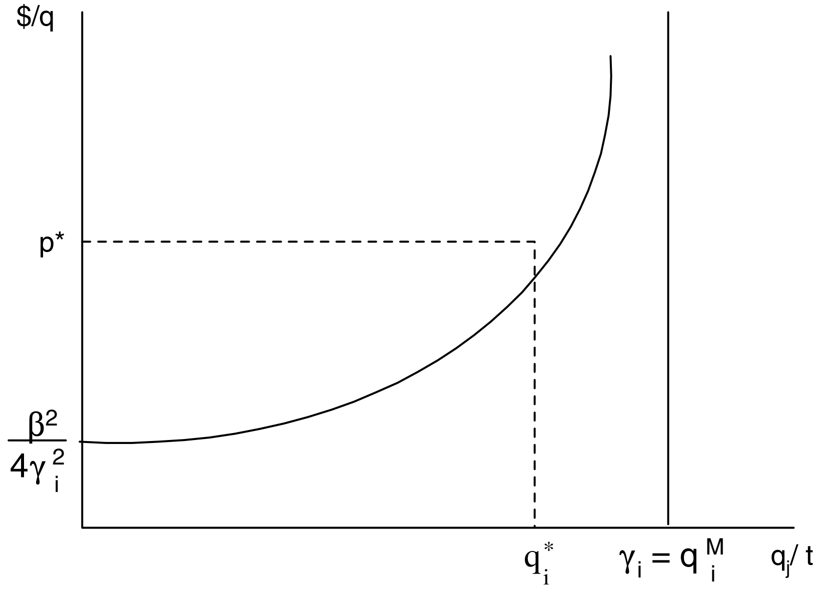


Figure A-8. Theoretical Supply Function for Integrated Facilities and Foundries

To specify the supply function of Eq. (A.10) for this analysis, the β parameter was computed by substituting a market supply elasticity for the product (ξ), the market price of the product (p), and the average annual production level across mills (q) into the following equation:

$$\beta = -\xi 4q\left[\frac{1}{p_s}\right]^{-\frac{1}{2}} \tag{A.11}$$

The β parameter was calculated by incorporating market price and elasticity of supply values into Eq. (A.11).

The intercept of the supply function, γ_1, approximates the productive capacity and varies across products at each facility. This parameter does not influence the facility's production responsiveness to price changes as does the β parameter. Thus, the parameter γ_1 is used to calibrate the economic model so that each individual facility's supply equation matches its baseline production data from 2000.

Modeling the Impact of Compliance Costs. The effect of the coke oven NESHAP is to increase the MC of producing furnace coke by the compliance costs. These costs include the variable component consisting of the operating and maintenance costs and the nonvariable component consisting of the control equipment required for the regulatory option. Regulatory control costs will shift the supply curve upward for each affected facility by the annualized compliance cost (operating and maintenance plus annualized capital) expressed per unit of coke production. Computing the supply shift in this way treats compliance costs as the conceptual equivalent of a unit tax on output. For coke facilities, the horizontal portion of its supply curve will rise by the per-unit total compliance costs. In this case, the MC curve will shift by this amount to allow the new higher reservation price for the coke battery to appropriately reflect the fixed costs of compliance in the operating decision. At a multiple-battery facility, the change in each battery's MC may cause a reordering of the steps because the compliance costs vary due to the technology, age, and existing controls of individual batteries.

Compliance costs on captive furnace coke batteries will directly affect production decisions at integrated mills, while compliance costs on merchant furnace coke batteries will indirectly affect these decisions through the change in the market price of furnace coke. In addition, direct compliance costs associated with the integrated iron and steel NESHAP will directly affect production decisions at these mills. Both of these impacts were modeled as reducing the net price integrated mills receive for steel mill products. Returning to the integrated mill's supply function presented in Eq. (A.10), the mill's production quantity with compliance costs is expressed as

$$q^{Ss}_{I(1)} = \gamma_1 + \frac{\beta}{2}\left[\frac{1}{p_s - r^{s}_{I(1)}\left[\alpha_1 \Delta c^{c}_{1} + (1-\alpha_1)\Delta p_c\right] - c^{s}_{1}}\right] \qquad \text{(A.12)}$$

where

$r^{s}_{I(l)}$ = the coke rate for integrated steel mill (l), which specifies the amount of furnace coke input per unit of steel mill product;

α_l = the share of integrated steel mill l's furnace coke provided by captive batteries;

Δc^{c}_{l} = change in per-unit cost of captive coke production at integrated steel mill l;

$(1-\alpha_l)$ = share of integrated steel mill l's furnace coke provided by the market;

Δp_c = change in the market price for furnace coke; and

Δc^{s}_{l} = change in per-unit compliance cost at integrated steel mill l.

The bracketed term in the denominator represents the increased costs due to the coke ovens NESHAP and integrated iron and steel NESHAP (i.e., both the direct and indirect effects). The coke oven NESHAP compliance costs, Δc^{c}_{l} and Δp_c, are expressed per ton of furnace coke and weighted to reflect each integrated mill's reliance on captive versus market furnace coke.[2] The change in the cost per ton of furnace coke due to the regulation is then multiplied by the mill's coke rate to obtain the change in the cost per ton of steel mill product. The integrated iron and steel NESHAP compliance costs, Δc^{s}_{l}, are also expressed in cost per ton of steel mill product. These changes in the cost per ton of steel mill product correspond to the shift in the affected facility supply curve shown in Figure A-5b.

Supply from Nonintegrated Mills. The supply of steel mill products from domestic nonintegrated mills is specified as

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[2] The captive versus market furnace coke weights are endogenous in the model because integrated mills exhaust their captive supply of coke first; hence, changes in coke consumption typically come from changes in market purchases, while captive consumption remains relatively constant.

$$q_{NI}^{Ss} = A_{NI}^{s} (p^{s})^{\xi_{NI}^{s}} \tag{A.13}$$

where

A_{NI}^{s} = multiplicative parameter for nonintegrated mill supply equation and

ξ_{NI}^{s} = the nonintegrated mill supply elasticity for steel mill products.

The multiplicative supply parameter is determined by backsolving Eq. (A.13), given baseline values of the market price, supply elasticities, and quantities supplied by nonintegrated mills and foreign mills.

Foreign Supply (Imports). The supply of steel mill products from foreign suppliers (imports) is specified as

$$q_{F}^{Ss} = A_{F}^{s} (p^{s})^{\xi_{F}^{s}} \tag{A.14}$$

where

A_{F}^{s} = multiplicative parameter for foreign supply equation and

ξ_{F}^{s} = the foreign supply elasticity for steel mill products.

The multiplicative supply parameters are determined by backsolving Eq. (A.14), given baseline values of the market price, supply elasticity, and level of imports.

A.3.2.2 Market Demand for Steel Mill Products

The market demand for steel mill products, Q^{Ds}, is the sum of domestic and foreign demand, i.e.,

$$Q^{Ds} = q_{D}^{Ds} + q_{F}^{Ds} \tag{A.15}$$

where

q_{D}^{Ds} = domestic demand for steel mill products and

q_{F}^{Ds} = foreign demand for steel mill products (exports).

Domestic Demand for Steel Mill Products. The domestic demand for steel mill products is expressed as

$$q_D^{Ds} = B_D^s \left(p^s\right)^{\eta_D^s} \tag{A.16}$$

where

B_D^s = multiplicative parameter for domestic steel mill products demand equation and

η_D^s = domestic demand elasticity for steel mill products.

The multiplicative demand parameter calibrates the domestic demand equation given baseline data on price and demand elasticity to replicate the observed 2000 level of domestic consumption.

Foreign Demand for Steel Mill Products (Exports). Foreign demand (exports) for steel mill products is expressed as

$$q_F^{Ds} = B_F^s \left(p^s\right)^{\eta_F^s} \tag{A.17}$$

where

B_F^s = multiplicative demand parameter for foreign steel mill products' demand equation and

η_F^s = foreign (export) demand elasticity for steel mill products.

The multiplicative demand parameter calibrates the foreign demand equation given data on price and demand elasticities to replicate the observed 2000 level of foreign exports.

A.3.3 Market for Foundry Coke

The market for furnace coke consists of supply from domestic merchant coke plants and imports and demand from foundries operating cupola furnaces. The domestic supply for foundry coke is modeled as a step-wise supply function developed from the marginal cost of production at individual foundry coke batteries. Imports are modeled using a representative supply curve. The domestic demand is derived from iron castings production at foundries operating cupola furnaces (domestic and foreign) as determined through the market for iron castings and coking rates. The following section details the market supply and demand components for this analysis.

A.3.3.1 Market Supply of Foundry Coke

The market supply of foundry coke, Q^{Sk}, is composed of the supply from domestic merchant plants reflecting plant-level production decisions for individual merchant coke batteries, and a single representative foreign supply curve, i.e.,

$$Q^{sk} = \underset{\text{Merchant}}{q_M^{Sk} + q_F^{Sk}} = \sum_{l} \sum_{j} q_{M(l,j)}^{Sk} + q_F^{Sk} \tag{A.18}$$

where

l = plants,

j = batteries,

$q_{M(l,j)}^{Sk}$ = supply of foundry coke from coke battery (j) at merchant plant (l), and

q_F^{Sk} = foundry coke supply from imports.

As was the case for furnace coke batteries, the marginal cost for an individual foundry coke battery is assumed to be constant reflecting a fixed-coefficient technology. Marginal cost curves were developed for all foundry coke batteries at merchant plants in the United States as detailed in Appendix B.

Foundry coke production decisions are based on the same approach used to model furnace coke production decisions. Thus, as illustrated previously in Figure A-7, the production decision is determined by an inverted L-shaped supply curve that is perfectly elastic to the capacity level of production and perfectly inelastic thereafter. Foundry coke batteries will supply 100 percent of capacity if its marginal cost is less than market price; otherwise, it will cease production. The regulatory costs shift each affected battery's marginal cost upward, affecting facilities' decision to operate or shut down individual batteries.

Foreign Supply of Foundry Coke. Foreign supply of foundry coke (q_F^{Sk}) is expressed as

$$q_F^{Sk} = A_F^k \, (p^k)^{\xi_F^k} \tag{A.19}$$

where

A_F^k = multiplicative parameter for the foreign foundry coke supply equation, and

ξ_F^k = foreign supply elasticity for foundry coke.

The multiplicative parameter (A_F^k) calibrates the foreign coke supply equation to replicate the observed 2000 level of foundry coke imports based on the market price and the foreign supply elasticity.

A.3.3.2 Market Demand for Foundry Coke

The market demand for foundry coke, Q^{Dk}, is composed of domestic and foreign demand by foundries operating cupola furnaces. Therefore, the foundry coke demand is derived from the production of iron castings from cupola furnaces. Increases in the price of foundry coke due to the regulation will lead to decreases in production of iron castings at foundries operating cupola furnaces. The demand function for foundry coke is expressed as follows:

where

$$Q^{Dk} = q_{CF}^{Dk} + q_{CFF}^{Dk} = r_{CF}^{i}\ q_{CF}^{Si} + q_{CFF}^{Dk} \qquad \text{(A.20)}$$

q_{CF}^{Dk} = derived demand for foundry coke from domestic cupola foundries;

q_{CFF}^{Dk} = demand for foundry coke from foreign cupola foundries;

r_{CF}^{i} = the coke rate for cupola foundries, which specifies the amount of foundry coke input per unit output; and

q_{CF}^{Si} = quantity of iron castings produced at domestic cupola foundries.

Changes in production at foundries using electric arc and electric induction furnaces to produce iron castings do not affect the demand for foundry coke.

Foreign Demand for Foundry Coke (Exports). Foreign demand for foundry coke is expressed as

$$q_F^{Dk} = B_F^k \, (p^k)^{\eta_F^k} \qquad \text{(A.21)}$$

where

B_F^k = multiplicative demand parameter for the foreign foundry coke demand equation and

η_F^k = foreign demand elasticity for foundry coke.

The multiplicative demand parameter, B_F^k, calibrates the foreign coke demand equation to replicate the observed 2000 level of foreign exports based on the market price and the foreign demand elasticity.

A.3.4 Markets for Iron and Steel Castings

The model includes two markets for this industry: iron castings and steel castings. Each market consists of supply from domestic foundries and foreign imports and of demand from domestic and foreign consumers. The rule is expected to increase production costs for selected cupola and electric foundries and thereby shift their supply curves upward and increase the prices.

A.3.4.1 Market Supply

The market supply for castings market i, Q^{St}, is defined as the sum of the supply from domestic and foreign foundries.

$$Q^{Si} = q_{AF}^{Si} + q_{UF}^{Si} + q_F^{Si} \qquad \text{(A.22)}$$

where

q_{AF}^{Si} = quantity of castings produced at affected domestic foundries,

q_{UF}^{Si} = supply from unaffected domestic foundries, and

q_F^{Si} = supply from foreign foundries.

The functional form of the supply curve for domestic foundries is specified as

$$q_{F_1}^{Si} = A_{F_1}^{i} \, (p^i - \Delta c)^{\xi_F^i} \qquad \text{(A.24)}$$

where

A_F^i = multiplicative parameter for foundries supply equation,

Δc = per-unit direct compliance costs of casting production[3], and

ξ_F^i = foundries supply elasticity.

The multiplicative supply parameter, A_F^i, is determined by backsolving Eq. (A.24), given baseline values of the market price, supply elasticity, and quantity supplied.

Foreign Supply (Imports). The functional form of the foreign supply curve is specified as

$$q_F^{Si} = A_F^i \, (p^i)^{\xi_F^i} \tag{A.25}$$

where

A_F^i = multiplicative parameter for foreign supply equation and

ξ_F^i = foreign supply elasticity.

The multiplicative supply parameter, A_F^i, is determined by backsolving Eq. (A.25), given baseline values of the market price, supply elasticity, and level of imports.

A.3.4.2 Market Demand

The market demand for castings market i, (Q^{Di}), is the sum of domestic and foreign demand, and it is expressed as a function of the price of castings:

$$Q^{Di} = q_D^{Di} + q_F^{Di} \tag{A.26}$$

where

q_D^{Di} = domestic demand for castings and

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[3] The economic model projects the foundry coke price remains unchanged after regulation. Therefore, there is no indirect effect of the regulation associated with changes in foundry coke prices.

q_F^{Di} = foreign demand (exports) for castings.

Domestic Demand. The domestic demand for castings is expressed as

$$q_D^{Di} = B_D^i \, (p^i)^{\eta_D^i} \qquad \text{(A.27)}$$

where

B_D^i = multiplicative parameter for domestic demand equation and

η_D^i = domestic demand elasticity.

The multiplicative demand parameter calibrates the domestic demand equation given baseline data on price and demand elasticity to replicate the observed 2000 level of domestic consumption.

Foreign Demand. Foreign demand (exports) is expressed as

$$q_F^{Di} = B_F^i \, (p^i)^{\eta_F^i} \qquad \text{(A.28)}$$

where

B_F^i = multiplicative demand parameter for demand equation and

η_F^i = foreign (export) demand elasticity.

The multiplicative demand parameter, B_F^i, is determined by backsolving Eq. (A.28), given baseline values of market price, demand elasticity, and level of exports.

A.3.5 Post-regulatory Market Equilibrium Determination

Integrated steel mills and iron foundries with cupola furnaces must determine output given the market prices for their finished products, which in turn determines their furnace and foundry coke requirements. The optimal output of steel mill products at integrated mills also depends on the cost of producing captive furnace coke and the market price of furnace coke; whereas iron and steel foundries with cupolas depend on only the market price of foundry coke because they have no captive operations. Excess production of captive furnace coke at integrated mills will spill over into the furnace coke market; whereas an excess demand will cause the mill to demand furnace coke from the market. For merchant coke plants, the optimal market supply of furnace and/or foundry coke will be determined by the market price of each coke product.

Facility responses and market adjustments can be conceptualized as an interactive feedback process. Facilities face increased costs from the regulation, which initially reduce output. The cumulative effect of these individual changes leads to an increase in the market price that all producers (affected and unaffected) and consumers face, which leads to further responses by producers (affected and unaffected) as well as consumers and thus new market prices, and so on. The new equilibrium after imposing the regulation is the result of a series of iterations between producer and consumer responses and market adjustments until a stable market price arises where market supply equals market demand for each product, i.e., $Q_S = Q_D$.

The Agency employed a Walrasian auctioneer process to determine equilibrium price (and output) associated with the increased production costs of the regulation. The auctioneer calls out a market price for each product and evaluates the reactions by all participants (producers and consumers), comparing total quantities supplied and demanded to determine the next price that will guide the market closer to equilibrium (i.e., where market supply equals market demand). Decision rules are established to ensure that the process will converge to an equilibrium, in addition to specifying the conditions for equilibrium. The result of this approach is a vector of prices with the regulation that equilibrates supply and demand for each product.

The algorithm for deriving the with-regulation equilibria in all markets can be generalized to five recursive steps:

1. Impose the control costs for each affected facility, thereby affecting their supply decisions.
2. Recalculate the production decisions for coke products and both final steel mill products and iron castings across all affected facilities. The adjusted production of steel mill products from integrated steel mills and iron castings from foundries with cupola furnaces determines the derived demand for furnace and foundry coke through the input ratios. Therefore, the domestic demand for furnace and foundry coke is simultaneously determined with the domestic supply of final steel mill products and iron castings from these suppliers. After accounting for these adjustments, recalculate the market supply of all products by aggregating across all producers, affected and unaffected.

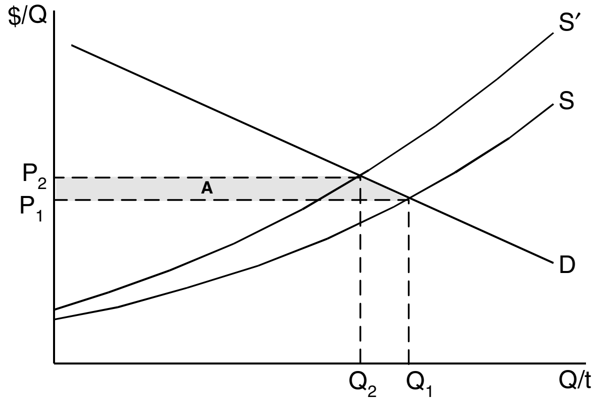
3. Determine the new prices via a price revision rule for all product markets.
4. Recalculate the supply functions of all facilities with the new prices, resulting in a new market supply of each product, in addition to derived (domestic) demand for furnace and foundry coke. Evaluate domestic demand for final steel mill products and iron castings, as well as import supply and export demand for appropriate products given the new prices.
5. Go to Step #3, resulting in new prices for each product. Repeat until equilibrium conditions are satisfied in all markets (i.e., the ratio of supply to demand is approximately one for each and every product).

A.3.6 Economic Welfare Impacts

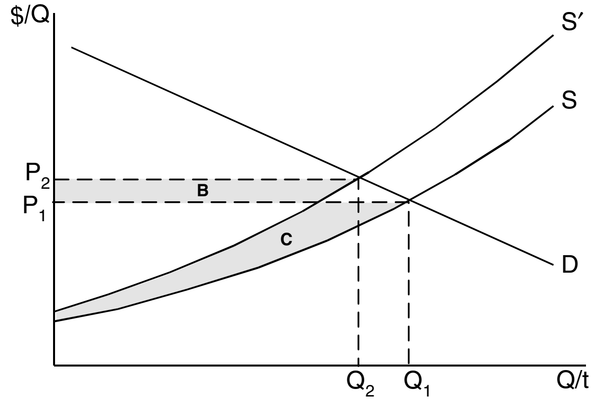
The economic welfare implications of the market price and output changes with the regulation can be examined using two slightly different tactics, each giving a somewhat different insight but the same implications: changes in the net benefits of consumers and producers based on the price changes and changes in the total benefits and costs of these products based on the quantity changes. This analysis focuses on the first measure—the changes in the net benefits of consumers and producers. Figure A-9 depicts the change in economic welfare by first measuring the change in consumer surplus and then the change in producer surplus. In essence, the demand and supply curves previously used as predictive devices are now being used as a valuation tool.

This method of estimating the change in economic welfare with the regulation divides society into consumers and producers. In a market environment, consumers and producers of the good or service derive welfare from a market transaction. The difference between the maximum price consumers are willing to pay for a good and the price they actually pay is referred to as “consumer surplus.” Consumer surplus is measured as the area under the demand curve and above the price of the product. Similarly, the difference between the minimum price producers are willing to accept for a good and the price they actually receive is referred to as “producer surplus” or profits. Producer surplus is measured as the area above the supply curve and below the price of the product. These areas can be thought of as consumers’ net benefits of consumption and producers’ net benefits of production, respectively.

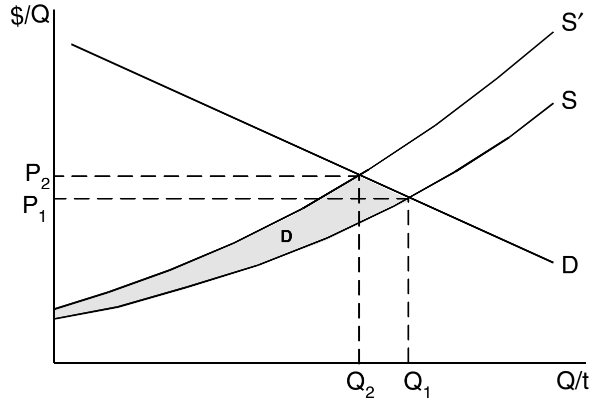
In Figure A-9, baseline equilibrium occurs at the intersection of the demand curve, D, and supply curve, S. Price is P_1 with quantity Q_1. The increased cost of production with the regulation will cause the market supply curve to shift upward to S′. The new equilibrium price of the product is P_2. With a higher price for the product, there is less consumer welfare,



(a) Change in Consumer Surplus with Regulation



(b) Change in Producer Surplus with Regulation



(c) Net Change in Economic Welfare with Regulation

Figure A-9. Economic Welfare Changes with Regulation: Consumer and Producer Surplus

all else being unchanged as real incomes are reduced. In Figure A-9(a), area A represents the dollar value of the annual net loss in consumers' benefits with the increased price. The rectangular portion represents the loss in consumer surplus on the quantity still consumed, Q_2, while the triangular area represents the foregone surplus resulting from the reduced quantity consumed, Q_1–Q_2.

In addition to the changes in consumer welfare, producer welfare also changes with the regulation. With the increase in market price, producers receive higher revenues on the quantity still purchased, Q_2. In Figure A-9(b), area B represents the increase in revenues due to this increase in price. The difference in the area under the supply curve up to the original market price, area C, measures the loss in producer surplus, which includes the loss associated with the quantity no longer produced. The net change in producer welfare is represented by area B–C.

The change in economic welfare attributable to the compliance costs of the regulation is the sum of consumer and producer surplus changes, that is, – (A) + (B–C). Figure A-9(c) shows the net (negative) change in economic welfare associated with the regulation as area D. However, this analysis does not include the benefits that occur outside the market (i.e., the value of the reduced levels of air pollution with the regulation). Including this benefit may reduce the net cost of the regulation or even make it positive.

APPENDIX B

DEVELOPMENT OF COKE BATTERY COST FUNCTIONS

This appendix outlines EPA's method for estimating 2000 baseline production costs for coke batteries. The Agency used a coke production cost model developed in support of the 1993 MACT on coke ovens. EPA's *Technical Approach for a Coke Production Cost Model* (EPA, 1979) provides a more detailed description of this model. For this analysis, the model was updated with reported technical characteristics of coke batteries from the Information Collection Request (ICR) survey responses and available price data (see Table B-1). In addition, the Agency incorporated estimates of MACT pollution abatement costs developed for the 1993 MACT on coke ovens (EPA, 1991b).

B.1 Variable Costs

Coke batteries use four variable inputs during the manufacturing process—metallurgical coal, labor, energy, and other materials/supplies. Metallurgical coal is essentially the only raw material used in the production of coke. Labor transports and delivers the raw materials as well as final products. Coke ovens and auxiliary equipment consume energy and supplies during the production process and periodic maintenance and repair of the coke batteries.

Coke production requires a fixed amount of each variable input per ton of coke, and these 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. Therefore, the average variable cost function (expressed in dollars per short ton of coke) can be written as

$$AVC = AV\_CI \bullet P_c + AV\_LI \bullet w + AV\_EI \bullet P_e + AV\_OI \bullet P_o \qquad (B.1)$$

where AV_CI, AV_LI, AV_EI, and AV_OI are the fixed requirements per ton of coke of metallurgical coal, labor, energy, and other material and supplies. P_c, w, P_e, and P_o are the prices of each variable input, respectively. As shown above, the contribution of each variable input to the per-unit coke cost is equal to the average variable input (fixed requirement of the input per ton of coke) times the price of the input. For example, the

Table B-1. Key Parameter Updates for Coke Production Cost Model: 2000[a]

Variable	Description	Units	2000
R1	Steam Cost	\$/1,000 lb steam	8.97
R2	Cooling Water	\$/1,000 gal	0.26
R3	Electricity	\$/kWh	Varies by state
R4	Underfire Gas	$\$/10^3$ cft	1.06
R7	Calcium Hydroxide	\$/ton	74.00
R8	Sulfuric Acid	\$/ton	79.00
R9	Sodium Carbonate	\$/ton	537.00
R10	Sodium Hydroxide	\$/ton	315.00
R11	Coal Tar Credit	\$/gal	0.82
R12	Crude Light Oil	\$/gal	1.27
R13	BTX Credit	\$/gal	0.94
R14	Ammonium Sulfate Credit	\$/ton	40.04
R14*	Anhydrous Ammonia Credit	\$/ton	239.21
R15	Elemental Sulfur Credit	\$/ton	287.48
R16	Sodium Phenolate Credit	\$/ton	864.12
R17	Benzene Credit	\$/gal	1.21
R18	Toluene Credit	\$/gal	0.85
R19	Xylene Credit	\$/gal	0.75
R20	Naphalene Credit	\$/lb	0.27
R21	Coke Breeze Credit	\$/ton	45.62
R22	Solvent Naptha Credit	\$/gal	0.88
R23	Wash Oil Cost	\$/gal	1.29
R25	Phosphoric Acid (commercial)	\$/ton	711.31
	Industrial Coke Price	\$/ton	112.00

[a] This table provides price updates for the coke production cost model (EPA, 1979, Table 2–3).

contribution of labor to the cost per ton of coke (AV_LI) is equal to the labor requirement per ton of coke times the price of labor (w).

The variable costs above include those costs associated with by- and co-product recovery operations associated with the coke battery. To more accurately reflect the costs specific to coke production, the Agency subtracted by- and co-product revenues/credits from Eq. (B.1). By-products include tar and coke oven gas among others, while co-products include coke breeze and other industrial coke. Following the same fixed coefficient approach, these revenues or credits (expressed per ton of coke) are derived for each recovered product at the coke battery by multiplying the appropriate yield (recovered product per ton of coke) by its price or value. The variable cost components and by-/co-product credits are identified below.

B.1.1 Metallurgical Coal (AVCI, P_c)

The ICR survey responses provided the fixed input requirement for metallurgical coal at each battery. Based on the responses from the survey, U.S. coke producers require an average of 1.36 tons of coal per ton of coke produced. This fixed input varies by type of producer. Integrated, or captive, producers require an average of 1.38 tons of coal per ton of coke produced, while merchant producers require an average of 1.31 tons of coal per ton of coke produced. The U.S. Department of Energy provides state-level coal price data for metallurgical coal. For each coke battery, EPA computed the cost of coal per short ton of coke by multiplying its input ratio times the appropriate state or regional price. As shown in Table B-2, the average cost of metallurgical coal per ton of coke in 2000 was $61.23 for captive producers and $57.98 for merchant producers.

Table B-2. Metallurgical Coal Costs by Producer Type: 2000 ($/ton of coke)

	Captive	Merchant	All Coke Batteries
Number of batteries	40	18	58
Average	$61.23	$57.98	$60.22
Minimum	$56.21	$52.17	$52.17
Maximum	$71.98	$68.39	$71.98

B.1.2 Labor (AVLI, w)

The cost model provides an estimate of the fixed labor requirement for operation, maintenance, and supervision labor at each battery. The Agency used these estimates to derive the average variable labor cost for each individual battery given its technical characteristics and the appropriate state-level wage rates obtained from the U.S. Bureau of Labor Statistics (2002). As shown in Table B-3, average labor costs per ton of coke are significantly lower for captive producers (e.g., $17.18 per ton of coke) relative to merchant

Table B-3. Labor Costs by Producer Type: 2000 ($/ton of coke)

	Captive	Merchant	All Coke Batteries
Number of batteries	40	18	58
Average	$17.18	$28.95	$20.83
Minimum	$9.19	$11.07	$9.19
Maximum	$38.35	$44.63	$44.63

producers (e.g., $28.95 per ton of coke). Captive batteries are typically larger capacity batteries and therefore require fewer person-hours per ton of coke.

B.1.3 Energy (AVEI, P_e)

The cost model estimates the fixed energy requirements (i.e., electricity, steam, and water) for each battery. These estimates are used to derive the energy costs per ton of coke for each battery. Captive producers have a lower electricity requirement (i.e., 47.58 kWh per ton of coke) relative to merchant producers (i.e., 50.96 kWh per ton of coke). As shown in Table B-4, the average energy cost per ton of coke across all coke batteries is $5.77. Average energy costs per ton of coke are lower for captive producers (e.g., $5.51 per ton of coke) relative to merchant producers (e.g., $6.34 per ton of coke). This difference reflects lower state/regional electricity prices in regions where captive batteries produce coke.

Table B-4. Energy Costs by Producer Type: 2000 ($/ton of coke)

	Captive	Merchant	All Coke Batteries
Number of batteries	40	18	58
Average	$5.51	$6.34	$5.77
Minimum	$3.91	$4.31	$3.91
Maximum	$16.11	$15.41	$16.11

B.1.4 Other Materials and Supplies (AVOI, P_o)

The fixed requirements for other materials and supplies associated with the production of coke include

- chemicals,
- maintenance materials,
- safety and clothing, and
- laboratory and miscellaneous supplies.

As shown in Table B-5, the cost model estimates the average cost for these items across all coke batteries is $4.76 per short ton of coke, ranging from $3.26 to $7.69 per ton of coke. These costs vary by producer type, with merchant producers averaging $5.53 per ton of coke versus captive producers who average $4.42 per ton of coke.

Table B-5. Other Costs by Producer Type: 2000 ($/ton of coke)

	Captive	Merchant	All Coke Batteries
Number of batteries	40	18	58
Average	$4.42	$5.53	$4.76
Minimum	$3.27	$3.26	$3.26
Maximum	$7.69	$7.42	$7.69

B.1.5 By- and Co-product Credits

In addition to the variable cost inputs described above, by- and co-products are associated with the manufacture of coke products. Therefore, the Agency modified Eq. (B.1) by subtracting (1) revenues generated from the sale of by-/co-products and (2) credits associated with using coke oven gas as an energy input in the production process. The following cost function adjustments were made to the engineering model to incorporate by- and co-products into the coke-making cost function:

- Coke breeze—ICR survey responses provided coke breeze output per ton of coke for each battery.

- Other industrial coke—ICR survey responses provided other industrial coke output per ton of coke for each battery.
- Coke oven gas—Based on secondary sources and discussions with engineers, furnace coke producers were assumed to produce 8,500 ft^3 per ton of coal, and foundry producers were assumed to produce 11,700 ft^3 per ton of coal (Lankford et al., 1985; EPA, 1988).

As shown in Table B-6, the average by-/co-product credit is $19.54 per ton of coke for captive producers and $24.05 per ton of coke for merchant producers.

Table B-6. By-/Co-Product Credits by Producer Type: 2000 ($/ton of coke)

	Captive	Merchant	All Coke Batteries
Number of batteries	40	18	58
Average	$19.54	$24.05	$20.94
Minimum	$16.09	$10.69	$10.69
Maximum	$35.99	$51.78	$51.78

B.2 MACT/LAER Pollution Abatement Costs

The 1990 Clean Air Act Amendments mandated two levels of control for emissions from coke ovens. The first control level, referred to as MACT, specified limits for leaking doors, lids, offtakes, and time of charge. This level of control was to be attained by 1995. The second level of control, Lowest Achievable Emissions Rate (LAER), specified more stringent limits for leaking doors and offtakes. Estimates of the MACT and LAER costs associated with these controls were developed for EPA's *Controlling Emissions from By-Product Coke Oven Charging, Door Leaks, and Topside Leaks: An Economic Impacts Analysis* (EPA, 1991a).[1] Table B-7 provides summary statistics for the projected costs associated with each level of control. However, the Agency determined that industry actions undertaken in the interim period to comply with the MACT limits have enabled them to also meet the LAER limits. Therefore, only the MACT-related pollution abatement costs have

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[1] The Agency estimated costs for the LAER control level using two scenarios. The first (LAER-MIN) assumed all batteries will require new doors and jambs. The second (LAER-MAX) also assumed all batteries will require new doors and jambs and in addition assumed batteries with the most serious door leak problems would be rebuilt. This analysis reports cost estimates for the LAER-MIN scenario.

Table B-7. Pollution Abatement Costs by Producer Type: 2000 ($/ton of coke)

	Captive	Merchant	All Coke Batteries
Number of batteries	40	18	58
MACT			
Average	$0.83	$2.34	$1.30
Minimum	$0.00	$0.00	$0.00
Maximum	$2.59	$11.14	$11.14
LAER			
Average	$1.64	$2.44	$1.88
Minimum	$0.07	$0.94	$0.07
Maximum	$2.63	$6.07	$6.07

been incorporated to determine the appropriate baseline costs for the 2000 economic model. As shown in Table B-7, the average MACT pollution abatement cost across all coke batteries is $1.30 per short ton of coke. The projected costs for captive producers range from zero to $2.59 per ton of coke, while projected costs for merchant producers range from zero to $11.14 per ton of coke.

B.3 Fixed Costs

Production of coke requires the combination of variable inputs outlined above with fixed capital equipment (e.g., coke ovens and auxiliary equipment). It also includes other overhead and administrative expenses. For each coke battery, the average fixed costs per ton of coke can be obtained by dividing the total fixed costs (TFC) estimated by the coke model by total battery coke production. Therefore, the average fixed cost function (expressed in dollars per ton of coke) can be written as

$$AFC = (PTI + ASE + PYOH + PLOH)/Q \tag{B.2}$$

where

- property taxes and insurance (PTI) = (0.02)•($225•Coke Capacity). This category accounts for the fixed costs associated with property taxes and insurance for the battery. The cost model estimates this component as 2 percent of capital cost. Capital costs are estimated to be $225 per annual short ton of capacity based on reported estimates of capital investment cost of a rebuilt by-product coke-making facility (USITC, 1994). As shown in Table B-8, the average PTI cost across all batteries is $4.47 per ton of coke.

Table B-8. Average Fixed Costs by Producer Type: 2000 ($/ton of coke)

	Captive	Merchant	All Coke Batteries
Number of batteries	40	18	58
Property taxes and insurance			
Average	$4.41	$4.58	$4.47
Minimum	$3.20	$3.55	$3.20
Maximum	$6.78	$6.11	$6.78
Administrative and sales expense			
Average	$4.96	$5.16	$5.02
Minimum	$3.60	$4.00	$3.60
Maximum	$7.63	$6.87	$7.63
Payroll overhead			
Average	$3.44	$5.79	$4.17
Minimum	$1.84	$2.21	$1.84
Maximum	$7.67	$8.93	$8.93
Plant overhead			
Average	$10.18	$18.91	$12.89
Minimum	$5.73	$7.92	$5.73
Maximum	$21.83	$28.62	$28.62

- administration and sales expense (ASE) = (0.02)•($225•Coke capacity). This category accounts for the fixed costs associated with administrative and sales expenses for the coke battery. The cost model also calculates this component as 2 percent of capital cost. As shown in Table B-8, the average cost across all coke batteries for ASE is $5.02 per ton of coke.

- payroll overhead (PYOH) = (0.2)•(Total labor costs). Payroll overhead is modified as 20 percent of total labor costs. Payroll overhead is used to capture fringe benefits because wage rates obtained from the Bureau of Labor Statistics exclude fringe benefits. As shown in Table B-8, the average payroll overhead is $3.44 per ton of coke for captive producers and $5.79 per ton of coke for merchant producers, reflecting the different labor requirements by producer type.

- plant overhead (PLOH) = (0.5)•(Total payroll + Total other expenses). The cost model computes plant overhead as 50 percent of total payroll and total other expenses by producer type. As shown in Table B-8, the average plant overhead cost is $10.18 for captive producers and $18.91 for merchant producers. As with payroll overhead, this difference reflects differences in labor requirements for captive and merchant producers.

B.4 Summary of Results

Table B-9 summarizes each cost component and aggregates them to estimate the average total costs per ton of coke by producer type. As shown, the average total cost (ATC) across all coke batteries is $98.49 per short ton of coke. The ATC for captive producers is $92.62 per short ton of coke and is significantly lower than the ATC for merchant producers at $111.52. This difference reflects both economies of scale and lower production costs associated with the production of furnace coke. These differences are also consistent with observed market prices for furnace coke of $112 (produced mainly by captive producers) and for foundry coke of $161 (produced solely by merchant producers with some furnace coke) (USITC, 2001b, 2001c). A correlation analysis of these cost estimates shows that ATC is negatively correlated with coke battery capacity (correlation coefficient of –0.70) and start/rebuild date (correlation coefficient of -0.63). Therefore, average total costs are lower for larger coke batteries and those that are new or recently rebuilt. Tables B-10 and B-11 present cost estimates for individual captive and merchant coke batteries, respectively.

B.5 Nonrecovery Coke Making

Several substitute technologies for by-product coke making have been developed in the United States and abroad. In the United States, the nonrecovery method is the only substitute that has a significant share of the coke market. This technology is relatively new, and, as a result, the original coke production cost model did not include estimates for these types of coke-making batteries. The nonrecovery process is less costly than the by-product process because of the absence of recovery operations and a lower labor input requirement per ton of coke. Therefore, the Agency modified the model to reflect these cost advantages in the following manner:

- No expenses/credits associated with by- and co-product recovery.
- Reduced labor input—labor requirement estimates generated by the model were multiplied by a factor of 0.11, which represents the ratio of employment per ton of coke at merchant batteries to employment per ton of coke at nonrecovery batteries.

Table B-9. Cost Summary by Producer Type: 2000 ($/ton of coke)

	Captive	Merchant	All Coke Batteries
Number of batteries	40	18	58
Average variable cost[a]			
Average	$68.80	$74.74	$70.64
Minimum	$57.95	$39.80	$39.80
Maximum	$82.94	$91.00	$91.00
MACT			
Average	$0.83	$2.34	$1.30
Minimum	$0.00	$0.00	$0.00
Maximum	$2.59	$11.14	$11.14
Average fixed cost			
Average	$22.99	$34.44	$26.55
Minimum	$15.61	$17.91	$15.61
Maximum	$43.91	$48.34	$48.34
Average total cost			
Average	$92.62	$111.52	$98.49
Minimum	$73.87	$69.92	$69.92
Maximum	$127.07	$141.84	$141.84

[a] Includes by-/co-product credits.

- Exceed current standards of pollution abatement (*Engineering and Mining Journal*, 1997)—MACT compliance costs were excluded.

As shown in Table B-12, the ATC for nonrecovery coke-making facilities is $69.25 per ton of coke, which is significantly lower than the average ATC of captive and merchant producers. These costs vary slightly across these batteries ranging from $67.51 to $70.12 per ton of coke. Table B-13 presents cost estimates for individual nonrecovery coke-making batteries.

Table B-10. Cost Data Summary for Captive Coke Batteries: 2000

Facility Name	Location	Producer Type[a]	Coke Type[b]	Capacity (short tons/yr)	Start/ Rebuild Date	AVC[c] ($/short ton)	MACT ($/short ton)	AFC ($/short ton)	ATC ($/short ton)
Acme Steel	Chicago, IL	C	1	250,000	1979	$74.41	$1.02	$20.69	$96.13
Acme Steel	Chicago, IL	C	1	250,000	1978	$74.26	$1.02	$20.69	$95.97
AK Steel	Ashland, KY	C	1	634,000	1978	$66.88	$1.28	$18.88	$87.05
AK Steel	Ashland, KY	C	1	366,000	1953	$69.25	$1.02	$21.15	$91.42
AK Steel	Middletown, OH	C	1	429,901	1952	$74.42	$1.23	$23.62	$99.27
Bethlehem Steel	Burns Harbor, IN	C	1	948,000	1972	$58.99	$0.72	$18.11	$77.82
Bethlehem Steel	Burns Harbor, IN	C	1	929,000	1983	$59.27	$0.71	$18.68	$78.66
Bethlehem Steel	Lackawanna, NY	C	1	375,000	1962	$65.66	$1.78	$21.41	$88.86
Bethlehem Steel	Lackawanna, NY	C	1	375,000	1952	$65.65	$1.83	$21.23	$88.71
Geneva Steel	Provo, UT	C	1	200,000	1944	$77.49	$0.27	$28.62	$106.38
Geneva Steel	Provo, UT	C	1	200,000	1944	$78.44	$0.27	$30.92	$109.62
Geneva Steel	Provo, UT	C	1	200,000	1944	$78.41	$0.22	$26.47	$105.10
Geneva Steel	Provo, UT	C	1	200,000	1944	$82.94	$0.22	$43.91	$127.07
Gulf States Steel	Gadsden, AL	C	1	250,000	1942	$75.28	$1.71	$27.56	$104.55
Gulf States Steel	Gadsden, AL	C	1	250,000	1965	$74.47	$2.59	$19.44	$96.51
LTV Steel	Chicago, IL	C	1	615,000	1982	$63.79	$0.36	$18.38	$82.52
LTV Steel	Warren, OH	C	1	549,000	1979	$69.00	$0.04	$22.18	$91.22
National Steel	Ecorse, MI	C	1	924,839	1992	$78.68	$0.27	$17.44	$96.38
National Steel	Granite City, IL	C	1	300,931	1982	$69.93	$0.68	$21.26	$91.87
National Steel	Granite City, IL	C	1	300,931	1980	$69.93	$0.68	$21.26	$91.88

(continued)

Table B-10. Cost Data Summary for Captive Coke Batteries: 2000 (continued)

Facility Name	Location	Producer Type[a]	Coke Type[b]	Capacity (short tons/yr)	Start/ Rebuild Date	AVC[c] ($/short ton)	MACT ($/short ton)	AFC ($/short ton)	ATC ($/short ton)
USX	Clairton, PA	C	1	844,610	1982	$59.24	$0.72	$15.75	$75.71
USX	Clairton, PA	C	1	668,680	1976	$60.62	$0.00	$20.32	$80.94
USX	Clairton, PA	C	1	668,680	1978	$60.62	$0.00	$20.32	$80.94
USX	Clairton, PA	C	1	373,395	1989	$63.33	$0.00	$21.71	$85.03
USX	Clairton, PA	C	1	373,395	1989	$63.33	$0.00	$21.71	$85.03
USX	Clairton, PA	C	1	373,395	1979	$63.33	$1.04	$21.71	$86.07
USX	Clairton, PA	C	1	378,505	1955	$65.43	$1.04	$22.73	$89.20
USX	Clairton, PA	C	1	378,505	1955	$65.43	$1.09	$22.73	$89.25
USX	Clairton, PA	C	1	378,505	1955	$65.43	$1.09	$22.73	$89.25
USX	Clairton, PA	C	1	378,505	1954	$66.39	$1.09	$22.46	$89.94
USX	Clairton, PA	C	1	378,505	1954	$66.39	$1.04	$22.46	$89.89
USX	Clairton, PA	C	1	378,505	1954	$66.39	$0.00	$22.46	$88.85
USX	Gary, IN	C	1	827,820	1976	$65.47	$0.65	$23.24	$89.36
USX	Gary, IN	C	1	827,820	1975	$66.41	$0.65	$22.60	$89.67
USX	Gary, IN	C	1	297,110	1954	$72.99	$1.51	$24.76	$99.26
USX	Gary, IN	C	1	297,110	1954	$73.22	$1.51	$25.94	$100.67
Wheeling-Pitt	Follansbee, WV	C	1	782,000	1977	$57.95	$0.31	$15.61	$73.87
Wheeling-Pitt	Follansbee, WV	C	1	163,000	1964	$73.58	$1.36	$30.00	$104.93
Wheeling-Pitt	Follansbee, WV	C	1	151,000	1955	$74.69	$1.11	$29.28	$105.07
Wheeling-Pitt	Follansbee, WV	C	1	151,000	1953	$74.69	$1.11	$29.28	$105.07

[a] C = Captive; M = Merchant.

[b] 1 = Furnace; 2 = Foundry; 3 = Both.

Table B-11. Cost Data Summary for Merchant Coke Batteries: 2000

Facility Name	Location	Producer Type[a]	Coke Type[b]	Capacity (short tons/yr)	Start/ Rebuild Date	AVC[c] ($/short ton)	MACT ($/short ton)	AFC ($/short ton)	ATC ($/short ton)
ABC Coke	Tarrant, AL	M	2	490,528	1968	$66.46	$1.22	$17.91	$85.59
ABC Coke	Tarrant, AL	M	3	112,477	1951	$81.68	$2.69	$32.48	$116.85
ABC Coke	Tarrant, AL	M	3	96,962	1941	$86.10	$2.56	$36.12	$124.78
Citizens Gas	Indianapolis, IN	M	3	389,116	1979	$47.46	$1.05	$21.41	$69.92
Citizens Gas	Indianapolis, IN	M	2	128,970	1946	$79.85	$2.02	$43.85	$125.72
Citizens Gas	Indianapolis, IN	M	2	116,845	1941	$84.51	$2.13	$48.34	$134.98
Empire Coke	Holt, AL	M	2	108,026	1978	$88.52	$7.38	$38.11	$134.01
Empire Coke	Holt, AL	M	2	54,013	1978	$90.09	$11.14	$40.61	$141.84
Erie Coke	Erie, PA	M	2	130,073	1943	$73.99	$1.73	$46.76	$122.48
Erie Coke	Erie, PA	M	2	84,878	1952	$75.12	$1.48	$48.19	$124.78
Koppers	Monessen, PA	M	1	245,815	1981	$79.25	$0.12	$30.25	$109.63
Koppers	Monessen, PA	M	1	126,766	1980	$91.00	$0.36	$39.67	$131.03
New Boston	Portsmouth, OH	M	1	346,126	1964	$78.73	$1.35	$27.76	$107.84
Shenango	Pittsburgh, PA	M	1	514,779	1983	$78.87	$0.00	$28.29	$107.16
Sloss Industries	Birmingham, AL	M	3	184,086	1959	$44.32	$1.61	$25.59	$71.52
Sloss Industries	Birmingham, AL	M	1	133,931	1952	$79.78	$1.61	$30.30	$111.69
Sloss Industries	Birmingham, AL	M	1	133,931	1956	$79.78	$1.61	$30.30	$111.69
Tonawanda	Buffalo, NY	M	2	268,964	1962	$39.80	$2.03	$34.09	$75.92

[a] C = Captive; M = Merchant.

[b] 1 = Furnace; 2 = Foundry; 3 = Both.

Table B-12. Cost Summary for Nonrecovery Coke Batteries: 2000 ($/ton of coke)

	Nonrecovery
Number of batteries	8
Metallurgical coal	
Average	$47.58
Minimum	$46.95
Maximum	$48.21
Labor	
Average	$2.07
Minimum	$1.47
Maximum	$2.68
Energy	
Average	$6.45
Minimum	$6.25
Maximum	$6.71
Other	
Average	$2.53
Minimum	$2.44
Maximum	$2.66
Average fixed cost	
Average	$10.62
Minimum	$10.07
Maximum	$11.13
Average total cost	
Average	$69.25
Minimum	$67.51
Maximum	$70.12

Table B-13. Cost Data Summary for Nonrecovery Coke Batteries: 1997

Facility Name	Location	Producer Type[a]	Coke Type[b]	Capacity (short tons/yr)	Start/ Rebuild Date	AVC[c] ($/short ton)	MACT ($/short ton)	AFC ($/short ton)	ATC ($/short ton)
Jewell Coke and Coal	Vansant, VA	M	1	197,000	1966	$58.59	$0.00	$9.90	$68.49
Jewell Coke and Coal	Vansant, VA	M	1	164,000	1983	$59.31	$0.00	$10.38	$69.69
Jewell Coke and Coal	Vansant, VA	M	1	124,000	1989	$59.98	$0.00	$10.85	$70.83
Jewell Coke and Coal	Vansant, VA	M	1	164,000	1990	$59.31	$0.00	$10.38	$69.69
Indiana Harbor Coke Co	East Chicago, IN	M	1	325,000	1998	$62.36	$0.00	$10.52	$72.88
Indiana Harbor Coke Co	East Chicago, IN	M	1	325,000	1998	$62.36	$0.00	$10.52	$72.88
Indiana Harbor Coke Co	East Chicago, IN	M	1	325,000	1998	$62.36	$0.00	$10.52	$72.88
Indiana Harbor Coke Co	East Chicago, IN	M	1	325,000	1998	$62.36	$0.00	$10.52	$72.88

[a] C = Captive; M = Merchant.

[b] 1 = Furnace; 2 = Foundry; 3 = Both.

[c] Includes by-/co-product credits.

APPENDIX C

ECONOMETRIC ESTIMATION OF THE DEMAND ELASTICITY FOR IRON CASTINGS

In this appendix, we summarize the econometric procedure used to estimate demand elasticities and present demand elasticity estimates for iron and steel castings. Elasticity estimates are based on national-level annual sales and price data. In addition, individual demand elasticity estimates are developed for three subcategories of iron castings:

- gray iron castings,
- ductile iron castings, and
- malleable iron castings.

C.1 Econometric Model

A partial equilibrium market supply/demand model is used to simulate the interaction of producers and consumers in the iron and steel casting markets. The model consists of a system of interdependent equations in which the price and output of a product are simultaneously determined. This class of model is referred to as a simultaneous equation model.

In simultaneous equation models, where variables in one equation feed back into variables in another equation, the error terms in each equation are correlated with the endogenous variables (price and output). In this case, single-equation ordinary least squares (OLS) estimation of individual equations will lead to biased and inconsistent parameter estimates.

We therefore use a two-stage least squares (2SLS) approach to correct for the correlation between the error term and the endogenous variables. The 2SLS approach requires that each equation be identified through the inclusion of exogenous variables to control for shifts in the supply and demand curves over time.

Exogenous variables influencing the demand for iron and steel castings include measures of economic activity such as U.S. gross domestic production, the number of motor vehicle sales, and the price of substitute products such as plastics, nonferrous castings and forgings, and steel mill products (typically proxied by the appropriate producer price indices). Exogenous variables influencing the level of supply include measures of the change in the costs of iron and steel castings production caused by changes in prices of key inputs such as raw materials, fuel, and labor (typically proxied by the producer price index for iron ore, coke, fuel, and electricity as well as the average hourly earnings for the industry's production workers).

The supply/demand system for a particular iron or steel casting over time (t) is defined as follows:

$$Q_t^d = f(P_t, Z_t) + u_t \qquad (C.1)$$

$$Q_t^s = g(P_t, W_t) + v_t \qquad (C.2)$$

$$Q_t^d = Q_t^s \qquad (C.3)$$

Eq. (C.1) represents quantity demanded, Q_t^d in year t as a function of price, P_t, and other demand factors, Z_t (e.g., measures of economic activity and prices of substitute products), and an error term, u_t. Eq. (C.2) represents quantity supplied, Q_t^s, in year t as a function of price and other supply factors, W_t (e.g., wage rate and other input prices), and an error term, v_t. Eq. (C.3) specifies the equilibrium condition, where quantity supplied equals quantity demanded in year t. Eq. (C.3) creates a system of three equations in three variables. Solving the system generates equilibrium values for the variables P_t^* and $Q_t^*=Q_t^{d*}=Q_t^{s*}$.

We use a 2SLS regression procedure to estimate the parameters and obtain the demand elasticities.[1] In the first stage of the 2SLS procedure, the observed price is regressed against the supply and demand "shifter" variables that are exogenous to the system. The first stage produces fitted (or imputed) values for the price variable that are, by definition, highly correlated with the true endogenous variable (the observed price) and uncorrelated with the error term. In the second stage, these fitted values are then employed as explanatory variables of the right-hand side in the demand function. The imputed value is uncorrelated with the error term by construction and thus does not incur the endogeneity bias.

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[1] The 2SLS approach was selected over the three-stage least squares (3SLS) approach because of the limited number of observations available for the regression analysis. The 3SLS approach requires more degrees of freedom for the estimation procedure.

The logarithm of the quantity demanded is modeled as a linear function of the logarithm of the commodity price. This specification enables us to interpret the price variable coefficient as a constant elasticity of demand.

C.2 Econometric Results

Demand elasticities are estimated based on commodity data from the U.S. Department of Commerce, U.S. Bureau of Labor Statistics, and other government sources. The average prices for iron and steel commodities are calculated based on value of shipments data from 1987 through 1997. Prior to estimating demand elasticities, all prices are deflated by the gross domestic product (GDP) implicit price deflator to reflect real rather than nominal prices.

Table C-1 provides demand elasticity estimates for iron and steel castings. The coefficients on the price variables, ln (price), are the estimates of the demand elasticity. Demand elasticity reflects how responsive consumers are to changes in the price of a product. For normal goods, consumption decreases as price increases, and this negative relationship is shown by a negative price variable coefficient. As economic theory predicts, our estimated coefficients on the price variables are negative.

As shown in Table C-1, all of the individual elasticity estimates are inelastic, implying that a 1 percent increase in price results in a less than 1 percent decrease in consumption. Individual demand elasticity estimates for the iron casting subcategories range from –0.41 for malleable iron castings to –0.67 for gray iron castings. As shown in Table C-1, the econometrically determined demand elasticity for all iron castings was –0.58. Similarly, the demand elasticity for steel castings was –0.59. Both estimates are significant at the 95 percent or higher confidence level.

Table C-1. Two Stage Least Squares Regression Estimation of Iron and Steel Castings Demand Equations

		Dependent Variables			
		Iron Castings			
Independent Variables	**Steel Castings**	**Gray Iron**	**Ductile Iron**	**Malleable Iron**	**All Iron**
Constant	–37.35	0.81	0.82	–3.12	–42.90
	(–1.59)	(0.43)	(0.20)	(–1.04)	(–8.15)***
ln(price)	–0.59	–0.67	–0.42	–0.41	–0.58
	(–2.26)**	(–2.80)**	(–1.89)*	(–1.51)	(–2.52)**
ln(gdpd)	2.75	—	—	—	5.17
	(1.82)				(11.10)***
ln(motor)	—	0.91	1.01	0.61	—
		(9.97)***	(4.62)***	(3.79)***	
ln(PPI_plast_parts_trans)	2.18	0.09	—	—	—
	(1.00)	(0.26)			
ln(PPI_nonferr_forge)	—	0.50	—	0.04	–2.57
		(1.37)		(0.07)	(–6.33)***
ln(PPI_nonferr_foundry)	2.92	—	1.83	—	—
	(2.09)*		(1.88)*		
ln(PPI_plast_parts_mfg)	—	—	–0.90	1.07	4.58
			(–1.22)	(3.48)***	(7.97)***
ln(pipe_price)[a]	—	0.16	–0.57	0.14	0.23
		(0.76)	(–0.95)	(0.41)	(0.95)
R-Squared	0.68	0.97	0.92	0.89	0.97
Adjusted R-Squared	0.52	0.94	0.87	0.81	0.94
F Value	4.23**	33.90***	17.08***	11.49***	38.46***
Observations	13	12	13	13	12
Degrees of Freedom	4	5	5	5	5

Note: T-statistics of parameter estimates are in parentheses. The F test analyzes the usefulness of the model. Asterisks indicate significance levels for these tests as follows: * = 90%, ** = 95%, *** = 99%

[a] Price of corresponding casting.

Variable Descriptions:

ln(gdp)	real gross domestic product	ln(PPI_nonferr_forge)	real producer price index for nonferrous metal forge shop products
ln(motor)	U.S. motor vehicle production	ln(PPI_plast_parts_mfg)	real producer price index for parts and components for manufacturing
ln(PPI_plast_parts_trans)	real producer price index for plastic parts for transportation	ln(pipe_price)	real producer of steel mill pipe and tube products
		ln(PPI_nonferr_foundry)	real producer price index for nonferrous foundry shop products

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16. ABSTRACT

This report evaluates the economic impacts of the final NESHAP for melting furnace; scrap preheating; pouring, cooling and shakeout (PCS); mold and core coating; and mold and core making operations at iron foundries. The social costs of the rule are estimated by incorporating the expected costs of compliance to a partial equilibrium model and projecting the market impacts for iron and steel castings and related products. The report also provides the screening analysis for small business impacts.

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