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Economic Impact Analysis of Proposed Iron and Steel Foundries NESHAP

Final Report

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Economic Impact Analysis of Proposed Iron and Steel Foundries NESHAP

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This report contains portions of the economic impact analysis report that are related to the industry profile.

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.

[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.

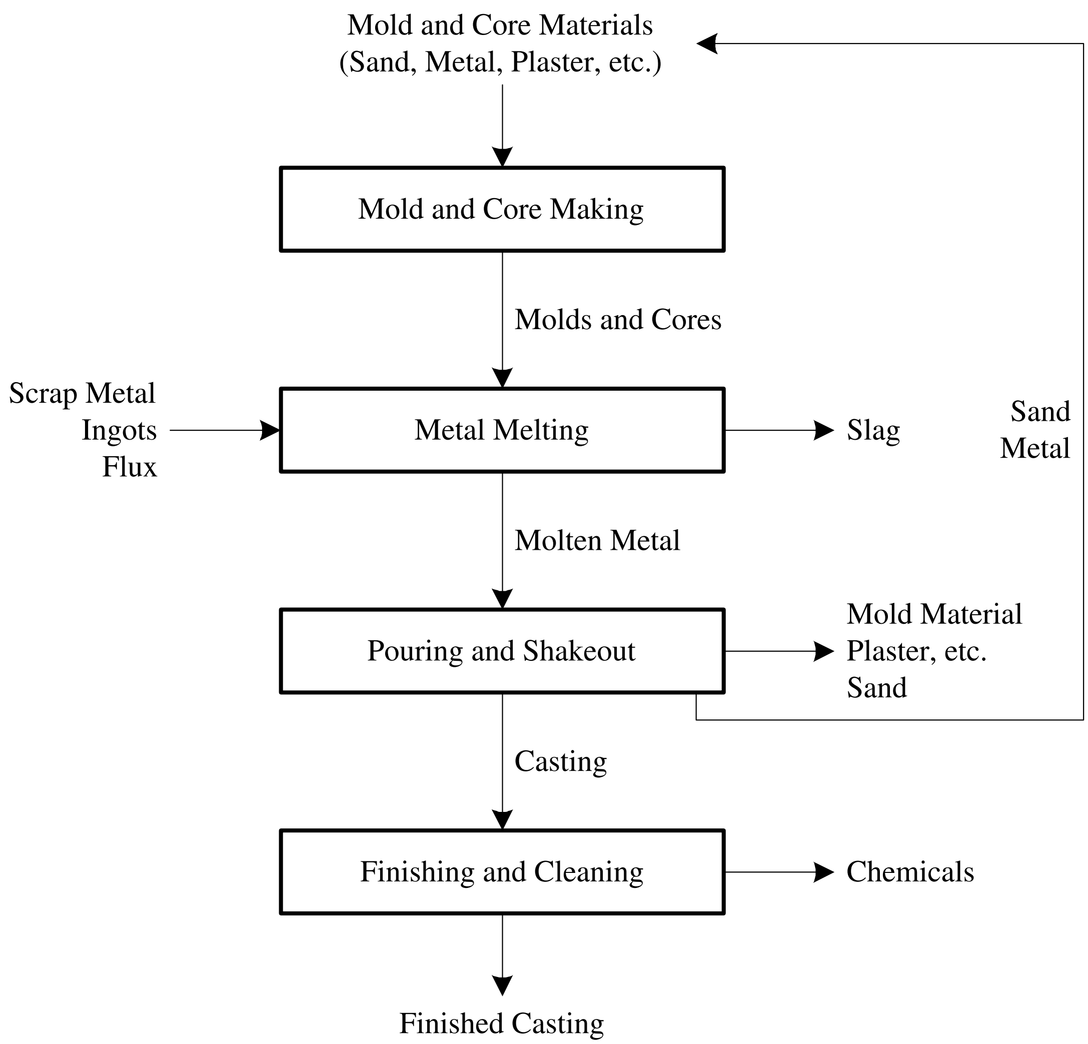


Figure 2-1. Overview of the Foundry Casting Processes

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. 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. 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.

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 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

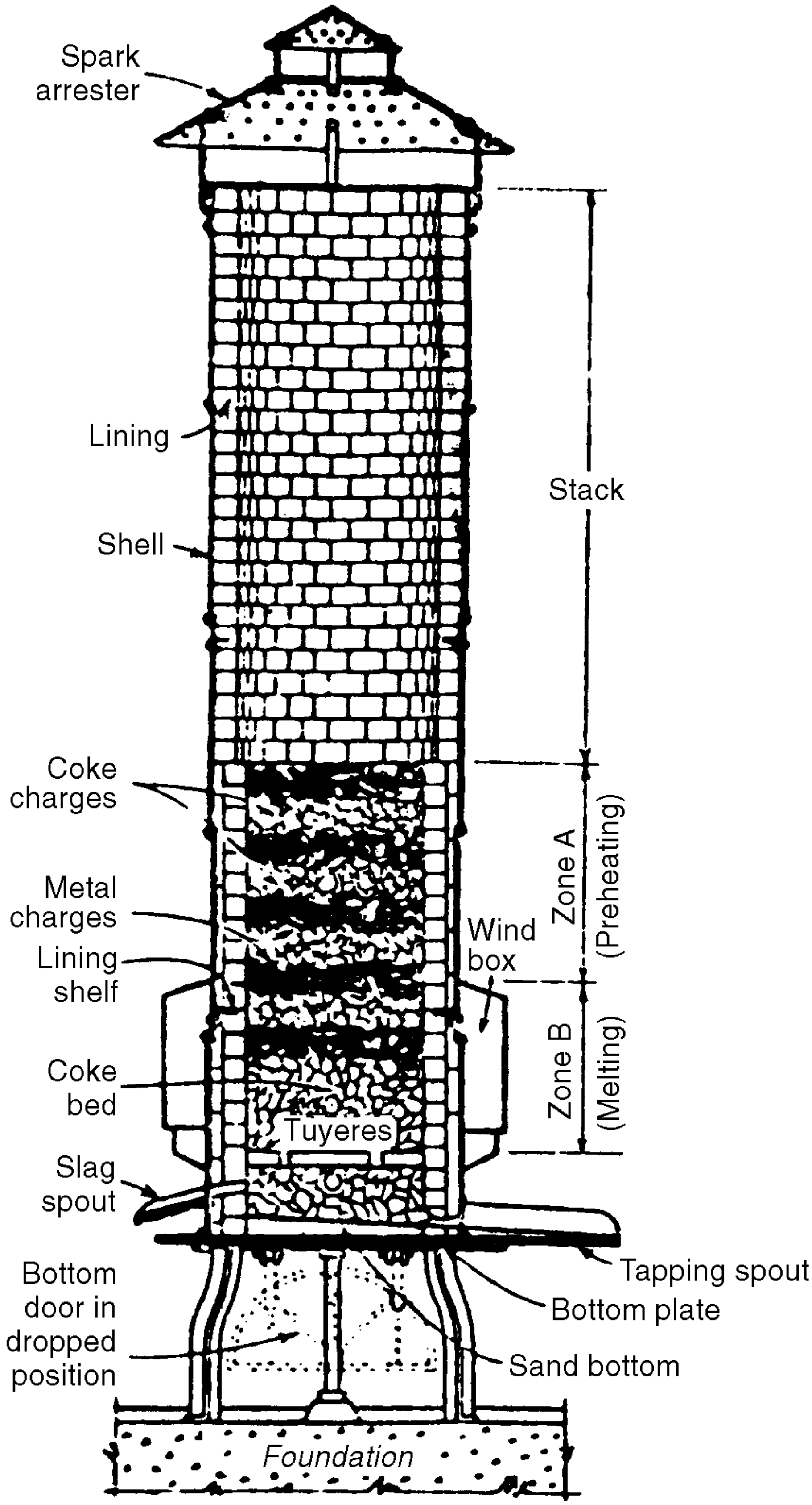
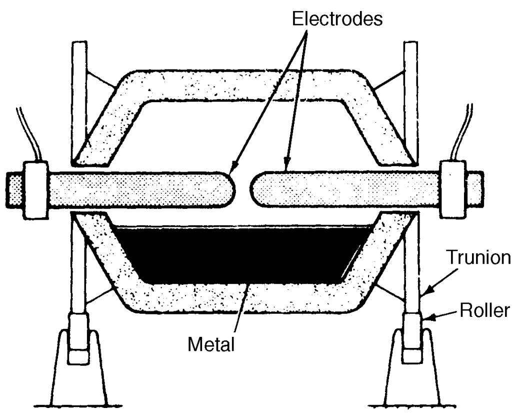


Figure 2-2. The Cupola Furnace

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

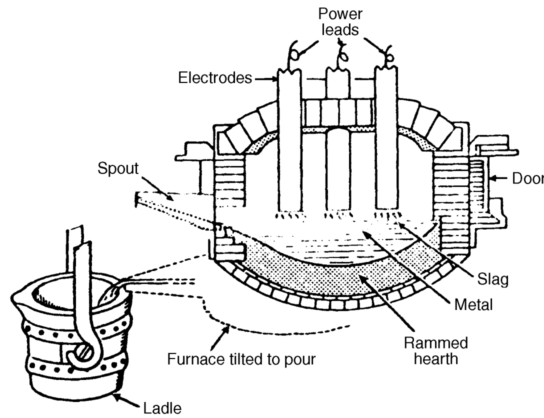


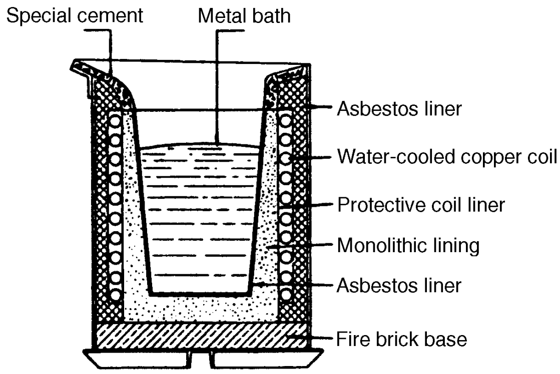
Figure 2-3. Indirect and Direct Electric Arc Furnaces

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.

Coreless



Channel

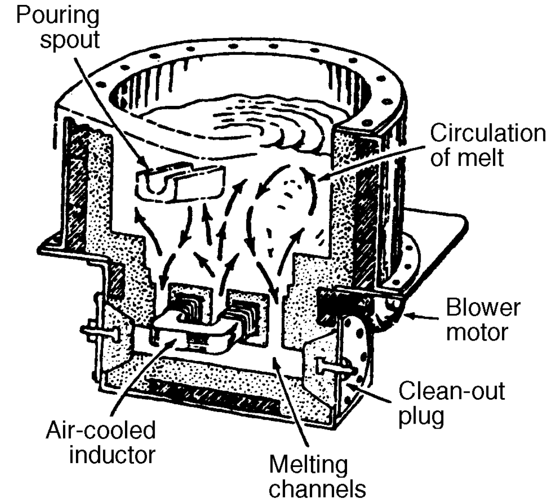


Figure 2-4. Coreless and Channel Electric Induction Furnaces

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.

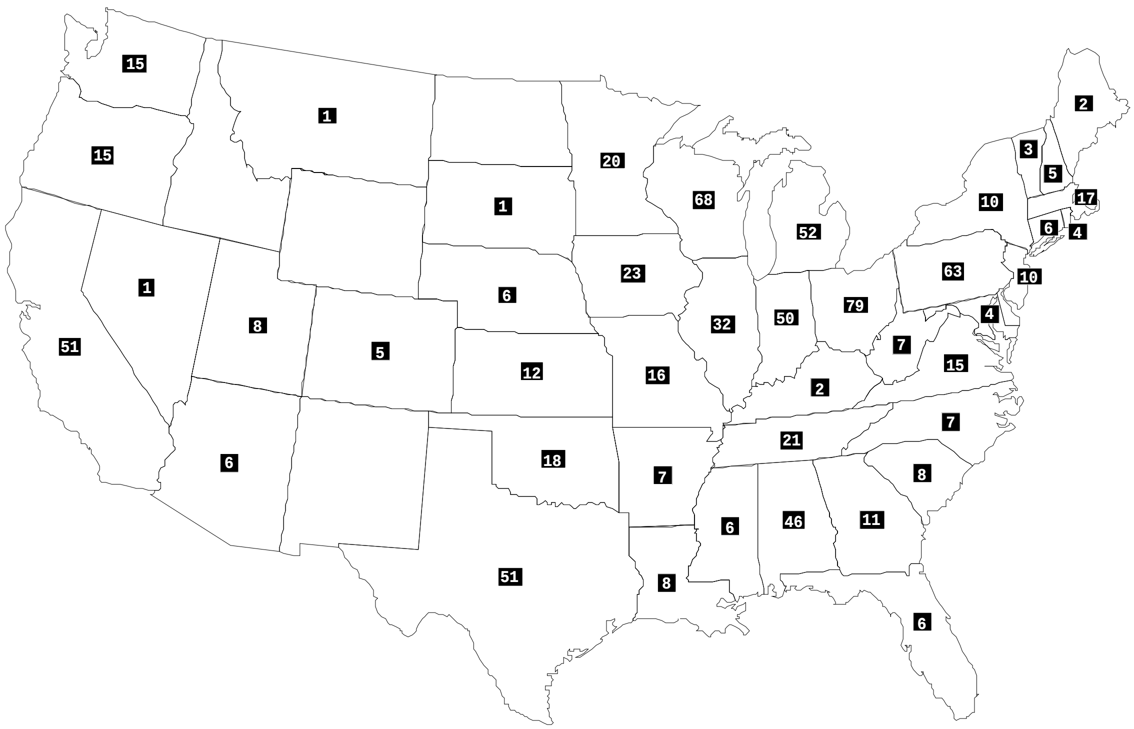


Figure 2-5. Number of U.S. Iron and Steel Foundries by State: 1997

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 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 proposed 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.

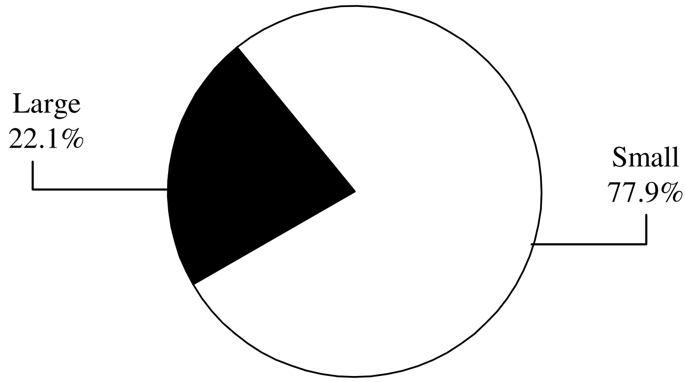


Figure 2-7. Distribution of Affected U.S. Companies by Size: 1997[a]

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

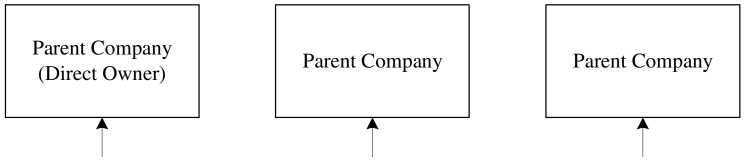


Figure 2-6. Possible Ownership Configurations for U.S. Iron and Steel Foundries

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.

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

Year	Iron Castings: Ductile	Iron Castings: Gray	Iron Castings: 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

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