The Chlorine Industry: A Profile

Draft Report

Prepared for

Aaiysha F. Khursheed
U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Strategies and Standards Division
MD-15
Research Triangle Park, NC 27711

Prepared by

Carol A. Mansfield
Brooks M. Depro
Virginia A. Perry
Research Triangle Institute
Center for Economics Research
Research Triangle Park, NC 27709

EPA Contract Number 68-D4-99-024

RTI Project Number 7647-001-016

August 2000

EPA Contract Number
68-D4-99-024

RTI Project Number
7647-001-016

The Chlorine Industry: A Profile

Draft Report

August 2000

Prepared for

Aaiysha F. Khursheed
U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Strategies and Standards Division
MD-15
Research Triangle Park, NC 27711

Prepared by

Carol A. Mansfield
Brooks M. Depro
Virginia A. Perry
Research Triangle Institute
Center for Economics Research
Research Triangle Park, NC 27709

CONTENTS

LIST OF FIGURES

LIST OF TABLES

SECTION 1
INTRODUCTION

This document provides background information on the chlorine production category that is subject to the U.S. Environmental Protection Agency's (EPA's) proposed National Emissions Standard for Hazardous Air Pollutants (NESHAP). This information will be used in support of the economic impact analysis (EIA) and regulatory flexibility analysis for that regulation. These analyses are economic assessments and, as such, this document focuses on economic aspects of the industry such as production technology, cost factors, product uses and substitutes, domestic market activity, and international trade.

The U.S. Census Bureau refers to the "chlorine" industry as the "alkalies and chlorine" industry (SIC 2812), but it is also referred to as the "chlor-alkali" industry. Although itself a significant economic commodity, chlorine is linked with other products because of the unique characteristics of its production process. As described in more detail below, chlorine is typically produced by a chemical process that jointly creates both chlorine and the alkali sodium hydroxide (caustic soda) in fixed proportions. As a result, chlorine and sodium hydroxide are joint commodities and must be considered together in an economic analysis. Both chlorine and sodium hydroxide are among the ten largest chemical commodities by volume in the United States (see Table 1-1) (Shakhahiri, 2000).

1.1 Regulated Source Category and Entities

The Background Information Document (BID) prepared for EPA (EC/R Incorporated, 1996) provides information related to the source category and entities affected by the NESHAP. This section summarizes information found in that document.

Section 112(c)(1) of the Clean Air Act (CAA) and its amendments direct EPA to publish a list of all categories and subcategories of major stationary and area sources of the identified hazardous air pollutants (HAP). A major source is defined as "any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has the potential to emit, in the aggregate, 10 tons per year or more of

Table 1-1. Top Ten U.S. Chemicals by Mass: 1997

Rank	Chemical	Mass (10^9 lbs)
1	Sulfuric acid	95.6
2	Nitrogen	82.8
3	Oxygen	64.8
4	Ethylene	51.1
5	Lime	42.5
6	Ammonia	38.4
7	Phosphoric acid	33.6
8	Propylene	27.5
9	Ethylene dichloride	26.3
10	Chlorine	26.0

Source: Shakhahiri, B.Z. 2000. Chemical of the Week: Sulfuric Acid. <http://www.scifun.chem.wisc.edu/CHEMWEEK/sulf&top/Sulf&top.html>. Obtained June 15, 2000.

any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants" (CAA, Section 112(a)(1)). The chlorine production category is being evaluated as a potential major source of HAP emissions.

The NESHAP will potentially affect forty-three (chlorine production) facilities known to be in operation in 1997. Thirty-nine of the facilities use the chlor-alkali processes, jointly producing sodium hydroxide. Three chlor-alkali processes exist: diaphragm cell, membrane cell, and mercury cell. The remaining facilities use one of four other processes that exist to produce chlorine: Downs sodium process, magnesium production process, hydrogen chloride (HCl) decomposition, and nitric acid salt process.

In their 1996 background information document (BID), EPA described production processes at 39 chlorine facilities. Thirty-six of the facilities analyzed used chlor-alkali production processes. The three remaining facilities used either the Downs sodium process, HCI decomposition, or the nitric acid salt process.

The BID estimates the following HAP emissions by source:

- Chlor-alkali facilities accounted for 77.7 tons per year of HAP emissions; 46.5 tons per year were from the cell room and process fugitives.

- The other four chlorine production processes reported 14.4 tons per year of chlorine emissions.
- Individual facility total HAP emissions ranged from 0 to 9 tons per year.
- The average facility HAP emissions are just under 2.4 tons per year.
- The highest-emitting facility was the Downs sodium facility at 9 tons per year.
- The highest-emitting chlor-alkali facility reported 8 tons per year.

No chlorine facilities have been identified as major sources of HAPs.[1] However, EPA has been unable to declare that there are no major HAP sources in the chlorine industry since some chlorine production facilities are located at plant sites where HAP emissions from the entire site exceed major source levels. This is because these sites produce multiple chemicals (EPA, 1996).

1.2 Data Sources

Information for this industry was obtained from the BID, government document searches, literature searches, and reference material. Government data on this industry are reported under Standard Industrial Classification (SIC) code 2812 (Alkalies and Chlorine). Products of this industry also are collected in the *Current Industrial Report* (CIR) MA-28A (U.S. Department of Commerce, year). The MA-28A records annual and quarterly data. Primary products of the chlor-alkali industry are chlorine (compressed or liquefied) and sodium hydroxide.

A primary reference for this profile was the *1992 Census of Manufactures* report on industrial inorganic chemicals (U.S. Department of Commerce, 1996). Data were collected for the chlor-alkali industry and reported under SIC code 2812. The Agency obtained production and other market data from the Chemical Economics Handbook (Berthiaume, Anderson, and Yoshida, 2000). Data on individual chlorine-producing facilities were gathered from the BID. Finally, the Chlorine Institute, an organization supported by the Chlorine Chemistry Council, provided data not available through these publications.

---

[1]Major sources are defined as plants that emit 10 tons per year or more of any single HAP or 25 tons per year or more of any combination of HAPs.

1.3 Regulatory Environment

Several prominent end uses for chlorine have raised considerable environmental concerns and have affected demand for the product. Because of their role in the depletion of the upper atmosphere ozone layer, chlorofluorocarbons (CFCs), which are chlorine derivatives, and certain other substances were banned from production on January 1, 1996, via the Montreal Protocol. Production data for three key CFCs subject to the ban are provided in Table 1-2 (*Chemical and Engineering News,* 1996). Some of the replacement compounds for CFCs are also chlorine derivatives, such as hydrochlorofluorocarbons, but they make up for only a small percentage of the loss in product due to the CFC ban.

Table 1-2. Chlorofluorocarbons Production (10^6 pounds)

Year	CFC-22	CFC-12	CFC-11
1985	235	302	176
1986	271	322	202
1987	275	335	198
1988	333	414	249
1989	343	392	192
1990	306	209	135
1991	314	157	99
1992	331	163	100
1993	291	185	72
1994	306	127	19
1995	262	55	NA
Average	297	242	144

CFC-22 is chlorodifluoromethane.
CFC-12 is dichlorodifluoromethane.
CFC-11 is trichlorofluoromethane.
NA = not available

Source: "Facts and Figures for the Chemical Industry." *Chemical and Engineering News*. June 24, 1996.

In addition, the pulp and paper industry has been under considerable pressure to reduce the dioxins found in water that result from chlorine bleaching. EPA has issued wastewater permit levels that specify levels of total organic compounds that can be released.

The permits, along with environmentally acceptable alternative pulp treatment processes, will result in a decrease in chlorine consumption by the pulp and paper industry.

1.4 Overview of Profile

The remainder of this profile begins by characterizing the supply side of the chlorine products industry, including the stages of the production process, the types of chlorine products, and the costs of production. Section 3 addresses the consumers, uses, and substitutes for chlorine products. The organization of the chlorine products industry is discussed in Section 4, including a description of U.S. manufacturing plants and the parent companies that own these plants. Finally, Section 5 presents historical statistics on U.S. production and consumption of chlorine products as well as data on the foreign trade of chlorine products.

SECTION 2

PRODUCTION OVERVIEW

This section describes the process by which chlorine and alkali co-products are produced and presents information on the configuration of production plants and the cost of production.

2.1 Chlor-Alkali Process[1]

More than 95 percent of the domestic chlorine produced results from the chlor-alkali process that involves the electrolysis of brine (*Chemical Week,* 1996). Figure 2-1 presents a simple diagram of this process. Chlorine and sodium hydroxide are co-products of electrolysis of sodium chloride brine. Electricity acts as a catalyst in this reaction, which takes place in electrolytic cells. The amount of electricity required depends on electrolytic cell parameters such as current density, voltage, anode and cathode material, and the cell design.

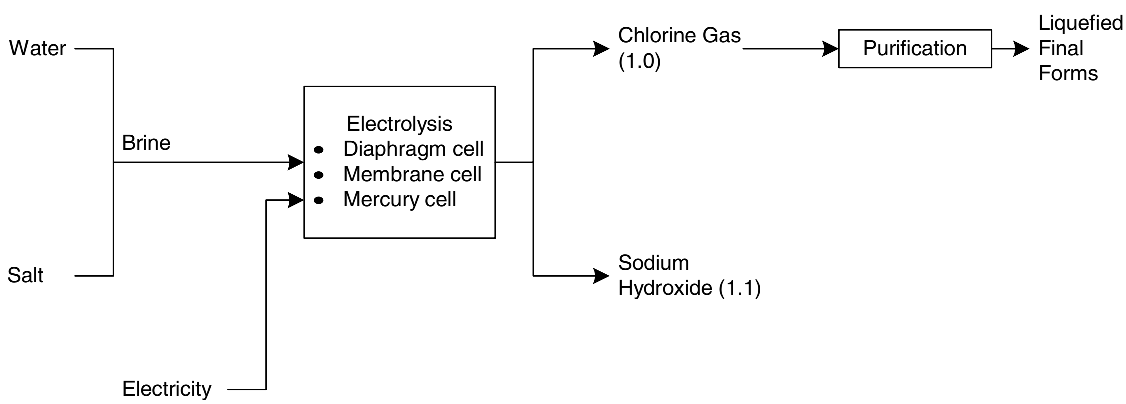

Figure 2-1. Chlor-Alkali Process

[1]The material in this section draws heavily from Kroschwitz (1991) and *Ullman's Encyclopedia of Industrial Chemistry* (1992). Any exceptions to this or specific references within these two sources are noted accordingly.

Conversion of sodium chloride brine to chlorine and sodium hydroxide can take place in one of three types of electrolytic cells: the diaphragm cell, the membrane cell, or the mercury cell. An important distinguishing feature of these cells is the manner by which the products are prevented from mixing with each other, thus ensuring generation of products having the proper purity (Kroschwitz, 1991).

The chlorine produced by the electrolysis of brine is then purified and liquified for commercial use. Important factors affecting the liquefaction process are the composition of the chlorine gas, the desired purity of the liquified chlorine, and the desired yield. Each of the main process steps is now described in more detail.

2.1.1 Chlorine Synthesis

As indicated previously, electrolysis is the primary method of chlorine production; however, other chlorine manufacturing processes exist. These operations generally capture chlorine as a co-product of the production of another chemical or as a result of a chemical reaction. Similarities exist across the cells used for electrolysis; however, there are important distinctions between the diaphragm cell, the membrane cell, and the mercury cell processes. The primary distinguishing characteristic is the manner by which the electrolysis products are prevented from mixing.

2.1.1.1 Diaphragm Cell Process

During the diaphragm production process, saturated brine enters the electrolytic cell and flows into an anode chamber (see Figure 2-2). As the brine flows past the anodes, chloride ions are stripped of the electrons to form chlorine gas. The solution passes through the diaphragm into the cathode chamber where sodium hydroxide (caustic soda) and hydrogen are produced. Chlorine gas is collected at the top of the cell, cooled, compressed, and liquified. The sodium hydroxide solution may undergo further purification steps, but it is generally suitable for over 80 percent of the caustic market. Hydrogen gas is collected at the top of the cell similar to chlorine, cooled and filtered, used on-site or sold off-site, or released to the atmosphere.

2.1.1.2 Membrane Cell Process

The membrane cell also contains an anode and cathode assembly, but they are separated by a semipermeable Nafion (Ion-exchange) membrane (see Figure 2-3). Brine flows into the annode chamber, but unlike the diaphragm process, chloride ions cannot

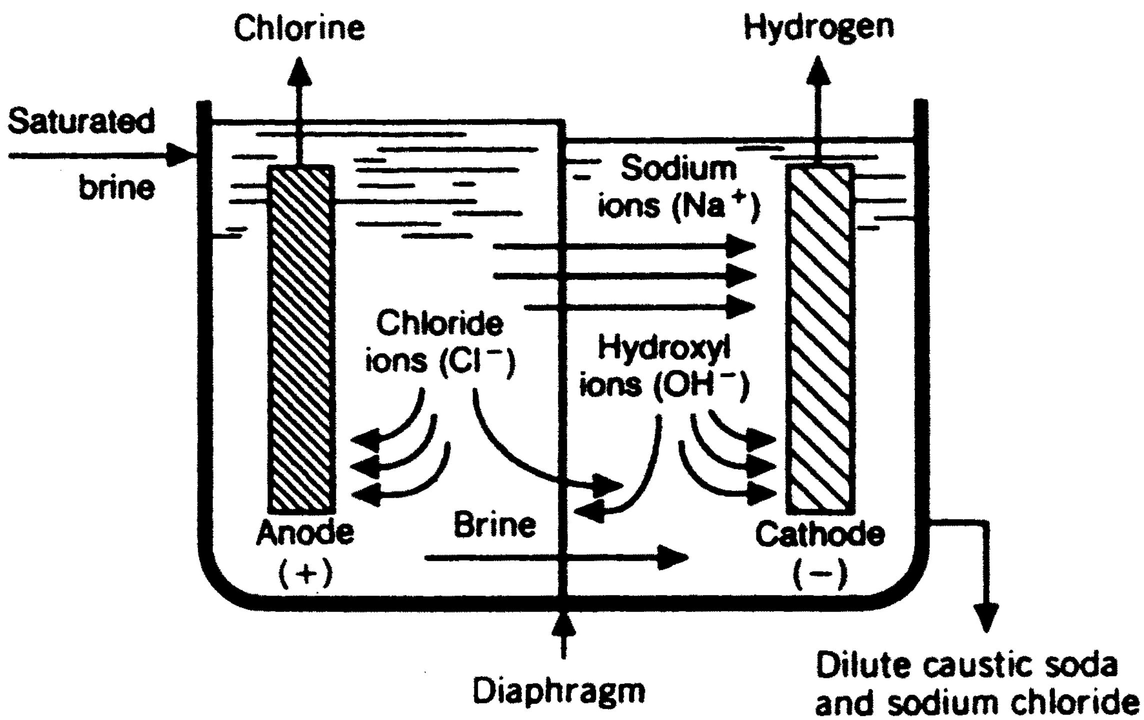

Figure 2-2. Schematic of the Diaphragm Cell Process

Source: Kroschwitz, Jacqueline. 1991. *Kirk-Othmer Encyclopedia of Chemical Technology*, 4th Ed. New York: John Wiley & Sons.

migrate through this membrane into the cathode chamber. An electric voltage is applied between the anode and cathode that generates chlorine gas in the anode and releases sodium ions and water into the cathode. The chlorine gas flows out of the anode chamber and is ducted to a chlorine purification section. In contrast, the catholyte solution is processed in an evaporation system where a sodium hydroxide (caustic soda) solution is obtained, filtered, and sold. The caustic soda derived from the membrane process is higher quality than that derived from the diaphragm process.

2.1.1.3 Mercury Cell Process

In the mercury cell process, chlor-alkali production involves two distinct cells. The electrolytic cell produces chlorine gas (see Figure 2-4), and a separate amalgam decomposer

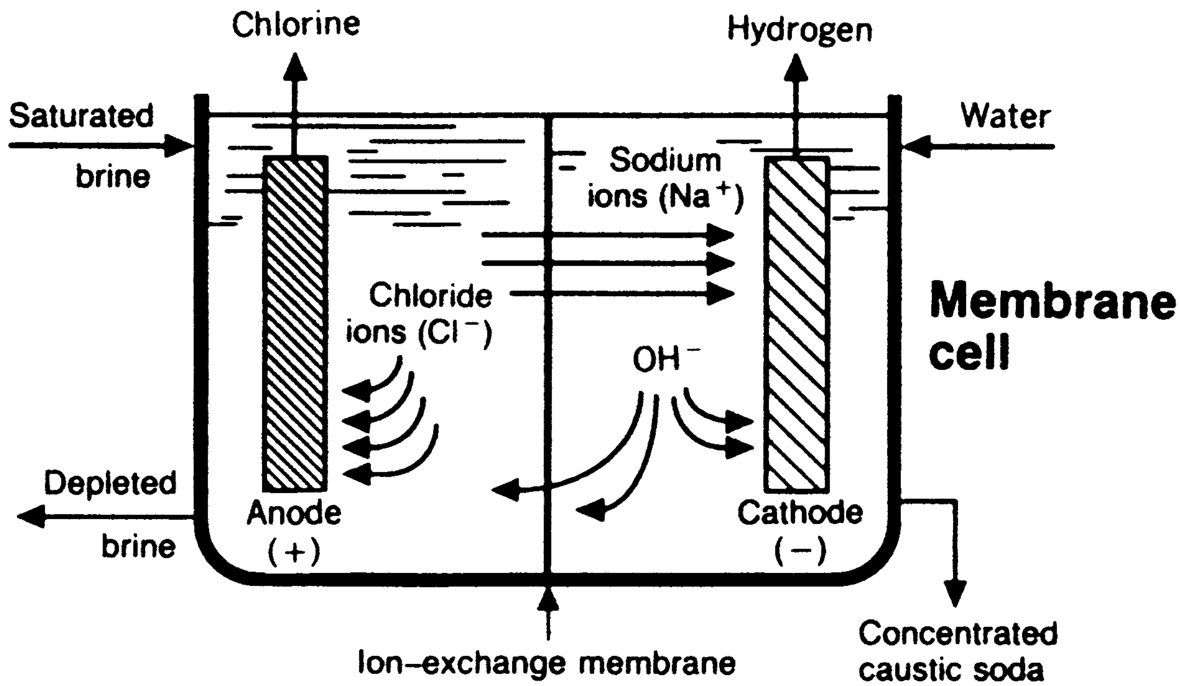

Figure 2-3. Schematic of the Membrane Cell Process

Source: EC/R Incorporated. September 12, 1996. *Background Information Document: Chlorine Production Summary Report.* Prepared for the U.S. Environmental Protection Agency. Durham, NC: EC/R Inc.

(not pictured) produces hydrogen gas and caustic solution.[2] A saturated salt brine is fed to the electrolytic cell, and the brine flows on top of a continuously fed mercury stream (which acts as the cathode in this process). An electric current is applied, causing a reaction that produces chlorine gas at the anodes suspended in the top of the cell and a mercury-sodium amalgam at the cathode. The chlorine is collected at the top of the cell while the amalgam proceeds to the decomposer. In the decomposer, the mercury amalgam comes in contact with deionized water where it reacts and regenerates into elemental mercury and produces caustic solution and hydrogen. Caustic solution and hydrogen are transferred to other processes for purification, and the mercury is recycled back into the cell. Like the diaphragm

[2]The decomposer is a short-circuited electrical cell in which graphite acts as the cathode and the amalgam as the anode.

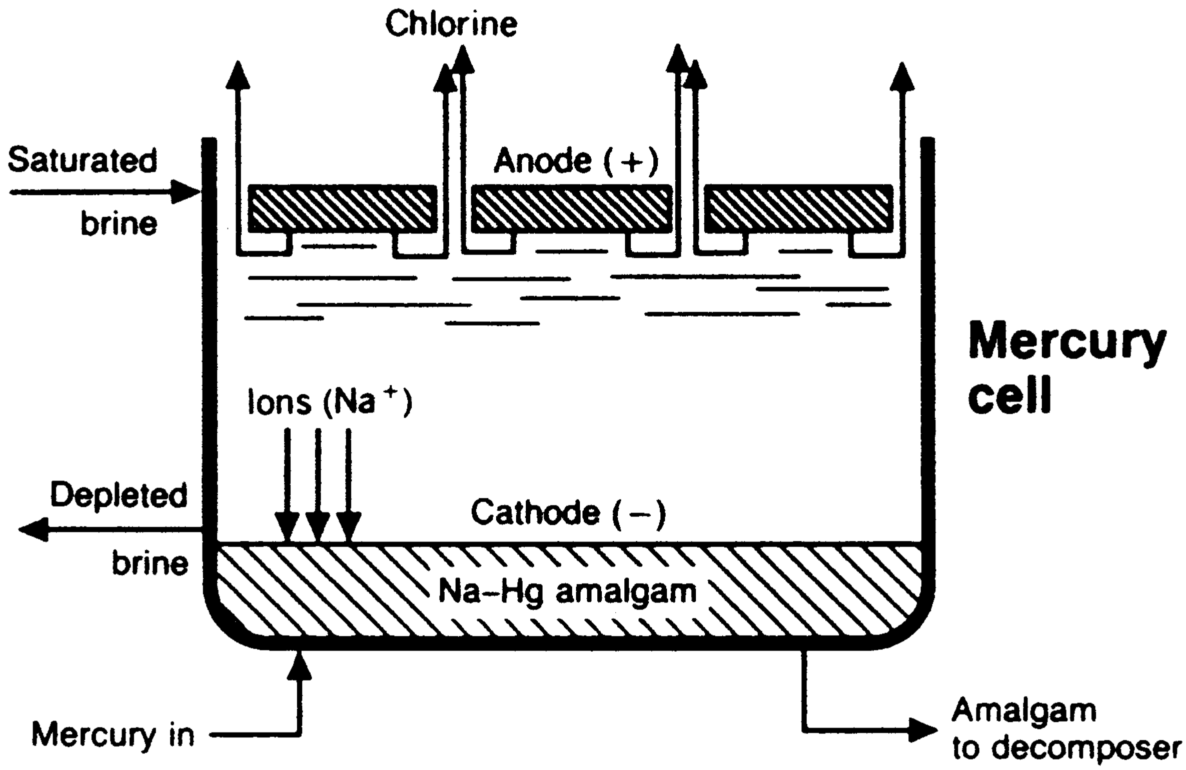

Figure 2-4. Schematic of the Mercury Cell Process

Source: EC/R Incorporated. September 12, 1996. *Background Information Document: Chlorine Production Summary Report.* Prepared for the U.S. Environmental Protection Agency. Durham, NC: EC/R Inc.

process, the mercury cell produces high quality caustic soda directly from the caustic solution.

Of the three electrolytic processes, the diaphragm and membrane processes are the most similar. Both share the advantage of lower electricity consumption. New plant construction has favored membrane cell construction because of low capital investment and operating costs relative to diaphragm and mercury processes. Membrane cells' share of domestic capacity increased from 3 percent in 1986 to 16 percent in 1999 (Chlorine Institute, 2000). Although still economical, the diaphragm process share of domestic capacity has declined slightly from 76 percent in 1986 to 71 percent in 1999. The diaphragm process produces a lower-quality caustic soda, which may be a contributing factor to this decline. The mercury cell process produces high-quality caustic soda with simple brine purification, but the use of mercury includes the cost disadvantages associated with environmental controls (Kroschwitz, 1991). Similar to the diaphragm process, the mercury process' share of domestic capacity has declined from 17 percent in 1986 to 12 percent in 1999. In addition, no new mercury cells have been built since 1970.

2.1.2 Other Chorine Synthesis Processes

While the vast majority of chlorine is produced by one of the three electrolytic methods, other commercial processes for chlorine also exist. EPA's Background Information Document (BID) identified facilities using the following "minor" chlorine production processes:

- Chloride production from hydrogen chloride: Electrolytic decomposition of aqueous hydrochloric acid is used to produce chlorine and hydrogen. The process is similar to the electrolytic processes described above with the exception that the input solution is hydrogen chloride (typically a 22 to 24 percent hydrogen chloride).

- Chlorine from sodium metal co-production with Downs cell: Molten salt consisting of sodium chloride, calcium chloride, and barium chloride is electrolytically broken down into sodium metal and chlorine gas using open top diaphragm cells. The Downs sodium cells require more maintenance (i.e., diaphragm replacement, purification) than the closed electrolytic chlor-alkali cells described earlier.

- Nitric acid salt process: One of the co-products during the electrolytic production of potassium hydroxide is chlorine. In this process, potassium chloride reacts with nitric acid and oxygen to form potassium nitrate, chlorine gas, and water. The potassium nitrate and water are drained form the reactor. Chlorine is liberated as a gas, along with nitrogen dioxide, and is liquified in refrigerated condensors.

- Co-production of magnesium and chlorine: Magnesium and chlorine are produced by fused salt electrolysis of magnesium dichloride. Chlorine is recycled through this process or it is sold commercially.

- Other production processes used to produce chlorine identified in the BID document include the nitrosyl chloride process, Kel-Chlor process, potash manufacture process, and sodium chloride/sulfuric acid process. However, no U.S. facilities were identified that use these processes.

2.1.3 Chlorine Purification

Regardless of the process, the chlorine stream leaving the synthesis stage is hot and saturated with water. Impurities in this chlorine stream include oxygen, nitrogen, carbon dioxide, carbon monoxide, hydrogen, and other contaminants produced through side reactions in the electrolytic process. To purify the chlorine, it is cooled, dried, and liquified. Chlorine gas is generally liquified for commercial use.

2.2 Forms of Output

2.2.1 Chlorine

Chlorine is a greenish-yellow gas belonging to the halogen family. It has a pungent odor and a density 2.5 times that of air. In liquid form, it is clear amber and solid chlorine forms pale yellow crystals. Chlorine is soluble in water and in salt solutions with solubility decreasing with salt strength and temperature. Chlorine is stored and transported as a liquefied gas. For shipping purposes, about 70 percent of chlorine is shipped by rail, 20 percent by pipeline, 7 percent by barges, and the remainder in cylinders (Kroschwitz, 1991).

2.2.2 Sodium Hydroxide

Sodium hydroxide, commonly referred to as caustic soda, is a brittle, white, translucent crystalline solid. Two types of caustic soda are produced:

- diaphragm caustic (50 percent rayon grade): This type is suitable for most applications and it accounts for approximately 85 percent of caustic soda consumption.
- membrane and mercury caustic: This type of caustic soda meets high purity requirements such as those required for rayon production. Membrane and mercury caustic are also produced in 73 percent caustic and anhydrous caustic forms.

2.3 Costs of Production

Energy and raw material costs represent the highest share of the chlor-alkali production costs. As shown in Table 2-1, these costs account for approximately 65 percent of total costs. The primary differences in operating costs between the three electrolysis processes (diaphragm, membrane, and mercury) result from variation in electricity requirements (Kroschwitz, 1991). Labor is another significant cost component, accounting for 21 percent of total production costs.

Table 2-1. Costs of Production for the Chlor-Alkali Industry (SIC 2812; NAICS 325181): 1997

	Value (10^3)	Share of Total Costs	Share of Value of Shipments
Raw materials and supplies	$537,520	33%	22%
Fuels and electricity	$527,228	32%	21%
Labor	$339,677	21%	14%
Depreciation	$145,890	9%	6%
Purchased services	$62,293	4%	3%
Rental payments	$13,862	1%	1%
Total	$1,626,470	100%	66%
Value of shipments	$2,465,183	NA	100%

NA = not available

Source: U.S. Department of Commerce, Bureau of the Census. 1999. *1997 Economic Census—Manufacturing Industry Series: Alkalies and Chlorine Manufacturing*. EC97M-3251E. Washington, DC. [online]. <http://www.census.gov/prod/www/abs/97ecmani.html>.

Total capital costs for a prototype 500 ton per day chlorine production plant are approximately $111 million (reported in 1990 dollars, the most recent year available). As shown in Table 2-2, the largest cost components are the electrolytic cells ($25.5 million) and the establishment of energy sources ($22.5 million). Although one company has recently converted a mercury process to a membrane process, conversion of mercury cells is generally considered a less attractive alternative to the construction of a new membrane plant. Cost estimates for this type of conversion range from $100,000 to $200,000 per ton per day. Electrolytic cells and membranes account for approximately 60 percent of the total investment (Kroschwitz, 1991).

Table 2-2. Capital Costs for 500 Ton per Day Chlorine Production Plant (10^6 $1990)

	Average Total Cost[a]
Cells	$25.5
Utilities and offsites	$22.5
Overhead	$11.7
Engineering	$11.7
Caustic evaporation	$8.3
Brine purification	$7.5
Miscellaneous	$6.7
Chlorine collection	$6.5
Caustic storage	$5.4
Rectifiers	$3.4
Hydrogen collection	$2.0
Total	$111.0

[a] Capital costs for mercury cell plants were not available and are not included in the calculation of averages.

Source: Kroschwitz, Jacqueline. 1991. *Kirk-Othmer Encyclopedia of Chemical Technology*, 4th Ed. New York: John Wiley & Sons.

SECTION 3

DEMAND FOR CHLORINE AND SODIUM HYDROXIDE

The previous section described supply side elements of the chlorine industry—how chlorine and its co-product, sodium hydroxide, are produced and what the costs of production are. This section addresses the demand side—the uses and consumers of chlorine and sodium hydroxide.

3.1 Chlorine Demand

Early uses of powdered and liquid chlorine included bleaching of textiles and paper, cleaning, and disinfecting (*Ullman's Encyclopedia of Industrial Chemistry*, 1992). Since 1950, chlorine has achieved increasing importance as a raw material in synthetic organic chemistry. Chlorine is an essential component of a multitude of end products that are used as materials for construction, solvents, and insecticides. In addition, chlorine is a component of intermediate goods used to make chlorine-free end products. These uses of chlorine generally influence chlorine production quantities in a given year.

3.1.1 Chlorine Uses

Consumers use chlorine in three major categories:

- organic chemicals,
- inorganic chemicals, and
- direct applications.

Chlorine is used as a material input into the production of organic and inorganic chemicals, which in turn are used in other production processes and/or products. Organic chemicals (those containing carbon) are typically used either as chemical intermediates or end products. Inorganic chemicals are used in the production of a wide variety of products, including basic chemicals for industrial processes (i.e., acids, alkalies, salts, oxidizing agents, industrial gases, and halogens); chemical products to be used in the manufacturing products (i.e., pigments, dry colors, and alkali metals); and finished goods for ultimate consumption (i.e., mineral fertilizers, glass, and construction materials) (EPA, 1995). Chlorine is also used in several direct applications, including bleaching (pulp and paper), waste water treatment, and sanitizing and disinfecting (i.e., for municipal water supplies and swimming pools).

As shown in Table 3-1, the composition of chlorine demand is expected to remain fairly stable, with a slight decrease in the percentage of chlorine consumed in direct applications.

Table 3-1. U.S. Chlorine Consumption

	Percentage of Total Production		
Use	**1995**	**1998**	**2003**
Organic chemicals	**74%**	**76%**	**80%**
PVC	26%	30%	33%
Inorganic chemicals	**14%**	**14%**	**13%**
Direct applications	**12%**	**10%**	**7%**
Pulp and paper	6%	4%	1%
Water treatment	4%	4%	4%

Source: Berthiaume, Sylvie, Eric Anderson, and Yuka Yoshida. 2000. *Chlorine/Sodium Hydroxide*. CEH Marketing Research Report. Chemical Economics Handbook—SRI International.

3.1.2 Major Chlorine Consumers[1]

Industry accounts for most of the direct chlorine consumption in the United States. The chemical industry consumes chlorine as an intermediate good in the production of other chemicals, such as polyvinyl chloride (PVC) resin. The pulp and paper and waste treatment industries use chlorine in direct applications. Households consume chlorine indirectly, as a component of other products such as PVC pipe, clean water, or cleaning products. Consumers of chlorine in 1998 are presented in Figure 3-1 and summarized below (Berthiaume, Anderson, and Yoshida, 2000).

[1]The material in this section draws heavily from Kroschwitz (1991) and *Ullman's Encyclopedia of Industrial Chemistry* (1992). Any exceptions to this or specific references within these two sources are noted accordingly.

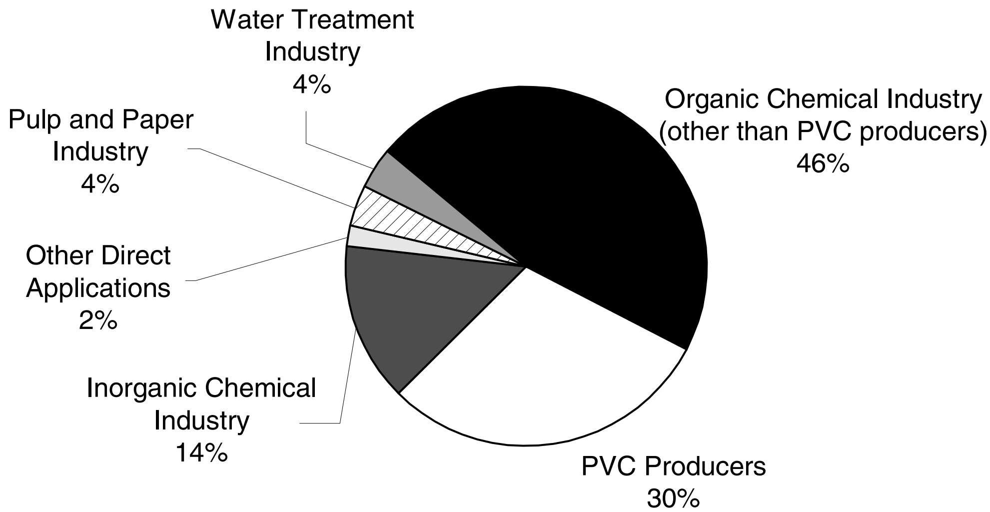

Figure 3-1. U.S. Chlorine Consumers, 1998

3.1.2.1 PVC Industry

In 1994, PVC accounted for approximately 34 percent of total chlorine demand. Chlorine is used primarily to manufacture ethylene dichloride, which is used in PVC production. More than 60 percent of PVC is used in building and infrastructure. Thus, construction and housing starts influence demand for chlorine. In developing countries, demand is particularly strong for pipes needed to upgrade areas to improve sanitation.

3.1.2.2 Propylene Oxide and Epichlorohydrin Industry

During the production of the organic chemical propylene oxide, chlorine reacts with propylene to make propylene chlorohydrin. After further processing, propylene oxide is made with other by-products (sodium or calcium chloride). Average annual growth of propylene oxide is between 1.5 and 2 percent per year and is based mostly on the growing demand for polyether polyol, a propylene oxide derivative used in urethane foam manufacturing. Epichlorohydrin, another organic chemical, is produced from dechlorinated allyl chloride and is primarily used to produce epoxy resins for the surface coating and composite industries. Chlorine consumption for epichlorohydrin is expected to grow between 2 and 2.5 percent annually and will be driven by the increased construction demand for epoxy resins.

3.1.2.3 Phosgene Industry

Phosgene, a chlorinated organic, is used primarily in polycarbonate production. Phosgene accounts for nearly 6 percent of chlorine consumption, and production is expected to grow around 3 percent annually. Polycarbonate resin is used for glazing and sheeting, polycarbonate composites, and alloys. Alloys are used to replace metal parts for the electronic and automobile industries.

3.1.2.4 C_1 Derivatives Industry

Industrial producers of carbon derivates (e.g., chlorinated methanes, chloroform, methylene chloride, and carbon tetrachloride) use chlorine as a material input during the production process. Aggregate growth in many of these organic compounds is expected to remain flat through the decade. Use of carbon tetrachloride in chloro-fluorocarbon manufacture will be phased out because of its contribution to ozone depletion. Some positive growth is expected for the use of chloroform in alternative CFCs, which have not been linked with ozone depletion.

3.1.2.5 Titanium Tetrachloride Industry

A majority of titanium dioxide production uses the chloride process where chlorine reacts with titanium to produce titanium tetrachloride. Titanium tetrachloride, an inorganic chemical, is further processed to create titanium dioxide, which is used primarily as a filler in pulp and paper manufacture and as a pigment in paint and plastics manufacture.

3.1.2.6 The Pulp and Paper Industry

In 1994, the pulp and paper industry accounted for 9 percent of U.S. chlorine consumption. However, concerns over chlorine's potential to form toxic chlorinated organics has had a negative effect on the use of chlorine in this industry. Growth in chlorine use in the pulp and paper industry has been negative in the 1990s, and recent substitutions of oxygen, hydrogen peroxide, and particularly chlorine dioxide for chlorine indicate the decline will be significant (Kroschwitz, 1991).

3.1.2.7 The Water Treatment Industry

Chlorine is an excellent bacteriostat unsurpassed for use in residual water treatment. Because of efforts by municipal and industrial water treatment facilities to increase chemical efficiency and concerns over chlorine's involvement in the formation of undesirable organic compounds, little growth is projected for chlorine used in water treatment. Chlorine demand in 1994 for use in water treatment was 5 percent of all uses, and demand in the year 2010 is projected to remain at 5 percent.

3.1.3 Substitutes for Chlorine

Because environmental regulations in general, and the proposed NESHAP in particular, have the potential to raise the price (and/or alter the quality) of the regulated commodities, the economic impact of the regulations may depend on the extent to which users of the commodity can substitute other commodities for the regulated one. To the extent that chlorine is used as a chemical ingredient in the production of a particular product, substitution of other materials is limited. However, factors that raise the price of a given chemical ingredient can lead to chemical reformulations that substitute away from that ingredient either by reducing its use per unit of output or by completely switching to another ingredient.

For example, chlorine is widely used as a bleaching agent. However, the characteristics that make chlorine a superb cleaning/bleaching agent also contribute to its adverse impact on surrounding environments when released from the production process. This has been particularly pronounced in the use of chlorine in pulp and paper productions, which leads to water effluents containing dioxin, a highly toxic substance. A combination of regulatory and voluntary efforts has led the pulp and paper industry to substantially reduce its releases of chlorine derivatives, partly through waste stream treatment improvements and partly through reduced use of chlorine. In recent years, many pulp makers have switched to elemental chlorine-free (ECF) pulp, which uses chlorine dioxide rather than elemental chlorine because the former essentially avoids the release of dioxin as a pollutant (Alliance for Environmental Technology, 1996).

Sodium hypochlorite is also a substitute for chlorine in waste water treatment and drinking water disinfection applications. Sodium hypochlorite is easier to handle than gaseous chlorine or calcium hypochlorite. It is, however, very corrosive and must be stored with care and kept away from equipment that can be damaged by corrosion. Hypochlorite solutions also decompose and should not be stored for more than 1 month (Minnesota Rural Water Association [MRWA], 2000).

3.2 Sodium Hydroxide Demand[2]

Three forms of sodium hydroxide are produced to meet marketplace demands (Kroschwitz, 1991). These are purified diaphragm sodium hydroxide (50 percent) grade, 73 percent sodium hydroxide, and anhydrous sodium hydroxide. Fifty percent grade sodium hydroxide accounts for 85 percent of the sodium hydroxide consumed in the United States. Five percent of sodium hydroxide produced on a yearly basis is concentrated to 73 percent solutions for special usage in rayon, for example. Seventy-three percent sodium hydroxide is a derivative of 50 percent sodium hydroxide and is stored in liquid tanks. The remainder is used to produce anhydrous sodium hydroxide. Anhydrous sodium hydroxide is produced from either 50 or 73 percent sodium hydroxide.

3.2.1 Sodium Hydroxide Uses

Sodium hydroxide has a wide variety of industrial applications, including its use as a cleaning agent, catalyst, anticorrosive compound, and an agent for maintaining alkaline pH levels.

The majority of 73 percent sodium hydroxide and anhydrous sodium hydroxide is used to manufacture rayon and for the synthesis of alkyl aryl sulfates. The majority of sodium hydroxide uses refer to 50 percent sodium hydroxide (Kroschwitz, 1991).

3.2.2 Major Sodium Hydroxide Consumers

As Figure 3-2 shows, sodium hydroxide is consumed by many of the same industries that consume chlorine, but it is consumed by a larger variety of industries than chlorine. Table 3-2 shows that the composition of sodium hydroxide demand is expected to remain stable for the next 5 years. Households consume sodium hydroxide only indirectly, when it is a component of other goods. The major industrial consumers of sodium hydroxide are discussed below.

---

[2]The material in this section draws heavily from Kroschwitz (1991) and *Ullman's Encyclopedia of Industrial Chemistry* (1992). Any exceptions to this or specific references within these two sources are noted accordingly.

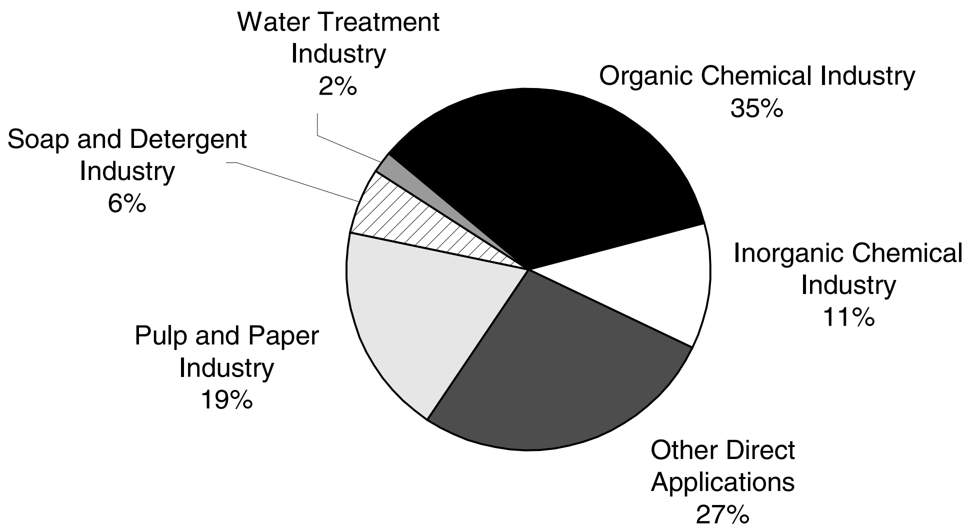

Figure 3-2. U.S. Sodium Hydroxide, 1998

Table 3-2. U.S. Sodium Hydroxide Consumption

	Percent of Total Production		
Use	**1995**	**1998**	**2003**
Organic chemicals	**36%**	**35%**	**35%**
Inorganic chemicals	**11%**	**11%**	**11%**
Direct applications	**52%**	**54%**	**54%**
Pulp and paper	19%	19%	16%
Soaps and detergents	6%	6%	6%
Water treatment	2%	2%	2%

Source: Berthiaume, Sylvie, Eric Anderson, and Yuka Yoshida. 2000. *Chlorine/Sodium Hydroxide*. CEH Marketing Research Report. Chemical Economics Handbook—SRI International.

3.2.2.1 The Chemical Industry

Chemical manufacturing accounts for over half of all U.S. sodium hydroxide demand. It is used primarily for neutralization, in off gas scrubbing, and as a catalyst. A large part of this category is used in the manufacture of organic intermediates, polymers, and end products. The majority of sodium hydroxide required here is for the production of propylene oxide, polycarbonate resin, epoxies, synthetic fibers, and surface-active agents.

3.2.2.2 The Pulp and Paper Industry

Pulp and paper manufacture accounts for about a quarter of total U.S. sodium hydroxide demand. The sodium hydroxide is used to pulp wood chips, to extract lignin during bleaching, and to neutralize acid waste streams. Changes in technologies aimed at decreasing chlorine use will also serve to decrease sodium hydroxide requirements. In addition, sodium hypochlorite, which requires sodium hydroxide in its manufacture, is under increased scrutiny in pulp and paper applications because of potential chloroform formation.

3.2.2.3 The Cleaning Product Industry

Sodium hydroxide is used in the production of a wide variety of cleaning products. This segment of the industry accounts for less than 10 percent of total consumption, but it is expected to continue growing by a small amount. Sodium hydroxide use in this segment goes into the production of soap and other detergent products, household bleaches, polishes, and cleaning goods.

3.2.2.4 Petroleum and Natural Gas

The sodium hydroxide used in the petroleum and natural gas industry is used to process oil and gas into marketable products, especially by removing acidic contaminants. The remainder is used primarily to decrease corrosion of drilling equipment and to increase the solubility of drilling mud components by maintaining an alkaline pH.

3.2.2.5 Cellulosics Producers

Rayon and other cellulose products such as cellophane and cellulose ethers also require sodium hydroxide. There are several very competitive substitute products and sodium hydroxide use in this area has decreased over the last 10 years.

3.2.3 Substitutes for Sodium Hydroxide

As discussed in Section 3.2.2, the NESHAP's effect on the price and quantity demanded of sodium hydroxide will be influenced by the availability of substitutes for sodium hydroxide. The more likely that sodium hydroxide consumers will substitute away from the product as its price rises, the more likely it is that the burden of regulatory costs will fall mostly on the producers of a commodity. Several close substitutes exist for caustic soda, including other alkalies and, in particular, soda ash and lime. Caustic soda has some attractive properties over substitute inputs for many uses, but it is usually more expensive. Many firms use caustic soda until the price increases too much; then they switch to lower-priced substitutes (Berthiaume, Anderson, and Yoshida, 2000).

SECTION 4

ORGANIZATION OF THE CHLOR-ALKALI INDUSTRY

This section identifies the major sources of chlorine and sodium hydroxide production and describes how these suppliers are organized in the respective markets. Firm-level data for owners of the production facilities are presented, where available. Market structure issues are also discussed in the context of key estimates of industry concentration.

4.1 Market Structure

Market structure is of interest because it determines the behavior of producers and consumers in the industry. In perfectly competitive industries, no producer or consumer is able to influence the price of the product sold. In addition, producers are unable to affect the price of inputs purchased for use in their products. This condition most likely holds if the industry has a large number of buyers and sellers, the products sold and inputs used in production are homogeneous, and entry and exit of firms are unrestricted. Entry and exit of firms are unrestricted for most industries, except in cases where the government regulates who is able to produce output, where one firm holds a patent on a product, where one firm owns the entire stock of a critical input, or where a single firms is able to supply the entire market. In industries that are not perfectly competitive, producer and/or consumer behavior can have an effect on price.

Concentration ratios (CRs) and Herfindahl-Hirschmann indices (HHIs) can provide some insight into the competitiveness of an industry. The U.S. Department of Commerce reports these ratios and indices for the four-digit SIC code level for 1992, the most recent year available. Table 4-1 provides the value of shipments, the four- and eight-firm concentration ratios, and the Herfindahl-Hirschmann index that have been calculated for the alkalies and chlorine industry (SIC 2812). It has been suggested that an industry be considered highly concentrated if the four-firm concentration ratio exceeds 50 percent, and in this industry, it far surpasses this threshold.

Table 4-1. Share of Value of Shipments by Number of Companies: SIC Code 2812—Alkalies and Chlorine in 1992

		Percentage Accounted for by		
Companies (number)	Total Value of Shipments ($$10^6$)	CR4	CR8	HHI[a]
34	2,786.9	75	90	1,994

[a] Herfindahl-Hirschmann Index is for the 50 largest companies.

Source: U.S. Department of Commerce, Bureau of the Census. 1999. *Concentration Ratios in Manufacturing*. MC92-5-2. Washington, DC. <http://www.census.gov/mcd/mancen/download/mc92cr.sum>. Last revised February 4, 1999.

The criteria for evaluating the HHIs are based on the 1992 Department of Justice's Horizontal Merger Guidelines. According to these criteria, industries with HHIs below 1,000 are considered unconcentrated (i.e., more competitive), those with HHIs between 1,000 and 1,800 are considered moderately concentrated (i.e., moderately competitive), and those with HHIs above 1,800 are considered highly concentrated (i.e., less competitive). In general, firms in less concentrated industries are more likely to be price takers, while those in more concentrated industries have more ability to influence market prices. Based on these criteria, the alkalies and chlorine industry is considered highly concentrated. The HHI data support the conclusion drawn from the concentration ratio data.

Though the concentration ratios and HHI indicate a highly concentrated market, several factors may mitigate the market power of chlorine companies. For the baseline year of 1997, EPA classified the 43 facilities as producing for either the merchant or captive markets. Vertically integrated firms produce the vast majority of chlorine as an input for a variety of final products (referred to as "captive production"). Only 27 percent of chlorine is sold on the merchant market, although 75 percent of the facilities affected by the proposed regulation operate in the merchant market. The HHI for the 12 companies that participate in the merchant market is 1,693—somewhat lower than the HHI for the industry as a whole. Furthermore, demand for chlorine is projected to grow slowly and the trend in the industry is towards vertical integration (Dungan, 2000), again potentially limiting the market power of chlorine producers.

Unlike the chlorine market, several close substitutes for caustic soda exist, in particular soda ash, and this limits the ability of caustic soda producers to significantly raise prices. Because most chlorine is produced for captive use and it is difficult to store, demand for chlorine dominates production decisions (Berthiaume, Anderson, and Yoshida, 2000). Thus, despite the concentrated nature of production, the market for caustic soda appears to be competitive.

4.2 Manufacturing Facilities

EPA identified 43 facilities in the United States engaged in chlorine production. The facilities are listed in Table 4-2 (EC/R Incorporated, 1996). As mentioned previously, the majority of chlorine production plants use the electrolyte processes (diaphragm, mercury, or membrane cells). These processes account for approximately 97 percent of chlorine production. Seven plants use a combination of two types of chlor-alkali cells. More specifically, diaphragm cells are used at 23 plants, mercury cells are used at 13 plants, and membrane cells are used at 8 plants. In addition, the HoltraChem facility in Acme, NC, facility recently converted from a mercury process to the diaphragm process. Figure 4-1 shows the distribution of chlorine production facilities across the United States. The facilities are concentrated in the Gulf Coast area because of the proximity of brine, a major input into chlorine production, and chemical companies that use chlorine as an input.

4.3 Industry Production and Capacity Utilization

Recent historical data on production capacity are presented in Tables 4-3 and 4-4 for chlorine and sodium hydroxide, respectively (Berthiaume, Anderson, and Yoshida, 2000; The Chlorine Institute, 2000). Because chlorine and sodium hydroxide are produced together and in fixed proportions, the capacity data possess very similar levels and trends.

Capacity increased slightly during the 1990s especially since 1995. Production levels rose steadily throughout the decade. Capacity utilization remained above 90 percent for most of the 1990s, reaching a peak in 1995. As a result, any future expansion in domestic output will likely need to come from new sources, either new plants or capacity expansion at existing plants.

Table 4-2. Summary of Chlorine Production Facilities by Location, Process, Age, and Type in 1997

Parent Company	Facility Location		Process	Year Built	Type[a]
ASHTA	Ashtabula	OH	Mercury	1963	Merchant
Bayer AG	Baytown	TX	HCL electrolysis	1987	Captive
Dow Chemical	Plaquemine	LA	Diaphragm	1958	Merchant
Dow Chemical	Freeport	TX	Diaphragm	1940	Merchant
Dupont Chemical	Niagra Falls	NY	Downs sodium	1898	Captive
Elf Aquitaine	Portland	OR	Diaphragm/membrane	1947	Merchant
Formosa Plastics	Baton Rouge	LA	Diaphragm	1937	Captive
Formosa Plastics	Point Comfort	TX	Membrane	1993	Captive
Fort James	Rincon	GA	Membrane	1990	Captive
Fort James	Muskogee	OK	Membrane	1980	Captive
Fort James	Green Bay	WI	Diaphragm	1968	Captive
General Electric	Burkville	AL	Diaphragm	1987	Captive
General Electric	Mt. Vernon	IN	Diaphragm	1976	Captive
Georgia Gulf	Plaquemine	LA	Diaphragm	1975	Captive
Georgia Pacific	Bellingham	WA	Mercury[b]	1965	Merchant
HoltraChem	Orrington	ME	Mercury	1967	Merchant
HoltraChem	Acme	NC	Mercury[c]	1963	Merchant
LaRoche Chemical	Grammercy	LA	Diaphragm	1958	Merchant
Magnesium Corporation	Rawley	UT	Magnesium production	NA	Captive
Occidental	Mobile	AL	Membrane	1964	Merchant
Occidental	Muscle Shoals	AL	Mercury	1952	Merchant
Occidental	Delaware City	DE	Mercury	1965	Merchant
Occidental	Convent	LA	Diaphragm	1981	Captive
Occidental	Taft	LA	Diaphragm/membrane	1966	Captive
Occidental	Niagra Falls	NY	Diaphragm	1898	Captive
Occidental	Ingleside	TX	Diaphragm	1974	Captive
Occidental	Laporte	TX	Diaphragm	1974	Merchant
Occidental	Deer Park	TX	Diaphragm/mercury	1938	Captive
Olin	McIntosh	AL	Diaphragm	1952	Merchant
Olin	Augusta	GA	Mercury	1965	Merchant
Olin	Niagra Falls	NY	Membrane	1987	Merchant
Olin	Charleston	TN	Mercury	1962	Merchant

(continued)

Table 4-2. Summary of Chlorine Production Facilities by Location, Process, Age, and Type in 1997 (continued)

Facility	Facility Location		Process	Year Built	Type[a]
Pioneer	St. Gabriel	LA	Mercury	1970	Merchant
Pioneer	Henderson	NV	Diaphragm	1942	Merchant
Pioneer	Tacoma	WA	Diaphragm/membrane	1929	Merchant
PPG	Lake Charles	LA	Diaphragm/mercury	1947	Captive
PPG	Natrium	WV	Diaphragm/mercury	1943	Merchant
Vicksburg Chemical	Vicksburg	NY	Nitric acid salt	1962	Merchant
Vulcan	Wichita	KS	Diaphragm/membrane	1952	Captive
Vulcan	Geismar	LA	Diaphragm	1976	Captive
Vulcan	Port Edwards	WI	Mercury	1967	Merchant
Westlake Monomers Corp	Calvert City	KY	Mercury	1966	Captive
Weyerhauser	Longview	WA	Diaphragm	1957	Captive

[a] Primary
[b] Closed 1999.
[c] Plant has recently converted to the process.

Sources: Berthiaume, Sylvie, Eric Anderson, and Yuka Yoshida. 2000. *Chlorine/Sodium Hydroxide*. CEH Marketing Research Report. Chemical Economics Handbook—SRI International.
The Chlorine Institute. 2000. *Chlor-Alkali Industry Plants and Production Data Report*. Washington, DC.
EC/R Incorporated. September 12, 1996. *Background Information Document; Chlorine Production Summary Report*. Prepared for the U.S. Environmental Protection Agency. Durham, NC: EC/R Inc.

4.4 Industry Employment

Table 4-5 lists data on employment and hours per worker for the chlor-alkali industry. Total and production-related employment both dropped between 1990 and 1997, following trends in the previous two decades. In 1997, there were roughly 4,900 total workers and 3,300 production workers engaged in chlor-alkali production.

Taken together, Tables 4-3 through 4-5 indicate an increasing level of industry output being produced by a progressively smaller labor force. There are two reasons for this. First, annual hours worked per production employee have increased over time, and secondly, labor productivity per hour has risen steadily (see Figure 4-2).

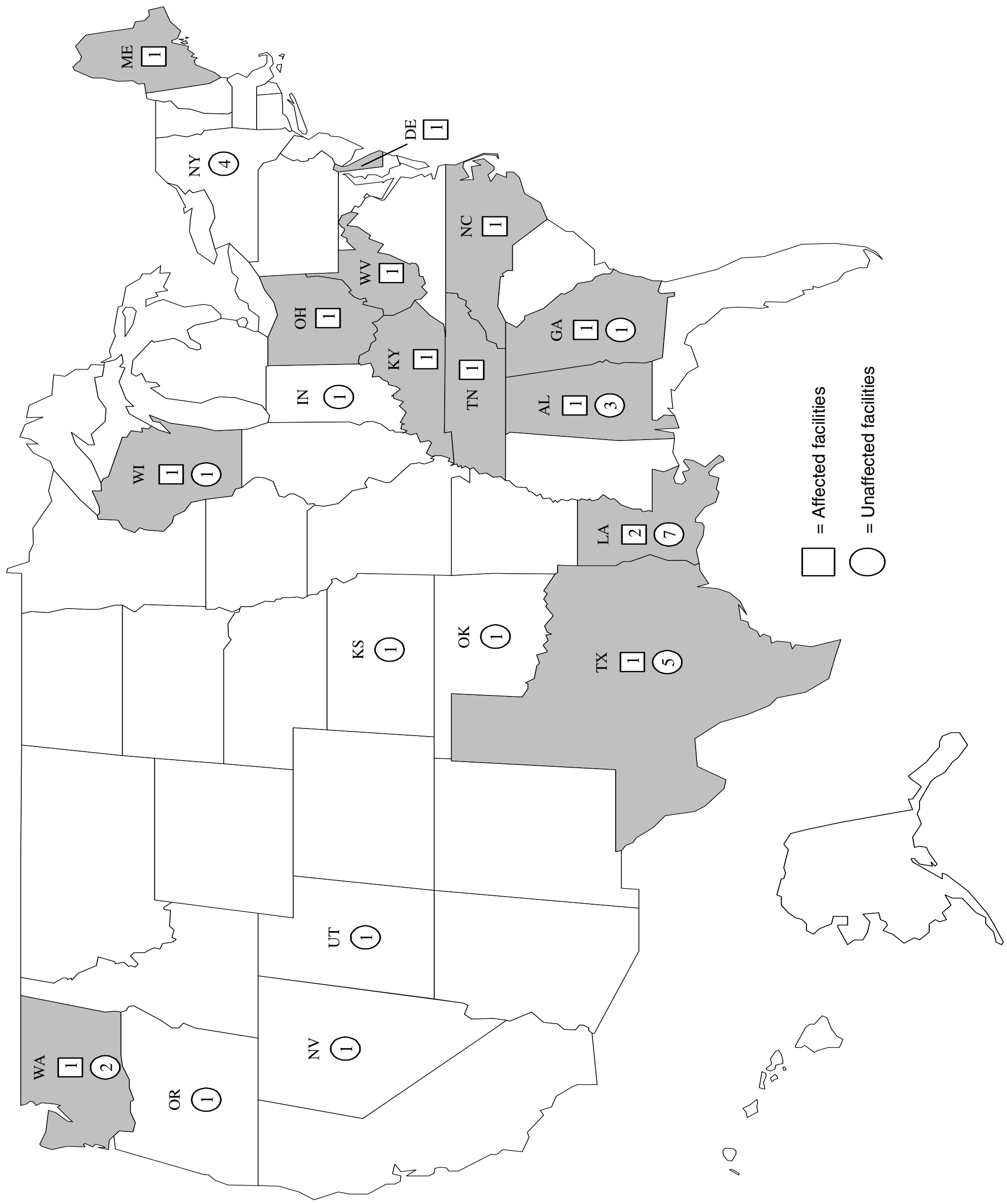

Figure 4-1. Distribution of Affected and Unaffected Chlorine Production Facilities by State

Note: The highlighted states contain affected facilities.

Table 4-3. U.S. Operating Rates for Chlorine (10^3 short tons)

Year	Capacity	Production	Capacity Utilization
1990	12,332	11,487	93.1%
1991	12,256	11,490	93.8%
1992	12,232	11,656	95.3%
1993	12,889	11,983	93.0%
1994	12,684	12,613	99.4%
1995	13,207	12,990	98.4%
1996	13,700	13,168	96.1%
1997	14,000	13,685	97.8%
1998	14,408	13,533	93.9%
1999	NA	13,807	NA

NA = not available

Sources: The Chlorine Institute. 2000. *Chlor-Alkali Industry Plants and Production Data Report*. Washington, DC.
Berthiaume, Sylvie, Eric Anderson, and Yuka Yoshida. 2000. *Chlorine/Sodium Hydroxide*. CEH Marketing Research Report. Chemical Economics Handbook—SRI International.

4.5 Companies

Companies affected by the proposed NESHAP include entities that own and operate one or more chlorine production plants that use the mercury cell process. The chain of ownership may be as simple as one plant owned by one company or as complex as multiple plants owned by subsidiary companies. The Agency identified 21 ultimate parent companies that own and operate 43 chlorine manufacturing facilities. Eight of these companies, or 38 percent, own plants that use the mercury cell process. For the economic analysis, EPA obtained company sales and employment data from one of the following sources:

- Gale Research, Inc. (1998),
- Hoover's Incorporated (2000),
- Information Access Corporation (2000), and

Table 4-4. U.S. Operating Rates for Sodium Hydroxide (10^3 short tons)

Year	Capacity	Production	Capacity Utilization
1990	13,091	12,459	95.2%
1991	13,273	12,151	91.5%
1992	13,442	12,336	91.8%
1993	14,147	12,623	89.2%
1994	13,771	13,293	96.5%
1995	13,771	13,688	99.4%
1996	14,285	13,857	97.0%
1997	14,598	14,328	98.2%
1998	15,585	14,183	91.0%

Source: Berthiaume, Sylvie, Eric Anderson, and Yuka Yoshida. 2000. *Chlorine/Sodium Hydroxide*. CEH Marketing Research Report. Chemical Economics Handbook—SRI International.

- Selected company 10-K reports.

Sales data were available for all 21 companies and employment data were available for 20 companies. All affected companies had sales and employment observations. Occidental (three facilities), Olin (two facilities), and PPG (two facilities) own approximately 60 percent of the mercury cell plants in the United States. Company size is likely to be a factor in the distribution of the regulation's financial impacts. Across all chlorine companies, the average (median) annual sales were $12 billion ($2.4 billion). The average (median) employment is 44,000 (8,900) employees.

4.5.1 Small Business Identification

The proposed environmental regulation potentially affects large and small chlorine manufacturers using mercury cells, but small firms may encounter special problems with compliance. The Regulatory Flexibility Act (RFA), as amended by the Small Business Regulatory Enforcement and Fairness Act of 1996 (SBREFA), requires EPA to consider the economic impacts of this regulatory action on these small entities. Companies operating chlorine manufacturing plants can be grouped into "large" and "small" categories using the

Table 4-5. Employment in the Chlor-Alkali Industry (SIC 2812; NAICS 325181) (10^3): 1990–1997

Year	Total Employment	Production Workers	Annual Hours of Production Workers
1990	6.8	4.7	10,100
1991	7.5	5.2	11,000
1992	8.0	5.4	11,300
1993	7.7	5.3	11,100
1994	6.2	4.2	8,900
1995	6.1	4.2	8,400
1996	5.9	4.0	8,400
1997	4.9	3.3	7,085

Sources: U.S. Department of Commerce, Bureau of the Census. 1999. *1997 Economic Census—Manufacturing Industry Series: Alkalies and Chlorine Manufacturing.* EC97M-3251 E. Washington, DC. <http://www.census.gov/prod/www/abs/97ecmani.html>.
U.S. Department of Commerce, Bureau of the Census. 1996-1998. *Annual Survey of Manufactures: Statistics for Industry Groups and Industries*. <http://www.census.gov/prod/www/abs/industry.html>.
U.S. Department of Commerce, Bureau of the Census. 1996. *1992 Census of Manufactures Industry Series: Industrial Inorganic Chemicals: Industries 2812, 2813, 2816, 2819.* MC92-I-28A. Washington, DC: [online]. <http://www.census.gov/prod/1/manmin/92mmi/mci28af.pdf>.

Small Business Administration's (SBA) general size standard definitions (SBA, 2000). For this analysis, the SBA size standard for the chlor-alkali industry (SIC 2812; NAICS 325181) is 1,000 employees. Based on this standard, six firms can be classified as small. Three of these small firms—ASHTA, HoltraChem Mfg Co., and Pioneer Chlor-Alkali Co.—own and operate facilities using the mercury cell process. As Table 4-6 shows, the six small firms' average (median) sales are $146 ($85) million; average (median) employment is 477 (435) employees. In contrast, the 15 large firms have average (median) sales of $17 ($8) billion, and average employment of 59,000 (34,000) employees.

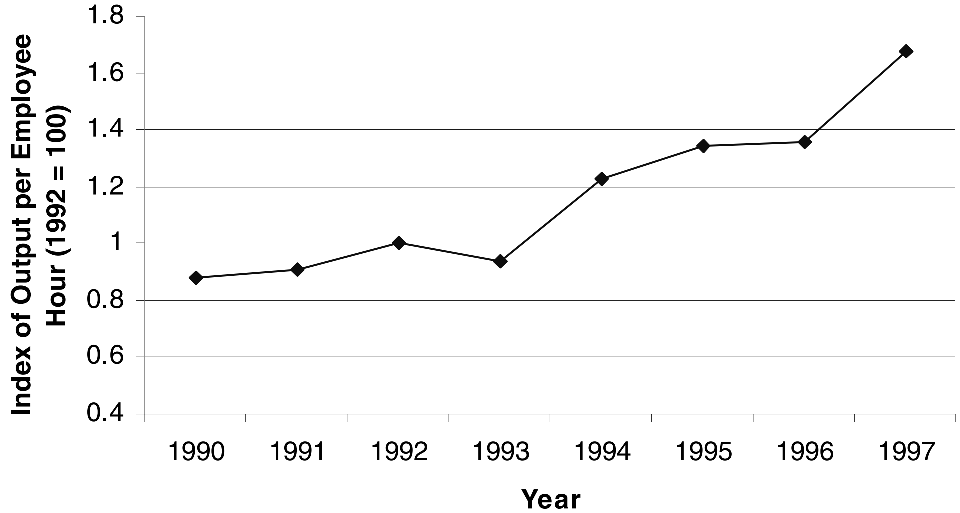

Figure 4-2. Labor Productivity Index for the Chlor-Alkali Industry: 1990-1997

Table 4-6. Summary Statistics for Chlorine Manufacturing Companies

	Annual Sales ($$10^6$)		Employment	
Companies	**Average**	**Median**	**Average**	**Median**
Small	$146	$85	477	435
Large	$16,857	$8,016	58,841	33,800
All	$12,082	$2,410	44,274	8,973

SECTION 5

MARKET DATA AND INDUSTRY TRENDS

This section presents historical market data, including foreign trade and market prices for chlorine by the major industry segments. Historical market data include U.S. production, foreign trade, and apparent consumption of chlorine across the industry segments for the years 1990 through 1997. The importance of foreign trade is measured by concentration ratios (i.e., the relation of exports to U.S. production and the relative importance of imports to U.S. apparent consumption). Furthermore, this section presents the quantities, values, and market prices of chlorine and sodium hydroxide in recent years.

5.1 Value of Shipments

Table 5-1 lists recent historical data (1990-1997) on total value of shipments for the chlor-alkali industry. In real terms, the industry's value of shipments increased through 1992, then mostly followed a downward trend to reach approximately $2.5 million in 1997.

5.2 U.S. Production and Apparent Consumption

Tables 5-2 and 5-3 present historical data on the respective quantities of chlorine and sodium hydroxide produced, imported, exported, and (apparently) consumed. "Apparent" domestic consumption is not directly observed in the data; rather it is calculated as total domestic production less exports plus imports. For chlorine, domestic consumption has increased slightly more than domestic production since 1990, indicating a 16 percent increase in (net) imports of chlorine. Nonetheless, foreign trade plays a fairly minor role in chlorine trade, with net imports less than 3 percent of apparent consumption.

Foreign trade plays a larger role in the sodium hydroxide market, because the United States is a net exporter of this commodity. Gross exports accounted for 11.6 percent of U.S. production in 1998; net imports accounted for 5 percent of apparent consumption that

Table 5-1. Value of Shipments for the Chlor-Alkali Industry (SIC 2812; NAICS 325181) ($$10^6$): 1990-1997

Year	Value of Shipments
1990	$2,710
1991	$2,729
1992	$2,787
1993	$2,481
1994	$2,171
1995	$2,730
1996	$2,850
1997	$2,465

Sources: U.S. Department of Commerce, Bureau of the Census. 1999. *1997 Economic Census—Manufacturing Industry Series: Alkalies and Chlorine Manufacturing*. EC97M-3251 E. Washington, DC. <http://www.census.gov/prod/www/abs/97ecmani.html>.
U.S. Department of Commerce, Bureau of the Census. 1996-1998. *Annual Survey of Manufactures: Statistics for Industry Groups and Industries*. <http://www.census.gov/prod/www/abs/industry.html>.
U.S. Department of Commerce, Bureau of the Census. 1996. *1992 Census of Manufactures—Industry Series: Industrial Inorganic Chemicals*. MC92-I-28A. Washington, DC. <http://www.census.gov/prod/1/manmin/92mmi/mci28af.pdf>.

year. However, the 1998 numbers mask the fact that exports (gross and net) had dropped rather dramatically from 1979 through 1994, with a rebound through 1998. Throughout the period observed, exports are highly variable in the sodium hydroxide market.

5.3 Market Prices

Price data for chlorine and sodium hydroxide are presented in Table 5-4. Unfortunately, these data are list prices and their lack of variation obscures the actual movement in transaction prices. Transactions prices are not readily available, so general inferences must be drawn from the list price data.

The data indicate a sharp decline in chlorine prices, yet a steady rise in sodium hydroxide prices in the early 1990s. The chlorine price rebounded in 1994, and the sodium hydroxide price continued to rise, declining slightly in 1997 and 1998.

Table 5-2. Production, Imports, Exports, and Consumption of Chlorine (10^3 short tons)

Year	Production	Imports	Exports	Apparent Consumption
1990	11,487	357	69	11,775
1991	11,490	296	45	11,741
1992	11,656	275	38	11,893
1993	11,983	323	41	12,265
1994	12,613	394	30	12,977
1995	12,990	396	26	13,360
1996	13,168	419	19	13,568
1997	13,685	453	27	14,111
1998	13,533	413	25	13,921
Average Annual Growth Rate	2.1%	2.6%	–9.4%	2.1%

Source: Berthiaume, Sylvie, Eric Anderson, and Yuka Yoshida. 2000. *Chlorine/Sodium Hydroxide*. CEH Marketing Research Report. Chemical Economics Handbook—SRI International.

5.4 Future Outlook

Global growth forecasts for chlorine range from 0.8–1.5 percent per year (*Chemical Week*, 1996). New demand is being driven by growth in PVC. PVC growth is projected at 4 to 5 percent per year, but declining use in pulp and paper, chlorofluorocarbons, and solvents will keep growth in check the next few years. The United States and the Mideast are widely viewed as the most attractive sites for new capacity because of low power rates and easy access to world markets. In 1995, operating rates continued to exceed 95 percent, which could lead to an increase in price if demand rises.

Table 5-3. Production, Imports, Exports, and Consumption of Sodium Hydroxide (10^3 short tons)

Year	Production	Imports	Exports	Apparent Consumption
1990	12,459	565	1,658	11,366
1991	12,151	474	1,555	11,070
1992	12,336	569	1,265	11,640
1993	12,623	502	965	12,160
1994	13,293	568	894	12,967
1995	13,688	553	1,697	12,544
1996	13,857	550	1,886	12,521
1997	14,328	560	1,481	13,407
1998	14,183	596	1,643	13,136
Average Annual Growth Rate	1.7%	1.3%	4.3%	1.9%

Source: Berthiaume, Sylvie, Eric Anderson, and Yuka Yoshida. 2000. *Chlorine/Sodium Hydroxide*. CEH Marketing Research Report. Chemical Economics Handbook—SRI International.

Table 5-4. U.S. List Prices for Chlorine and Sodium Hydroxide ($/short tons)

Year	Chlorine (Gas)	Sodium Hydroxide	
		Solid	Liquid
1990	$190–$200	$560	$290–$320
1991	$125–$200	$560	$300–$330
1992	$125–$200	$560	$300–$330
1993	$125–$200	$580	$300–$330
1994	$225–$255	$580	$300–$330
1995	$200	$600	$300–$330
1996	$155–$160	$600	$300–$330
1997	$245–$250	$595	$300–$330
1998	$245–$255	$575	$300–$330

Source: Berthiaume, Sylvie, Eric Anderson, and Yuka Yoshida. 2000. *Chlorine/Sodium Hydroxide*. CEH Marketing Research Report. Chemical Economics Handbook—SRI International.

REFERENCES

Alliance for Environmental Technology, Press release, April 15, 1996.

Berthiaume, Sylvie, Eric Anderson, and Yuka Yoshida. 2000. *Chlorine/Sodium Hydroxide*. CEH Marketing Research Report. Chemical Economics Handbook—SRI International.

Chemical Week. 1996. <http://www.chemweek.com/marketplace/product_focus/1996 chlorine.html>

The Chlorine Institute. 2000. *Chlor-Alkali Industry Plants and Production Data Report*. Washington, DC: The Chlorine Institute.

Dungan, Arthur, The Chlorine Institute. June 2, 2000. Personal communication with Carol Mansfield, Research Triangle Institute. Chlorine discussion.

EC/R Incorporated. September 12, 1996. *Background Information Document: Chlorine Production Summary Report*. Prepared for the U.S. Environmental Protection Agency. Durham, NC: EC/R Inc.

"Facts and Figures for the Chemical Industry." *Chemical and Engineering News*. June 24, 1996.

Gale Research. 1998. *Ward's Business Directory of U.S. Private and Public Companies*. Detroit, MI: Gale Research.

Hoover's Incorporated. 2000. Hoover's Company Profiles. Austin, TX: Hoover's Incorporated. <http://www.hoovers.com/>.

Information Access Corporation. 2000. Business & Company ProFile [computer file]. Foster City, CA: Information Access Corporation.

Kroschwitz, Jacqueline. 1991. *Kirk-Othmer Encyclopedia of Chemical Technology*, 4th Ed. New York: John Wiley & Sons.

Minnesota Rural Water Association. 2000. Disinfection. <http:www.mrwa.com/sum97ds.htm>. Obtained on August 7, 2000.

Shakhahiri, B.Z. 2000. Chemical of the Week: Sulfuric Acid. <http://www.scifun.chem.wisc.edu/CHEMWEEK/sulf&top/Sulf&top.html>. Obtained June 6, 2000.

U.S. Small Business Administration (SBA). 2000. Size Standards by SIC Industry. <http://www.sba.gov/regulations/sicodes/siccodes.htm>.

U.S. Department of Commerce, Bureau of the Census. 1999. Concentration Ratios in Manufacturing. MC92-5-2. Washington, DC. <http://www.census.gov/mcd/mancen/download/mc92cr.sum>. Last revised February 4, 1999.

U.S. Department of Commerce. Current Industrial Reports, Series MA-28A. Washington, DC, U.S. Department of Commerce, Bureau of the Census.

Ullman's Encyclopedia of Industrial Chemistry. 1992.

Selected company 10-K reports.

U.S. Department of Commerce, Bureau of the Census. 1996. *1992 Census of Manufactures Subject Series: Concentration Ratios in Manufacturing*. Washington, DC: Government Printing Office.

U.S. Department of Commerce, Bureau of the Census. 1996. *1992 Census of Manufactures Industry Series: Industrial Inorganic Chemicals.* MC92-I-28A. Washington, DC: [online]. <http://www.census.gov/prod/1/manmin/92mmi/mci28af.pdf>.

U.S. Department of Commerce, Bureau of the Census. 1999. *1997 Economic Census—Manufacturing Industry Series: Alkalies and Chlorine Manufacturing.* EC97M-3251E. Washington, DC: [online]. <http://www.census.gov/prod/www/abs/97ecmani.html>.

U.S. Department of Commerce, Bureau of the Census. 1993-1996. *Annual Survey of Manufactures: Statistics for Industry Groups and Industries.* <http://www.census.gov/prod/www/abs/industry.html>.

U.S. Department of Commerce, Bureau of the Census. 1996-1998. *Annual Survey of Manufactures: Statistics for Industry Groups and Industries. Washington, DC: Government Printing Office.*