Chlorine

Cl_2

(liquified gas)

D Direct Use Chemical **P** Precursor Chemical

Inputs to Manufacturing Process:
Sodium Chloride

Derivative Water Treatment Chemicals:
Hydrochloric Acid
Ferric Chloride
Sodium Hypochlorite
Ferrous Chloride
Calcium Hypochlorite

% of Total Domestic Consumption Attributed to Water Sector:
Approximately 5%

Understanding Chemical Supply Chains

Map of Suppliers & Manufacturers

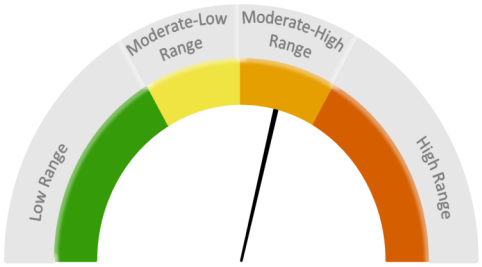
Product Family:
Chlor-alkali

CAS No.:
7782-50-5

Shelf Life:
6-12 Months

RISK OF SUPPLY DISRUPTION (Assessed in 2022)

RISK RATING: Moderate-High



RISK DRIVERS

From 2020 through 2022, a combination of events resulted in reduced production capacity, includ-ing extreme weather events, equipment failures, and planned reductions. The loss in production capacity was compounded by increased demand for other uses of chlorine, such as the production of high-value chemicals.

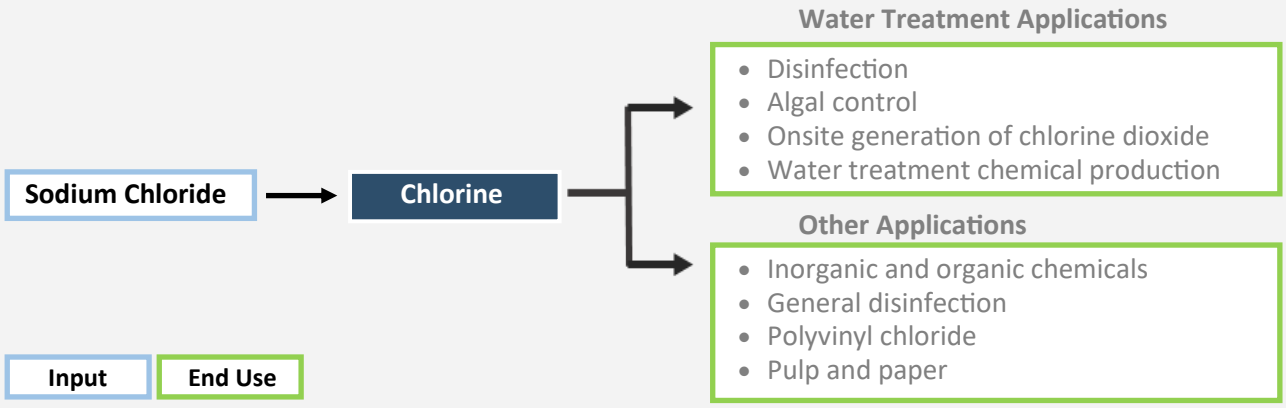
RISK PARAMETERS

Criticality: High. Essential for water disinfection and production of water treatment chemicals.

Likelihood: High. Previous wide-spread disruptions in supply that impacted the water sector.

Vulnerability: Low. Distributed domestic manufacturing and supply.

MANUFACTURING PROCESS



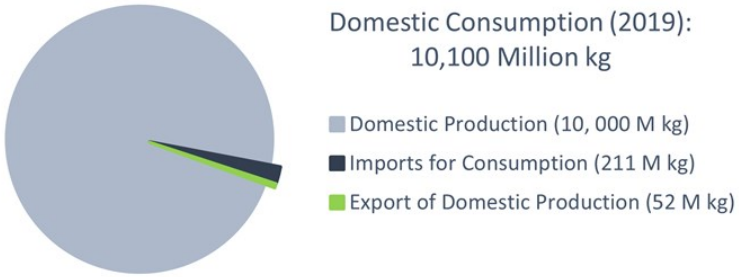
DOMESTIC PRODUCTION AND CONSUMPTION, AND INTERNATIONAL TRADE

Domestic Manufacturing Locations (2019):
49, distributed throughout the U.S.

International Trade (2019)

Primary Trading Partner (Imports): Canada

Primary Trading Partner (Exports): Mexico



Product Description

Chlorine (Cl_2), an inorganic chemical and strong oxidant, is a widely used water disinfectant. It is a foundational product of the chlor-alkali industry, primarily manufactured through electrolysis of a sodium chloride brine. The majority of chlorine manufactured in the U.S. is used in organic and inorganic chemical production.

Use in Water Treatment

Chlorine has several uses in water treatment, including primary and residual disinfection, algae control, oxidation, and on-site generation of chlorine dioxide (AWWA, 2018).

Use as a Precursor to Other Water Treatment Chemicals

Chlorine is used to manufacture hydrochloric acid, sodium hypochlorite, calcium hypochlorite, ferric chloride, and ferrous chloride (NCBI, 2020).

Other Applications

Chlorine has a wide range of applications. The leading use of chlorine is the production of organic chemicals, including polyvinyl chloride, for which there is high demand. It is widely used in the production of pulp and paper, rubber, and solvents. Chlorine is also used as a pesticide and for shrink proofing wool (NCBI, 2020).

Primary Industrial Consumers

In 2021, it is estimated that construction applications such as polyvinyl chlorine and epoxies accounted for the largest single demand of chlorine. Presently, chlorine is used widely by chlor-alkali manufacturing facilities for derivative chemical production, a process referred to as captive consumption. A fraction of overall production (estimated to be 3,600 million (M) kg or 32% in 2022) is destined for sale on the merchant market. Of the chlorine demand from the merchant market, production of propylene oxide accounts for the largest percentage. Water treatment (including industrial applications) accounts for the second largest use of merchant market chlorine. It is estimated that in 2022, water treatment (including industrial applications) will account for 9% (1.039 M kg of 11.4 B kg) of all domestic production and 27.2% of chlorine available for merchant market purchase. Municipal wastewater and drinking water applications are anticipated to account for 60% (628 M kg) of the demand for water treatment, representing approximately 5% of consumption of all domestically produced chlorine. Of the anticipated 628 M kg of demand for water treatment applications, municipal wastewater and drinking water are estimated to account for 67% and 33%, respectively (Kreuz et al., 2022).

Manufacturing, Transport, & Storage

Manufacturing Process

Sodium chloride is the raw material most commonly used to produce chlorine. Potassium chloride or magnesium chloride can also be used but are less common raw materials for domestic production (The Chlorine Institute, 2014).

Approximately 95% of chlorine is produced using the chlor-alkali process, which involves passing a direct electric current through a sodium chloride brine (i.e., electrolysis), converting chloride ions to elemental chlorine at the anode while sodium ions and hydrogen gas collect at the cathode to react and form sodium hydroxide (The Chlorine Institute, 2014). The general equation for this process is shown in Figure 1. Chlorine is separated from the solution using one of the following processes: (1) the diaphragm cell; (2) the membrane cell; (3) the mercury cell; or (4) brine to bleach. The diaphragm method is the most common separation process used in North America (The Chlorine Institute, 2014). In 2021, membrane cell technology, asbestos diaphragm technology, and non-asbestos diaphragm cell technology accounted for 46%, 36%, and 1%, respectively, of all domestic chlorine

production. Potassium chloride membrane cell technology, metal production, and brine to bleach accounted for the remaining 9% of domestic production (Kreuz et al., 2022).

Sodium Chloride Brine	→	**Chlorine Gas** + **Hydrogen Gas** + **Sodium Hydroxide**
$2NaCl + 2H_2O$	→	Cl_2 H_2 2NaOH
		↓ ↓ ↓
		Anode Cathode Cathode

Figure 1. Chemical Equation for the Reaction to Manufacture Chlorine

Product Transport

Chlorine is highly corrosive and reacts violently with petroleum products (The Chlorine Institute, 2014; Olin Corporation, 2020), which dictates how it can be transported. Liquified chlorine gas is sold in bulk quantities and primarily delivered by specialized railcars to suppliers who repackage and sell the product directly to customers. Transport of chlorine must adhere to the appropriate methods and regulations related to its status as a toxic substance, and transit routes designated for chlorine must be go through an approval process. Bulk transport by rail is very significant. In 2006, it was estimated that rail accounted for 85% of long-distance chlorine movements nationally (Branscomb et al., 2010). More recently, the Chlorine Institute has noted that rail represents the largest bulk volume of shipped chlorine (The Chlorine Institute, 2022).

Storage and Shelf Life

Chlorine gas can be pressurized and cooled to a liquified gas and stored in pressure vessels. Small, pressurized cylinders may be used by smaller water systems, while larger systems may require bulk deliveries of a ton or more (Hawkins, Inc., 2020; Madison Water Utility, 2020). Pressurized storage vessels should be stored in a cool place away from direct sunlight. When stored properly, liquified chlorine gas can have a shelf life of 6 to 12 months, depending on purity and size of storage container (Olin Corporation, 2020). Storage durations beyond recommended shelf life can lead to product degradation and loss of efficacy.

Domestic Production & Consumption

Domestic Production

Production data was collected from the Chlorine Institute, while trade data was collected from the USITC Dataweb, as shown in Table 1. Both production and trade data are specific to chlorine.

Table 1. Chlorine Production and Trade Data Sources

Production and Trade Data			
Category	**Data Source**	**Identifier**	**Description**
Domestic Production	The Chlorine Institute	CAS No.: 7782-50-5	Chlorine
Imports and Exports	U.S. International Trade Commission	HS Code: 2801.10	Chlorine

Total U.S. domestic production of chlorine was approximately 10,000 M kg in 2019 (The Chlorine Institute, 2020). Domestic commercial manufacture of chlorine takes place at chlor-alkali facilities located throughout the contiguous U.S. The majority of these facilities are owned by a relatively small number of companies including *Olin Corporation*, *Westlake Corporation*, and *Oxy Chemical Corporation* (The Chlorine Institute, 2020). *Westlake Corporation* is a leading global and domestic manufacturer of chlorine, specializing in chlorine derivatives including polyvinyl chloride (PVC). While *Westlake Corporation* manufactures and distributes millions of tons of chlorine each year, a significant percentage of the chlorine manufactured serves as feedstock for the chlorine

derivative products the company produces (Westlake Corporation, 2016). It is estimated that in 2022, 68% of domestically produced chlorine will be used in captive consumption such as the applications noted above, leaving a fraction of domestic production available for merchant market purchase (Kreuz et al., 2022). The number of domestic manufacturing locations shown in Figure 2 represents operating facilities as of 2019. Supply of NSF/ANSI Standard 60 certified chlorine for use in drinking water treatment is also widely distributed throughout the U.S. (NSF International, 2021). For a more current listing of manufacturing locations and supplier locations, visit the U.S. Environmental Protection Agency's (EPA's) Chemical Locator Tool (EPA, 2022).

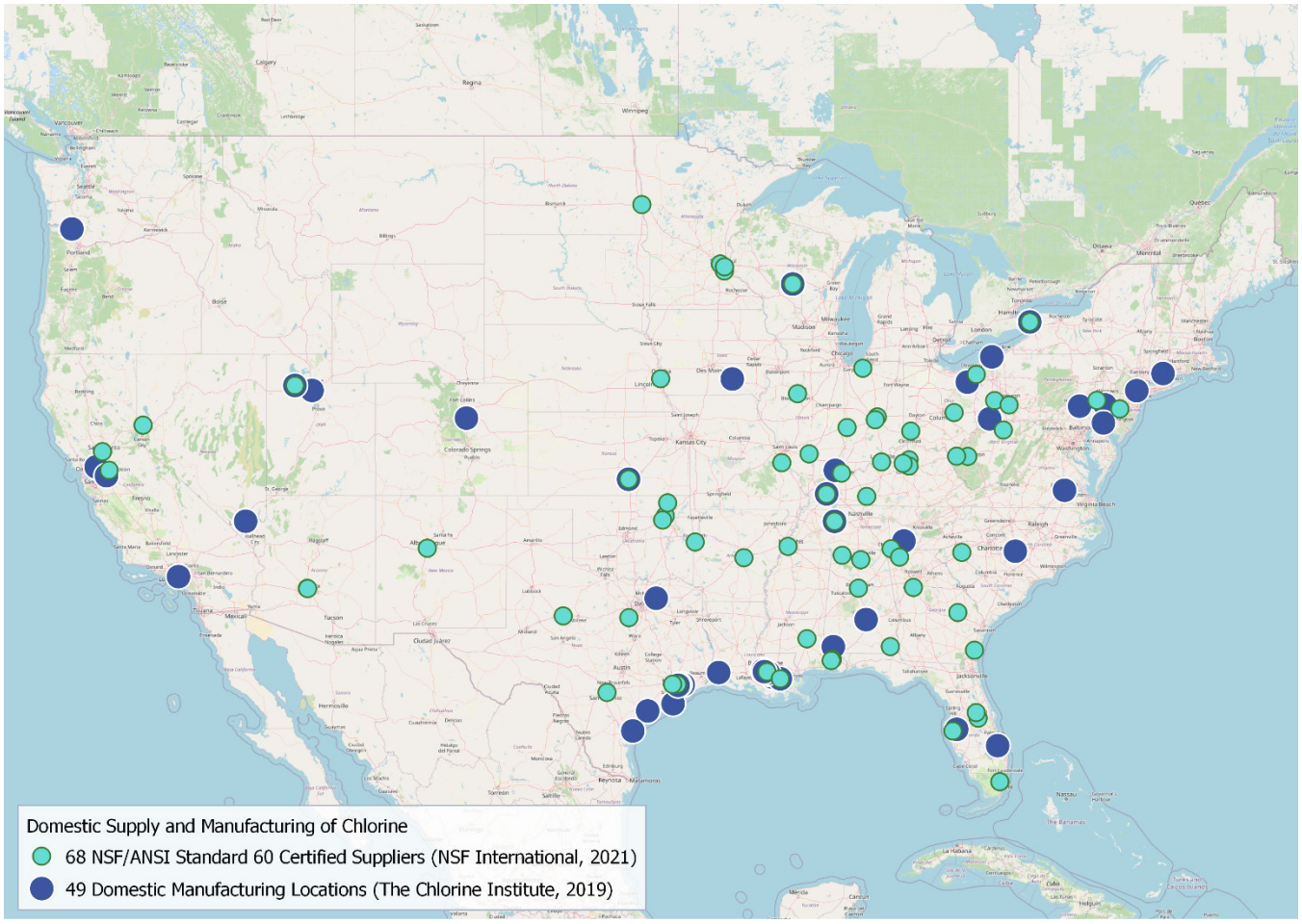


Figure 2. Domestic Supply and Manufacturing of Chlorine

Domestic Consumption

U.S. consumption of chlorine in 2019 is estimated at 10,100 M kg. This estimate includes production of 10,000 M kg, import of 211 M kg, minus export of 52 M kg (The Chlorine Institute, 2020; USITC, 2020), as shown in Figure 3. Imports and exports represent small quantities when compared to domestic production. In the case of chlorine, there is limited spare capacity in primary sources of chlorine imports (Canada and Mexico).

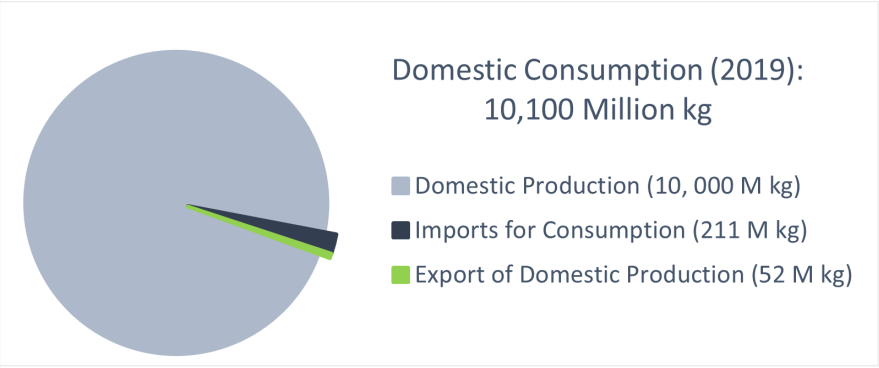


Figure 3. Domestic Production and Consumption of Chlorine in 2019

Trade & Tariffs

Worldwide Trade

Worldwide import and export data for chlorine are reported through the World Bank's World Integrated Trade Solutions (WITS) software, as a category specific to chlorine. In 2021, the U.S. ranked third worldwide in total exports and first in total imports of chlorine. In 2021, Canada ranked first worldwide in total exports (WITS, 2022), as shown in Table 2.

Table 2. WITS Worldwide Export and Import of Chlorine in 2021

2021 Worldwide Trade Chlorine (HS Code 2801.10)			
Top 5 Worldwide Exporters		Top 5 Worldwide Importers	
Canada	275 M kg	**United States**	**305 M kg**
France	55 M kg	Hungary	27 M kg
United States	**44 M kg**	Belgium	23 M kg
Thailand	19 M kg	Malaysia	18 M kg
Belgium	18 M kg	Switzerland	17 M kg

Domestic Imports and Exports

Domestic imports and export data are reported by USITC in categories specific to chlorine. Figure 4 summarizes imports for consumption[1] and domestic exports[2] of chlorine between 2015 and 2020. During this period, the overall quantity of exports and imports remained relatively steady, with imports for consumption exceeding domestic exports. Over this five-year period, Mexico was the primary recipient of domestic exports while Canada was the primary source of imports (USITC, 2020). There is limited spare capacity for additional imports to the U.S. from Canada due to the level of demand in Canada and limited transportation (rail) logistics from Mexico.

[1] Imports for consumption are a subset of general imports, representing the total amount cleared through customs and entering consumption channels, not anticipated to be reshipped to foreign points, but may include some reexports.

[2] Domestic exports are a subset of total exports, representing export of domestic merchandise which are produced or manufactured in the U.S. and commodities of foreign origin which have been changed in the U.S.

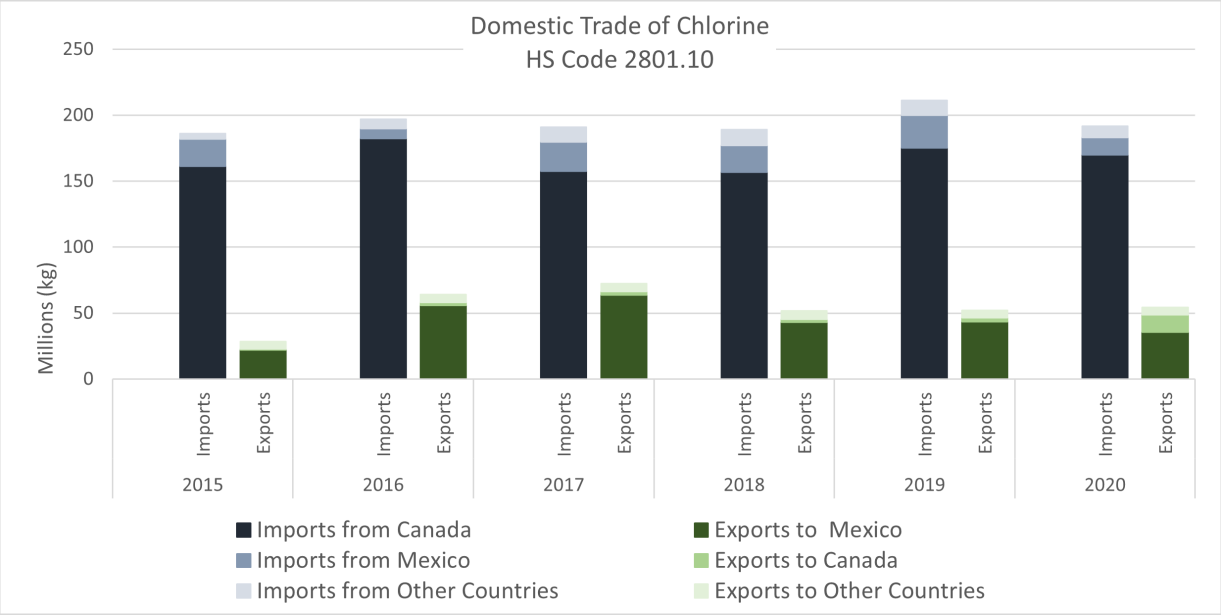


Figure 4. USITC Domestic Import and Export of Chlorine between 2015 and 2020

Tariffs

Imports of chlorine are almost exclusively supplied from Canada and Mexico. There is no general duty for import of chlorine (USITC, 2022), as summarized in Table 3. Imports from China are subject to an additional duty of 25%, though this has not had an impact on domestic trade dynamics for elemental chlorine. China, one of the largest chlor-alkali producing nations, is expected to drive future growth in chlor-alkali production (Kreuz et al., 2022).

Table 3. 2020 Domestic Tariff Schedule for Chlorine

HS Code	General Duty	Additional Duty - China (Section 301 Tariff List)	Special Duty
2801.10	None	25%	None

Market History & Risk Assessment

History of Shortages

During the COVID-19 pandemic there was a significant increase in the demand for many chlorine derivative products due to increased disinfection of buildings, equipment, surfaces, etc. in an effort to reduce the spread of COVID-19. Concurrent with this increased demand, there was a temporary loss of approximately 28% of domestic chlor-alkali production capacity when Winter Storm Uri directly hit the Gulf Coast region in February 2021 (The Chlorine Institute, 2021). Furthermore, in spring and summer of 2021, a number of chlor-alkali production facilities experienced significant equipment failures resulting in additional, temporary losses in production capacity. While some of these impacted facilities were located in the Gulf Coast region, others were located in West Virginia, Utah, and Washington. Later in the summer of 2021, there was a permanent reduction in chlor-alkali production capacity at facilities located in New York, Alabama, Louisiana, and Texas. The reductions in chlor-alkali production capacity that occurred in 2021 were compounded by the impacts of COVID-19 (Powder and Bulk Solids, 2021; Prohaska, 2021). Changes to domestic chlorine production are known to have a direct impact on the availability of chlorine for domestic consumption, since imports represent a small fraction of overall consumption (Kreuz et al., 2022). This was exemplified by decreased allocations of chlorine

and sodium hypochlorite for drinking water and wastewater systems in California, Oregon, Washington, Alaska, Utah, Missouri, Ohio, Pennsylvania, New York, Massachusetts, Louisiana, and Florida, as reported directly to EPA.

A threatened rail carrier work stoppage in September 2022 highlighted the dependence of the domestic chlorine supply chain on a complex national rail network for producers, suppliers, and end-users. Due to the concentration of chlor-alkali facilities along the Gulf Coast combined with widespread need for chlorine, long-distance transport of chlorine is often required. Additionally, a significant number of domestic manufacturers of derivative water treatment chemicals are almost exclusively reliant on rail delivery of chlorine for production needs (Branscomb et al., 2010).

Risk Evaluation

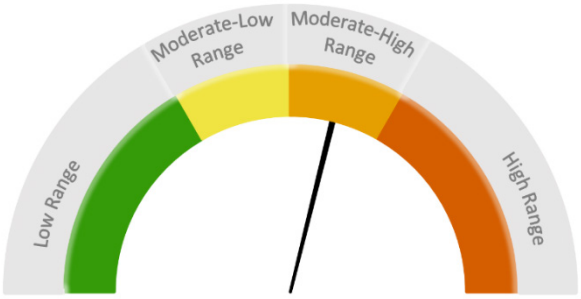
The complete risk evaluation methodology is described in *Understanding Water Treatment Chemical Supply Chains and the Risk of Disruptions* (EPA, 2022b). The risk rating is calculated as the product of the following three risk parameters:

Risk = Criticality x Likelihood x Vulnerability	
Criticality	Measure of the importance of a chemical to the water sector
Likelihood	Measure of the probability that the chemical will experience a supply disruption in the future, which is estimated based on past occurrence of supply disruptions
Vulnerability	Measure of the market dynamics that make a chemical market more or less resilient to supply disruptions

The individual parameter rating is based on evaluation of one or more attributes of the chemical or its supply chain. The ratings and drivers for these three risk parameters are shown below in Table 4.

Table 4. Supply Chain Risk Evaluation for Chlorine

Risk Parameter Ratings and Drivers		
Criticality: High	**Likelihood: High**	**Vulnerability: Low**
Chlorine is essential and has widespread application as a disinfectant and strong oxidant in both drinking water and wastewater treatment. It is a precursor in the production of several other critical water treatment chemicals, and changes in availability or price may impact availability of derivative water treatment chemicals.	The water sector has experienced widespread chlorine supply disruptions in the past. From 2020 through 2022 disruptions in the supply of chlorine occurred due to an increase in demand due to the COVID-19 pandemic and a decrease in supply as a result of both temporary losses in production capacity due to equipment failures and extreme weather events and permanent, planned reductions in production capacity.	Strong domestic manufacturing capabilities and a distributed manufacturing base provide some resilience to supply disruptions. However, facility closures in 2021 and the potential for future losses in production capacity could increase vulnerability.
Risk Rating: Moderate-High		



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