Carbon Dioxide

CO_2

D Direct Use Chemical

(liquified gas)

Inputs to Manufacturing Process: Byproduct in manufacturing of Ethanol, Anhydrous Ammonia, Hydrogen

% of Total Domestic Consumption Attributed to Water Sector: Less than 10%

Product Family: Corn Substrate

CAS No.: 124-38-9

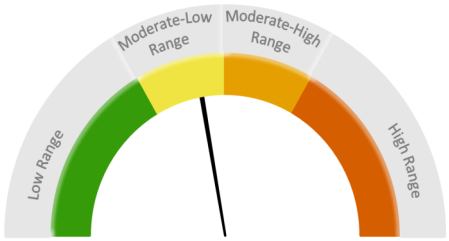
Derivative Water Treatment Chemicals: None

Understanding Chemical Supply Chains
Map of Suppliers & Manufacturers

Shelf Life: 60 Months

RISK OF SUPPLY DISRUPTION (Assessed in 2022)

RISK RATING: Moderate-Low



RISK DRIVERS

Ethanol production is the largest domestic source of purified carbon dioxide, followed by production of anhydrous ammonia. Reductions in production of ethanol due to reduced demand for transportation fuels has led to idling or permanent plant closures, dramatically reducing availability of purified carbon dioxide. Fluctuations in demand for fertilizer may also impact production.

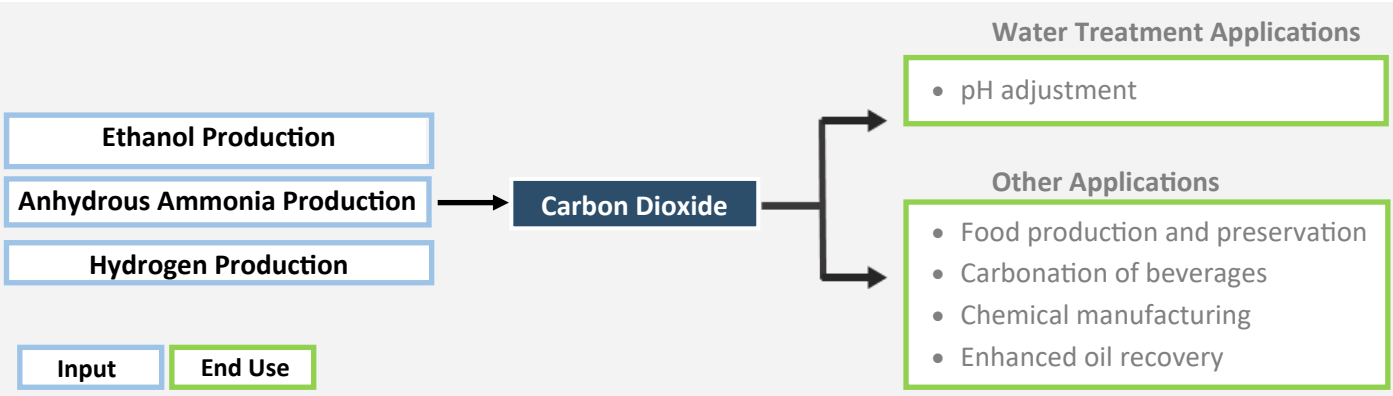
RISK PARAMETERS

Criticality: High. Essential and widely used for pH adjustment.

Likelihood: High. History of price increases, force majeure, and regional disruptions in supply that impacted the water sector.

Vulnerability: Low. Distributed domestic manufacturing and supply. Supply output tied to ethanol production.

MANUFACTURING PROCESS



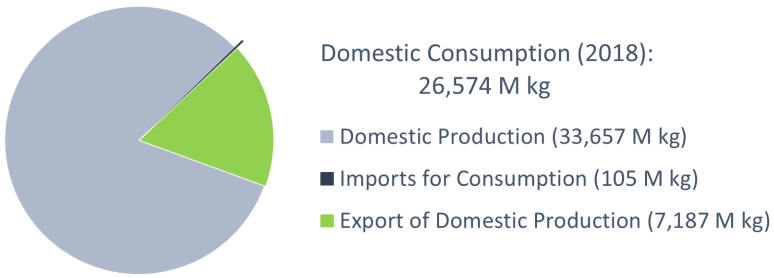
DOMESTIC PRODUCTION AND CONSUMPTION, AND INTERNATIONAL TRADE

Domestic Manufacturing Locations (2021): 75, distributed throughout the U.S.

International Trade (2019)

Primary Trading Partner (Imports): Canada

Primary Trading Partner (Exports): Mexico



Product Description

Carbon Dioxide (CO_2), a naturally occurring component of the atmosphere, is commercially produced primarily as a co-product of chemical manufacturing, most commonly ethanol and ammonia production. Further purification steps of recovered carbon dioxide yield a product that is widely used in numerous industries, most prominently in food and beverage production.

Use in Water Treatment

Carbon dioxide is used in both water and wastewater treatment for pH adjustment (AWWA, 2018).

Use as a Precursor to Other Water Treatment Chemicals

Carbon dioxide is not used to manufacture other water treatment chemicals.

Other Applications

Carbon dioxide is used food production and preservation, carbonation of beverages, chemical manufacturing (e.g., urea), enhanced oil recovery, pulp and paper processing pH adjustment, medical procedures, semiconductor manufacturing, animal slaughter, and in greenhouses to stimulate plant growth. Purified carbon dioxide in the solid state (i.e., dry ice) is used to preserve substances that must be transported and shipped at a low temperature, including some vaccines (FTC, 2018; NCBI, 2021).

Primary Industrial Consumers

A majority of the purified carbon dioxide produced domestically is used in food preparation and preservation and carbonation of beverages. Other primary uses include chemical manufacturing, enhanced oil recovery, metal working, and healthcare (FTC, 2018; NCBI, 2021). The food and beverage sector, which is inclusive of many uses of carbon dioxide, accounts for approximately 70% of the domestic demand for carbon dioxide supplied as a byproduct of ethanol production (Rushing, 2020). It is estimated that water treatment applications account for less than 10% of domestic use.

Manufacturing, Transport, & Storage

Manufacturing Process

Carbon dioxide is produced from naturally-occurring carbon dioxide reservoirs, as a byproduct from the energy and industrial production processes (e.g., ammonia production, fossil fuel combustion, ethanol production), and as a byproduct from the production of crude oil and natural gas. Domestic production of carbon dioxide is largely supplied by recovery of carbon dioxide as a co-product of chemical manufacturing, primarily from ethanol, ammonia, and hydrogen manufacturing facilities. Fermentation from ethanol plants is the largest single source of carbon dioxide for the U.S. market, and has historically produced more than half of the carbon dioxide sold in the domestic market. Ethanol production yields waste gas in excess of 90% carbon dioxide, while the production of ammonia yields nearly 40% carbon dioxide (State CO_2-EOR Deployment Work Group, 2017). Carbon dioxide is processed to a liquefied gas after distillation of the crude gas using a cryogenic process, often at facilities located near carbon dioxide sources.

The source of carbon dioxide varies regionally and from country to country, depending on the predominant industry producing carbon dioxide as a byproduct. This can lead to regional vulnerabilities in supply. Where carbon dioxide production is heavily reliant on the production of ammonia, there are planned downtimes to production, with peaks during winter months and a slowdown in the spring. Where carbon dioxide production is a byproduct of natural gas production, availability of carbon dioxide is tied to fluctuations in natural gas production (DeCarlo and Marrero, 2018).

Product Transport

Carbon dioxide is classified as a hazardous material, which dictates how it can be transported and may add significant cost to long-distance transport. Liquefaction, which allows for transport of greater volumes of carbon dioxide, is routinely used for transport by container via truck, barge, rail, and ship. While a pipeline network is extensive in the Midwest and Western U.S., transport of carbon dioxide in this network is primarily intended for delivery to enhanced oil recovery projects (FTC, 2018; IPCC, 2005).

Storage and Shelf Life

Carbon dioxide 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. Pressurized storage vessels should be stored in a cool, dry location away from direct sunlight. When stored properly, liquified carbon dioxide can have a shelf life of 60 months (Air Products, 2014; Linde, 2021).

Domestic Production & Consumption

Domestic Production

Production data was collected from the 2020 EPA Toxic Substances Control Act (TSCA) Chemical Data Reporting (CDR) for the year 2018, while trade data was collected from the USITC Dataweb, as shown in Table 1. Both production and trade data are specific to carbon dioxide.

Table 1. Carbon Dioxide Production and Trade Data Sources

Production and Trade Data			
Category	**Data Source**	**Identifier**	**Description**
Domestic Production	2020 TSCA Chemical Data Reporting	CAS No.: 124-38-9	Carbon Dioxide
Imports and Exports	U.S. International Trade Commission	HS Code: 2811.21	Carbon Dioxide

Total U.S. domestic production of carbon dioxide was approximately 33,657 million kilograms (M kg) in 2018 (EPA, 2020). Several significant producers claimed confidential business information and did not offer production volumes. Independent reporting indicates that annual domestic production capacity may be as high as 60,000 M kg (Rushing, 2020). It is estimated that in 2018 approximately 30% of reported production volume was used in captive consumption (EPA, 2020). The top five domestic carbon dioxide suppliers to the commercial market in 2018 were *Linde*, *Air Liquide*, *Praxair*, *Matheson Tri-Gas*, and *Reliant Holdings*. All of these suppliers operate numerous liquid carbon dioxide production facilities and produce or contract for supply of raw carbon dioxide. In 2018 *Linde* had a daily carbon dioxide production capacity of nearly one-quarter of total domestic capacity (NREL, 2019). The number of domestic manufacturing locations shown in Figure 1 represents operating facilities as of 2021. Supply of NSF/ANSI Standard 60 certified carbon dioxide for use in drinking water treatment is 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, 2022a).

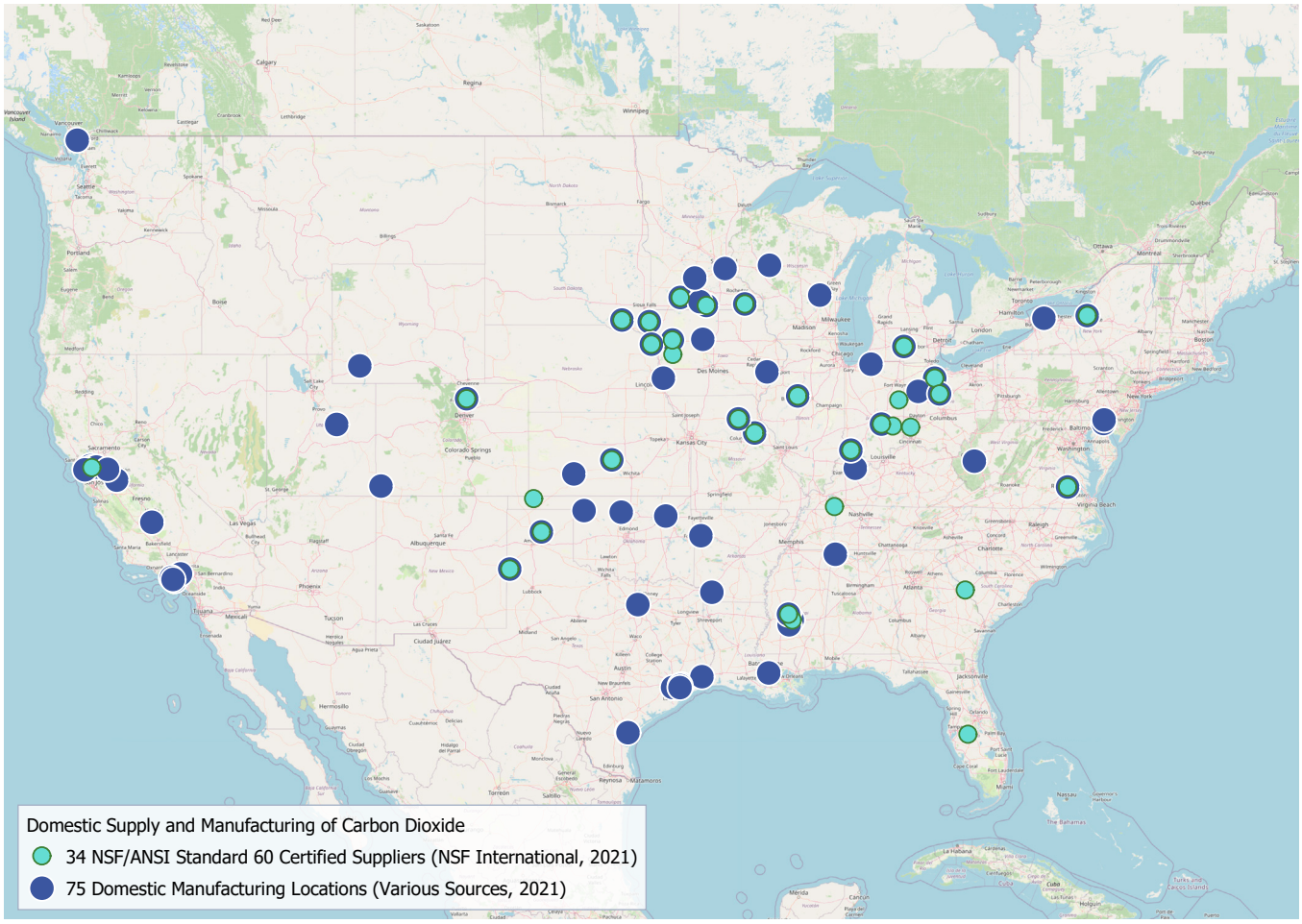


Figure 1. Domestic Supply and Manufacturing of Carbon Dioxide

Domestic Consumption

U.S. consumption of carbon dioxide in 2018 is estimated at 26,574 M kg. This estimate includes production of 33,657 M kg, import of 105 M kg, minus export of 7,187 M kg (EPA, 2020; USITC, 2021), as shown in Figure 2.

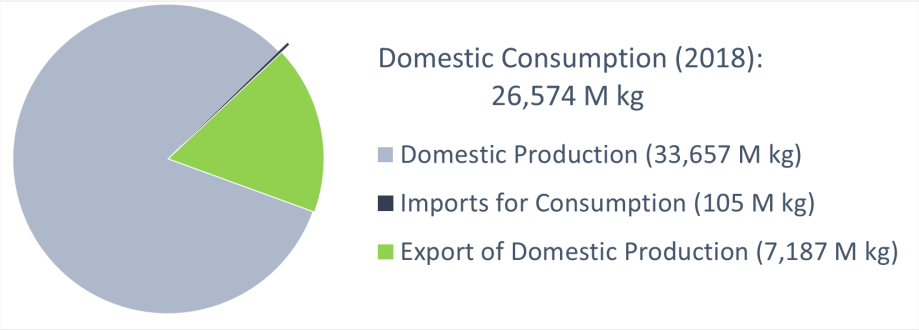


Figure 2. Domestic Production and Consumption of Carbon Dioxide in 2018

Trade & Tariffs

Worldwide Trade

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

Table 2. WITS Worldwide Export and Import of Carbon Dioxide in 2021

2021 Worldwide Trade Carbon Dioxide (HS Code 2811.21)			
Top 5 Worldwide Exporters		Top 5 Worldwide Importers	
United States	**10,044 M kg**	Germany	237 M kg
Hungary	117 M kg	Belgium	154 M kg
Canada	107 M kg	**United States**	**129 M kg**
Norway	87 M kg	Mexico	117 M kg
Belgium	87 M kg	United Kingdom	113 M kg

Domestic Imports and Exports

Domestic imports and export data are reported by USITC in categories specific to carbon dioxide. Figure 3 summarizes imports for consumption[1] and domestic exports[2] of carbon dioxide between 2015 and 2020. During this period, the overall quantity of imports remained relatively steady, while the overall quantity of domestic exports grew significantly starting in late 2018. Through this five-year period, domestic exports exceeded imports for consumption. Over this five-year period, Mexico was the primary recipient of domestic exports while Canada was the primary source of imports (USITC, 2021).

A carbon dioxide shortage in Mexico occurred in late 2018 through 2019 due to reductions in availability of the primary source of carbon dioxide in Mexico, natural gas (DeCarlo and Marrero, 2018). This led to a temporary but dramatic increase in exports to Mexico in 2019 at a level not seen previously. Since 2018, exports to Mexico have remained higher than in past years and account for a persistent increase in overall domestic exports (USTIC, 2021).

[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.

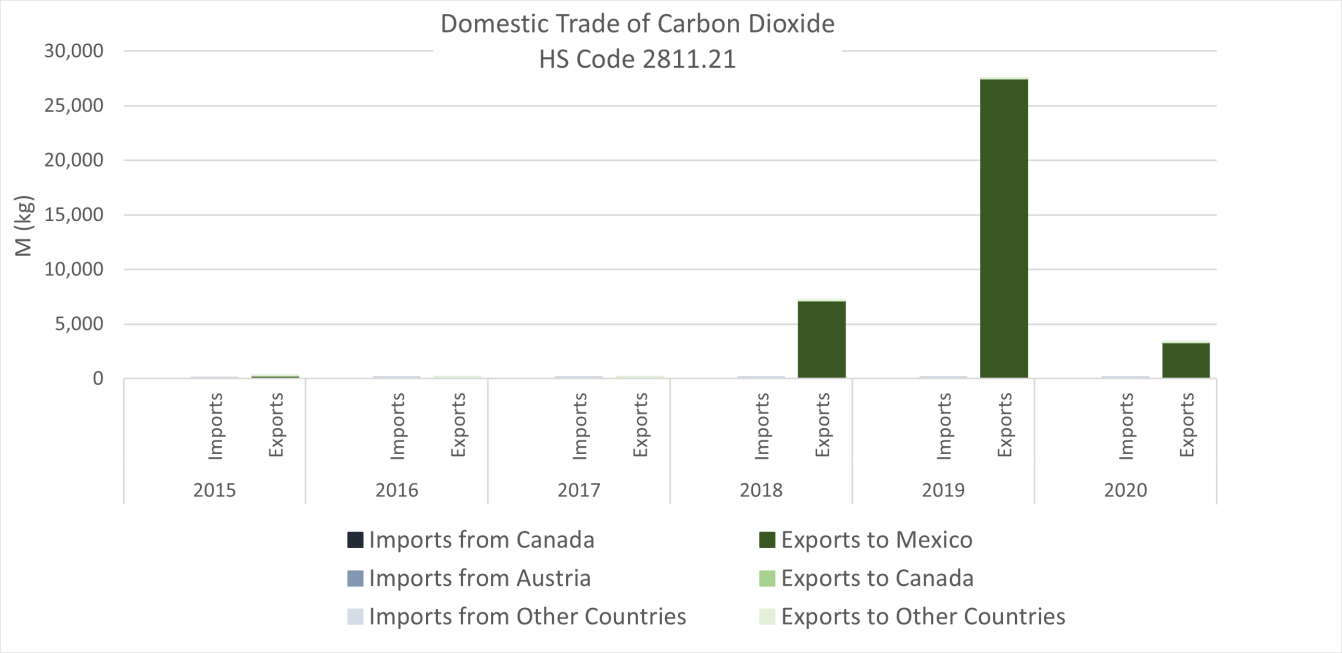


Figure 3. USITC Domestic Import and Export of Carbon Dioxide between 2015 and 2020

Tariffs

There is a 3.7% general duty, and a 25% additional duty for China, for import of carbon dioxide (USITC, 2022), as summarized in Table 3.

Table 3. 2020 Domestic Tariff Schedule for Carbon Dioxide

HS Code	General Duty	Additional Duty - China (Section 301 Tariff List)	Special Duty
2811.21	3.7%	25%	Free (A, AU, BH, CA, CL, CO, D, E, IL, JO, KR, MA, MX, OM, P, PA, PE, SG)[3]

Market History & Risk Evaluation

History of Shortages

Between 2017 and 2021 numerous water systems received force majeure notices from their contracted carbon dioxide suppliers. Many suppliers referred to a lack of feedstock (ethanol) due to temporary shutdown of ethanol production facilities. The fluctuation in demand for ethanol due to fluctuating demand for refined petroleum products directly affected the availability of refined carbon dioxide. Carbon dioxide production can fluctuate seasonally as well, as it may be tied to corn harvest (ethanol) and fertilizer production (ammonia). Both industries have planned downtimes for annual maintenance.

The COVID-19 pandemic created significant volatility in the commercial market for carbon dioxide. A confluence of events reduced demand for ethanol and ammonia-based fertilizer, and the supply of purified carbon dioxide dramatically decreased. Certain areas of the U.S. were more heavily impacted by the volatile carbon dioxide

[3] Symbols used to designate the various preference programs and trade agreements. A full list of special trade agreements and associated acronyms can be found at https://help.cbp.gov/s/article/Article-310?language=en_US and the General Notes Section of the Harmonized Tariff Schedule https://hts.usitc.gov/current

market conditions in 2020. The Northeast, Southeast, and Southwest were all impacted by closures or idling of regional carbon dioxide purification plants in 2020-2021. Water systems in Florida were uniquely vulnerable to disruptions in the supply of carbon dioxide given the closure of the only regional plant consistently supplying the Florida market, located in southern Georgia. These events created price volatility and led to significant increases in cost of supply for some water systems.

Risk Evaluation

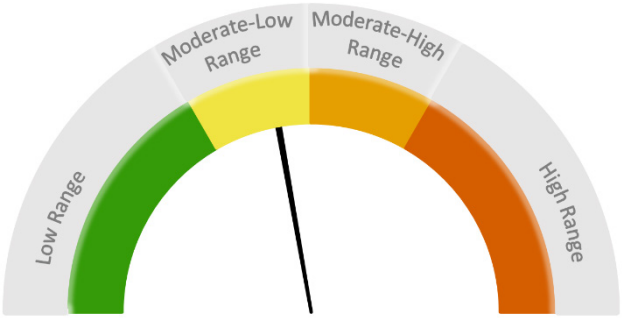
The complete risk evaluation methodology is described in *Understanding Water Treatment Chemical Supply Chains and the Risk of Disruptions* (EPA, 2022b). The risk rating is calculated as the product of the following three risk parameters:

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 Carbon Dioxide

Risk Parameter Ratings and Drivers		
Criticality: High	**Likelihood: High**	**Vulnerability: Low**
Carbon dioxide is essential and widely used for pH adjustment.	The water sector has experienced several regional carbon dioxide supply disruptions in the past. From 2017 through 2021 disruptions in the supply of carbon dioxide occurred due to a decrease in supply as a result of both losses in production capacity due facility closures and reduced production of ethanol.	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-Low		



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