Oxygen

O_2 (liquified gas)

Direct Use Chemical Precursor Chemical

Inputs to Manufacturing Process: Atmospheric air separation

% of Total Domestic Consumption Attributed to Water Sector: Less than 5%

Product Family: Atmospheric Gas

CAS No.: 7782-44-7

Derivative Water Treatment Chemicals: Sulfur Dioxide, Sulfuric Acid

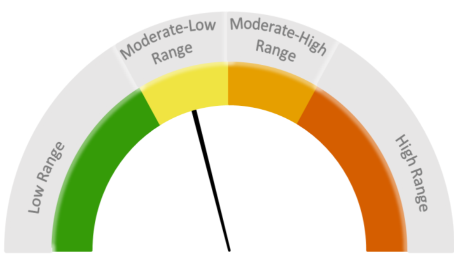
Understanding Chemical Supply Chains

Map of Suppliers & Manufacturers

Shelf Life: 60 Months

RISK OF SUPPLY DISRUPTION (Assessed in 2022)

RISK RATING: Moderate-Low



RISK DRIVERS

Highly purified oxygen, though widely produced, has significant demand for critical use in healthcare. Transport of liquid oxygen to customers by truck requires certified drivers with specialized training. Increased demand for medical oxygen and insufficient transportation resources has led to past shortages.

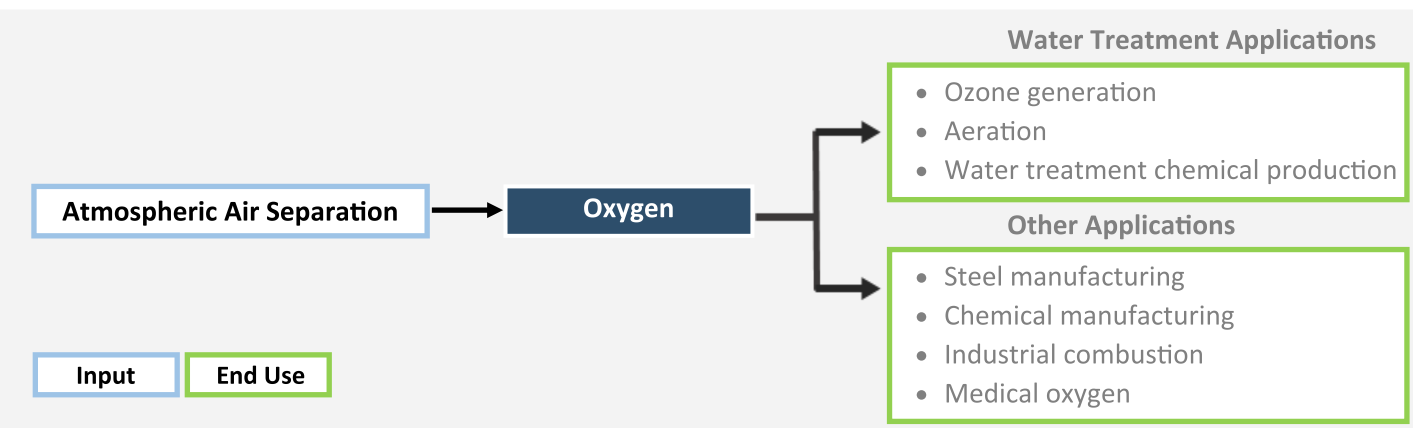
RISK PARAMETERS

Criticality: High. Essential and widely used for oxidation, aeration, and production of water treatment chemicals.

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. However, transport requires specialized certification and can be costly.

MANUFACTURING PROCESS



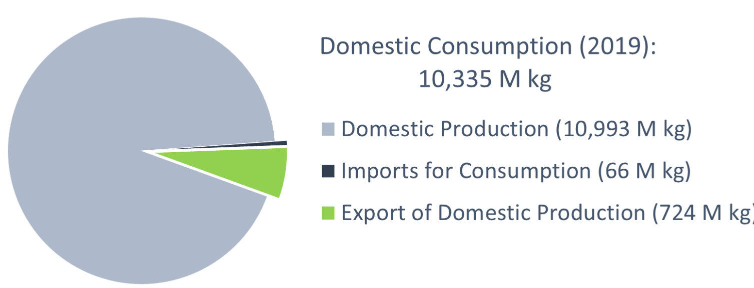
DOMESTIC PRODUCTION AND CONSUMPTION, AND INTERNATIONAL TRADE

Domestic Manufacturing Locations (2021): 110, distributed throughout the U.S.

International Trade (2019)

Primary Trading Partner (Imports): Mexico

Primary Trading Partner (Exports): Dominican Republic



Product Description

Oxygen (O_2), an inorganic gas recovered from atmospheric air, is one of the most widely used industrial gases. Purified oxygen is primarily recovered through cryogenic air separation at numerous plants throughout the U.S. Oxygen is most commonly used for industrial combustion in steelmaking, and chemical manufacturing.

Use in Water Treatment

Oxygen has several uses in water treatment, including ozone generation and aeration (AWWA, 2018). Industrial grade oxygen that is at least 99.5% pure is recommended for use in water treatment.

Use as a Precursor to Other Water Treatment Chemicals

Purified oxygen is used as a chemical reactant in the production of sulfur dioxide and sulfuric acid. Though atmospheric air is commonly used in other chemical syntheses, an enriched oxygen environment or purified oxygen may be used in the manufacture of many other chemicals such as ferric chloride, ferric sulfate, and potassium permanganate. In these manufacturing methods, oxygen may be used to regenerate catalysts or improve oxidation or combustion efficiency.

Other Applications

Consumption of purified oxygen can be considered in categories for industrial applications such as steel manufacturing, and high-grade applications such as medical use. Common industrial applications include steel manufacturing, chemical manufacturing, manufacturing combustion (e.g., cast iron melting, glass manufacturing), metal fabrication, welding, and pulp bleaching. High-grade oxygen applications include use in healthcare settings for applications such as oxygen deficiency and anesthesia, and in food preparation (FTC, 2018; NETL, 2022; NCBI, 2021).

Primary Industrial Consumers

The primary application of oxygen is industrial combustion. Historically, steel manufacturing has been the largest single industrial application of purified oxygen, and has accounted for up to 65% of domestic consumption, though it is unclear whether this accounts for on-site production of purified oxygen (NCBI, 2021). Chemical manufacturing, other industrial combustion applications such as welding, glassmaking and ceramics, and pulp and paper bleaching are other prominent industrial applications. Medical oxygen use, a subset of all healthcare oxygen consumption, is estimated at approximately 6% of demand (Raquet, 2020). The overall water sector market for oxygen is estimated at less than 5% of total U.S. consumption.

Manufacturing, Transport, & Storage

Manufacturing Process

Purified, commercial-grade oxygen is primarily produced through gas separation of air via cryogenic distillation in an air separation unit (ASU). Most cryogenic air separation facilities produce liquid oxygen (LOX) at greater than 99% purity to cover a broad range of applications, including industrial applications (Cockerill, 2021).

Cryogenic separation is used when a high purity, large quantity of liquified oxygen is required. Prior to cryogenic separation, impurities such as carbon dioxide and hydrocarbons are removed via a silica and zeolite molecular sieve. Subsequent fractional distillation based on temperature separation is used to separate oxygen from nitrogen and argon. Further distillation and fractionation provides higher purity oxygen or LOX. The LOX is drawn out of the bottom of the fractionating column and cooled (NETL, 2022; Rao and Muller, 2007).

Medical oxygen has a distinct supply chain and production requirements. Air separation plants generally produce oxygen of varying grades and for a variety of industrial standards. Thus, an increase in the demand for medical oxygen utilizes air separation plant capacity that would otherwise be used to produce other grades of oxygen (NETL, 2022).

Product Transport

LOX is considered a hazardous material, which dictates how it can be transported and may add significant cost to long-distance transport. Methods of distribution and consumption are based on the volume of gas required. Industrial LOX users generally require volumes too large to purchase in cylinders, but not great enough to require an on-site ASU or pipeline. Cryogenic trailers are typically used for bulk deliveries of LOX. High distribution costs determine the geographic distribution range from the production site, often necessitating regional production for cost-effective distribution (FTC, 2004; Linde, 2018).

Storage and Shelf Life

Oxygen can be pressurized and cooled to a liquified gas and stored in pressure vessels. Pressurized storage vessels should be stored in a cool, dry location away from direct sunlight. When stored properly, LOX can have a shelf life of 60 months (Air Products, 2017).

Domestic Production & Consumption

Domestic Production

Production data was collected from a trade publication, *gasworld*, for the year 2019, while trade data was collected from the USITC Dataweb, as shown in Table 1. Both production and trade data are specific to oxygen.

Table 1. Oxygen Production and Trade Data Sources

Production and Trade Data			
Category	**Data Source**	**Identifier**	**Description**
Domestic Production	Trade Publication, *gasworld*	CAS No.: 7782-44-7	Oxygen
Imports and Exports	U.S. International Trade Commission	HS Code: 2804.40	Oxygen

Total U.S. domestic production of oxygen was approximately 10,335 Million kilograms (M kg) in 2019 (Raquet, 2020). The top domestic oxygen suppliers to the commercial market are *Air Products, Air Liquide*, *Linde*, and *Matheson Tri-Gas*. All of these suppliers operate numerous oxygen production facilities and distribution networks. Air separation plants that purify oxygen from air are widely dispersed across the country and each provides significant production capacity. Many of these ASU plants produce LOX. Though supply is widespread, some regions of the country may be served by only one or two producers. The number of domestic manufacturing locations shown in Figure 1 represents operating facilities as of 2021. Supply of NSF/ANSI Standard 60 certified oxygen 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).

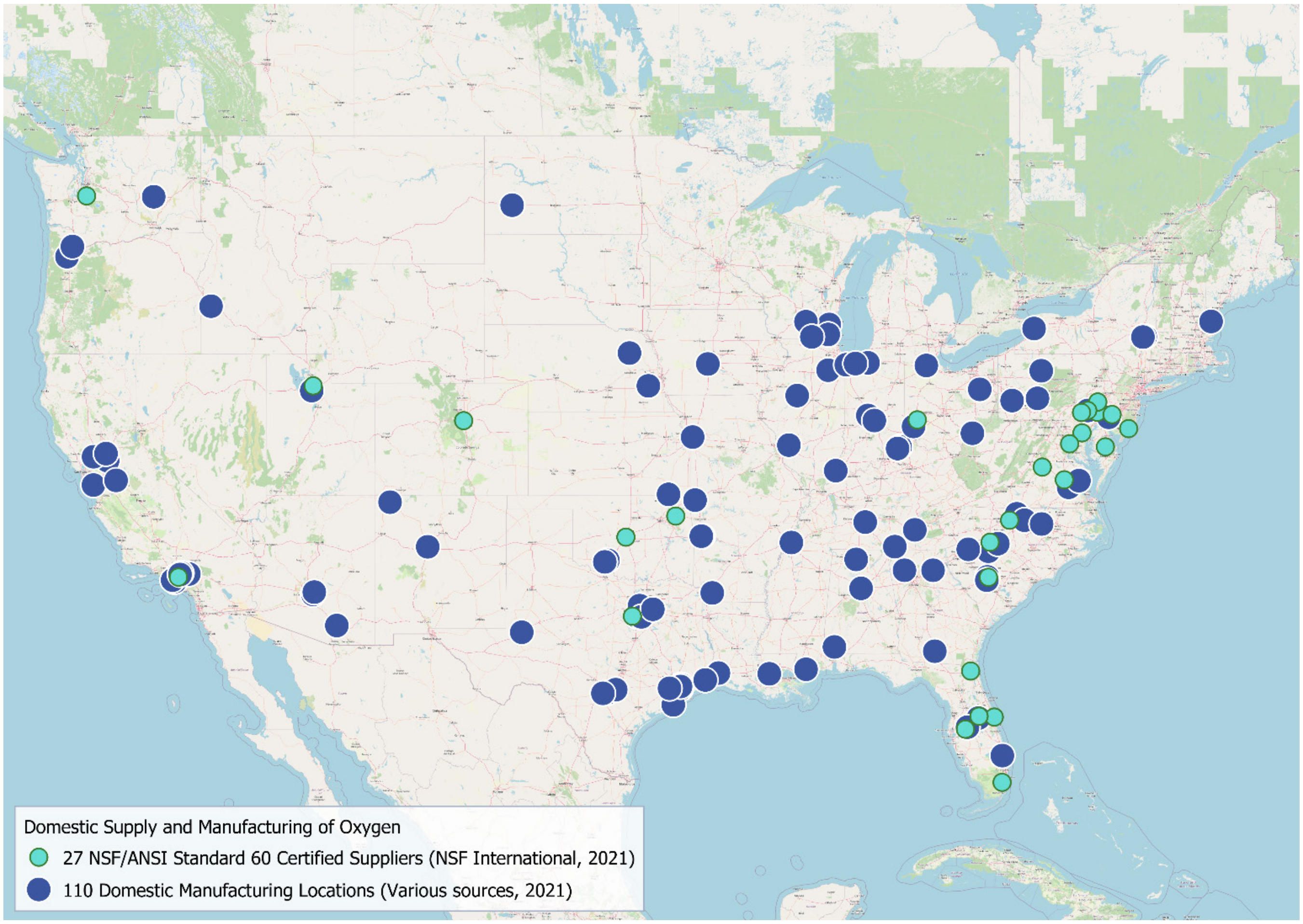


Figure 1. Domestic Supply and Manufacturing of Oxygen

Domestic Consumption

U.S. consumption of oxygen in 2019 is estimated at 10,335 M kg. This estimate includes production of 10,993 M kg, import of 66 M kg, minus export of 724 M kg (Raquet, 2020; USITC, 2021), as shown in Figure 2.

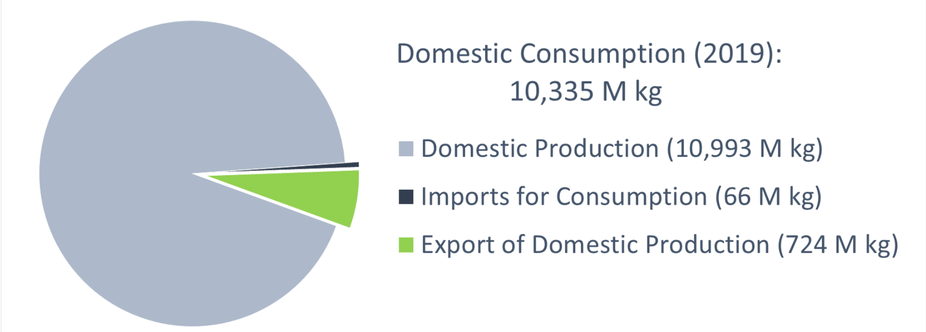


Figure 2. Domestic Production and Consumption of Oxygen in 2019

Trade & Tariffs

Worldwide Trade

Worldwide import and export data for oxygen are reported through the World Bank's World Integrated Trade Solutions (WITS) software, as a category specific to oxygen. In 2021, the U.S. ranked first worldwide in total exports and 16th in total imports of oxygen. In 2021, Netherlands ranked first worldwide in total imports (WITS, 2022), as shown in Table 2. Trade of oxygen was not reported by WITS in 2021 for numerous countries, including Canada, China, France, and the Russian Federation.

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

2021 Worldwide Trade Oxygen (HS Code 2804.40)			
Top 5 Worldwide Exporters		Top 5 Worldwide Importers	
United States	**1,252 M kg**	Netherlands	206 M kg
Belgium	536 M kg	Luxembourg	133 M kg
Poland	74 M kg	Jordan	95 M kg
Germany	73 M kg	Greece	85 M kg
Guatemala	54 M kg	Slovak Republic	80 M kg

Domestic Imports and Exports

Domestic imports and export data are reported by USITC in categories specific to oxygen. Figure 3 summarizes imports for consumption[1] and domestic exports[2] between 2015 and 2020. During this period, the overall quantities of exports and imports fluctuated, with domestic exports consistently exceeding imports for consumption. Over this five-year period, the Dominican Republic was the primary recipient of domestic exports while Mexico and Japan were the primary sources of imports (USITC, 2021).

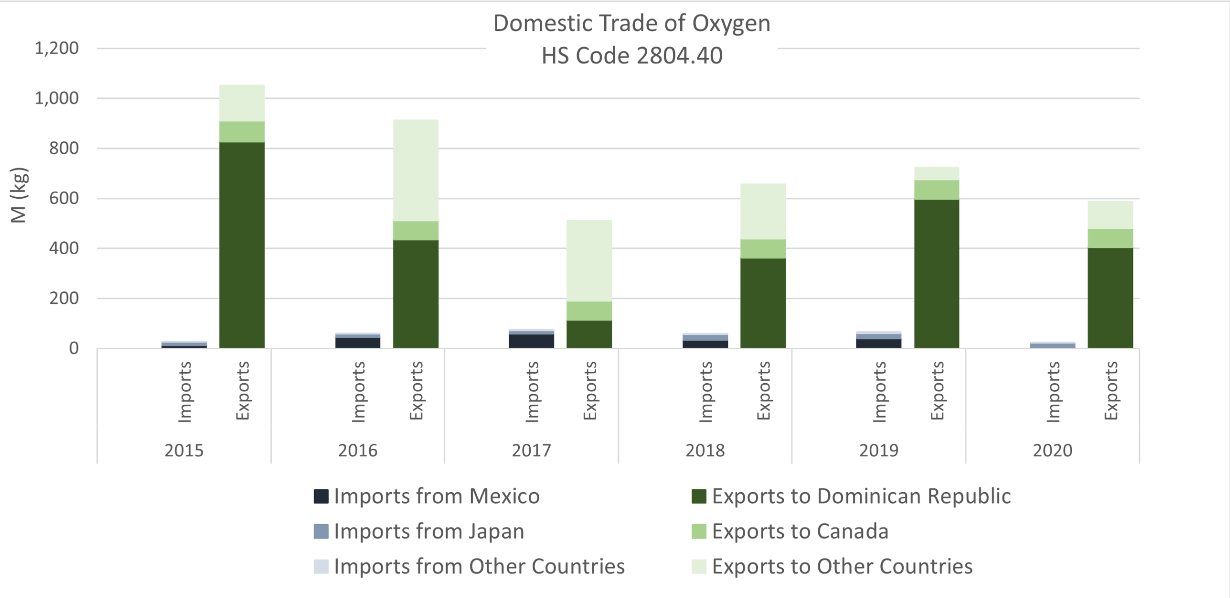


Figure 3. USITC Domestic Import and Export of Oxygen between 2015 and 2020

[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.

Tariffs

There is a 3.7% general duty for import of oxygen, and an additional 25% tariff on imports from China (USITC, 2022), as summarized in Table 3.

Table 3. 2020 Domestic Tariff Schedule for Oxygen

HS Code	General Duty	Additional Duty - China (Section 301 Tariff List)	Special Duty
2804.40	3.7%	25%	Free (A, AU, BH, CL, CO, D, E, IL, JO, KR, MA, OM, P, PA, PE, S, SG)[3]

Market History & Risk Assessment

History of Shortages

In the summer of 2021, COVID-19 hospitalizations, and the accompanying demand for LOX in healthcare settings, soared. During this same period, several LOX suppliers issued force majeure notices to industrial customers, which included drinking water and wastewater systems. In extreme cases, water system customers were placed on zero allocation for an unspecified duration. Force majeure notices were also issued to water treatment chemical producers which require LOX. The two primary reasons cited in force majeure notices were the increased demand for LOX in healthcare settings for COVID-19 patients, as well as a lack of commercial drivers with a Hazardous Materials Endorsement and experience offloading LOX. The increase in demand due to dramatic regional increases in COVID-19 hospitalizations coupled with insufficient transportation resources resulted in a severe regional shortage in Florida.

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:

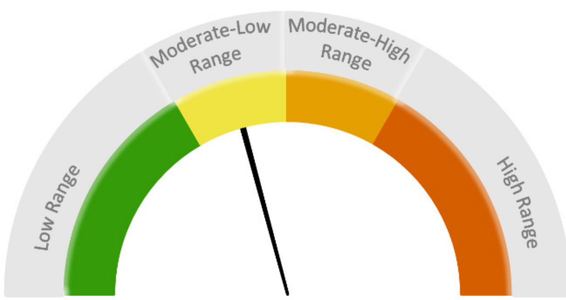
Risk = Criticality x Likelihood x Vulnerability	
Criticality	Measure of the importance of a chemical to the water sector
Likelihood	Measure of the probability that the chemical will experience a supply disruption in the future, which is estimated based on past occurrence of supply disruptions
Vulnerability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

[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

Table 4. Supply Chain Risk Evaluation for Oxygen

Risk Parameter Ratings and Drivers		
Criticality High	**Likelihood High**	**Vulnerability Low**
Oxygen is essential and has widespread application as an oxidant (ozone) and for aeration in both drinking water and wastewater treatment. It is a precursor in the production of other critical water treatment chemicals, and changes in availability or price may impact availability of derivative water treatment chemicals.	The water sector has experienced regional oxygen supply disruptions in the past. From 2020 through 2022 disruptions in the supply of oxygen occurred due to an increase in demand due to the COVID-19 pandemic and insufficient transportation logistics.	Strong domestic manufacturing capabilities and a distributed manufacturing base provide some resilience to supply disruptions. However, long-distance transport is costly and requires specialized equipment and certification.
Risk Rating: Moderate-Low		



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