RECLAMATION

Managing Water in the West

Lake Mead

Revised Carbon Dioxide Study Plan

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Environmental Applications & Research
Technical Service Center
Denver, Colorado

June 2013

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Lake Mead

Revised Carbon Dioxide Study Plan

Research and Development Office
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Denver, Colorado

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I. Background

Since their discovery in the late 1980s, the invasive zebra mussel (*Dreissena polymorpha*) and the closely related quagga mussel (*Dreissena bugensis*) have expanded their range threatening severe ecological and economic impacts on a large proportion of North American waterways and associated water delivery infrastructure. In 2007, quagga mussel adults were discovered in Lake Mead. As of yet, there does not appear to be a practical means of eradicating quagga mussels from the Colorado River system. Therefore, the Bureau of Reclamation (Reclamation) is taking steps to minimize their impact on power generation and water delivery operations at Hoover, Davis and Parker dams.

In a white paper submitted to the Research and Development Office and the Lower Colorado (LC) Region, *An Initial Assessment of Carbon Dioxide as an Alternative Control Strategy for Quagga and Zebra Mussel Biofouling*, carbon dioxide was described as having the potential to be used as a molluscicide for quagga mussel control. Like most bivalves, these organisms are susceptible to even relatively modest increases in the ambient concentration of carbon dioxide, since they do not contain oxygen-carrying proteins to buffer blood pH. Inhibition of byssogenesis (attachment) and mortality of adult mussels have been achieved by injecting carbon dioxide-enriched gas mixtures into the water. The white paper recommended carrying out exploratory research to determine the efficacy of carbon dioxide treatment on the byssogenesis and mortality rates of quagga and zebra mussels simulating conditions in an infested pipe structure.

The original scope of this study plan was to investigate the feasibility of utilizing carbon dioxide on-site to prevent or mitigate quagga mussel impact on dam operations at Hoover, Davis or Parker Dams. However, at the request of the LC Region, the study plan is being revised to first perform a small-scale feasibility study at one of three lower Colorado River locations; Katherine Landing on Lake Mohave, the U.S. Fish and Wildlife Service Willow Beach National Fish Hatchery on Lake Mohave, or the Nevada Department of Wildlife Lake Mead Fish Hatchery on Lake Mead. The requirements were that testing must involve lower Colorado River water and quagga mussels. After consulting with all three locations, the Lake Mead Fish Hatchery was chosen primarily due the availability of space and utilities. Based on the description provided here, hatchery personnel expect that they would be able to accommodate this study and provide collection permits. An agreement in regard to electrical usage, water, and space would need to be approved. Hatchery water supply comes directly from Lake Mead through the BMI pipeline and this facility is often used by scientists to study quagga mussels. Since the study plan is revised to exclude direct testing on an infested pipe at one of Reclamation facilities, an apparatus to simulate similar conditions would be required. This revised study plan provides a description of the apparatus and methodologies to be used, an assessment of environmental compliance, and safety considerations. The study plan is proposed to occur in fiscal year 2014 during November through March.

II. Theory

Carbon dioxide is a natural gas comprising approximately 0.039% (388 parts per million [ppm]) of the Earth's atmosphere. Successful application of carbon dioxide as a biocontrol agent for zebra and quagga mussels requires an initial understanding of its equilibrium behavior between the gaseous and aqueous phases, as well as its carbonic acid equilibrium in the water. A brief summary is provided here as it relates to the water of Lake Mead.

Once carbon dioxide becomes soluble in water, a fraction of the aqueous carbon dioxide chemically reacts with water to form carbonic acid. Carbonic acid is a weak acid that dissociates in chemical equilibrium with bicarbonate and carbonate, which decreases the pH of the water. Figure 1 shows the equilibrium distribution of dissolved carbon dioxide in the forms of carbonic acid (H_2CO_3), bicarbonate (HCO_3^-), and carbonate (CO_3^{2-}) as a function of pH. Since Lake Mead is a naturally alkaline water body with a total alkalinity of approximately 140 mg/L (as $CaCO_3$) and a pH of 8.1, bicarbonate is expected to be the predominant species.

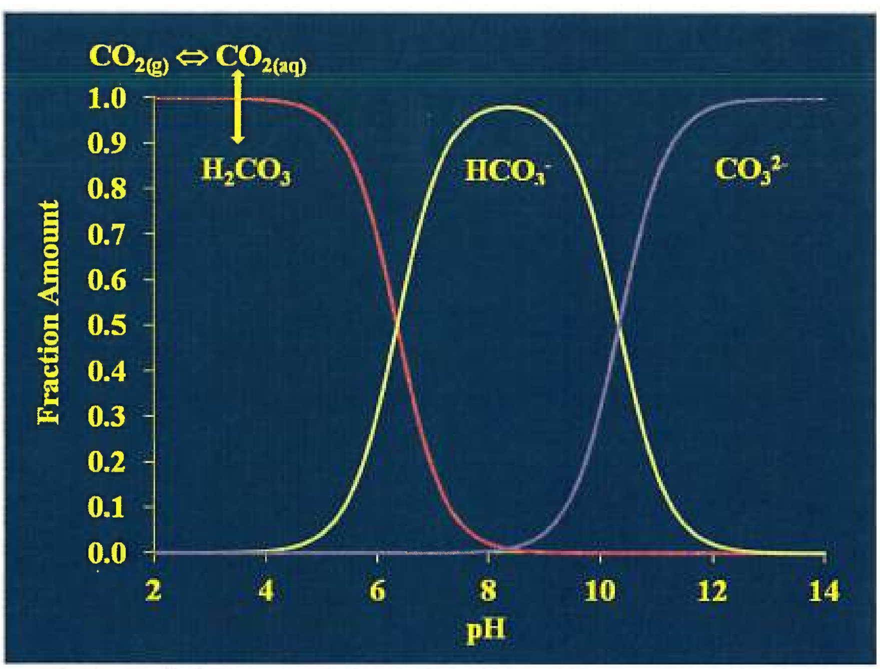


Figure 1. Relative proportions of aqueous CO_2 as a function of pH.

Therefore, when Lake Mead water is injected with carbon dioxide at elevated partial pressures, the resultant pH of the water depends primarily upon the concentration of aqueous carbon dioxide and the alkalinity of the water, as described by the Henderson-Hasselbalch equation:

$$pH = pK_1 - \log [(CO_2) / (HCO_3^-)]$$

Where

pK_1	=	6.35 (at 25˚C)
(CO_2)	=	the concentration of dissolved CO_2
(HCO_3^-)	=	the concentration of bicarbonate, which is usually the alkalinity because it is the predominate form of CO_2 in most naturally alkaline water

Figure 2 shows the relationship between carbon dioxide and pH at different levels of alkalinity (as $CaCO_3$). It is important to note here that while the basicity of Lake Mead water may be reduced, the alkalinity does not change with the addition of carbon dioxide. Although there may be other minor chemical contributors to total alkalinity in Lake Mead, the carbonic acid – bicarbonate – carbonate system is expected to be the dominant equilibrium system. With a pK_1 of 6.35 (25°C) for carbonic acid, there would be an initial steep drop in aqueous pH and a gradual leveling of the pH as it nears and drops below pH = 6.35. Eventually, adding more carbon dioxide will have little effect on the pH. When Lake Mead water is allowed to re-equilibrate upon exposure to the atmosphere (e.g., discharged from conduit), excess aqueous carbon dioxide is naturally degassed and the original pH is restored. Therefore, unlike most mussel controls, no residuals or byproducts remain in the water which may impact aquatic ecology and non-target species downstream of the treatment zone.

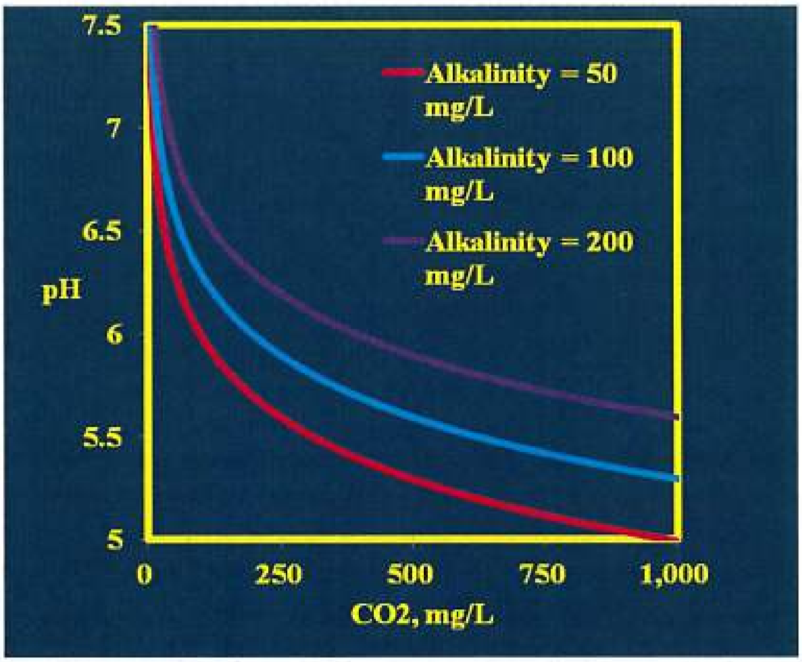


Figure 2. $[CO_2]$ vs pH (Henderson-Hasselbalch equation).

As an approximation, we can make use of the Henderson-Hasselbalch equation to estimate the amount of aqueous carbon dioxide required to achieve target pH values for Lake Mead water, as shown in Table 1. For carbon dioxide injection in a pipe, a pH feedback loop set at the target pH will be used to control the amount of carbon dioxide injected into the water, as described below. Field conditions will likely deviate somewhat from standard conditions (e.g., water temperature) and the actual amount of aqueous carbon dioxide required to achieve target pH values must be adjusted empirically at the time of carbon dioxide application.

Table 1. Theoretical solubility of CO_2 vs pH in Lake Mead water

[CO_2], mg/L	pH	[CO2], mg/L	pH
10	7.44	60	6.66
20	7.14	70	6.60
30	6.96	80	6.54
40	6.84	90	6.49
50	6.74	100	6.44

The threshold pH for survival of adult dreissenid mussels appears to be near pH 6.5. For veligers and juveniles, the threshold appears to be higher, at pH 6.9. The incipient lethal level for veligers begins near pH 7.4. Like many invertebrates, quagga mussels have an open circulatory system where blood (hemolymph) is not completely contained within blood vessels, and the hemolymph has no specialized oxygen-transporting pigments. When mussels are exposed to elevated levels of carbon dioxide, diffusion of carbon dioxide into mussel tissues results in decreased body fluid and hemolymph pH. At the same time, hemolymph acidosis would be compounded by the decrease of external water pH associated with elevated levels of dissolved carbon dioxide in the water. Mussels would have a reduced ability to buffer blood pH because they are forced to use the less efficient mobilization of shell carbonate to buffer the hemolymph. Reduction in hemolymph and intracellular pH would then inactivate metabolic enzymes that may lead to rapid death. As it can be seen in Table 1, an aqueous carbon dioxide concentration of 90 mg/L is expected to bring down the pH of Lake Mead water to below 6.5, which is the survival threshold for adult dreissenid mussels.

However, it has also been demonstrated that sublethal dosage levels of carbon dioxide cause byssus detachment and the suppression of byssal thread production. It may not be necessary to cause mortality in order to mitigate quagga or zebra mussel colonization in a pipe. In this situation, elevated levels of carbon dioxide serve as a repellent instead of a pesticide. Living mussels voluntarily detach, and migrate or flush downstream out of the pipe. Problems associated with dead and decaying mussels are avoided. A lower carbon dioxide consumption rate is used for dosages causing byssus detachment or the suppression of byssal thread production than what is required to cause mussel mortality. For these reasons, this revised study plan also proposes to determine the rate of detachment at different levels of carbon dioxide exposure.

The solubility of carbon dioxide gas in water is governed by Henry's Law:

$$P = k_H C$$

Where

P = the partial pressure of the solute in the gas above the water
k_H = the Henry's Law constant, 29.4 L•atm/mol (at 298 K)
C = the concentration of the solute in water

Under standard conditions, an aqueous carbon dioxide concentration of 100 mg/L and a pH of 6.44 in Lake Mead water (Table 1) would require an elevated partial pressure of approximately 0.0668 atm carbon dioxide in the gas phase in equilibrium with the water or approximately 170 times the natural atmospheric concentration of carbon dioxide. This can be achieved by controlling the injection rate of carbon dioxide into Lake Mead water as it passes through or held static within the confine of an infested conduit, as described below.

A simple diagram illustrating the basic set up of a carbon dioxide injection system on a pressurized pipe is shown in Figure 3.

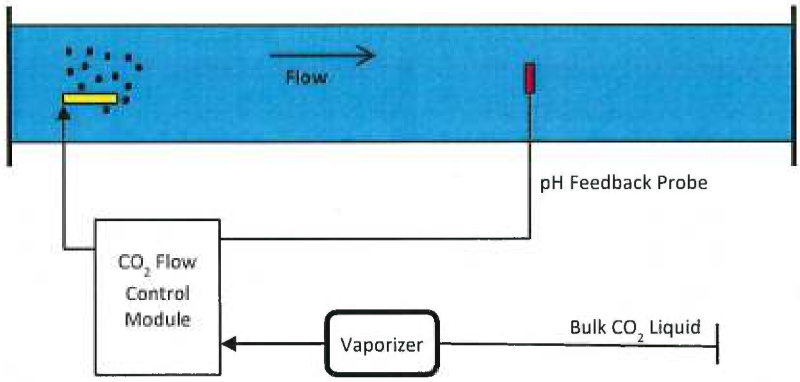


Figure 3. Simple illustration of the CO_2 injection system.

As described earlier with the Henderson-Hasselbalch equation, the key parameter for controlling the amount of carbon dioxide added to the water would be the target pH monitored during treatment. This allows for real-time and automated adjustments to the carbon dioxide dosage due to fluctuating water quality. For example, water temperature or alkalinity may vary with reservoir depth. Water quality may fluctuate at the pipe intake due to the rise and fall of the reservoir water surface elevation. Changing water quality has been shown to affect the efficacy of most water treatments. However, since carbon dioxide chemically reacts with water to form carbonic acid, the treatment naturally lead itself to real-time and automated control of carbon dioxide injection by a downstream pH feedback loop, and the target carbon dioxide dosage is maintained despite fluctuations in water quality.

Carbon dioxide injection systems are commercially available or can be customized for a particular facility or structure to be treated. An example of a carbon dioxide injection control system is the Water Treatment Gaseous Carbon Dioxide Flow Control Module from Praxair® (see Photograph 1). This system is being used on a separate Reclamation project to investigate the feasibility of controlling zebra mussels in a pipe line that delivered raw water from an infested lake to a river. Further details of this flow control module are provided in Appendix A.

In summary, bulk carbon dioxide liquid is plumbed into the flow control module via secured piping through a vaporizer to convert the liquid carbon dioxide to gaseous carbon dioxide, which is then piped to the left side of the flow control module (see Photograph 1). On the right side of the flow control module, secured piping allows gaseous carbon dioxide to be injected into the pipe via a reinforced sparger tube. The pH is monitored downstream of the injection point and controlled in real time via a feedback loop. The pH feedback probe can be a long-term industrial probe such as the Rosemount® 399 sensor or equivalent. When use in combination with a process controller that will output 4-20 mA, a signal is applied to the current-to-pressure (I-to-P) transducer on the carbon dioxide flow control module, which then operates a normally closed valve to allow variable flow of gaseous carbon dioxide into the raw water pipe line. By maintaining a target pH, adjustments are made automatically to the carbon dioxide injection gas flow rate to maintain a constant and desired level of dissolved carbon dioxide concentration in the water.

Photograph 1 – Praxair® Water Treatment Gaseous Carbon Dioxide Flow Control Module

III. Revised Study Approach

To eliminate the cost of fabricating a test apparatus and to perform this study following tried and proven methods, this revised study plan is tailored based on other studies investigating the use of carbon dioxide for the suppression of invasive Bullfrog larvae (Abbey-Lambertz et al., 2013) and for the control of biological fouling in pipelines (Watten et al., 2005). The same testing apparatus will be used.

The goal is to test the effects of exposure to elevated concentrations of carbon dioxide on the survival and detachment of quagga mussels. The objectives are to 1) determine mortality (LT_{50}) to different levels of dissolved carbon dioxide and 2) document lethal and sublethal changes in byssus attachment. This study would be the first to demonstrate the effects of elevated levels of carbon dioxide on quagga mussels in water from the lower Colorado River.

A. Materials and Methods

Animal Collection and Handling. Live quagga mussels will be harvested from Lake Mead following a collection permit from the Nevada Department of Wildlife. During harvesting, the byssal threads of each mussel will be cut with razor blades at the byssal shell gape. Individual mussels will then be sorted separately, based on shell length, and further divided evenly into separate perforated and clear plastic containers. Containers of live mussels will be placed in an acclimatization tank at the Lake Mead Fish Hatchery that is continually refreshed with Lake Mead water via the BMI pipeline (see Photograph 2). Water is discharged from the acclimatization tank along with the rest of the fish

Photograph 2 – Hatchery Building at Lake Mead Fish Hatchery

hatchery discharge water into a settlement pond and ultimately returned to Lake Mead. Mussels will be placed on the upper surface of their containers while they are acclimatizing in the recovery tank for at least 12 hours, during which time they will be allowed to byssally reattached to the top surface of their containers.

Water Parameters. To eliminate outside factors of mortality and detachment, flow through Lake Mead raw water will be monitored for the following parameters; temperature, dissolved oxygen (DO), pH, conductivity, and total alkalinity (as $CaCO_3$). Since hatchery source water is continuously refreshed with Lake Mead water via the BMI pipeline, the water temperature during acclimatization and carbon dioxide testing will be the same as the source water (Lake Mead) throughout the study. Furthermore, hatchery source water is also aerated (see Photograph 3), which should discount hypoxia as a factor and aid recovery during periods of acclimatization.

Photograph 3 – Lake Mead Fish Hatchery Water Aeration Tower

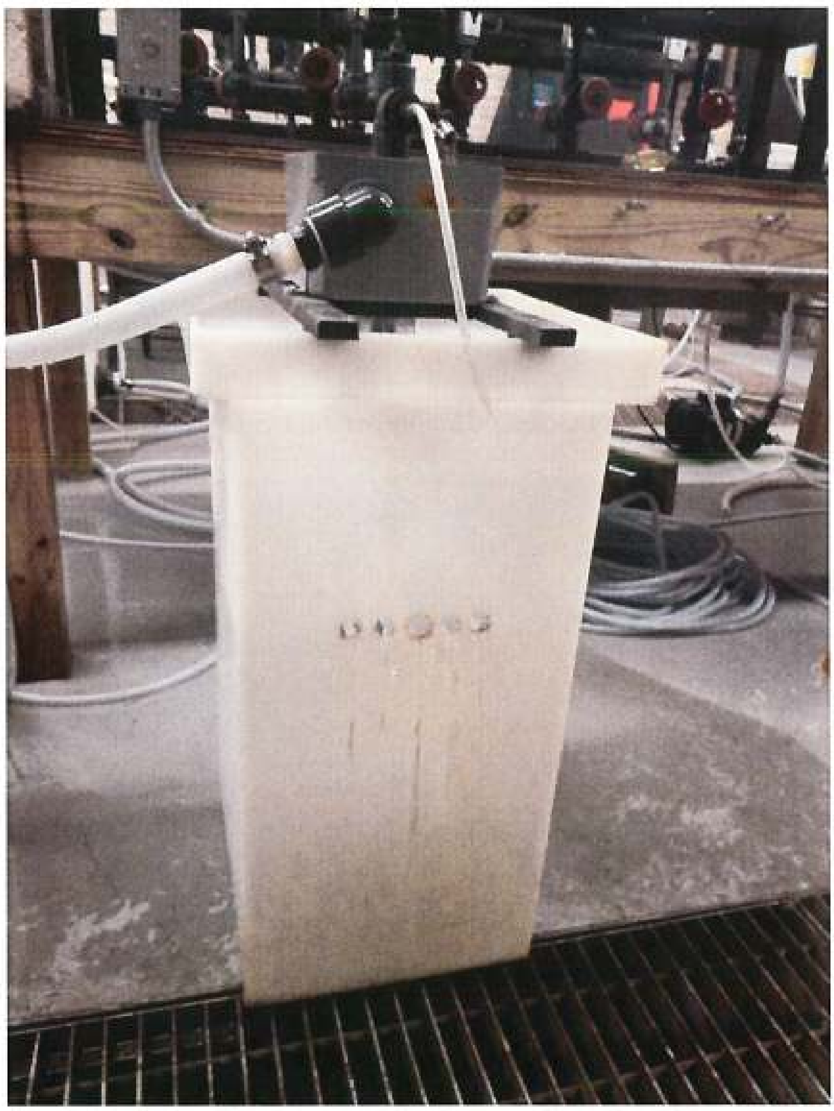
Experimental CO_2 Apparatus. To test the effects of carbon dioxide on quagga mussels, four USGS hyperbaric chamber systems from Watten et al. (2005) will be adapted for this study.

A single system includes nine 3-L hyperbaric chambers, as shown in Figure 4. All hyperbaric chambers will be set up so that they will use the same source water (Lake Mead) at the same flow rate and the same source carbon dioxide (bulk storage), where flow rate is adjusted depending on treatment. From bulk storage, carbon dioxide gas feed is split into separate and independent lines, each regulated by a mass flow meter adjusted until the flow rate reached the desired dissolved carbon dioxide concentration. Using a 1/3 hp pump, source water is forced into a pressurized vertical column carbonator where the water is mixed uniformly with carbon dioxide (see Photograph 4). Water flow rates through the hyperbaric chambers are individually monitored with variable area flow meters and adjusted individual chamber flow control valves to maintain a desired flow rate.

Photograph 4 – A carbon dioxide hyberbaric chamber system (on table). In the foreground on the floor is the carbonator where water and carbon dioxide are mixed together.

Photograph 5 – A carbon dioxide IR analyzer connected to the headspace sampling port of the gas liquid contacting chamber.

Concentrations of dissolved carbon dioxide in the effluent waters will be measured at 4-hour intervals using a head space unit that incorporated a portable infrared (IR) carbon dioxide analyzer (see Photograph 5). Headspace readings of carbon dioxide allow for the calculation of dissolved carbon dioxide given local barometric pressure. In brief, the IR gas analyzer measures concentrations of head space carbon dioxide by measuring carbon dioxide concentrations in gas captured in a gas liquid contacting chamber in the headspace unit (see Photograph 6) that is vented through the head space of the box and ultimately interfaces with the IR analyzer through a gas sample port. As described earlier using Henry's Law, dissolved carbon dioxide in discharge water can be monitored from headspace carbon dioxide levels measured in the gas liquid contacting chamber.



Photograph 6 – Headspace unit where carbon dioxide concentrations are measured with the IR analyzer.

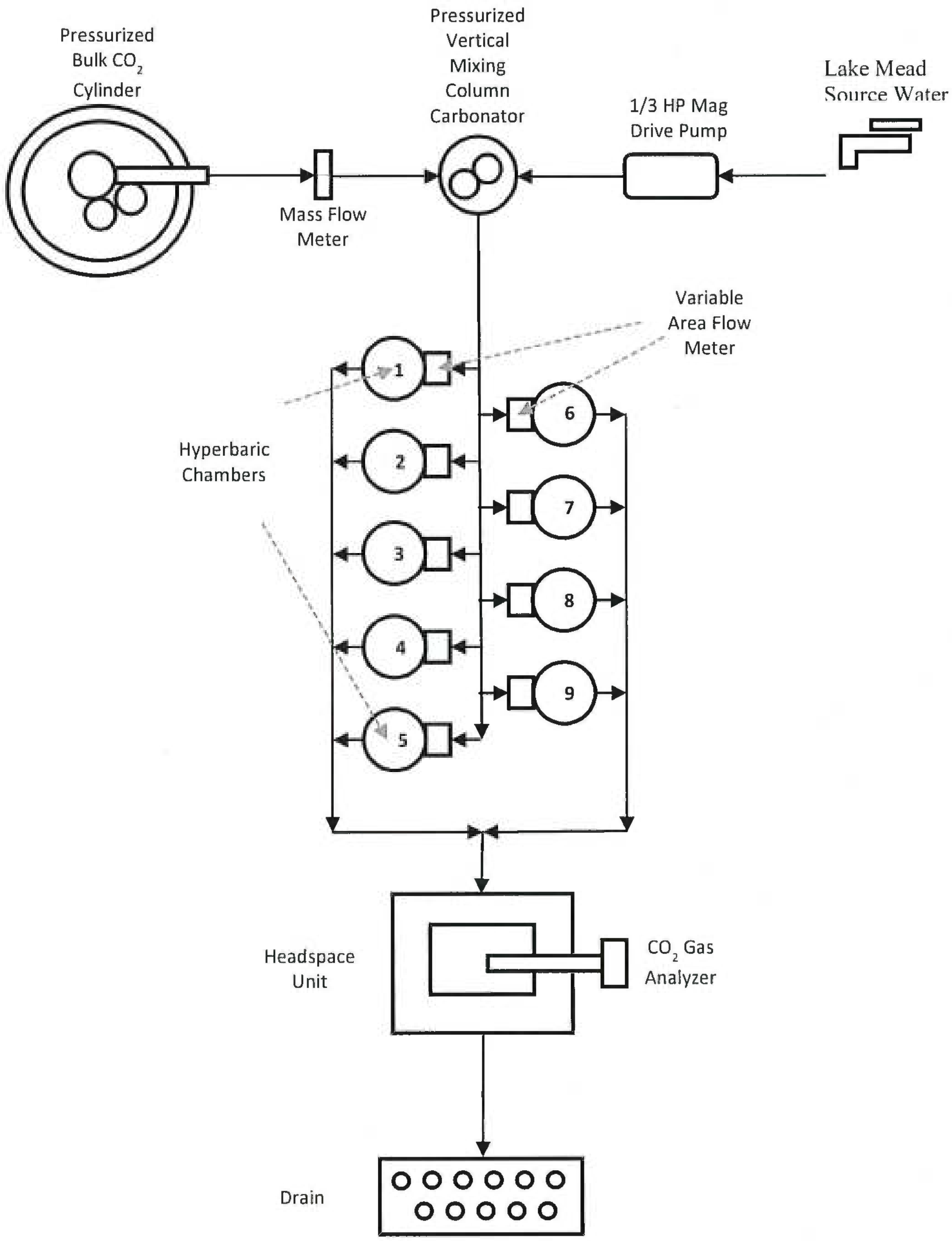


Figure 4. Schematic of a carbon dioxide hyperbaric chamber system. Arrows indicate direction of water and carbon dioxide flows. (reference: Abbey-Lambertz et al., 2013)

Determination of LT_{50}. Size-sorted and evenly divided subsets of re-attached and acclimatized quagga mussels will be exposed to 4 levels of carbon dioxide dosage (e.g., 35, 69, 172, and 276 kPa), in addition to control groups (no carbon dioxide exposure), using the nine 3-L cylindrical hyperbaric chamber system (Figure 4) for 24 hours. These levels of carbon dioxide dosage have been used elsewhere and appear to be a good starting point. Concentrations of dissolved carbon dioxide are adjusted to meet targets by regulating gas feed rates into the carbonator using the system described previously. Since multiple and separate hyperbaric chamber systems are available, simultaneous running of independent treatments during each 24-hour dosing period is possible.

After 24 hours, individual quagga mussels will be removed and placed in the recovery tank for 1 hour. Mortality will be checked after the 1 hour recovery period by gently prodding the posterior mantle edges and siphons of all gaping mussels with the tip of a blunted dissection needle. Living individuals will resist entry, while dead ones will offer no resistance. Mortality will be recorded as a function of carbon dioxide exposure period. The carbon dioxide exposure period resulting in 50% mortality will be determined based on probit scale analyses. Data and parameters measured from this study will be subjected to ANOVA statistical analyses to test for factor effects and interactions, as described below.

Determination of Detachment Rate. During the carbon dioxide exposure trails described above, the total number of live and dead mussels that have detached will also be recorded. The rate of byssus detachment at different levels of carbon dioxide dosage and exposure period will be determined. However, during the initial LT_{50} trials performed at 4 different levels of carbon dioxide exposure (i.e., 35, 69, 172, and 276 kPa), it may become evident that different dosage levels of carbon dioxide are warranted. If so, experiments may be repeated at adjusted carbon dioxide dosage levels to better determine detachment rates.

Statistical Analyses. One-way analysis of variance (ANOVA) will be performed on data to test for differences in dissolved carbon dioxide among treatments to confirm that quagga mussels are exposed to statistically different dissolved carbon dioxide concentrations. After confirming that treatment levels of dissolved carbon dioxide were unique, ANOVA will be used to test for differences in other parameters, especially mussel shell length. Simple linear correlations will be attempted to characterize possible associations among measured water quality parameters to determine if the introduction of elevated levels of carbon dioxide may have influence source water characteristics.

IV. Study Report

Raw field data, methods used, and quality controls will be independently reviewed to assess result reliability and conformance to this revised study plan. A public document shall be prepared, peer reviewed, and submitted to the Research and Development Office, which then may determine the best method of distribution to stakeholders and other interested parties.

The final study report will provide for the following:

1. Full tabulation of results under different treatment regimes, including controls.
2. Description of equipment and methodologies used.
3. Photographs and field notes.
4. Description of project collaboration and partnerships.
5. Discussion of any deviations from the study plan.
6. An assessment of the efficacy of carbon dioxide treatment on mortality and byssus detachment.
7. Conclusion on the feasibility of utilizing carbon dioxide to mitigate quagga mussel impact on LCR Reclamation facilities, including pipe engineering and carbon dioxide cost considerations.
8. Recommendations for future efforts.

Information produced from this study may be utilized by other water managers, stakeholders, and working groups to formulate a permanent solution to keep quagga and zebra mussels from impacting water delivery and pipe operations.

V. Safety

Material Safety Data Sheets (MSDS) for bulk carbon dioxide liquid, and gaseous carbon dioxide are included in Appendix B. Many Reclamation hydropower plants are equipped with carbon dioxide systems for generator and large-motor fire protection. Over the years, Reclamation has had good experience with the use of carbon dioxide. Typically, Reclamation facilities with carbon dioxide protection use high-pressure systems that are fed by banks of carbon dioxide storage vessels through valves and piping, which are activated by electrical devices that rapidly discharge the storage vessels. Some installations use, or are in the process of converting to, modern refrigerated, low-pressure bulk carbon dioxide liquid storage systems, such as what is described here.

Since Reclamation has many years of experience in transporting, handling, and using carbon dioxide as a fire extinguisher on hydropower facilities, safety protocols are well established. For this study, the same safety protocols will be followed. To maintain established Reclamation standard practices, a Job Hazard Analysis (JHA) that has been developed and approved will be used in this study. A JHA is prepared to identify the scope of the work to be performed, specific safety procedures to be used, potential hazards, and emergency response contact information.

Bulk carbon dioxide liquid and storage vessel are commercially available and maintained by the vendor via a supply schedule agreement. Empty storage vessels or unused bulk carbon dioxide liquid are returned in the same transport/storage vessel it was delivered in. Since carbon dioxide is naturally degassed into the atmosphere, no wastewater or hazardous waste is generated.

VI. Permits

An initial environmental compliance scoping analysis was performed by the LC Region Environmental Compliance Group (LC-2600), based on information provided in the white paper and discussion of the parameters described in this revised study plan. This assessment was provided earlier to the Research and Development Office.

The cost and level of environmental compliance necessary for a project of this type can vary depending upon many factors. This study plan proposes to conduct the feasibility research in a small-scale closed system at an off-site location (Lake Mead Fish Hatchery). Therefore, impacts to the environment are anticipated to be minimal. The LC Region Environmental Compliance Group anticipates that the study would be categorically excluded from further National Environmental Policy Act (NEPA) review. The cost to document this in a Categorical Exclusion Checklist (CEC) is estimated at $1,500 to $2,000. Due to the small scope of this study plan and the availability of quagga mussel related funds, it is possible for this documentation to be accomplished during FY13, prior to the implementation of this study plan during FY14. Because of their familiarity with the study location and background in environmental compliance preparation for activities in the Lower Colorado Region, the LC Region Environmental Compliance Group will prepare the CEC based on this study plan.

The Lake Mead Fish Hatchery is run by the State of Nevada and is operated on National Park Service (NPS) lands. Reclamation initiated and is funding this study therefore would be the lead Federal agency for NEPA.

If the results of this study support further exploration at a dam facility, NEPA and other associated environmental compliance would need to be conducted. The selected dam location and potential impacts to resources in the dam project area will determine the level of compliance needed and the amount of coordination needed with other agencies and the public. The LC Region Environmental Compliance Group would be able to initiate this environmental compliance after site-specific details are finalized. The cost for performing this compliance would depend on the level of compliance needed and the complexity of the action. A CEC typically costs between $1,500 to $4,000. An Environmental Assessment typically costs between $10,000 to $50,000. At this time and without a specific dam location identified, this environmental compliance is beyond the scope and funding level of this study plan.

Multiple agencies are currently involved with using carbon dioxide on a variety of aquatic taxa including invertebrates, amphibians, and fish. For example, the USGS (Upper Midwest Environmental Sciences Center) is currently working with the EPA to determine registration eligibility and requirements for using carbon dioxide as a pesticide in fish production facilities. The U.S. Fish and Wildlife Service also started carbon dioxide testing on a variety of fish species of concern.

With the increasing use of carbon dioxide to mitigate problems from aquatic species, there has been an increasing focus on environmental compliance activities for carbon dioxide and much of the work done in this area should be utilized by Reclamation after a specific dam site location where carbon dioxide may be tested is identified.

VII. Study Partners

Information and photographs provided here in this study plan would not have been possible without the assistance and cooperation of the following organizations. Numerous communications with individuals from these organizations over the past months have led to this revised study plan. Although multiple individuals provided help, a single point of contact from each organization below is listed. Should this feasibility study occur, in-kind contributions from these partners will be critical to the success of this project.

Nevada Department of Wildlife
Pat Kelly, Wildlife Staff Specialist
Fisheries Division
Reno, NV
www.ndow.org

Praxair, Inc.
Ron Switzer, Market and Business Development Manager
Environmental Applications
Danbury, CT
www.praxair.com

U.S. Geological Survey
Dr. Barnaby J. Watten, Chief
Leetown Science Center, Conte Anadromous Fish Branch
Turners Falls, MA
www.lsc.usgs.gov

VIII. Literature Reviewed

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Appendix A

Praxair® Water Treatment Gaseous Carbon Dioxide Flow Control Module

2 EQUIPMENT DESCRIPTION

Controlling the pH of water may be necessary if it is going to be discharged into a lake or river, consumed, or used in another process. Introducing carbon dioxide (CO_2) into water causes the formation of carbonic acid (H_2CO_3), which raises the acid level and lowers the pH. The Water Treatment Gaseous Carbon Dioxide Flow Control Module is designed to regulate the flow of gaseous carbon dioxide injected into water to control the pH.

When carbon dioxide is introduced to water, it forms a weak acid, carbonic acid, that dissociates to form carbonate (CO_3^{2-}) and bicarbonate ions (HCO_3^-). The basic reactions are summarized below.

$$CO_2 + H_2O \longleftrightarrow H_2CO_3$$
$$H_2CO_3 \longleftrightarrow 2H^+ + CO_3^{2-}$$
$$H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$
$$HCO_3^- \longleftrightarrow H^+ + CO_3^{2-}$$

The addition of carbon dioxide, therefore, raises the number of H^+ ions in the water. Since pH is a measure of H^+ ion concentration ($-\log[H^+]$), the pH is reduced as carbon dioxide is added.

Figure 2-1 illustrates the overall system. Typically, a supply of liquid carbon dioxide is supplied from bulk gaseous carbon dioxide vessels at 0°F and 300 psig (-17.8°C and 2059.4 kPa). A process controller measures the pH of the water with a probe and sends a signal to the Water Treatment Gaseous Carbon Dioxide Flow Control Module to regulate the amount of carbon dioxide fed to the water.

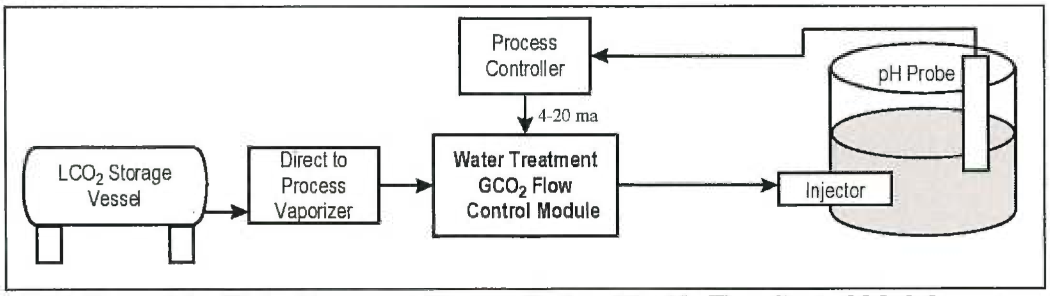

Figure 2-1: Water Treatment Gaseous Carbon Dioxide Flow Control Module

The basic Water Treatment Gaseous Carbon Dioxide Flow Control Module specifications are listed in Table 2-1.

Table 2-1
Specifications

Dimensions	51" long x 48" high x 10" deep (129.5 cm long x 121.9 cm high x 25.4 cm deep)
Weight	90 pounds (40.5 kg)
Connections	½" female NPT
Maximum CO_2 Flow Rate	8,100 scfh (59142.1 sq cm^3/hr)
Pressure Ratings: Piping and Fittings I-to-P Transducer	 450 psig (3102.7 kPa) 22 psig (151.7 kPa)
Environment	Outdoors, Non-Hazardous
Temperature	-40 to 150°F (-40 to 65.6°C)

2.1 Carbon Dioxide Supply System

Carbon dioxide is normally supplied from bulk liquid carbon dioxide storage vessels that are at 0°F and 300 psig (-17.8°C and 2059.4 kPa). Many liquid carbon dioxide vessels have foam insulation and a refrigeration system to prevent the loss of carbon dioxide due to heat leak. Some newer liquid carbon dioxide vessels have vacuum insulation and do not require refrigeration (but do have losses due to heat leak).

An electric or a steam vaporizer converts the liquid carbon dioxide into gaseous carbon dioxide, which is then piped to the flow control module. Refer to the documentation accompanying the carbon dioxide supply system for your application for additional information.

2.2 Process Controller and pH Probe

A process controller and a pH probe are required to measure the water pH and send a signal to the Water Treatment Gaseous Carbon Dioxide Flow Control Module. Controller output is typically 4-20 mA.

NOTE

Process controllers and pH probes are not supplied by Praxair, Inc.

Figure 2-2 is a general flow piping diagram of the Water Treatment Gaseous Carbon Dioxide Flow Control Module.

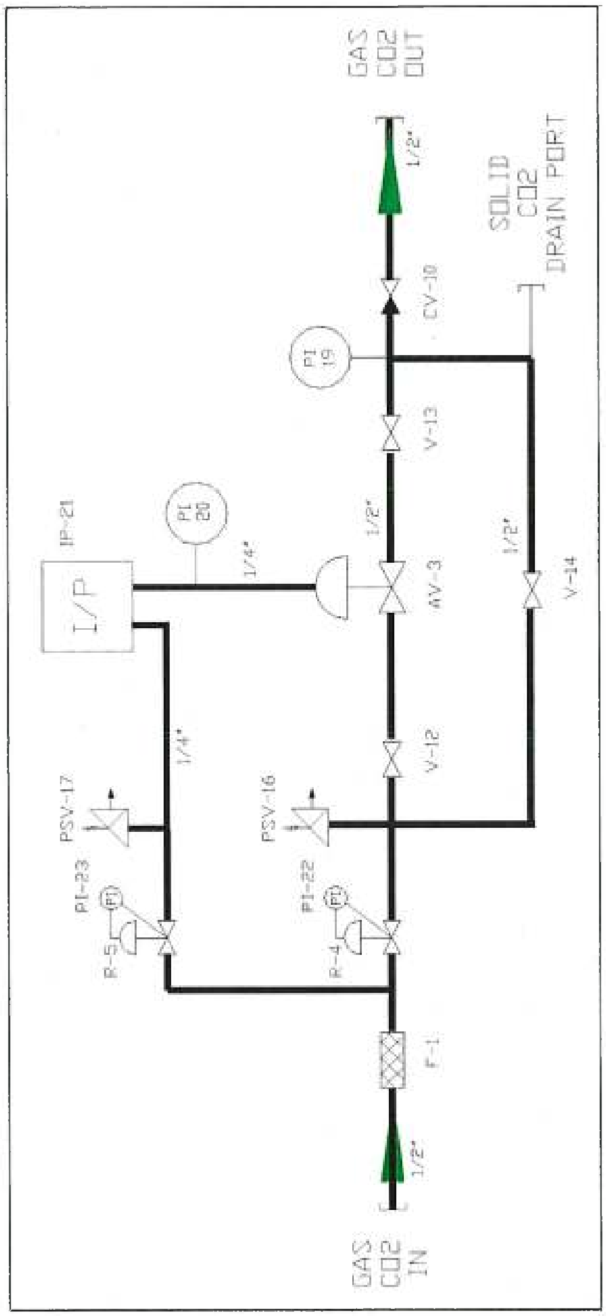

Figure 2-2: General Piping Diagram

2.3 System Components

The following version of Water Treatment Gaseous Carbon Dioxide Flow Control Module is available:

- BAG-1492, Floor Mounted

Figure 2-3 details the basic Water Treatment Gaseous Carbon Dioxide Flow Control Module system and external connections. It contains the valves and other components needed to regulate the flow of gaseous carbon dioxide based upon an external signal from a process controller.

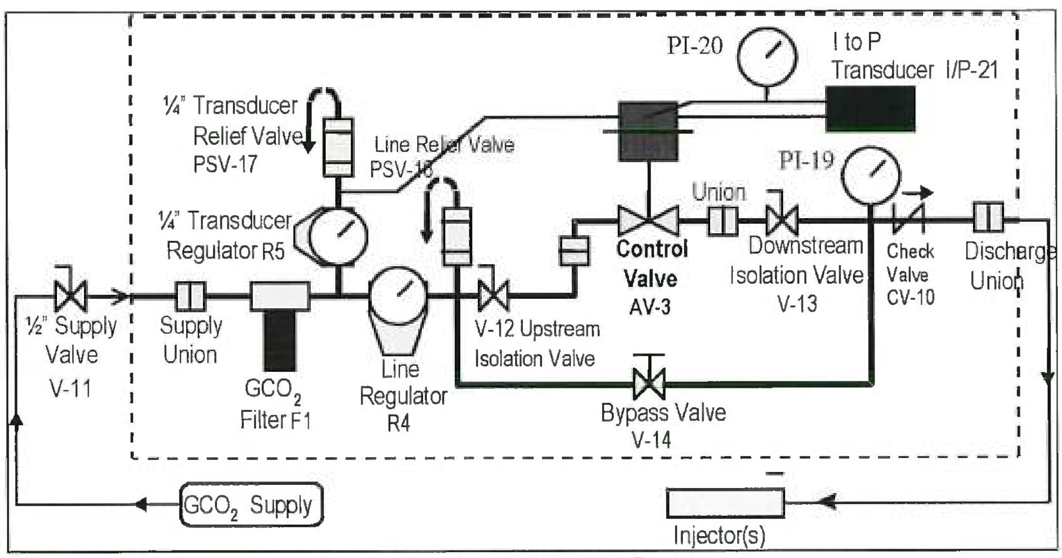

Figure 2-3: Detailed System Diagram

The Water Treatment Gaseous Carbon Dioxide Flow Control Module requires the following external connections:

- Gaseous carbon dioxide supply at 250 psig (1723.7 kPa) minimum
- Gas discharge connection to injection equipment

The gaseous carbon dioxide piping is designed to withstand pressures up to 450 psig (31027 kPa) and is equipped with pressure relief valve PSV-16 set at 100 psig (689.5 kPa). The flow control module is equipped with a filter to prevent solid particles that might interfere with the injection equipment from passing through the system. Pressure regulator R-4 controls the incoming pressure to the flow control module (approximately 300 psig, 2068.4 kPa) and reduces it to 5 - 125 psig (34.5 - 861.8 kPa).

The flow of gaseous carbon dioxide to the injectors is controlled by the position of the pneumatically actuated 1-inch control valve AV-3. This normally closed valve is equipped with an air-to-open actuator that operates from a 3 - 15 psig (20.7 - 103.4 kPa) pressure signal that is produced by an I-to-P transducer. The process controller, monitoring the water pH with a probe, sends a 4-20 mA signal to the I-to-P transducer to control the 3 - 15 psig (20.7 - 104.4 kPa) signal to the control valve.

Pressure for the I-to-P transducer is supplied from the gaseous carbon dioxide supply line via regulator R-5 that reduces the gas pressure to 20 psig (137.9 kPa). Pressure relief valve PSV-17 protects the I-to-P transducer from high pressures.

The Control Module is equipped with pressure gages that display:

- Module discharge pressure (PI-19)
- Transducer supply pressure (gauge on regulator R-5)
- Control valve inlet pressure (gauge on regulator R-4)

Bypass valve V-14 is installed to allow the system to remain in operation if the control valve is inoperable. With the control valve circuit shutdown, the bypass valve can be used to manually control the flow of carbon dioxide into the water. See section 4.4.

The gaseous carbon dioxide exiting the Water Treatment Gaseous Carbon Dioxide Flow Control Module is directed to suitable carbon dioxide injection devices. These devices may be placed in a tank containing water or in a pipe.

NOTE

Use only brass, copper, or stainless steel components for all piping, connections, and components (except in injection equipment) in the carbon dioxide stream.

2.4 Gaseous Carbon Dioxide Injection Equipment

Injectors are the devices that actually introduce the carbon dioxide to the water. Their design varies according to the nature of the application. Injectors can be mounted in line or in a basin and are available in many designs, sizes, and materials. In general, the type of gaseous carbon dioxide injection equipment used does **not** affect the operation of the Water Treatment Gaseous Carbon Dioxide Flow Control Module.

Appendix B

Material Safety Data Sheets

Praxair Material Safety Data Sheet

1. Chemical Product and Company Identification

Product Name: Carbon dioxide, refrigerated liquid (MSDS No. P-4573-D)	**Trade Names:** *Liquiflow*™ Liquid Carbon Dioxide, *Medipure*® Liquid Carbon Dioxide
Chemical Name: Carbon dioxide	**Synonyms:** Carbon dioxide (cryogenic liquid), LCO_2, liquefied CO_2
Chemical Family: Acid anhydride	**Product Grades:** Industrial, USP

Telephone: **Emergencies:** 1-800-645-4633* **CHEMTREC:** 1-800-424-9300* **Routine:** 1-800-PRAXAIR

Company Name: Praxair, Inc.
39 Old Ridgebury Road
Danbury, CT 06810-5113

**Call emergency numbers 24 hours a day only for spills, leaks, fire, exposure, or accidents involving this product. For routine information, contact your supplier, Praxair sales representative, or call 1-800-PRAXAIR (1-800-772-9247).*

2. Hazards Identification

EMERGENCY OVERVIEW

WARNING! Cold liquid and gas under pressure.
Can cause rapid suffocation.
Can increase respiration and heart rate.
May cause nervous system damage.
May cause frostbite.
May cause dizziness and drowsiness.
Self-contained breathing apparatus and protective clothing may be required by rescue workers.
This product is a colorless, odorless liquid that transforms to white crystalline particles when discharged from its container. The gas is slightly acidic and may be felt to have a slight, pungent odor and biting taste.

OSHA REGULATORY STATUS: This material is considered hazardous by the OSHA Hazard Communications Standard (29 CFR 1910.1200).

POTENTIAL HEALTH EFFECTS:

Effects of a Single (Acute) Overexposure

Inhalation. Carbon dioxide gas is an asphyxiant with effects due to lack of oxygen. It is also physiologically active, affecting circulation and breathing. Moderate concentrations may cause headache, drowsiness, dizziness, stinging of the nose and throat, excitation, rapid breathing and heart rate, excess salivation, vomiting, and unconsciousness. Lack of oxygen can kill.

Skin Contact. No harm expected from vapor. Prolonged contact with carbon dioxide crystals (snow) could cause frostbite. Cold gas, or liquid or solid carbon dioxide may cause severe frostbite.

A vertical line in the left margin indicates revised or new material.

Swallowing. An unlikely route of exposure. This product is a gas at normal temperature and pressure. But severe frostbite of the lips and mouth may result from contact with the liquid or solid.

Eye Contact. No harm expected from vapor. Cold gas, or liquid or solid carbon dioxide may cause severe frostbite.

Effects of Repeated (Chronic) Overexposure. No harm expected to healthy individuals. Where competent medical authority deems that such illness would be aggravated by exposure to carbon dioxide, persons in ill health should be restricted from working with or handling this product.

Other Effects of Overexposure. Damage to retinal or ganglion cells and central nervous system may occur.

Medical Conditions Aggravated by Overexposure. The toxicology and the physical and chemical properties of carbon dioxide suggest that overexposure is unlikely to aggravate existing medical conditions.

CARCINOGENICITY: Carbon dioxide is not listed by NTP, OSHA, or IARC.

POTENTIAL ENVIRONMENTAL EFFECTS: None known. For further information, see section 12, Ecological Information.

3. Composition/Information on Ingredients

See section 16 for important information about mixtures.

COMPONENT	CAS NUMBER	CONCENTRATION
Carbon dioxide	124-38-9	>99%*

**The symbol > means "greater than."*

4. First Aid Measures

INHALATION: Immediately remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, qualified personnel may give oxygen. Call a physician.

SKIN CONTACT: For exposure to cold liquid, vapor, or solid, immediately warm frostbite area with warm water not to exceed 105°F (41°C). In case of massive exposure, remove contaminated clothing while showering with warm water. Call a physician.

SWALLOWING: An unlikely route of exposure. This product is a gas at normal temperature and pressure.

EYE CONTACT: For exposure to cold liquid, vapor, or solid, immediately flush eyes thoroughly with warm water for at least 15 minutes. Hold the eyelids open and away from the eyeballs to ensure that all surfaces are flushed thoroughly. See a physician, preferably an ophthalmologist, immediately.

***NOTES TO PHYSICIAN:** There is no specific antidote. Treatment of overexposure should be directed at the control of symptoms and the clinical condition of the patient.*

5. Fire Fighting Measures

FLAMMABLE PROPERTIES: Carbon dioxide cannot catch fire.

SUITABLE EXTINGUISHING MEDIA: Nonflammable—use media appropriate for surrounding fire.

PRODUCTS OF COMBUSTION: Not applicable.

PROTECTION OF FIREFIGHTERS: WARNING! Cold liquid and gas under pressure. Evacuate all personnel from danger area. Immediately spray containers with water from maximum distance until cool, taking care not to direct spray onto vents on top of container. Do not discharge sprays into liquid carbon dioxide, which will freeze water rapidly. When containers have cooled, move them away from fire area if without risk. Self-contained breathing apparatus and protective clothing may be required by rescue workers. On-site fire brigades must comply with OSHA 29 CFR 1910.156.

Specific Physical and Chemical Hazards. Heat of fire can build pressure in cylinder and cause it to rupture. No part of container should be subjected to a temperature higher than 125°F (52°C). Liquid carbon dioxide containers are equipped with pressure relief devices.

Protective Equipment and Precautions for Firefighters. Firefighters should wear appropriate gear for surrounding fire.

6. Accidental Release Measures

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED:

WARNING! Cold liquid and gas under pressure.

Personal Precautions. Carbon dioxide is an asphyxiant. Lack of oxygen can kill. Evacuate all personnel from danger area. Use self-contained breathing apparatus and protective clothing where needed. Liquid carbon dioxide will not "spill." Flakes of solid carbon dioxide will form at pressures below 67 psig (461.95 kPa) and fall as snow. Shut off leak if you can do so without risk. Ventilate area or move container to a well-ventilated area. Test for sufficient oxygen, especially in confined spaces, before allowing reentry.

Environmental Precautions. Prevent waste from contaminating the surrounding environment. Keep personnel away. Discard any product, residue, disposable container, or liner in an environmentally acceptable manner, in full compliance with federal, state, and local regulations. If necessary, call your local supplier for assistance.

7. Handling and Storage

PRECAUTIONS TO BE TAKEN IN HANDLING: Never allow any unprotected part of your body to touch uninsulated pipes or vessels containing refrigerated liquids. Flesh will stick to the extremely cold metal and tears when you try to pull free. Use a suitable hand truck to move containers. Containers must be handled and stored in an upright position. Do not drop or tip containers, or roll them on their sides. If valve is hard to open, discontinue use and contact your supplier. For other precautions in using carbon dioxide, see section 16.

PRECAUTIONS TO BE TAKEN IN STORAGE: Gas can cause rapid suffocation due to oxygen deficiency. Store and use with adequate ventilation. Do not store in a confined space. Carbon dioxide is heavier than air. It tends to accumulate near the floor of an enclosed space, displacing air and pushing it upward. This creates an oxygen-deficient atmosphere near the floor. Ventilate space before entry. Verify sufficient oxygen concentration. Close container valve after each use; keep closed even when empty. Storage areas should be clean and dry, free of oils and dust. These collect on condensing coils and impair their efficiency. Temperatures should not exceed 125°F (51.1°C). Cryogenic containers are equipped with a pressure relief device and a pressure-controlling valve. Under normal conditions, these containers periodically vent product to control internal pressure. Use adequate pressure relief devices in systems and piping to prevent pressure buildup; entrapped liquid can generate extremely high pressures.

RECOMMENDED PUBLICATIONS: For further information on storage, handling, and use, see Praxair publications P-14-153, *Guidelines for Handling Gas Cylinders and Containers;* P-15-073, *Safety Precautions for Carbon Dioxide;* and P-3499, *Safety Precautions and Emergency Response Planning.* Obtain from your local supplier.

8. Exposure Controls/Personal Protection

See section 16 for important information on by-products generated during use in welding and cutting.

COMPONENT	OSHA PEL	ACGIH TLV-TWA (2009)
Carbon dioxide	5,000 ppm	5,000 ppm; 30,000 ppm, 15 min STEL

TLV-TWAs should be used as a guide in the control of health hazards and not as fine lines between safe and dangerous concentrations.

IDLH = 40,000 ppm

ENGINEERING CONTROLS:

Local Exhaust. Use a local exhaust system, if necessary, to keep the concentration of carbon dioxide below all applicable exposure limits in the worker's breathing zone.

Mechanical (General). Under certain conditions, general exhaust ventilation may be acceptable to keep carbon dioxide below the exposure limit.

Special. None

Other. None

PERSONAL PROTECTIVE EQUIPMENT:

Skin Protection. Wear insulated neoprene gloves and metatarsal shoes for cylinder handling. Protective clothing where needed. Cuffless trousers should be worn outside shoes. Select in accordance with OSHA 29 CFR 1910.132 and 1910.133. When using carbon dioxide or carbon dioxide mixtures in welding and cutting, see Praxair MSDS P-4574, gaseous carbon dioxide, for requirements. Regardless of protective equipment, never touch live electrical parts.

Eye/Face Protection. Select in accordance with OSHA 29 CFR 1910.133.

Respiratory Protection. A respiratory protection program that meet OSHA 29 CFR 1910.134, ANSI Z88.2, or MSHA 30 CFR 72.710 (where applicable) requirements must be followed whenever workplace conditions warrant respirator use. Use an air-supplied or air-purifying cartridge if the action level is exceeded. Ensure the respirator has the appropriate protection factor for the exposure level. If cartridge type respirators are used, the cartridge must be appropriate for the chemical exposure (e.g., an organic vapor cartridge). For emergencies or instances with unknown exposure levels, use a self-contained breathing apparatus.

9. Physical and Chemical Properties

APPEARANCE:	Colorless liquid		
ODOR:	Slight, pungent		
ODOR THRESHOLD:	Not available.		
PHYSICAL STATE:	Refrigerated liquid		
pH:	3.7 (for carbonic acid)		
SUBLIMATION POINT at 1 atm:	-109.3°F (-78.5°C)		
FLASH POINT (test method):	Not applicable.		
EVAPORATION RATE (Butyl Acetate = 1):	High		
FLAMMABILITY:	Nonflammable		
FLAMMABLE LIMITS IN AIR, % by volume:	**LOWER:** Not applicable.	**UPPER:** Not applicable.	
VAPOR PRESSURE at 70°F (21.1°C):	838 psig (5778 kPa)		
LIQUID DENSITY (saturated) at 70°F (21.1°C) and 1 atm:	47.6 lb/ft^3 (762 kg/m^3)		
SPECIFIC GRAVITY (H_2O = 1):	Not available.		
SPECIFIC GRAVITY (Air = 1) at 70°F (21.1°C) and 1 atm:	1.52		
SOLUBILITY IN WATER vol/vol at 68°F (20°C) and 1 atm:	0.90		
PARTITION COEFFICIENT: n-octanol/water:	Not available.		
AUTOIGNITION TEMPERATURE:	Not applicable.		
DECOMPOSITION TEMPERATURE:	None		
PERCENT VOLATILES BY VOLUME:	100		
MOLECULAR WEIGHT:	44.01		
MOLECULAR FORMULA:	CO_2		

10. Stability and Reactivity

CHEMICAL STABILITY: ☐ Unstable ☒ Stable

CONDITIONS TO AVOID: Contact with incompatible materials, exposure to electrical discharges, and/or high temperatures as stated below.

INCOMPATIBLE MATERIALS: Alkali metals, alkaline earth metals, metal acetylides, chromium, titanium above 1022°F (550°C), uranium above 1382°F (750°C), magnesium above 1427°F (775°C)

HAZARDOUS DECOMPOSITION PRODUCTS: Electrical discharges and high temperatures decompose carbon dioxide into carbon monoxide and oxygen.

POSSIBILITY OF HAZARDOUS REACTIONS: ☒ May Occur ☐ Will Not Occur

Decomposition into toxic, flammable, and/or oxidizing materials under above-stated conditions.

11. Toxicological Information

ACUTE DOSE EFFECTS: The welding process may generate hazardous fumes and gases. If using carbon dioxide for welding and cutting, see Praxair MSDS P-4574, gaseous carbon dioxide.

Carbon dioxide is an asphyxiant. It initially stimulates respiration and then causes respiratory depression. High concentrations result in narcosis. Symptoms in humans are as follows:

EFFECT:	CONCENTRATION:
Breathing rate increases slightly.	1%
Breathing rate increases to 50% above normal level. Prolonged exposure can cause headache, tiredness.	2%
Breathing increases to twice normal rate and becomes labored. Weak narcotic effect. Impaired hearing, headache, increased blood pressure and pulse rate.	3%
Breathing increases to approximately four times normal rate, symptoms of intoxication become evident, and slight choking may be felt.	4 - 5%
Characteristic sharp odor noticeable. Very labored breathing, headache, visual impairment, and ringing in the ears. Judgment may be impaired, followed within minutes by loss of consciousness.	5 - 10%
Unconsciousness occurs more rapidly above 10% level. Prolonged exposure to high concentrations may eventually result in death from asphyxiation.	10 - 100%

REPRODUCTIVE EFFECTS: A single study has shown an increase in heart defects in rats exposed to 6 percent carbon dioxide in air for 24 hours at different times during gestation. There is no evidence that carbon dioxide is teratogenic in humans.

12. Ecological Information

ECOTOXICITY: No adverse ecological effects expected.

OTHER ADVERSE EFFECTS: Carbon dioxide does not contain any Class I or Class II ozone-depleting chemicals.

13. Disposal Considerations

WASTE DISPOSAL METHOD: Do not attempt to dispose of residual or unused quantities. Return cylinder to supplier.

14. Transport Information

DOT/IMO SHIPPING NAME: Carbon dioxide, refrigerated liquid

HAZARD CLASS: 2.2	PACKING GROUP/Zone: NA*	IDENTIFICATION NUMBER: UN2187	PRODUCT RQ: None

SHIPPING LABEL(s): NONFLAMMABLE GAS

PLACARD (when required): NONFLAMMABLE GAS

**NA = Not applicable.*

SPECIAL SHIPPING INFORMATION: Cylinders should be transported in a secure position, in a well-ventilated vehicle. Cylinders transported in an enclosed, nonventilated compartment of a vehicle can present serious safety hazards.

Shipment of compressed gas cylinders that were filled without the owner's consent is a violation of federal law [49 CFR 173.301(b)].

MARINE POLLUTANTS: Carbon dioxide is not listed as a marine pollutant by DOT.

15. Regulatory Information

The following selected regulatory requirements may apply to this product. Not all such requirements are identified. Users of this product are solely responsible for compliance with all applicable federal, state, and local regulations.

U.S. FEDERAL REGULATIONS:

EPA (ENVIRONMENTAL PROTECTION AGENCY)

CERCLA: COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT OF 1980 (40 CFR Parts 117 and 302):

Reportable Quantity (RQ): None

SARA: SUPERFUND AMENDMENT AND REAUTHORIZATION ACT:

SECTIONS 302/304: Require emergency planning based on Threshold Planning Quantity (TPQ) and release reporting based on Reportable Quantities (RQ) of Extremely Hazardous Substances (EHS) (40 CFR Part 355):

TPQ: None
EHS RQ (40 CFR 355): None

SECTIONS 311/312: Require submission of MSDSs and reporting of chemical inventories with identification of EPA hazard categories. The hazard categories for this product are as follows:

IMMEDIATE: Yes	**PRESSURE:** Yes
DELAYED: No	**REACTIVITY:** No
	FIRE: No

SECTION 313: Requires submission of annual reports of release of toxic chemicals that appear in 40 CFR Part 372.

Carbon dioxide is not subject to reporting under Section 313.

40 CFR 68: RISK MANAGEMENT PROGRAM FOR CHEMICAL ACCIDENTAL RELEASE PREVENTION: Requires development and implementation of risk management programs at facilities that manufacture, use, store, or otherwise handle regulated substances in quantities that exceed specified thresholds.

Carbon dioxide is not listed as a regulated substance.

TSCA: TOXIC SUBSTANCES CONTROL ACT: Carbon dioxide is listed on the TSCA inventory.

OSHA: OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:

29 CFR 1910.119: PROCESS SAFETY MANAGEMENT OF HIGHLY HAZARDOUS CHEMICALS: Requires facilities to develop a process safety management program based on Threshold Quantities (TQ) of highly hazardous chemicals.

Carbon dioxide is not listed in Appendix A as a highly hazardous chemical.

STATE REGULATIONS:

CALIFORNIA: Carbon dioxide is not listed by California under the SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT OF 1986 (Proposition 65).

PENNSYLVANIA: Carbon dioxide is subject to the PENNSYLVANIA WORKER AND COMMUNITY RIGHT-TO-KNOW ACT (35 P.S. Sections 7301-7320).

16. Other Information

Be sure to read and understand all labels and instructions supplied with all containers of this product.

OTHER HAZARDOUS CONDITIONS OF HANDLING, STORAGE, AND USE: ***Cold liquid and gas under pressure.*** Contact may cause frostbite. Use piping and equipment adequately designed to withstand pressures to be encountered. Use a backflow prevention device in any piping. Avoid materials incompatible with cryogenic use; some metals such as carbon steel may fracture easily at low temperature. Never work on a pressurized system. If there is a leak, close the container valve. Blow the system down in a safe and environmentally sound manner in compliance with all federal, state, and local laws; then repair the leak. Never place a compressed gas cylinder where it may become part of an electrical circuit.

Mixtures. When you mix two or more chemicals, you can create additional, unexpected hazards. Obtain and evaluate the safety information for each component before you produce the mixture. Consult an industrial hygienist or other trained person when you evaluate the end product. Remember, chemicals have properties that can cause serious injury or death.

HAZARD RATING SYSTEMS:

NFPA RATINGS:		HMIS RATINGS:	
HEALTH	= 3	HEALTH	= 3
FLAMMABILITY	= 0	FLAMMABILITY	= 0
INSTABILITY	= 0	PHYSICAL HAZARD	= 2
SPECIAL	= SA (CGA recommends this to designate Simple Asphyxiant.)		

STANDARD VALVE CONNECTIONS FOR U.S. AND CANADA:

THREADED:	CGA-320 CGA-320 for withdrawal of refrigerated liquid
PIN-INDEXED YOKE:	Not applicable.
ULTRA-HIGH-INTEGRITY CONNECTION:	Not applicable.

Use the proper CGA connections. **DO NOT USE ADAPTERS.** Additional limited-standard connections may apply. See CGA pamphlet V-1 listed below. Ask your supplier about free Praxair safety literature as referred to in this MSDS and on the label for this product. Further information can be found in the following materials published by the Compressed Gas Association, Inc. (CGA), 4221 Walney Road, 5th Floor, Chantilly, VA 20151-2923, Telephone (703) 788-2700, http://www.cganet.com/Publication.asp.

AV-1	*Safe Handling and Storage of Compressed Gases*
AV-7	*Characteristics and Safe Handling of Carbon Dioxide*
G-6	*Carbon Dioxide*
G-6.1	*Standard for Low Pressure Carbon Dioxide Systems at Customer Sites*
G-6.2	*Commodity Specification for Carbon Dioxide*
P-1	*Safe Handling of Compressed Gases in Containers*
P-2	*Characteristics and Safe Handling of Medical Gases*
SB-2	*Oxygen-Deficient Atmospheres*
V-1	*Compressed Gas Cylinder Valve Inlet and Outlet Connections*
—	*Handbook of Compressed Gases, Fourth Edition*

Praxair asks users of this product to study this MSDS and become aware of product hazards and safety information. To promote safe use of this product, a user should (1) notify employees, agents, and contractors of the information in this MSDS and of any other known product hazards and safety information, (2) furnish this information to each purchaser of the product, and (3) ask each purchaser to notify its employees and customers of the product hazards and safety information.

The opinions expressed herein are those of qualified experts within Praxair, Inc. We believe that the information contained herein is current as of the date of this Material Safety Data Sheet. Since the use of this information and the conditions of use of the product are not within the control of Praxair, Inc., it is the user's obligation to determine the conditions of safe use of the product.

Praxair MSDSs are furnished on sale or delivery by Praxair or the independent distributors and suppliers who package and sell our products. To obtain current MSDSs for these products, contact your Praxair sales representative or local distributor or supplier, or download from www.praxair.com. If you have questions regarding Praxair MSDSs, would like the form number and date of the latest MSDS, or would like the names of the Praxair suppliers in your area, phone or write the Praxair Call Center (**Phone:** 1-800-PRAXAIR; **Address:** Praxair Call Center, Praxair, Inc., PO Box 44, Tonawanda, NY 14151-0044).

PRAXAIR

Praxair, Inc.
39 Old Ridgebury Road
Danbury, CT 06810-5113

Praxair Material Safety Data Sheet

1. Chemical Product and Company Identification

Product Name: Carbon dioxide (MSDS No. P-4574-J)	**Trade Names:** Carbon Dioxide, Medipure® Carbon Dioxide
Chemical Name: Carbon dioxide	**Synonyms:** Carbonic anhydride, carbonic acid gas, refrigerant gas R744
Chemical Family: Acid anhydride	**Product Grades:** Industrial; 3.0; 4.0 anaerobic, instrument, laser; 4.5, 5.0, 5.5 LaserStar™; 4.8 research, supercritical fluid chromatography, semiconductor process gas; 5.0 supercritical fluid extraction

Telephone: **Emergencies:** 1-800-645-4633* **Company Name:** Praxair, Inc.
CHEMTREC: 1-800-424-9300* 39 Old Ridgebury Road
Routine: 1-800-PRAXAIR Danbury, CT 06810-5113

**Call emergency numbers 24 hours a day only for spills, leaks, fire, exposure, or accidents involving this product. For routine information, contact your supplier, Praxair sales representative, or call 1-800-PRAXAIR (1-800-772-9247).*

2. Hazards Identification

EMERGENCY OVERVIEW

CAUTION! High-pressure liquid and gas.
Can cause rapid suffocation.
Can increase respiration and heart rate.
May cause nervous system damage.
May cause frostbite.
May cause dizziness and drowsiness.
Self-contained breathing apparatus may be required by rescue workers.
This product is a colorless, odorless gas at normal temperature and pressure.
The gas is slightly acidic and may be felt to have a slight, pungent odor and biting taste.

OSHA REGULATORY STATUS: This material is considered hazardous by the OSHA Hazard Communications Standard (29 CFR 1910.1200).

POTENTIAL HEALTH EFFECTS:

Effects of a Single (Acute) Overexposure

Inhalation. Carbon dioxide gas is an asphyxiant with effects due to lack of oxygen. It is also physiologically active, affecting circulation and breathing. Moderate concentrations may cause headache, drowsiness, dizziness, stinging of the nose and throat, excitation,

A vertical line in the left margin indicates revised or new material.

rapid breathing and heart rate, excess salivation, vomiting, and unconsciousness. Lack of oxygen can kill.

Skin Contact. No harm expected from vapor. Cold gas, or liquid or solid carbon dioxide may cause severe frostbite.

Swallowing. An unlikely route of exposure. This product is a gas at normal temperature and pressure.

Eye Contact. No harm expected from vapor. Cold gas, or liquid or solid carbon dioxide may cause severe frostbite.

Effects of Repeated (Chronic) Overexposure. No harm expected.

Other Effects of Overexposure. Damage to retinal or ganglion cells and central nervous system may occur.

Medical Conditions Aggravated by Overexposure. The toxicology and the physical and chemical properties of carbon dioxide suggest that overexposure is unlikely to aggravate existing medical conditions.

CARCINOGENICITY: Carbon dioxide is not listed by NTP, OSHA, or IARC.

POTENTIAL ENVIRONMENTAL EFFECTS: None known. For further information, see section 12, Ecological Information.

3. Composition/Information on Ingredients

This section covers materials of manufacture only. See sections 8, 10, 11, and 16 for information on by-products generated during use in welding and cutting. See section 16 for important information about mixtures.

COMPONENT	CAS NUMBER	CONCENTRATION
Carbon dioxide	124-38-9	>99%*

**The symbol > means "greater than."*

4. First Aid Measures

INHALATION: Immediately remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, qualified personnel may give oxygen. Call a physician.

SKIN CONTACT: For exposure to cold vapor or solid, immediately warm frostbite area with warm water not to exceed 105°F (41°C). In case of massive exposure, remove contaminated clothing while showering with warm water. Call a physician.

SWALLOWING: An unlikely route of exposure. This product is a gas at normal temperature and pressure.

EYE CONTACT: For exposure to cold vapor or solid, immediately flush eyes thoroughly with warm water for at least 15 minutes. Hold the eyelids open and away from the eyeballs to ensure that all surfaces are flushed thoroughly. See a physician, preferably an ophthalmologist, immediately.

NOTES TO PHYSICIAN: *There is no specific antidote. Treatment of overexposure should be directed at the control of symptoms and the clinical condition of the patient.*

5. Fire Fighting Measures

FLAMMABLE PROPERTIES: Nonflammable

SUITABLE EXTINGUISHING MEDIA: Carbon dioxide cannot catch fire. Use media appropriate for surrounding fire.

PRODUCTS OF COMBUSTION: Not applicable.

PROTECTION OF FIREFIGHTERS: CAUTION! High-pressure gas liquid and gas. Evacuate all personnel from danger area. Immediately deluge cylinders with water from maximum distance until cool; then move them away from fire area if without risk. Self-contained breathing apparatus may be required by rescue workers. On-site fire brigades must comply with OSHA 29 CFR 1910.156.

Specific Physical and Chemical Hazards. Heat of fire can build pressure in cylinder and cause it to rupture. No part of cylinder should be subjected to a temperature higher than 125°F (52°C). Carbon dioxide cylinders are equipped with a pressure relief device. (Exceptions may exist where authorized by DOT.)

Protective Equipment and Precautions for Firefighters. Firefighters should wear personal protective equipment and fire-fighting turnout gear as appropriate for surrounding fire.

6. Accidental Release Measures

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED:

CAUTION! High-pressure liquid and gas.

Personal Precautions. Carbon dioxide is an asphyxiant. Lack of oxygen can kill. Evacuate all personnel from danger area. Use self-contained breathing apparatus where needed. Shut off leak if you can do so without risk. Ventilate area or move cylinder to a well-ventilated area. Test for sufficient oxygen, especially in confined spaces, before allowing reentry.

Environmental Precautions. Prevent waste from contaminating the surrounding environment. Keep personnel away. Discard any product, residue, disposable container, or liner in an environmentally acceptable manner, in full compliance with federal, state, and local regulations. If necessary, call your local supplier for assistance.

7. Handling and Storage

PRECAUTIONS TO BE TAKEN IN HANDLING: Avoid breathing gas. Do not get liquid in eyes, on skin, or clothing. ***Protect cylinders from damage.*** Use a suitable hand truck to move cylinders; do not drag, roll, slide, or drop. Never attempt to lift a cylinder by its cap; the cap is intended solely to protect the valve. ***Never insert an object (e.g., wrench, screwdriver, pry bar) into cap openings***; doing so may damage the valve and cause a leak. Use an adjustable strap wrench to remove over-tight or rusted caps. ***Open valve slowly.*** If valve is hard to open, discontinue use and contact your supplier. Keep cylinder upright when in use. ***Never apply flame or localized heat directly to any part of the cylinder.*** High temperatures may damage the cylinder and could cause the pressure relief device to fail prematurely, venting the cylinder contents. For other precautions in using carbon dioxide, see section 16.

PRECAUTIONS TO BE TAKEN IN STORAGE: ***Gas can cause rapid suffocation due to oxygen deficiency.*** Store and use with adequate ventilation. Store only where temperature will not exceed 125°F (52°C). Carbon dioxide is heavier than air. It tends to accumulate near the floor of an enclosed space, displacing air and pushing it upward. This creates an oxygen-deficient atmosphere near the floor. Ventilate space before entry. Verify sufficient oxygen concentration. Close cylinder valve after each use; keep closed even when empty. ***Prevent reverse flow.*** Reverse flow into cylinder may cause rupture. Use a check valve or other protective device in any line or piping from the cylinder. ***Do not strike an arc on the cylinder.*** The defect produced by an arc burn could lead to cylinder rupture. Do not ground the cylinder or allow it to become part of an electrical circuit. ***Firmly secure cylinders upright to keep them from falling or being knocked over.*** Screw valve protection cap firmly in place by hand. ***Store full and empty cylinders separately.*** Use a first-in, first-out inventory system to prevent storing full cylinders for long periods.

RECOMMENDED PUBLICATIONS: For further information on storage, handling, and use, see Praxair publications P-14-153, *Guidelines for Handling Gas Cylinders and Containers;* P-15-073, *Safety Precautions for Carbon Dioxide;* and P-3499, *Safety Precautions and Emergency Response Planning.* Obtain from your local supplier.

8. Exposure Controls/Personal Protection

See section 16 for important information on by-products generated during use in welding and cutting.

COMPONENT	OSHA PEL	ACGIH TLV-TWA (2007)
Carbon dioxide	5,000 ppm	5,000 ppm, 30,000 ppm 15 min STEL

TLV-TWAs should be used as a guide in the control of health hazards and not as fine lines between safe and dangerous concentrations.

IDLH = 40,000 ppm

ENGINEERING CONTROLS:

Local Exhaust. Use a local exhaust system, if necessary, to keep the concentration of carbon dioxide below all applicable exposure limits in the worker's breathing zone.

Mechanical (General). Under certain conditions, general exhaust ventilation may be acceptable to keep carbon dioxide below the exposure limits.

Special. None

Other. None

PERSONAL PROTECTIVE EQUIPMENT:

Skin Protection. Wear insulated neoprene gloves for cylinder handling; welding gloves for welding. Metatarsal shoes for cylinder handling. Select in accordance with OSHA 29 CFR 1910.132 and 1910.133. See section 16 for requirements when using carbon dioxide or carbon dioxide mixtures in welding and cutting. Regardless of protective equipment, never touch live electrical parts.

Eye/Face Protection. Select in accordance with OSHA 29 CFR 1910.133. See section 16 for requirements when using carbon dioxide or carbon dioxide mixtures in welding and cutting.

Respiratory Protection. None required under normal use. An air-supplied respirator must be used in confined spaces. Respiratory protection must conform to OSHA rules as specified in 29 CFR 1910.134. Select per OSHA 29 CFR 1910.134 and ANSI Z88.2.

9. Physical and Chemical Properties

APPEARANCE:	Colorless gas
ODOR:	Odorless. It is felt by some to have a slight, pungent odor and biting taste.
ODOR THRESHOLD:	Not applicable.
PHYSICAL STATE:	Gas at normal temperature and pressure
pH:	3.7 (for carbonic acid)
SUBLIMATION POINT at 1 atm:	-109.3°F (-78.5°C)
BOILING POINT at 1 atm:	Not applicable.
FLASH POINT (test method):	Not applicable.
EVAPORATION RATE (Butyl Acetate = 1):	High
FLAMMABILITY:	Nonflammable
FLAMMABLE LIMITS IN AIR, % by volume:	**LOWER:** Not applicable. **UPPER:** Not applicable.
VAPOR PRESSURE at 68°F (20°C):	838 psig (5778 kPa)
LIQUID DENSITY (saturated) at 70°F (21.1°C) and 1 atm:	47.6 lb/ft^3 (762 kg/m^3)
SPECIFIC GRAVITY (H_2O = 1) at 19.4°F (-7°C):	1.22
SPECIFIC GRAVITY (Air = 1) at 70°F (21.1°C) and 1 atm:	1.52
SOLUBILITY IN WATER vol/vol at 68°F (20°C):	0.90
PARTITION COEFFICIENT: n-octanol/water:	Not available.
AUTOIGNITION TEMPERATURE:	Not applicable.
DECOMPOSITION TEMPERATURE:	Not available.
PERCENT VOLATILES BY VOLUME:	100
MOLECULAR WEIGHT:	44.01
MOLECULAR FORMULA:	CO_2

10. Stability and Reactivity

CHEMICAL STABILITY: ☐ Unstable ☒ Stable

CONDITIONS TO AVOID: Contact with incompatible materials, exposure to electrical discharges, and/or high temperatures as stated below.

INCOMPATIBLE MATERIALS: Alkali metals, alkaline earth metals, metal acetylides, chromium, titanium above 1022°F (550°C), uranium above 1382°F (750°C), magnesium above 1427°F (775°C)

HAZARDOUS DECOMPOSITION PRODUCTS: Electrical discharges and high temperatures decompose carbon dioxide into carbon monoxide and oxygen.

POSSIBILITY OF HAZARDOUS REACTIONS: ☒ May Occur ☐ Will Not Occur
Decomposition into toxic, flammable, and/or oxidizing materials under above-stated conditions.

11. Toxicological Information

ACUTE DOSE EFFECTS: LC_{Lo} = 90,000 ppm, 5 min., human

The welding process may generate hazardous fumes and gases. (See sections 10 and 16.)

Carbon dioxide is an asphyxiant. It initially stimulates respiration and then causes respiratory depression. High concentrations result in narcosis. Symptoms in humans are as follows:

EFFECT:	CONCENTRATION:
Breathing rate increases slightly.	1%
Breathing rate increases to 50% above normal level. Prolonged exposure can cause headache, tiredness.	2%
Breathing increases to twice normal rate and becomes labored. Weak narcotic effect. Impaired hearing, headache, increased blood pressure and pulse rate.	3%
Breathing increases to approximately four times normal rate, symptoms of intoxication become evident, and slight choking may be felt.	4 - 5%
Characteristic sharp odor noticeable. Very labored breathing, headache, visual impairment, and ringing in the ears. Judgment may be impaired, followed within minutes by loss of consciousness.	5 - 10%
Unconsciousness occurs more rapidly above 10% level. Prolonged exposure to high concentrations may eventually result in death from asphyxiation.	10 - 100%

REPRODUCTIVE EFFECTS: A single study has shown an increase in heart defects in rats exposed to 6% carbon dioxide in air for 24 hours at different times during gestation. There is no evidence that carbon dioxide is teratogenic in humans.

12. Ecological Information

ECOTOXICITY: No known effects.

OTHER ADVERSE EFFECTS: No adverse ecological effects expected. Carbon dioxide does not contain any Class I or Class II ozone-depleting chemicals.

13. Disposal Considerations

WASTE DISPOSAL METHOD: Do not attempt to dispose of residual or unused quantities. Return cylinder to supplier.

14. Transport Information

DOT/IMO SHIPPING NAME: Carbon dioxide

HAZARD CLASS:	PACKING GROUP/Zone:	IDENTIFICATION NUMBER:	PRODUCT RQ:
2.2	NA*	UN1013	None

SHIPPING LABEL(s): NONFLAMMABLE GAS
PLACARD (when required): NONFLAMMABLE GAS

**NA = Not applicable.*

SPECIAL SHIPPING INFORMATION: Cylinders should be transported in a secure position, in a well-ventilated vehicle. Cylinders transported in an enclosed, nonventilated compartment of a vehicle can present serious safety hazards.

Shipment of compressed gas cylinders that have been filled without the owner's consent is a violation of federal law [49 CFR 173.301(b)].

MARINE POLLUTANTS: Carbon dioxide is not listed as a marine pollutant by DOT.

15. Regulatory Information

The following selected regulatory requirements may apply to this product. Not all such requirements are identified. Users of this product are solely responsible for compliance with all applicable federal, state, and local regulations.

U.S. FEDERAL REGULATIONS:

EPA (ENVIRONMENTAL PROTECTION AGENCY)

CERCLA: COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT OF 1980 (40 CFR Parts 117 and 302):

Reportable Quantity (RQ): None

SARA: SUPERFUND AMENDMENT AND REAUTHORIZATION ACT:

SECTIONS 302/304: Require emergency planning based on Threshold Planning Quantity (TPQ) and release reporting based on Reportable Quantities (RQ) of Extremely Hazardous Substances (EHS) (40 CFR Part 355):

TPQ: None
EHS RQ (40 CFR 355): None

SECTIONS 311/312: Require submission of MSDSs and reporting of chemical inventories with identification of EPA hazard categories. The hazard categories for this product are as follows:

IMMEDIATE: Yes
DELAYED: No
PRESSURE: Yes
REACTIVITY: No
FIRE: No

SECTION 313: Requires submission of annual reports of release of toxic chemicals that appear in 40 CFR Part 372.

Carbon dioxide is not subject to reporting under Section 313.

40 CFR 68: RISK MANAGEMENT PROGRAM FOR CHEMICAL ACCIDENTAL RELEASE PREVENTION: Requires development and implementation of risk management programs at facilities that manufacture, use, store, or otherwise handle regulated substances in quantities that exceed specified thresholds.

Carbon dioxide is not listed as a regulated substance.

TSCA: TOXIC SUBSTANCES CONTROL ACT: Carbon dioxide is listed on the TSCA inventory.

OSHA: OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION:

29 CFR 1910.119: PROCESS SAFETY MANAGEMENT OF HIGHLY HAZARDOUS CHEMICALS: Requires facilities to develop a process safety management program based on Threshold Quantities (TQ) of highly hazardous chemicals.

Carbon dioxide is not listed in Appendix A as a highly hazardous chemical.

STATE REGULATIONS:

CALIFORNIA: Carbon dioxide is not listed by California under the SAFE DRINKING WATER AND TOXIC ENFORCEMENT ACT OF 1986 (Proposition 65).

PENNSYLVANIA: Carbon dioxide is subject to the PENNSYLVANIA WORKER AND COMMUNITY RIGHT-TO-KNOW ACT (35 P.S. Sections 7301-7320).

16. Other Information

Be sure to read and understand all labels and instructions supplied with all containers of this product.

ADDITIONAL SAFETY AND HEALTH HAZARDS: Using carbon dioxide or mixtures containing carbon dioxide in welding and cutting may create additional hazards.

Read and understand the manufacturer's instructions and the precautionary labels on the products used in welding and cutting. Ask your welding products supplier for a copy of Praxair's free safety booklets, P-2035, *Precautions and Safe Practices for Gas Welding, Cutting, and Heating*, and P-52-529, *Precautions and Safe Practices for Electric Welding and Cutting*, and for other manufacturers' safety publications. For a detailed treatment, get ANSI Z49.1, *Safety in Welding, Cutting, and Allied Processes*, published by the American Welding Society (AWS), or see OSHA's Web site at *http://www.osha-slc.gov/SLTC/weldingcuttingbrazing/*. Order AWS documents from Global Engineering Documents, 15 Inverness Way East, Englewood, CO 80112-5710, http://global.ihs.com/.

FUMES AND GASES can be dangerous to your health and may cause serious lung disease.

- **Keep your head out of fumes. Do not breathe fumes and gases. Use enough ventilation, local exhaust, or both to keep fumes and gases from your breathing zone and the general area. Short-term overexposure to fumes may cause dizziness; nausea; and dryness or irritation of the nose, throat, and eyes; or may cause other similar discomfort.**

Fumes and gases cannot be classified simply. The amount and type depend on the metal being worked and the process, procedure, equipment, and supplies used. Possible dangerous materials may be found in fluxes, electrodes, and other materials. Get an MSDS for every material you use.

Contaminants in the air may add to the hazard of fumes and gases. One such contaminant, chlorinated hydrocarbon vapors from cleaning and degreasing activities, poses a special risk.

- **Do not use electric arcs in the presence of chlorinated hydrocarbon vapors—highly toxic phosgene may be produced.**

Metal coatings such as paint, plating, or galvanizing may generate harmful fumes when heated. Residues from cleaning materials may also be harmful.

- **Avoid arc operations on parts with phosphate residues (anti-rust, cleaning preparations)—highly toxic phosphine may be produced.**

To find the quantity and content of fumes and gases, you can take air samples. By analyzing these samples, you can find out what respiratory protection you need. One recommended sampling method is to take air from inside the worker's helmet or from the worker's breathing zone. See AWS F1.1, *Methods for Sampling and Analyzing Gases for Welding and Allied Processes*, available from the American Welding Society, 550 N.W. Le Jeune Rd., Miami, FL 33126.

NOTES TO PHYSICIAN:

Acute: *Gases, fumes, and dusts may cause irritation to the eyes, lungs, nose, and throat. Some toxic gases associated with welding and related processes may cause pulmonary edema, asphyxiation, and death. Acute overexposure may include signs and symptoms such as watery eyes, nose and throat irritation, headache, dizziness, difficulty breathing, frequent coughing, or chest pains.*

Chronic: *Protracted inhalation of air contaminants may lead to their accumulation in the lungs, a condition that may be seen as dense areas on chest x-rays. The severity of change is proportional to the length of exposure. The changes seen are not necessarily associated with symptoms or signs of reduced lung function or disease. In addition, the changes on x-rays may be caused by non-work-related factors such as smoking, etc.*

PROTECTIVE CLOTHING AND EQUIPMENT FOR WELDING OPERATIONS:

PROTECTIVE GLOVES: Wear welding gloves.

EYE PROTECTION: Wear a helmet or use a face shield with a filter lens. Select lens per ANSI Z49.1. Provide protective screens and flash goggles if needed to protect others; select per OSHA 29 CFR 1910.133.

OTHER PROTECTIVE EQUIPMENT: Wear hand, head, and body protection. (See ANSI Z49.1.) Worn as needed, these help prevent injury from radiation, sparks, and electrical shock. Minimum protection includes welder's gloves and a face shield. For added protection consider arm protectors, aprons, hats, shoulder protection, and dark, substantial clothing.

OTHER HAZARDOUS CONDITIONS OF HANDLING, STORAGE, AND USE: ***High-pressure liquid and gas.*** Use piping and equipment adequately designed to withstand pressures to be encountered. ***Prevent reverse flow.*** Reverse flow into cylinder may cause rupture. Use a check valve or other protective device in any line or piping from the cylinder. ***Do not strike an arc on the cylinder.*** The defect produced by an arc burn could lead to cylinder rupture. ***Never work on a pressurized system.*** If there is a leak, close the cylinder valve. Blow the system down in a safe and environmentally sound manner in compliance with all federal, state, and local laws; then repair the leak. ***Never place a compressed gas cylinder where it may become part of an electrical circuit.*** When using compressed gases in and around electric welding applications, never ground the cylinders. Grounding exposes the cylinders to damage by the electric welding arc.

Mixtures. When you mix two or more gases or liquefied gases, you can create additional, unexpected hazards. Obtain and evaluate the safety information for each component before you produce the mixture. Consult an industrial hygienist or other trained person when you evaluate the end product. Remember, gases and liquids have properties that can cause serious injury or death.

HAZARD RATING SYSTEMS:

NFPA RATINGS:		**HMIS RATINGS:**	
HEALTH	= 1	HEALTH	= 1
FLAMMABILITY	= 0	FLAMMABILITY	= 0
INSTABILITY	= 0	PHYSICAL HAZARD	= 3
SPECIAL	= SA (CGA recommends this to designate Simple Asphyxiant.)		

STANDARD VALVE CONNECTIONS FOR U.S. AND CANADA:

THREADED:	CGA-320
PIN-INDEXED YOKE:	CGA-940 (medical use)
ULTRA-HIGH-INTEGRITY CONNECTION:	CGA-716

Use the proper CGA connections. **DO NOT USE ADAPTERS.** Additional limited-standard connections may apply. See CGA pamphlet V-1 listed below.

Ask your supplier about free Praxair safety literature as referred to in this MSDS and on the label for this product. Further information can be found in the following materials published by the Compressed Gas Association, Inc. (CGA), 4221 Walney Road, 5th Floor, Chantilly, VA 20151-2923, Telephone (703) 788-2700, http://www.cganet.com/Publication.asp.

AV-1 *Safe Handling and Storage of Compressed Gases*
AV-7 *Characteristics and Safe Handling of Carbon Dioxide*
G-6 *Carbon Dioxide*
G-6.1 *Standard for Low Pressure Carbon Dioxide Systems at Customer Sites*
G-6.2 *Commodity Specification for Carbon Dioxide*
P-1 *Safe Handling of Compressed Gases in Containers*
SB-2 *Oxygen-Deficient Atmospheres*
V-1 *Compressed Gas Cylinder Valve Inlet and Outlet Connections*
— *Handbook of Compressed Gases, Fourth Edition*

Praxair asks users of this product to study this MSDS and become aware of product hazards and safety information. To promote safe use of this product, a user should (1) notify employees, agents, and contractors of the information in this MSDS and of any other known product hazards and safety information, (2) furnish this information to each purchaser of the product, and (3) ask each purchaser to notify its employees and customers of the product hazards and safety information.

The opinions expressed herein are those of qualified experts within Praxair, Inc. We believe that the information contained herein is current as of the date of this Material Safety Data Sheet. Since the use of this information and the conditions of use of the product are not within the control of Praxair, Inc., it is the user's obligation to determine the conditions of safe use of the product.

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