Appendix E

Carbon Dioxide Pipeline Risk Analysis

APPENDIX E
CARBON DIOXIDE PIPELINE RISK ANALYSIS

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Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
ALOHA	Areal Locations of Hazardous Atmospheres
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
DOT	U.S. Department of Transportation
EOR	Enhanced Oil Recovery
GHG	Greenhouse Gases
HECA	Hydrogen Energy California
HEI	Hydrogen Energy International LLC
IDLH	Immediately Dangerous to Life and Health
km	kilometers
LORS	laws, ordinances, regulations, and standards
MPa	million Pascals
NIOSH	National Institute for Occupational Safety and Health
NRC	National Response Center
OCA	Offsite Consequence Analysis
OSHA	U.S. Occupational Safety & Health Administration
PEL	Permissible Exposure Limit
ppm	parts per million
SARA	Superfund Amendment and Reauthorization Act
STEL	Short Term Exposure Limit
TLV	Threshold Limit Value
USEPA	U.S. Environmental Protection Agency
USDOE	U.S. Department of Energy

1.0 Risk Evaluation

This appendix sets forth the Risk Evaluation conducted for an accidental worst-case release scenario from the Project's carbon dioxide pipeline. Carbon dioxide does not manifest hazardous properties (i.e., toxicity, reactivity, flammability, or explosivity) that would result in regulatory classification as a hazardous material. However, as further discussed in Section 1.1 below, the current U.S. Department of Transportation (DOT) requirement for pipelines transporting carbon dioxide (49 Code of Federal Regulations [CFR] 195) directs the operator to perform a risk assessment. Pursuant to this DOT requirement and industry practice, the Project conducted a risk analysis for the carbon dioxide pipeline.

Carbon dioxide captured in the gasification processes at the Project will be compressed and transported to the custody transfer point for injection into deep underground hydrocarbon reservoirs for CO_2 enhanced oil recovery (EOR) and sequestration (storage)[1]. A compressor will pressurize (up to 2,800 psig) the carbon dioxide for offsite delivery. The carbon dioxide pipeline will transfer the carbon dioxide from the Project Site southwest to the custody transfer point.

The carbon dioxide pipeline will consist of an underground pipeline buried approximately 5 feet below grade for the majority of the route. Where crossing under the California Aqueduct and Kern River Flood Control Channel, the carbon dioxide pipeline will be buried as deep as 100 feet below grade. The length of the pipeline exposed above the subsurface, which connects the compressor and underground pipeline, will be approximately 200 feet long and entirely within the Project Site.

The carbon dioxide pipeline will be equipped with a series of emergency block valves that will isolate various segments of the pipeline. The first block valve will be located at the end of the 200-foot aboveground pipeline segment from the compressor discharge, before the pipeline transitions below ground. The pipeline will have block valves placed approximately 200 feet, 3,100 feet, 5,800 feet, and 21,800 feet from the point of origin. The last block valve is placed at the custody transfer point, which is the pipeline terminus within the Elk Hills Field. The evaluation of the potential risk associated with a worst-case release from the carbon dioxide pipeline will be limited to pipeline segments from compressor discharge to the custody transfer point.

Transporting carbon dioxide in pipelines under high-pressure conditions is a process that is commonly found in the petroleum and chemical industries. Within the United States alone, approximately 3,500 miles of carbon dioxide pipelines are operating safely and securely under standard industrial practices at pressurized conditions similar to those at the Project (see Figure 1). To understand and manage the potential risks posed by the proposed pipeline, the following analysis was conducted.

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[1] This carbon dioxide will be compressed and transported via pipeline to the custody transfer point at the adjacent Elk Hills Field, where it will be injected. The CO_2 EOR process involves the injection and reinjection of carbon dioxide to reduce the viscosity and enhance other properties of the trapped oil, thus allowing it to flow through the reservoir and improve extraction. During the process, the injected carbon dioxide becomes sequestered in a secure geologic formation. This process is referred to herein as CO_2 EOR and Sequestration.

1.1 U.S. DEPARTMENT OF TRANSPORTATION (DOT) REGULATIONS

DOT has promulgated regulations for the construction, operation and maintenance of carbon dioxide pipelines that could affect a high consequence area, as defined in the regulations (49 CFR Part 195). Pursuant to Section 195.452, a pipeline operator must develop a written integrity management program before commencing operation of the pipeline. Although the Project's carbon dioxide pipeline may not affect a high consequence area, the Project will develop an integrity management program in accordance with the regulatory requirements prior to operation. In addition, operators must perform a risk assessment of the carbon dioxide pipeline using the applicable criteria set forth in the regulation. The Project performed a risk assessment as set forth in this Appendix.

1.2 REGULATORY FRAMEWORK GOVERNING CARBON DIOXIDE

The Project also examined the following federal and state statutes and regulations to determine whether carbon dioxide is regulated as a hazardous substance under the project conditions:

- Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)
- Superfund Amendment and Reauthorization Act (SARA)
- Emergency Planning and Community Right-to-Know Act of 1986
- Risk Management Program for Chemical Accidental Release Prevention
- California Accidental Release Prevention Program
- Title 22, California Code of Regulations, Section 66261.20 et seq.

Carbon dioxide captured and distributed by the Project was not identified as a regulated substance based on any of the regulations referenced above.

As an additional measure to be compliant with emerging rules and/or regulations dealing with the use and/or generation of carbon dioxide, the Project also examined the proposed amendments to the Clean Air Act proposed by the U.S. Environmental Protection Agency (USEPA) Proposed Greenhouse Gases (GHG) Endangerment Finding. At this time regulatory requirements are being developed to limit the emission of man-made GHGs, such as carbon dioxide, due to the potential harm and health impacts those GHGs may present. Although pertinent to carbon dioxide, the proposed rules/regulations focus on GHG emissions from new motor vehicles instead of an accidental release from a facility, making this emerging rule/regulation not directly applicable to the Project. Additionally, although these GHGs are being deemed to pose potential harm and health impacts, the GHGs are not being identified as regulated hazardous substances by the endangerment findings.

1.3 INDUSTRIAL EVALUATIONS FOR CARBON DIOXIDE PIPELINES

The Project examined the environmental and risk evaluations conducted by other projects designing a carbon dioxide pipeline. The carbon dioxide pipeline project data examined relates directly to the application of carbon dioxide for EOR and sequestration processes (USDOE, 2007). In addition, risk assessments are regularly conducted for the evaluation of facilities separating, compressing, and/or transporting carbon dioxide to injection sites. The risk assessment approach is based on qualitative and quantitative estimates of carbon dioxide releases under different failure scenarios. Failures of the engineered system include catastrophic events, leakage, and fugitive releases of captured carbon dioxide. The dispersion of the released carbon dioxide in the air is estimated using analytical modeling for heavy gas. Estimated concentrations of carbon dioxide in air are then used to estimate the potential for exposure and any resulting impacts on human and ecological receptors.

1.4 RISK DEFINITION

For the purpose of this study, risk was defined as a combination of the probability of occurrence of a scenario versus the severity of its consequences. The following methodology was used to define the magnitude of risk for this study:

- Identify scenarios or events that may occur and have adverse consequences;
- Estimate potential consequences from the release;
- Estimate the likelihood of this event occurring; and
- Evaluate the risk.

For this study, a semi-quantitative analysis based on historical data was used to develop a risk matrix that determines the risk to the surrounding community from the proposed carbon dioxide pipeline. Methodology for the development of this risk matrix followed accepted quantitative risk assessment criteria (Deshotels and Zimmerman 1995) and hazardous materials transportation risk analysis (Rhyne 1994). Indices of frequency (i.e., frequently, likely, rare, etc.) and consequences (acceptable, severe, negligible, etc.) were combined to develop a risk matrix for the Project (Tables 1-1 through 1-4). As presented in the risk matrix, Table 1-3, risk levels of 35 and above are considered an unacceptable risk category, levels of 21 and above present undesirable risk levels, levels of 8 through 20 present a risk that is acceptable with controls or mitigation, and the rest of the levels of risks are acceptable based on standard industrial practices.

Table 1-1
Frequency Index

Range	Frequency	Description
7	Continual	Expected to present itself during every point of operation
6	Very Frequent	Once a month; Can be expected to occur in most operational circumstances
5	Frequent	Once in three month ; May occur in most operational circumstances
4	Infrequent	Once a year; May occur at some time
3	Possible	Once in 5 years; Could occur at some time
2	Rare	Once in 50 years; May only occur in exceptional circumstances
1	Extremely Rare	Once in 100 years; May only occur in exceptional circumstances

Table 1-2
Consequence Index

Range	Consequences	Health Impacts	Critical Services Interruption	Organizational Outcomes/ Objectives	Non-Compliance
7	Extreme (Catastrophic)	Multiple deaths and serious prolonged health impacts	Facility closure and cessation of all activities	Complete performance failure	Serious, willful breach; criminal negligence or act
6	Large (More than Severe)	Multiple severe health crises/injury or death	Indeterminate prolonged suspension of work; nonperformance	Nonachievement of objective/ outcome; performance failure	Serious, willful breach; criminal negligence or act
5	Medium (Severe)	Severe health crisis	Prolonged suspension of work – additional resources required; performance affected	Significant delays; performance significantly under target	Deliberate breach or gross negligence; formal investigation
4	Small (Moderate)	Routine medical attention required	Short term temporary suspension – backlog cleared < 1 day	Minimal impact on organizational objectives	Breach; objection/complaint lodged; minor harm with investigation
3	Low (Minute)	First aid or equivalent only	No material disruption	Minor impact on organizational objectives	Innocent procedural breach; evidence of good faith and proper mitigation measures; minor offsite impact; no impact on sensitive receptors (schools, hospitals, playgrounds, daycare centers, residences, etc.)
2	Limited (Negligible)	May require first aid or equivalent only	No material disruption	Insignificant impact on organizational objectives	Innocent procedural breach; evidence of good faith and proper mitigation measures; no offsite impact
1	None (No Consequence)	None	None	None	None

Table 1-3 Risk Index

Range	Consequences	Description
1 to 7	Acceptable	Acceptable risk without requiring any changes
8 to 20	Acceptable with Controls	Acceptable risk after recommended changes and modifications are made to reduce risk
21 to 34	Undesirable	Undesirable risk requires design changes or safety evaluation
35 and above	Unacceptable	Unacceptable risk major modifications and design changes required

Table 1-4 Sample Risk Matrix – Combination of the Above-Mentioned Indices

		Frequency						
		Extremely Rare	**Rare**	**Possible**	**Infrequent**	**Frequent**	**Very Frequent**	**Continual**
Consequence		**1**	**2**	**3**	**4**	**5**	**6**	**7**
Extreme (Catastrophic)	**7**	7	14	21	28	35	42	49
Large (More than Severe)	**6**	6	12	18	24	30	36	42
Medium (Severe)	**5**	5	10	15	20	25	30	35
Small (Moderate)	**4**	4	8	12	16	20	24	28
Low (Minute)	**3**	3	6	9	12	15	18	21
Limited (Negligible)	**2**	2	4	6	8	10	12	14
None (No Consequence)	**1**	1	2	3	4	5	6	7

1.5 CAUSE AND EFFECT ANALYSIS

This section provides a cause and effect analysis based on certain upset conditions that can lead to a release of carbon dioxide from pipelines and associated equipment. The list presented below is representative but not all inclusive. Some of the parameters identified that could cause an upset condition are as follows:

- High pressure/temperature conditions
- Pipeline corrosion
- External conditions
- Human errors
- Abnormal operation and maintenance

A cause and effect analysis of process deviations on piping and valves of the carbon dioxide pipeline system are presented in Table 1-5.

Table 1-5
Pipes and Valves

Deviation	Cause	Consequence	Example Safeguards
Pipe & Valve Failure	• Corrosion • Maintenance errors • External impacts (including third-party damage)	• Release of carbon dioxide	• Pipeline controls; Pressure and temperature indicators • Automated block valves for isolation • Inspections and preventative maintenance • Cathodic protection • Pipeline will be pressure rated to greater than the maximum discharge pressure of carbon dioxide centrifugal compressor
Operator Error	• Maintenance errors • External impacts (including third-party damage)	• Release of carbon dioxide	• Supervision of all personnel; including inspection of maintenance and operation activities • Appropriate training and experience requirements for all personnel

2.0 Quantitative Failure Analysis

The following sections describe the risk of upset assessment for the proposed carbon dioxide pipeline and estimate the probability of failure and adverse consequences based on historical accident records of carbon dioxide pipelines.

2.1 DATABASES USED IN THE STATISTICAL ANALYSIS

In order to estimate the historical failure rate of carbon dioxide pipelines, two sets of information (databases) are necessary: (1) accident/spill records of carbon dioxide pipelines in the United States; and (2) corresponding carbon dioxide pipelines currently in operation. At present (2009), more than 3,500 miles of carbon dioxide pipelines are operating in the United States (see Figure 1 and Table 2-1) (Duncan 2009). These pipelines, at diameters ranging from 8 inches to 30 inches, are mainly used to carry carbon dioxide from naturally occurring underground reservoirs to oil fields for use in CO_2 EOR and Sequestration operations. These pipelines operate at conditions similar to those proposed for the Project carbon dioxide pipeline. The pipelines are largely situated in the midwestern to western portions of the United States where most of the EOR is occurring.

Table 2-1
Existing Long-Distance Carbon Dioxide Pipelines in United States

Pipeline	Location	Operator	Capacity (Million Metric Tons of Carbon Dioxide per year)	Length (mile)	Year Finished
Cortez	Colorado to Texas	Kinder Morgan	19.3	502	1984
Sheep Mountain	Colorado to Texas	Occidental	9.5	410	-
Bravo	Colorado to Texas	Occidental, Kinder Morgan, Crosstimbers	7.3	217	1984
Canyon Reef Carriers	Texas	Kinder Morgan	5.2	139	1972
Val Verdes	Texas	Petrosource	2.5	81	1998
Weyburn	North Dakota, United States to Canada	North Dakota Gasification Co.	5	203	2000
North East Jackson Dome	Mississippi	Denbury	11.5	182	1986
Free State	Mississippi	Denbury	6.7	86	2005
Delta	Mississippi	Denbury	7.7	31	2008
Cranfield	Mississippi to Louisiana	Denbury	2.88	51	1963
Total			**77.58**	**1,902**	

Source: Duncan et al., 2008.

The accident/spill records of carbon dioxide pipelines were obtained from the data provided by the Office of Pipeline Safety at the DOT. Incident failure rate was also obtained from the European Gas Pipeline Incident Data Group and analysis in the Oil and Gas Journal. Based on these data, the failure and accident frequency of carbon dioxide pipelines may be calculated.

2.1.1 Historical Failure Rates

Records covering the period 1986 to 2008 were obtained from DOT's Office of Pipeline Safety through the National Response Center (NRC). For each reported accident, the database contains information on such parameters as accident date, location, system component that failed, cause of failure, commodity spilled, and failure consequences (fire, explosion, fatality, injury, and the amount of property damage).

According to the NRC's accident database, a total of 13 accidents regarding carbon dioxide pipelines occurred in the United States between 1986 and 2008 (Table 2-2). Of these 13 accidents, none had reported human injuries or fatalities, compared to the more than 5,000 accidents and 107 fatalities in the same period caused by natural gas and hazardous liquid pipelines (Parfomak and Folger 2007). This information on carbon dioxide pipeline incidents was used to estimate the failure rate (i.e., 13 accidents in 22 years in 3,500 miles of pipelines).

Table 2-2
Detailed Report on Carbon Dioxide Pipeline Accidents between 1986 and 2008

Date of Incident	Description	Cause	Location	Suspected Responsible Party	Medium Affected
02/27/1994	Hazardous Liquid Pipeline/Gasket Failure	Equipment Failure	Texas	Inron Liquids Pipeline Co.	Air
04/15/1994	8-Inch Pipeline/External Corrosion	Equipment Failure	Oklahoma	Arco Permian	Air
06/15/1998	12-Inch carbon dioxide pipeline/DOT Regulated/semi-truck ran into a structure	Operator Error	Oklahoma	Transpectco	Air
11/19/2000	Strong odor reported from private citizen and confirmed release from pipeline 12 inches below ground	Equipment Failure	North Dakota	Dakota Gasification Co.	Air
01/13/2001	8-Inch transportation line discovered leaking into the atmosphere due to a unknown cause	Unknown	North Dakota	Dakota Gasification Co.	Air
02/25/2001	14-inch distribution line leaked carbon dioxide and hydrogen sulfide into the atmosphere	Equipment Failure	Texas	Borger CO_2 Pipeline LLC	Air
03/07/2002	Third-party company contracted a backhoe and hit a carbon dioxide underground pipeline during digging.	Operator Error	Oklahoma		Air
02/25/2003	8-Inch transmission pipeline failed due to corrosion and caused material to release	Equipment Failure	Texas	Chaparral Energy	Air

Table 2-2
Detailed Report on Carbon Dioxide Pipeline Accidents between 1986 and 2008

Date of Incident	Description	Cause	Location	Suspected Responsible Party	Medium Affected
11/14/2003	Release of carbon dioxide due to valve failure	Equipment Failure	Mississippi	Denbury Resources	Air
10/14/2004	A leak was found on the CRC pipeline releasing carbon dioxide	Under Investigation	Texas	Kinder Morgan CO_2 Co.	Land
09/22/2006	A magnetic flux leakage (MFL) pig was struck in a pipeline and when efforts were made to remove the object, the line developed a crack and discharged carbon dioxide in to the air.	Equipment Failure	North Dakota	Dakota Gasification Co.	Air
01/09/2007	Carbon dioxide was released to the atmosphere from a 20-inch underground pipeline.	Unknown	Mississippi	Denbury Onshore LLC	Air
03/15/2007	An ice mound formed on a line used for liquid carbon dioxide injection from Texas to Oklahoma due to a pinhole leak.	Equipment Failure	Texas	Chaparral Energy	Other

Table 2-3 shows that 46 percent of the accidents were caused by equipment failure. Close examination of these accidents revealed that the majority were caused by failure of a subcomponent (such as valve or gasket). The second most common cause was “Unknown,” accounting for approximately 23 percent of all accidents. The average failure rate for this period of time was 0.000169 failure per mile of carbon dioxide pipeline per year.

Based on these data, the upper bound of the projected failure rate for the approximately 4 miles of carbon dioxide pipeline at the Project is 0.0007 failure per year.

Table 2-3
Failure Rates for Carbon Dioxide Pipelines

Failure Mode	Total Number of Accident Between 1986 and 2008	Percentage	Historical Failure Rate per Mile of Carbon Dioxide Pipeline per year
Equipment Failure	6	46	7.77E-05
Corrosion	2	15.5	2.70E-05
Operation Error	2	15.5	2.70E-05
Unknown	3	23	3.89E-05
Total	**13**	**100**	**1.69E-04**

2.1.2 European Gas Pipeline Incident Data Group/Oil and Gas Journal

In 2002, the European Gas Pipeline Incident Data Group reported that gas pipeline incidents had been significantly reduced between 1970 and 2001. An analysis performed by Guijt in 2004 (Guijt 2004), which was published in the *Oil and Gas Journal*, also reported similar data. Guijt presented an incident rate of almost 0.0010 kilometer $(km)^{-1}$ $year^{-1}$ (0.0016 $mile^{-1}$ $year^{-1}$) in 1972, which decreased to below 0.0002 km^{-1} $year^{-1}$ (3.22E-04 $mile^{-1}$ $year^{-1}$) in 2002. These incidents include all unintentional releases outside of the limits of facilities originating from pipelines whose design pressures are greater than 1.5 million-Pascals (MPa).

Applying the Guijt figures for European pipelines, the projected failure rate for the carbon dioxide pipeline at the Project is 1.32E-03 failures per year.

2.2 POTENTIAL ADVERSE CONSEQUENCES

A carbon dioxide pipeline failure could result in loss of product containment, causing a release, and, in rare instances, a large-scale rupture. According the incident statistics for carbon dioxide pipeline compiled by Gale and Davison (2002), ten accidents occurred between the period from 1990 to 2002, with property damage totaling US$ 469,000, and no injuries or fatalities, since unlike oil and gas, carbon dioxide is not flammable or explosive. As presented in Table 2-3, the major reasons for the incidents were equipment failures and corrosion. This is contrary to natural gas pipeline incidents, where an outside force, such as an excavator, is the principal cause of incidents.

Carbon dioxide leakage can also be a potential physiological hazard for humans and animals. The consequences of carbon dioxide incidents are modeled in the next section.

2.3 STANDARD INDUSTRY PRACTICES

Due to the adverse consequences that may occur from a possible carbon dioxide pipeline failure, the industry has developed standard means to control the integrity and safe operation of pipelines. These practices include routine inspections of the pipeline rights-of-way for third-party actions, internal pipe inspections performed by in-line inspection tools (e.g., pigs), cathodic protection programs, as well as leak detection systems. The specific industry practices for the mitigation of carbon dioxide pipeline releases that will be used in the Project are presented in Section 5 of this appendix.

3.0 Potential Hazard Impacts and Consequence Modeling

The risk assessment methodology for the carbon dioxide pipeline and the regulatory reference for conducting the assessment are presented in Sections 1 and 2 of this appendix. This section presents an evaluation of a hypothetical worst-case release scenario to assess the maximum potential consequence from the proposed pipeline as a precursor to the overall risk analysis presented in Section 4, Offsite Consequence Analysis

An Offsite Consequence Analysis (OCA) was performed, using the methodology prescribed under the California Accidental Release Prevention program and the federal Clean Air Act Risk Management Program, to address the maximum potential consequence from a worst-case release from the carbon dioxide pipeline. The models provide an examination of the dispersion of carbon dioxide in the form of a vapor cloud. The modeling assumptions for a worst-case release scenario are that the total contents from the largest inventory are accidentally released into the atmosphere.

The modeling assumed worst-case atmospheric conditions during such a release, where applicable. These conditions provide conservative results because these extreme and unlikely climatic conditions maximize the vaporization to create the vapor cloud and minimize its dispersion. For purposes of this analysis, the worst-case climate condition consists of an ambient temperature of 115 degrees Fahrenheit (ºF) (the highest average temperature in the Project area), a 50 percent average humidity, a wind speed of 1.5 meters per second, and a level F atmospheric stability.[2]

3.1 CARBON DIOXIDE EXPOSURE LIMITS

The modeling conducted to evaluate the potential impact area associated from a worst-case carbon dioxide pipeline release used exposure limit concentrations levels of carbon dioxide as established by the U.S. Occupational Safety & Health Administration (OSHA), the American Conference of Governmental Industrial Hygienists (ACGIH), and the National Institute for Occupational Safety and Health (NIOSH). The concentrations were examined to determine which concentration levels would present the greatest hazard during a worst-case release scenario.

These concentrations are stated in terms of (1) Permissible Exposure Limit (PEL), (2) Threshold Limit Value (TLV), (3) Short Term Exposure Limit (STEL), and (4) Immediately Dangerous to Life or Health (IDLH). Both the PEL and TLV specify airborne concentration levels under which nearly all workers may be repeatedly exposed without potential adverse effects. The STEL represents the concentration to which workers can be exposed continuously for a short period of time without suffering from irritation, chronic or irreversible tissue damage, or narcosis of sufficient degree to increase the likelihood of accidental injury, impaired judgment, or materially reduction in work efficiency.

[2] Level F atmospheric stability provides the most stable atmospheric environment where the tendency of the atmosphere is to resist or enhance vertical motion and/or turbulence—this also contributes to minimum dissipation of the vapor cloud.

Table 3-1
Concentrations of Concern for Carbon Dioxide

Exposure Limit for Carbon Dioxide	Concentration	Exposure Period
OSHA PEL	5,000 ppm	Time weighted average concentration for 8-hour work day
ACGIH TLV	5,000 ppm	Time weighted average concentration for normal 8-hour work day or 40-hour work week
OSHA STEL	30,000 ppm	Maximum concentration for 15-minute period (maximum of 4 periods per day with at least 60 minutes between exposure periods)
NIOSH IDLH	40,000 ppm	The maximum level to which a healthy individual can be exposed to a chemical for 30 minutes and escape without suffering irreversible health effects or impairing symptoms

Notes:
ACGIH = American Conference of Governmental Industrial Hygienists
IDLH = Immediately Dangerous to Life or Health
NIOSH = National Institute for Occupational Safety and Health
OSHA = Occupational Safety & Health Administration
PEL = Permissible Exposure Limit
ppm = parts per million
STEL = Short Term Exposure Limit
TLV = Threshold Limit Value

3.2 CONSEQUENCE MODEL AND METHODOLOGY

The extent of potential impact from the hypothetical accidental release was computed by using the Areal Locations of Hazardous Atmospheres (ALOHA) 5.4.1 air dispersion modeling program. ALOHA is a Gaussian plume model that incorporates continuous source and meteorological parameters.

The ALOHA model was selected to model the release, as it is suitable for modeling the release of a heavy gas (i.e., gas that is heavier than air) such as carbon dioxide. All the basic phenomena associated with a heavy gas release, such as horizontal spreading, the mass exchange between the plume and the plume temperature are considered through the ALOHA program. Operating through Gaussian plume dispersion, the ALOHA model also takes into consideration the specific atmospheric conditions that may affect a potential release.

3.2.1 Carbon Dioxide Worst-Case Release Scenario

In order to provide conservative results as to the extent of impact of a carbon dioxide release from the Project, OCA models for hypothetical worst-case scenario releases were examined. The modeling for the worst-case release scenario examined an instantaneous release from a complete lateral shear and de-pressurization of pipeline sections isolated by emergency block valves. Models were conducted to evaluate the release from four segments of the carbon dioxide pipeline:

- Segment 1: 200 linear feet of 12-inch-diameter aboveground pipeline — from the compressor discharge to the first block valve;
- Segment 2: 2,904 linear feet of 12-inch-diameter underground pipeline — from the first block valve to the second block valve;
- Segment 3: 2693 linear feet of 12-inch-diameter underground pipeline — from the second block valve, under the aqueduct, to the third block valve; and
- Segment 4; 15,893 linear feet of-12-inch-diameter underground pipeline — from the third block to the final block valve at the custody transfer point.

The carbon dioxide will be transported as a supercritical fluid under highly pressurized conditions. Due to the highly pressurized conditions, a complete shear or rupture of the pipeline may displace the soil above the pipeline. Upon release and adiabatic expansion, it is estimated that approximately 75 percent of the carbon dioxide volume within the affected pipeline segment will be discharged as a gas. The remaining 25 percent of the carbon dioxide volume will solidify, then vaporize slowly, resulting in a gaseous release into the atmosphere (GPSA, 2004.)

Since the weight of the soil above the pipeline would decrease the release rate, the worst-case scenario of carbon dioxide release at each pipeline section was assumed to occur at the piping connecting to the valve boxes, which are located near the ground surface level, resulting in a release to the atmosphere. Additionally, the evaluation of the worst-case release scenario focused on the estimated gas volume of the supercritical carbon dioxide released, because the carbon dioxide gas volume presents the greatest potential for dispersion upon release into the atmosphere. Based on these assumptions, this OCA analyzed the potential impacts of the carbon dioxide within the affected pipeline segment being modeled at a ground-level elevation, which is the worst-case scenario.

For the worst-case release scenario, the rupturing of the carbon dioxide pipeline was assumed to produce an 0.8-square-foot aperture (meaning a complete severing of the 12-inch-diameter pipeline) at the connection to the valve box through which carbon dioxide would escape. The worst-case scenario assumes that the total carbon dioxide volume of each section will release through the rupture within 1 minute (the minimum duration used by the ALOHA model for immediate releases). The atmospheric conditions modeled represent the least favorable conditions for the normal dissipation of a concentrated carbon dioxide release.

In addition to the gas volume released from each isolated pipeline segment, the analysis also accounted for the additional carbon dioxide that would be released during the reaction time for activation of the automated emergency block valves. It would take approximately 20 seconds for the carbon dioxide pipeline emergency block valves to activate based on pressure loss conditions identified for the pipeline. Based on the foregoing, the total quantities of carbon dioxide released for each segment of pipeline were calculated and are provided in Table 3-2.

Table 3-2
Potential Quantities of Carbon Dioxide Released Per Pipeline Segment After Worst-Case Scenario Release

Length of Carbon Dioxide Pipeline (feet)	Total Potential Quantity Released (pounds)
200	8,817
2904	86,824
2693	80,736
15,893	461,540

Modeling results derived from the use of the ALOHA modeling program are provided in Section 3.3 of this appendix.

3.3 MODELING RESULTS

The modeling of the worst-case scenarios demonstrated the following concentrations may be reached at the following approximate distances during the hypothetical release. This information was used for the risk analysis.

Table 3-3
Approximate Distances to Concentrations of Concern

Length of CO_2 Pipeline (feet)	Concentration of Concern (ppm)	Approximate Distance to Concentration of Concern (feet)
200	30,000(STEL)	864
	40,000 (IDLH)	756
2,904	30,000(STEL)	1,701
	40,000 (IDLH)	1,452
2,693	30,000 (STEL)	1,668
	40,000 (IDLH)	1,431
15,893	30,000(STEL)	2,409
	40,000 (IDLH)	2,058

The area surrounding the pipeline route is mainly composed of native terrain and agriculturally developed lands. As such, U.S. Census data shows minimal population density levels to be present in areas that would potentially be impacted from the hypothetical worst-case scenario release. No sensitive receptors were identified to be present within the potential area of impact.

Individuals who may be present in potential areas of impacts primarily include occasional agricultural and oil production workers. The likelihood of a release occurring during the presence of an occasional worker is low and remote.

4.0 Risk Analysis

The Risk Analysis provided in this appendix is based on the OCA evaluation of the worst-case release scenario for the carbon dioxide pipeline and historical data regarding the operation of carbon dioxide pipelines throughout the country. The worst-case release scenario OCA provided the most conservative results as to the potential maximum area of impact that may be affected from a total release of carbon dioxide from each of the individual pipeline segments. This analysis was supplemented by historical data from government records on recorded carbon dioxide releases, which was used to calculate the potential for such a release to occur.

The information gathered in the prior sections and the modeling results from the OCA were used to perform the risk analysis described below.

4.1 RISK PROBABILITY

Based on historical data obtained from the DOT's Office of Pipeline Safety covering the period 1986 to 2008 through the National Response Center, the failure rate for this period of time was determined to equal about 0.000169 failure per mile of carbon dioxide pipeline per year. No record of catastrophic explosion or rupture has been recorded since the 1970s.

The probability of occurrence of an actual failure event was calculated using the incident data from 1986 through 2008. As calculated in Section 2.1.1, the historical failure rate for the 4-mile carbon dioxide pipeline is estimated to be about 0.0007 failures per year, which will not present a significant likelihood of occurrence. The projected failure rate for each Failure Mode is calculated through the equation below and presented within Table 4-1.

$$\begin{array}{c}\textit{Projected Failure Rate}\\ \textit{of each Failure Mode}\end{array} = \begin{array}{c}\textit{Historical Failure Rate per Mile of Carbon Dioxide Pipeline}\\ \textit{per Year} \times \textit{Total length of Carbon Dioxide Pipeline}\end{array}$$

Table 4-1
Failure Rates for Carbon Dioxide Pipelines

Failure Mode	Historical Failure Rate per 4 Miles of Carbon Dioxide Pipeline per year
Equipment Failure	3.19E-04
Corrosion	1.11E-04
Operation Error	1.11E-04
Unknown	1.59E-04
Total	7.0E-04

4.2 RISK EVALUATION

The OCA modeled worst-case releases assuming worst-case conditions and scenarios. These modeling assumptions by definition present a very rare occurrence and thus have a very low risk factor as set forth in the Risk Matrix presented in Table 4-2. In addition, various potential scenarios that have a higher probability of occurrence, as confirmed by historical industry experience in Section 2, were analyzed in the risk calculations for the Project. All potential failures described in Section 2.1.1 were assessed for the Project and compiled in Table 4-2.

Table 4-2
Project Risk Matrix

Deviation	Potential Scenario	Consequence	Frequency	Risk
Equipment Failure	Complete release of carbon dioxide volume within pipeline.	7	1	7
Equipment Failure	Partial carbon dioxide pipeline breach and moderate release	5	1	5
Equipment Failure	Minor leak in carbon dioxide pipeline.	3	1	3
Operator Error	Complete release of carbon dioxide volume within pipeline.	7	1	7
Operator Error	Partial carbon dioxide pipeline breach and moderate release.	5	1	5
Operator Error	Minor leak in carbon dioxide pipeline.	3	1	3

Based on Table 4-2, a catastrophic incident has a value of 7 on the Consequence Index. However, since a catastrophic incident, where the entire contents of the pipeline are immediately released, is extremely rare, it is rated a 1 on the Frequency Index. This scenario will result in a risk factor of 7 on the Risk Matrix (Table 4-2). In the case of moderate carbon dioxide releases and minor leaks, the frequency value is calculated based on the historical data presented in Table 4-1, which still shows a frequency of less than 1 incident per year per mile of carbon dioxide pipeline. These releases have similar frequency, resulting in a risk rating ranging from 3 to 7. This range of risk values is acceptable based upon the standard risk methodology, as shown in Tables 1-3 and 1-4, and demonstrates that the carbon dioxide pipeline will have a less-than-significant risk. Results from this evaluation showed that the potential impact of any release occurring from the Project's carbon dioxide pipeline will be less than significant.

5.0 Proposed Mitigation Measures

Although the carbon dioxide pipeline for the Project will pose less-than-significant risks, in order to reduce the potential impacts from an accidental release, the Project will incorporate various mitigation measures to reasonably prevent and control any potential accidental carbon dioxide releases. The Project will design, construct, operate, and maintain the carbon dioxide pipeline in accordance with applicable laws, ordinances, regulations, and standards (LORS). The following factors were considered in defining control and mitigation measures for pipeline safety:

- **Pipeline Design Pressure and Temperature:** The design pressure and temperature will be selected in accordance with prudent engineering practice and applicable LORS.

- **Depth of Burial:** The carbon dioxide pipeline will be buried approximately 5 feet below grade. This is an additional 2 feet greater than required by the DOT.

- **Pipeline Routing:** Pipeline route identification markers will be placed at regular intervals or prescribed locations to identify the buried pipeline and the Project will comply with applicable regulatory requirements to reduce the likelihood of third-party damage. Most of the pipeline route will pass through private property. HEI will enter into arrangements with property owners for controlled access of the area.

- **Pipe Material Selection:** The pipe will be constructed with steel that meets design criteria for operations internal pressures and external loads, and pressures anticipated for the pipeline system. The pipe will be constructed with materials in accordance with prudent engineering practice and applicable LORS.

- **Internal-Corrosion Control:** The Project will employ internal-corrosion control measures in accordance with prudent engineering practice and applicable LORS. An internal-corrosion inspection, monitoring, and assessment program will be established.

- **External Internal-Corrosion Control:** The Project will employ external internal-corrosion control measures in accordance with prudent engineering practice and applicable LORS. An internal-corrosion inspection, monitoring, and assessment program will be established.

- **Block Valves:** Block valves will be installed on the carbon dioxide pipeline to block-in the pipeline in the unlikely event of a loss of integrity.

- **Pipeline Control:** A Project control system will provide reliable and responsive controls to detect potential leaks. Real-time monitoring of key parameters, including pressure, temperature, and flow rate, enables timely intervention in the event of a release.

- **Right-of-Way Inspections:** At intervals not exceeding 3 weeks, but at least 26 times each calendar year, the Project will inspect the surface conditions on or adjacent to each pipeline right-of-way.

Industry experience to date demonstrates that carbon dioxide can be safely handled and stored, and suggests that the likelihood of an accidental release of carbon dioxide to be remote when proper handling procedures are effectively applied. The implementation of the appropriate prevention and control mitigation measures noted above will further reduce the likelihood and potential impact of an accidental pipeline release, thereby further reducing the potential risk from the operation of the carbon dioxide pipeline.

6.0 References

Deshotels, Robert and Robert Zimmerman, 1995. “Cost Effective Risk Assessment for Process Design.”

Duncan, Ian, Nicot, Jean-Philippe and Choi, Jong-Won, 2008. “Risk Assessment for future CO_2 Sequestration Projects Based CO_2 Enhanced Oil Recovery in the U.S.” November 16-20, 2008 (April 23, 2009). http://www.beg.utexas.edu/gccc/bookshelf/2008/GHGT9/08-03i-Final.pdf.

Duncan, Ian, 2009. “Statement by Ian Duncan – The Future of Coal under Climate Legislation – Carbon Sequestration Risks, Opportunities, and Learning from the CO_2-EOR Industry.” March 10, 2009. (April 23, 2009). http://www.energycommerce.house.gov/ Press_111/20090310/testimony_duncan.pdf.

Gale, J. and J. Davison, 2002. Transmission of CO_2 – safety and economic considerations.

GPSA (Gas Processor Association), 2004. Properties of Carbon Dioxide. GPSA Engineering Data Book FPS Volume II.

Guijt, W., 2004. Analyses of incident data show U.S., European pipelines becoming safer. Oil and Gas Journal, January 26, 2004, pp. 68-73.

Parfomak, Paul W. and Peter Folger, 2007. “CRS Report for Congress – Carbon Dioxide (CO_2) Pipelines for Carbon Sequestration: Emerging Policy Issues.” April 19, 2007. (July 2, 2008). http://ncseonline.org/NLE/CRSreports/07May/RL33971.pdf.

Rhyne, William R., 1994. “Hazardous Materials Transportation Risk Analysis – Quantitative Approaches for Truck and Train.”

Stromberg, Professor Lars, 2005. “CO_2 Capture and Storage – Part of the Solution to the Climate Change Problem?, European Energy Forum.” January 17, 2005. (April 23, 2009). http://www.europeanenergyforum.eu/archives/european-energy-forum/ environmental-matters/co2-capture-and-storage-2013-part-of-the-solution-to-the-climate-change-problem.

USDOE (U.S. Department of Energy), 2006. Final Risk Assessment Report for the FutureGen Project Environmental Impact Statement.

Willbros Group Inc., 2000. “Cortez Carbon Dioxide Pipeline – Shell Pipeline Company” July 24, 2000. (April 27, 2009). http://www.willbros.com/_filelib/FileCabinet/Projects/ North_America/Cortez.pdf?FileName=0025.pdf.

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CARBON DIOXIDE PIPELINES IN THE U.S.

May 2009
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Hydrogen Energy California (HECA)
Kern County, California

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FIGURE 1