Navigator CO_2

HEARTLAND
GREENWAY

HEARTLAND GREENWAY SYSTEM

CO2 AIR DISPERSION GUIDANCE

Rev.	Description	By	Check'd	Appv'd
A	Initial Issuance	NGK	JRM	SRL
B	P2 Stage Gate Project Development	NGK	JRM	SRL

Navigator CO_2	HGS CO2 AIR DISPERSION GUIDANCE			
AUTHOR: NGK	REVIEWED BY: JRM	APPROVED BY: SRL	REV: B	SHEET NO: 1 of 12

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1.0 INTENT & PURPOSE

1.1 This Document is intended to outline Navigator CO2 Ventures' ("NCO2V") Heartland Greenway System ("HGS") guidance and philosophy for carbon dioxide ("CO2") air dispersion modeling, as a tool for risk analysis. NCO2V air dispersion modeling shall address scenarios for both controlled and uncontrolled releases of a CO2 dense phase pipeline. NCO2V used a representative modeling approach for developing design criteria which will be applied to the 1,350-mile HGS system (inclusive of the pipeline construction spreads and facility nodes). This Document is confidential and was developed solely for use by internal and external stakeholders.

1.2 This Document focuses on guidance for the HGS which will be operated in the dense phase (above the supercritical pressure) to transport CO2. The Document scope consists of the pipeline segments, mainline booster pump stations, and a small segment of the upstream capture facilities; but excludes the downstream facilities (sequestration) from the scope of responsibility.

1.3 NCO2V has established a tiered hazard approach to risk-ranking the potential impact to human health and safety from CO2 releases, as predicted by the air dispersion models described herein. The hazard levels are based on emergency exposure limits which are expressed as a concentration or dose over time. These limits are based upon published information available from domestic and international agencies. The highest level of risk will be established to mimic the Potential Impact Radius ("PIR") calculation and method found within in 49 CFR 192 (192.903).

1.4 This Document is intended to be technical in nature and guidance is to be applied by NCO2V Project Managers during the HGS project development and execution. Future versions of this Document are intended to include engineering studies yet to be conducted, which shall be used in the design process as they are developed and accepted within the industry.

1.5 This Document does not establish procedures for emergency response, emergency management, nor Integrity Management which will be managed by the NCO2V Operations Department.

1.6 Phase 1 of the HGS consists of forty (40) nodes split between fourteen (14) pipeline spreads (totaling ~1,350-miles of pipeline), four (4) booster stations, twenty-one (21) inlet custody transfer locations, and two (2) outlet sequestration custody transfer locations. Additional information including a breakdown of the pipeline spreads (by length and nominal pipe diameter) and booster pump station locations can be found in Appendix A.

2.0 GENERAL

2.1 NCO2V performed a risk assessment and will utilize the criteria listed within this document to categorize segments of the HGS where elevated levels of risk are present, and where additional measures will be required to mitigate risk. This risk assessment far exceeds all current criteria of 49 CFR 195 and addresses the requirements of DNV-RP-F104. Air dispersion modeling is an accepted method for establishing potential risk areas, and tools are publicly available and used by emergency responders during incident response (for hazardous liquids and gases). However, NCO2V shall establish criteria which can be used for a risk-based preventative approach to engineering design and construction.

2.2 NCO2V has conducted and will continue air dispersion modeling efforts to demonstrate the potential hazards associated with both controlled and uncontrolled releases of CO2. NCO2V has taken multiple approaches to predict the behavior of a CO2 plume as it disperses throughout the atmosphere. NCO2V has utilized the Areal Locations of Hazardous Atmospheres Software ("ALOHA") and has verified and validated the results using the PHAST Software which has been proprietarily managed by DNV GL USA ("DNV") and improved by validations to experimentally collected data. PHAST has a crater model which specifically includes a physics-based approach for streams which are ejected into the atmosphere.

2.3 This Document should note that FEMA manages the Interagency Modeling and Atmospheric Response Center ("IMAAC") who coordinates and disseminates federal atmospheric dispersion modeling and hazard prediction products. The IMAAC provides plume models for real-world emergencies involving significant hazardous atmospheric releases and atmospheric modeling support for National Level Exercises and local exercises. State, local, and federal officials can request IMAAC support by contacting the IMAAC Technical Operations Hub, managed by the Defense Threat Reduction Agency, at (703) 767-2003 or emailing IMAAC@fema.dhs.gov. For general inquiries, please send an email to imaacinquiries@fema.dhs.gov.

3.0 HGS DESIGN

3.1 All HGS laterals, the trunkline, facilities, and metering locations shall have a Maximum Operating Pressure ("MOP") of 2,200 psig at 120 °F. The minimum booster station suction pressure will be 1,300 psig. The maximum booster station discharge pressure shall not exceed the pipeline MOP of 2,200 psig. For the system hydraulics design, the maximum discharge pressure should not exceed 2,100 psig. All air dispersion modeling should consider the MOP as the worst-case scenario.

3.2 All HGS Main Line Valves ("MLVs") shall be placed in accordance with the requirements of 49 CFR 195, specifically by the baseline requirements listed in 195.260, and in addition to the requirements of 195.452. NCO2V shall consider CO2 as a highly volatile liquid ("HVL") when considering valve placement requirements, which defines the HVL valve spacing limit of 7.5 miles within High Consequence Areas ("HCAs"); specifically, Highly Populous Areas ("HPA's") and Other Populous Areas ("OPA's). However, the air dispersion modeling will consider valve spacing at 20 miles to cover the most conservative representative scenario. Pipeline segments where MLVs are spaced at less than 7.5 miles (between MLVs), could be considered a risk mitigation method for Hazard Level 3 locations.

4.0 MODEL DEVELOPMENT

4.1 The development of scenarios is partially dependent on the inputs that are available with the respective software and which mathematical model the respective software applies. The following table from Sherpa Consulting[1] summarizes a comparison of available software for CO2 air dispersion modeling.

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Model Category	Model Name	Free?	Availability of Graphical User Interface	Complexity of Inputs	Validated against dense gas experiments	Validated against CO_2 experiments	Able to represent a range of source configurations	Ability to account for complex terrain and obstructions	Ability to account for complex meteorology
Integral	SLAB	Yes	Purchase	Medium	Yes	Low	Medium	None	Low
	DEGADIS	Yes	Purchase	Medium to High	Yes	Medium	Low	None	Low
	HGSYSTEM	Yes	No	Medium to High	Yes	Medium	High	Low	Low
	ALOHA	Yes	Free	Low	Yes	Low	Low	None	Low
	EFFECTS (v10)	No	Purchase	Medium	Yes	High	High	None	Low
	SAFER/TRACE	No	Purchase	Medium	Yes	Low	High	None	Low
	GASTAR	No	Purchase	Medium	Yes	Low	High	Medium	Medium
	PHAST	No	Purchase	Medium	Yes	High	High	None	Low
Lagrangian	*QUIC[b]*	*Yes*	*Free*	*Medium*	*Yes*	*Low*	*High*	*High*	*High*
	SCIPUFF	Yes	Free	High	Yes	Low	High	Medium	Medium
	ArRisk[a]	No	Purchase	Medium	Yes	Low	High	High	High
	CHARM (flat terrain)	No	Purchase	Medium	Yes	Low	High	None	Medium
	CHARM (complex terrain)	No	Purchase	Medium	No	Low	High	High	Medium
FD	FLUENT, PANACHE, FLACS, ANSYS-CFX	No	Purchase	High	Yes	Low	High	High	High
	OpenFOAM	Yes	Purchase	High	Yes	Low	High	High	High

(a) Includes MicroSWIFT-SPRAY
(b) Currently only available for non-profit research purposes.

Document: 20873-RP-001
Revision: 1
Revision Date: 23 September 2015
Document ID: Dispersion Modelling Techniques - Final (1).docx

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4.2 ALOHA was selected by NCO2V as one solution for addressing CO2 air dispersion modeling because its attributes are highly effective for emergency preparedness and response. ALOHA is a free software and was developed and is supported by the Emergency Response Division ("ERD"), a division within the National Oceanic and Atmospheric Administration ("NOAA") in collaboration with the Office of Emergency Management of the U. S. Environmental Protection Agency ("EPA"). Its primary purpose is to provide emergency response personnel estimates of the spatial extent of some common hazards associated with chemical spills. NCO2V has confirmed that ALOHA is familiar to the National Weather Service ("NWS") and Emergency Management agencies if they have qualified staff for air dispersion modeling. NCO2V's intent is to develop pre-planned scenarios in ALOHA with Emergency Management agencies. NCO2V engaged Integrity Solutions Ltd to develop the P1 ALOHA air dispersion models. Inputs to the ALOHA model are:

4.2.1 Chemical Type & Properties

4.2.2 Release Rate (if not using ALOHA Tank release rate estimate)

4.2.3 Release Pressure (MOP)

4.2.4 Wind Speed

4.2.5 Ground Roughness

4.2.6 Air Temperature

4.2.7 Cloud Cover

4.2.8 Atmospheric Stability Class

4.2.9 Relative Humidity

4.2.10 Pipe Inside Diameter (for ALOHA Tank release rate estimate)

4.3 PHAST was selected because it is regularly updated and supported by DNV who incorporates results from real-world CO2 experiments into PHAST. DNV publishes their results from their experiments and one of the most well-known studies is their COSHER Joint Industry Project ("JIP") covering a real-world simulated guillotine rupture of a CO2 pipeline at Spadeadam, UK. PHAST is a globally adopted solution for modeling atmospheric discharge, dispersion, fires, explosions, and toxic effects of a wide range of loss of containment scenarios. Process safety professionals benefit from 40 years of development and validation by industry experts and its continued use by more than 10,000 users across 1,000 organizations. An advantage of PHAST is that it contains a physics/momentum calculation which predicts scenarios for above and below ground pipelines. The buried pipeline is simulated through the crater-model which has been proprietarily developed by DNV for PHAST. NCO2V engaged DNV to develop the P1 PHAST air dispersion models. Inputs to the PHAST model are:

4.3.1 Chemical Type & Properties

4.3.2 Pipe direction

4.3.3 Release Direction

4.3.4 Release orientation (indegrees)

4.3.5 Release Rate

4.3.6 Release Pressure (MOP)

4.3.7 Above or buried piping

4.3.8 Pipeline isolation segments (MLV max distance)

4.3.9 Wind Speed

4.3.10 Ground Roughness

4.3.11 Air Temperature

4.3.12 Cloud Cover

4.3.13 Atmospheric Stability Class

4.3.14 Relative Humidity

4.3.15 Pipe Inside Diameter

4.4 NCO2V has applied a 360° wind direction rationale to all modeling, to assume the worst-case could occur in any direction. Future quantitative risk assessments could include a probabilistic approach which would consider meteorological rose plots.

4.5 NCO2V has considered a minimum of three (3) approaches to estimating the rate of an uncontrolled release.

4.5.1 ALOHA can estimate an uncontrolled release rate which can be used in the prediction of a guillotine rupture wherein the pipeline has been completely severed and the volume of the release is the combined volume of both pipe segments.

4.5.2 DNV's PHAST model offers two (2) representative rates which are intended to strike a balance between the high instantaneous release rate and the speed at which the release slows down. The highest rate is calculated by averaging the instantaneous release rate at 0 seconds and 20 seconds. The lower rate is calculated by averaging the instantaneous release rate at 0 seconds and 60 seconds.

4.6 Atmospheric conditions were selected with the understanding of the capabilities and limitations of the software being used. Gaussian models are not time dependent and will predict a concentration profile with a singular release rate. The worst-case scenario buffers, when not considering transient effects, could be during high transmissivity conditions where the CO2 plume is distributed in a long and linear manner.

4.6.1 It is immediately apparent that modeling technologies will address the compromises required from approaches that vary between emergency responders and desktop designers. NCO2V utilized Gaussian models to provide a representative model of CO2 dispersion across the system footprint.

4.7 The worst-case release scenario is defined as a guillotine rupture (e.g., failure of a girth weld) which has caused the pipe to separate and discharge the pipeline contents into the atmosphere.

4.8 The P1 project development cycle includes analysis and evaluations of the worst-case scenario for all five (5) nominal pipe sizes 6", 8", 12", 16", and 20", and used representative Gaussian modeling. The results / findings of the modeling activities are included within Appendix B.

4.9 The HGS Routing Philosophy used the P1 Air Dispersion results by selecting the most conservative results for a guillotine rupture release for each line size, as a preventative approach to risk management. The HGS Routing Philosophy applies a baseline design buffer distance for each nominal pipe size which applies to residential structures and vulnerable places of gathering. The HGS HCA Analysis and subsequent Emergency Flow Restricting Device ("EFRD") Analysis will utilize the results of the P1 Air Dispersion study to establish criteria for areas where HGS could affect HCAs.

5.0 TOXICOLOGY OF CO2

5.1 General exposure effects for CO2 are listed in the table below.

CO_2 Concentration (%)	Time	Effects
17 - 30	Within 1 minute	Loss of controlled and purposeful activity, unconsciousness, convulsions, coma, death
>17	<1 minute	Convulsions, coma, death
>10 - 15	1 minute to several minutes	Dizziness, drowsiness, severe muscle twitching, unconsciousness
7 - 10	1.5 minutes to 1 hour	Headache, increased heart rate, shortness of breath, dizziness, sweating, rapid breathing
6	1 – 2 minutes	Hearing and visual disturbances
	≤ 16 minutes	Headache, dyspnea
	Several hours	Tremors
4 - 5	Within a few minutes	Headache, dizziness, increased blood pressure, uncomfortable dyspnea
3	1 hour	Mild headache, sweating, and dyspnea at rest
2	Several hours	Headache, dyspnea upon mild exertion

Sources: (USEPA 2000), (Langford 2005)
The clinical definition of dyspnea is an uncomfortable awareness of one's breathing effort. It is a normal symptom of heavy exertion but becomes pathological if it occurs in unexpected situations (Shiber and Santana 2006).

5.2 The UK Health and Safety Executive ("HSE") publishes Dangerous Toxic Load ("DTL") assessments of chemicals which describes the exposure conditions in terms of airborne concentration and duration of exposure, which would produce a particular level of toxicity in the general population. The UK HSE defines the Specified Level of Toxicity ("SLOT"). as causing severe distress to almost everyone in the area; substantial fraction of exposed population requiring medical attention; some people seriously injured requiring prolonged treatment; and a 1-5% lethality rate from single exposure over a known amount of time.

6.0 HAZARD LEVELS & EMERGENCY EXPOSURE LIMITS

6.1 Emergency exposure limits for CO2 were selected by NCO2V with the intent of protecting employees and the public from immediate danger in the event of a release. The limits established by NCO2V are a combination of guidelines set by the American Conference of Governmental Industrial Hygienists' ("ACGIH"), the National Institute of Occupational Safety and Health ("NIOSH"), and the UK Health Safety Executive ("UK HSE").

6.2 PHMSA has not developed emergency exposure limits for CO2 nor are any limits currently prescribed by 49 CFR 195. NIOSH has not developed any emergency exposure levels for CO2. There are no Acute Exposure Guideline Levels ("AEGLs") for CO2 defined by the US EPA and no Emergency Response Planning Guidelines ("ERPGs") for CO2 defined by the American Industrial Hygiene Association ("AIHA"). AEGLs and ERPGs are the tools used by emergency responders to describe the human health effects from exposure to airborne chemicals. Since AEGLs and ERPGs do not include guidance for CO2 exposure they cannot be used for the HGS risk analysis.

6.3 The HGS Hazard Levels are listed below which are ranked from 1 to 4 in increasing severity.

Hazard Level	Published Toxicity Threshold	Exposure	Concentration (ppm)
4	[redacted]	[redacted]	105,000
3	[redacted]	[redacted]	63,000
2	NIOSH IDLH	30 min	40,000
1	ACGIH TLV-Short Term	10 min	30,000

6.4 Hazard Level 1 – Public Awareness: The American Conference of Governmental Industrial Hygienists' ("ACGIH") Threshold Limit Values ("TLV") Short Term 10-minute limit was selected to determine the area where normal breathing could not be sustained without sustaining mild symptoms (such as headaches and dyspnea).

6.5 Hazard Level 2 – Emergency Response: NCO2V shall coordinate with Emergency Response Management and other First Responders whose jurisdictions fall within the boundaries of this Hazard Level. NIOSH defines IDLH as the atmospheric concentration of any toxic, corrosive, or asphyxiant substance that poses an immediate threat to life, could cause irreversible or delayed adverse health effects, or could interfere with an individual's ability to escape from a dangerous atmosphere. The IDLH threshold was selected as the exposure limit where an increased risk is present. This is recognized as an increased risk level as persons might need to evacuate from an IDLH environment via self-evacuation or assisted by first responders.

6.6 Hazard Level 3 – Design & Operations Enhancements: NCO2V will implement additional design and operational measures for Hazard Level 3 and above, where residential structures and areas of public gathering are present within a potential Hazard Area.

6.7 Hazard Level 4 – Initial Routing: NCO2V has implemented guidance for pipeline routing based on Hazard Level 4. The UK HSE criteria for SLOT discussed in section 5.2 is similar to the consequence of the PIR. The PIR is used in natural gas pipeline regulation 49 CFR 192 and is the accepted risk management distance associated with the consequences of a natural gas pipeline explosion. Residential structures should be kept outside the Hazard Level 4 buffer as practicable to mitigate the risk of a worst-case scenario rupture.

6.8 HGS Facilities where dense phase CO2 is present will have a CO2 static monitoring system with alarms tied to the HGS Supervisory Control and Data Acquisition ("SCADA") system with visible alarms at the point of the leak. The CO2 static detection system will apply alarm thresholds less than those required for emergency response.

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7.0 RESULTS & KEY FINDINGS

7.1 The Emergency Response Guidebook (ERG) recommends evacuation of a 330' buffer from a CO2 release, for reference.

7.2 Using the rationale outlined above, NCO2V has summarized the findings from the PHAST and ALOHA modeling efforts below, which illustrates the calculated dispersion buffer (distance) ranges for each Hazard Level and nominal pipe diameter. A detailed summary of the analyses performed, and the associated inputs, can be found in the referenced HGS CO2 Air Dispersion Result documents.

Nominal Pipe Diameter	Hazard Level 4	Hazard Level 3	Hazard Level 2	Hazard Level 1
6"	321'	[redacted]	1,240'	1,971'
8"	417'	[redacted]	1,855'	2,753'
12"	[redacted]	[redacted]	[redacted]	3,291'
16"	[redacted]	[redacted]	[redacted]	3,644'
20"	1,029'	[redacted]	2,920'	4,250'

8.0 REFERENCES & RESOURCES

1. Sherpa Consulting Pty Ltd "Dispersion Modelling Techniques for Carbon Dioxide Pipelines in Australia (20873-RP-001)", 2015
2. J. Wilday, J.L. Saw, M. Wardman, "The CO2PipeHaz Good Practice Guidelines for CO2 pipeline safety – Technical Report", WP 3.1 – FP7 Project CO2 PipeHaz, 2013
3. DNV, "Design & Operation of CO2 Pipelines," DNV-RP-F104, updated 2021
4. The National Institute for Occupational Safety and Health (NIOSH), "Immediately Dangerous to Life or Heath (IDLH) Values," 1994.
5. HSE UK, "Toxicity levels of chemicals," https://www.hse.gov.uk/chemicals/haztox.htm, (accessed 2021).
6. HSE UK, "Assessment of the major hazard potential of carbon dioxide (CO2)," 2011.
7. M. Ahmada (DNV) , B. Lowesmith (DNV), G. De Koeijer (STATOIL), S. Nilsen (Statoil), H. Tonda (TOTAL), C. Spinelli (ENI), R.Cooper (National Grid), S. Clausen (GASSCO) , Renato Mendes (PETROBRAS), O. Florisson (DNV), "COSHER joint industry project: Large scale pipeline rupture tests to study CO2 release and dispersion".
8. ACGIH. Carbon dioxide. In: "Documentation of the threshold limit values for substances in workroom air." 3rd ed. Cincinnati, OH: American Conference of Governmental Industrial Hygienists, p. 39, 1971.
9. AIHA. Carbon dioxide. In: "Hygienic guide series:. Am Ind Hyg Assoc J 25:519-521, 1964.
10. Heartland Greenway System CO2 Air Dispersion Results, 2023

APPENDIX A – HGS SEGMENT & FACILITY INFORMATION

SPREAD	PHASE 1 SPREAD NAME	DESCRIPTION	NOMINAL PIPE SIZE	LENGTH (MILES)	[redacted]
1	Spread 1 – MS River HDD to Sequestration (include MS River HDD)	Trunkline	20"	151.1	[redacted]
1A	Spread 1A – BRR Galva to Trunkline	Galva Lateral	6"	99.6	[redacted]
1B	Spread 1B – Trunkline to Sequestration	Montgomery Lateral	20"	42.0	[redacted]
2	Spread 2 – Charles City Lateral to MS River	Trunkline	20"	188.4	[redacted]
2A	Spread 2A – Trunkline to OCI and BRR Burlington	OCI Lateral	8"	20.3	[redacted]
		Burlington Lateral	6"	15.1	[redacted]
3	Spread 3 – Hartley to Charles City Lateral	Trunkline	16"	99.9	[redacted]
			20"	36.4	[redacted]
		Albert City Lateral	6"	0.7	[redacted]
3A	Spread 3A – Ft Dodge to Trunkline (including Poet Gowrie, Poet Jewell, & VLO Fort Dodge)	Fort Dodge Lateral	6"	0.2	[redacted]
		Gowrie Lateral	8"	8.5	[redacted]
		Jewell Lateral	6"	9.2	[redacted]
4	Spread 4 – Charles City + BRR Dyersville & POET Fairbanks to Trunkline	Charles City Lateral	8"	26.3	[redacted]
			12"	73.3	[redacted]
		Iowa Falls Lateral	6"	3.7	[redacted]
		Shell Rock Lateral	6"	0.4	[redacted]
4A	Spread 4A – Charles City lateral to BRR Dyersville (including Poet Fairbank)	Dyersville Lateral	8"	88.7	[redacted]
		Fairbank Lateral	6"	0.8	[redacted]
5	Spread 5 – Trunkline to VLO Lakota; VLO Welcome to Lateral Tie-in	Lakota Lateral	6"	27.1	[redacted]
			8"	51.0	[redacted]
		Welcome Lateral	6"	22.4	[redacted]
6	Spread 6 – Aurora to Hartley	Aurora Lateral	8"	63.7	[redacted]
			12"	58.5	[redacted]
6A	Spread 6A – Poet Ashton, Chancellor, and Hudson Flow Lines	Chancellor Lateral	6"	31.8	[redacted]
		Hudson Lateral	6"	25.8	[redacted]
		Ashton Lateral	6"	1.3	[redacted]
7	Spread 7 – Hartley to NE Line	Nebraska Lateral	12"	84.8	[redacted]
8	Spread 8 – NE Line (Include Missouri River HDD) to Albion	Nebraska Lateral	12"	112.6	[redacted]
		SLE Lateral	6"	6.5	[redacted]

Booster Station P-85 (Phase 1) Fort Dodge
AFE: 2201-1004

Approximate Location:	Latitude: 42°32'4.44"N	
	Longitude: 94°21'53.49"W	
State:	Iowa	
County:	Webster	

Booster Station P-173 (Phase 1) Newton
AFE: 2201-1003

[redacted]	[redacted]
	[redacted]
[redacted]	[redacted]
[redacted]	[redacted]

Booster Station P-310 (Phase 1) New Boston
AFE: 2201-1002

Approximate Location:	Latitude: 40°33'41.16"N
	Longitude: 91°30'51.04"W
State:	Iowa
County:	Lee

Booster Station P-406 (Phase 1) Jacksonville
AFE: 2201-1001

Location:	Latitude: 39°47'21.09"N
	Longitude: 90°13'49.82"W
State:	Illinois
County:	Morgan

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APPENDIX B – AIR DISPERSION RESULTS

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HEARTLAND GREENWAY SYSTEM (HGS) - CO2 AIR DISPERSION RESULTS (6" NOMINAL PIPE DIAMETER)

Outer Diameter (in)	Wall Thickness (in)	Pipeline Length (mi)	Fluid	Modeling Method	Depth of Soil Cover (ft)	Soil Type	Release Calculation Method	Release Direction	CO2 Release Rate (lb/s)	Atmospheric Temperature (F)	Atmospheric Stability Class	Wind Speed (mph)	HAZARD LEVEL 1	HAZARD LEVEL 2	HAZARD LEVEL 3	HAZARD LEVEL 4
													Distance to 30,000 ppm (ft)	Distance to 40,000 ppm (ft)	Distance to 63,000 ppm (ft)	Distance to 105,000 ppm (ft)
6.625	0.250	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	F	3.3	1,480	882	[redacted]	0
6.625	0.250	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	D	11.2	341	12	[redacted]	9
6.625	0.250	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	F	3.3	1,971	1,240	[redacted]	88
6.625	0.250	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	D	11.2	763	14	[redacted]	10
6.625	0.250	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	F	3.3	666	517	[redacted]	206
6.625	0.250	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	D	11.2	716	539	[redacted]	194
6.625	0.250	n/a	CO2	Phast - Crater Buried	5	Mixed	ALOHA - Tank	Vertical	[redacted]	90	D	17.9	979	660	[redacted]	11
6.625	0.250	n/a	CO2	Phast - Above ground	-	-	ALOHA - Tank	Horizontal	[redacted]	90	D	17.9	1,075	805	[redacted]	289
6.625	0.250	n/a	CO2	ALOHA - Above ground	-	-	ALOHA - Tank	n/a	[redacted]	90	D	17.9	933	750	[redacted]	321

Highlighted cells indicate the highest buffer distance for each case analyzed (for the respective CO2 concentration)

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HEARTLAND GREENWAY SYSTEM (HGS) - CO2 AIR DISPERSION RESULTS (8" NOMINAL PIPE DIAMETER)

Outer Diameter (in)	Wall Thickness (in)	Pipeline Length (mi)	Fluid	Modeling Method	Depth of Soil Cover (ft)	Soil Type	Release Calculation Method	Release Direction	CO2 Release Rate (lb/s)	Atmospheric Temperature (F)	Atmospheric Stability Class	Wind Speed (mph)	HAZARD LEVEL 1 Distance to 30,000 ppm (ft)	HAZARD LEVEL 2 Distance to 40,000 ppm (ft)	HAZARD LEVEL 3 Distance to 63,000 ppm (ft)	HAZARD LEVEL 4 Distance to 105,000 ppm (ft)
8.625	0.277	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	F	3.3	2,753	1,710	[redacted]	225
8.625	0.277	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	D	11.2	1,126	420	[redacted]	12
8.625	0.277	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	F	3.3	2,724	1,855	[redacted]	240
8.625	0.277	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	D	11.2	1,339	500	[redacted]	12
8.625	0.277	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	F	3.3	846	656	[redacted]	258
8.625	0.277	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	D	11.2	938	708	[redacted]	251
8.625	0.277	n/a	CO2	Phast - Crater Buried	5	Mixed	ALOHA - Tank	Vertical	[redacted]	90	D	17.9	1,440	1,079	[redacted]	14
8.625	0.277	n/a	CO2	Phast - Above ground	-	-	ALOHA - Tank	Horizontal	[redacted]	90	D	17.9	1,371	1,032	[redacted]	375
8.625	0.277	n/a	CO2	ALOHA - Above ground	-	-	ALOHA - Tank	n/a	[redacted]	90	D	17.9	1,248	1,002	[redacted]	417

Highlighted cells indicate the highest buffer distance for each case analyzed (for the respective CO2 concentration)

Navigator CO_2

HEARTLAND GREENWAY SYSTEM (HGS) - CO2 AIR DISPERSION RESULTS (12" NOMINAL PIPE DIAMETER)

Outer Diameter (in)	Wall Thickness (in)	Pipeline Length (mi)	Fluid	Modeling Method	Depth of Soil Cover (ft)	Soil Type	Release Calculation Method	Release Direction	CO2 Release Rate (lb/s)	Atmospheric Temperature (F)	Atmospheric Stability Class	Wind Speed (mph)	HAZARD LEVEL 1 Distance to 30,000 ppm (ft)	HAZARD LEVEL 2 Distance to 40,000 ppm (ft)	HAZARD LEVEL 3 Distance to 63,000 ppm (ft)	HAZARD LEVEL 4 Distance to 105,000 ppm (ft)
12.75	0 344	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	F	3 3	3,089	[redacted]	[redacted]	[redacted]
12.75	0 344	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	D	11.2	1,530	[redacted]	[redacted]	[redacted]
12.75	0 344	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	F	3 3	3,291	[redacted]	[redacted]	[redacted]
12.75	0 344	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	D	11.2	1,711	[redacted]	[redacted]	[redacted]
12.75	0 344	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	F	3 3	1,276	[redacted]	[redacted]	[redacted]
12.75	0 344	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	D	11.2	1,447	[redacted]	[redacted]	[redacted]
12.75	0 344	n/a	CO2	Phast - Crater Buried	5	Mixed	ALOHA - Tank	Vertical	[redacted]	90	D	17.9	2,198	[redacted]	[redacted]	[redacted]
12.75	0 344	n/a	CO2	Phast - Above ground	-	-	ALOHA - Tank	Horizontal	[redacted]	90	D	17.9	1,996	[redacted]	[redacted]	[redacted]
12.75	0 344	n/a	CO2	ALOHA - Above ground	-	-	ALOHA - Tank	n/a	[redacted]	90	D	17.9	1,932	[redacted]	[redacted]	[redacted]

Highlighted cells indicate the highest buffer distance for each case analyzed (for the respective CO2 concentration)

Navigator CO_2

HEARTLAND GREENWAY SYSTEM (HGS) - CO2 AIR DISPERSION RESULTS (16" NOMINAL PIPE DIAMETER)

Outer Diameter (in)	Wall Thickness (in)	Pipeline Length (mi)	Fluid	Modeling Method	Depth of Soil Cover (ft)	Soil Type	Release Calculation Method	Release Direction	CO2 Release Rate (lb/s)	Atmospheric Temperature (F)	Atmospheric Stability Class	Wind Speed (mph)	HAZARD LEVEL 1 Distance to 30,000 ppm (ft)	HAZARD LEVEL 2 Distance to 40,000 ppm (ft)	HAZARD LEVEL 3 Distance to 63,000 ppm (ft)	HAZARD LEVEL 4 Distance to 105,000 ppm (ft)
16	0.429	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	F	3.3	3,459	[redacted]	[redacted]	[redacted]
16	0.429	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	D	11.2	1,778	[redacted]	[redacted]	[redacted]
16	0.429	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	F	3.3	3,644	[redacted]	[redacted]	[redacted]
16	0.429	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	D	11.2	1,972	[redacted]	[redacted]	[redacted]
16	0.429	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	F	3.3	1,638	[redacted]	[redacted]	[redacted]
16	0.429	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	D	11.2	1,864	[redacted]	[redacted]	[redacted]
16	0.429	n/a	CO2	Phast - Crater Buried	5	Mixed	ALOHA - Tank	Vertical	[redacted]	90	D	17.9	2,773	[redacted]	[redacted]	[redacted]
16	0.429	n/a	CO2	Phast - Above ground	-	-	ALOHA - Tank	Horizontal	[redacted]	90	D	17.9	2,450	[redacted]	[redacted]	[redacted]
16	0.429	n/a	CO2	ALOHA - Above ground	-	-	ALOHA - Tank	n/a	[redacted]	90	D	17.9	2,460	[redacted]	[redacted]	[redacted]

Highlighted cells indicate the highest buffer distance for each case analyzed (for the respective CO2 concentration)

Navigator CO_2

HEARTLAND GREENWAY SYSTEM (HGS) - CO2 AIR DISPERSION RESULTS (20" NOMINAL PIPE DIAMETER)

Outer Diameter (in)	Wall Thickness (in)	Pipeline Length (mi)	Fluid	Modeling Method	Depth of Soil Cover (ft)	Soil Type	Release Calculation Method	Release Direction	CO2 Release Rate (lb/s)	Atmospheric Temperature (F)	Atmospheric Stability Class	Wind Speed (mph)	HAZARD LEVEL 1 Distance to 30,000 ppm (ft)	HAZARD LEVEL 2 Distance to 40,000 ppm (ft)	HAZARD LEVEL 3 Distance to 63,000 ppm (ft)	HAZARD LEVEL 4 Distance to 105,000 ppm (ft)
20	0.535	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	F	3.3	4,250	2,920	[redacted]	155
20	0.535	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-60s	Vertical	[redacted]	90	D	11.2	2,289	1,083	[redacted]	22
20	0.535	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	F	3.3	4,042	2,861	[redacted]	0
20	0.535	20	CO2	Phast - Crater Buried	5	Mixed	Average between 0-20s	Vertical	[redacted]	90	D	11.2	2,385	1,120	[redacted]	22
20	0.535	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	F	3.3	2,081	1,651	[redacted]	720
20	0.535	20	CO2	Phast - Above ground	-	-	Average between 0-60s	15deg angle above horiz	[redacted]	90	D	11.2	2,374	1,848	[redacted]	751
20	0.535	n/a	CO2	Phast - Crater Buried	5	Mixed	ALOHA - Tank	Vertical	[redacted]	90	D	17.9	3,552	2,208	[redacted]	24
20	0.535	n/a	CO2	Phast - Above ground	-	-	ALOHA - Tank	Horizontal	[redacted]	90	D	17.9	2,991	2,301	[redacted]	933
20	0.535	n/a	CO2	ALOHA - Above ground	-	-	ALOHA - Tank	n/a	[redacted]	90	D	17.9	3,120	2,514	[redacted]	1,029

Highlighted cells indicate the highest buffer distance for each case analyzed (for the respective CO2 concentration)