Summary of PHMSA's CO_2 Potential Impact Radius R&D Project

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Department of Energy - Roadmap for CO_2 Transport Fundamental Research Workshop

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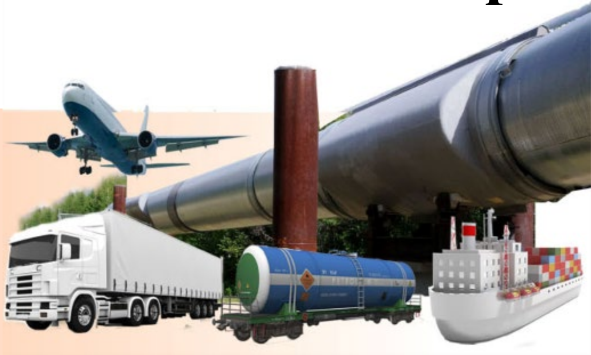


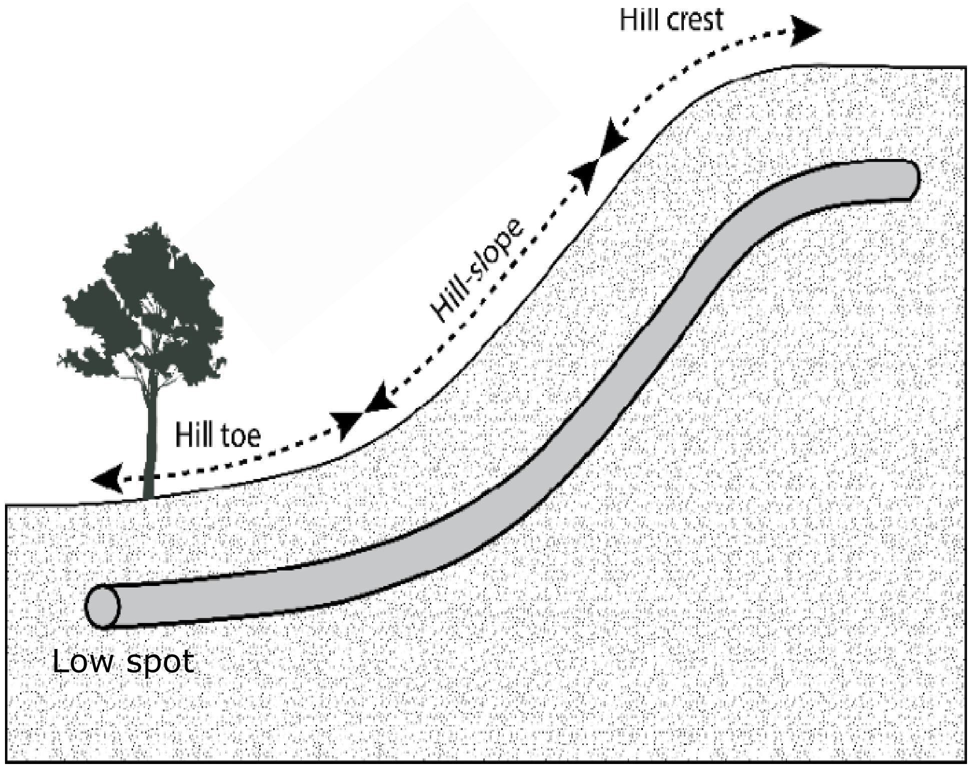
U.S. Department of Transportation
Pipeline and Hazardous Materials Safety Administration

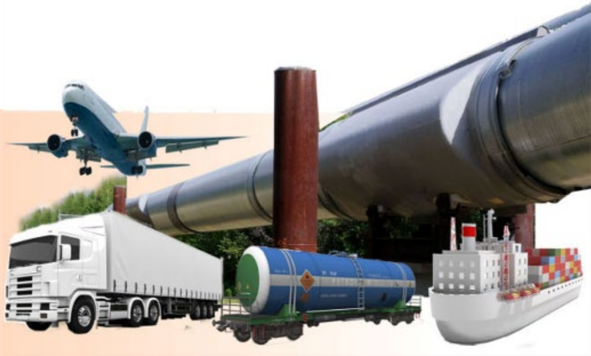
Safety Research Program Mission

To sponsor research and development projects focused on providing **near-term solutions** for the Nation's pipeline transportation system and LNG and underground natural gas storage facilities that will improve **safety**, reduce **environmental impact**, and enhance **reliability**.

CO_2 Pipeline Odorization

	Odorization
PHMSA Research Project	Developing Design and Welding Requirements Including Material Testing and Qualification of New and Existing Pipelines for Transporting CO_2 https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=996
Issues	Note: Natural gas is not odorized in transmission pipelines; atmospheric monitoring in low spots around CO_2 pipeline ROWs or odorization may be required.
Summary	Odorization issues addressed in the PHMSA project and one funded by PRCI.





Determination of Potential Impact Radius for CO_2 Pipelines Using Machine Learning Approach

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Introduction

Potential Impact Radius (PIR), the range of the potential failure of a pipeline with significant impact on people or property, is a key element of the Gas Integrity Management Rule (49 CFR 192, Subpart O).

$$r = \sqrt{\frac{14490 \cdot \mu \cdot X_g \cdot \lambda \cdot C_d \cdot \varphi \cdot H_c \cdot p \cdot d^2}{a_o \cdot I}}$$

Factor (Ethylene)	Value
Sonic velocity (ft/sec), a_0, = $\sqrt{\gamma RT/m}$	1055.3
Discharge coefficient (dimensionless), C_d	0.62
Heat of Combustion (Btu/lbm), H_c	20,275
Threshold Heat Flux (Btu/hr-ft^2), I_{th}	5,000
Molecular Weight (lbm/lb-mole), m	28.054
Gas Constant (ft-lbf/lb-mole-°R), R	1534
Gas Temperature (°R), T	518.4
Emissivity Factor (dimensionless), X_g	0.35
Specific Heat Ratio (dimensionless), γ	1.22
Release Rate Decay Factor (dimensionless), λ	0.31
Efficiency Factor (dimensionless), η	0.40
Flow Factor (dimensionless), $\varphi = \gamma \cdot \left(\frac{2}{\gamma+1}\right)^{\frac{\gamma+1}{2(\gamma-1)}}$	0.72

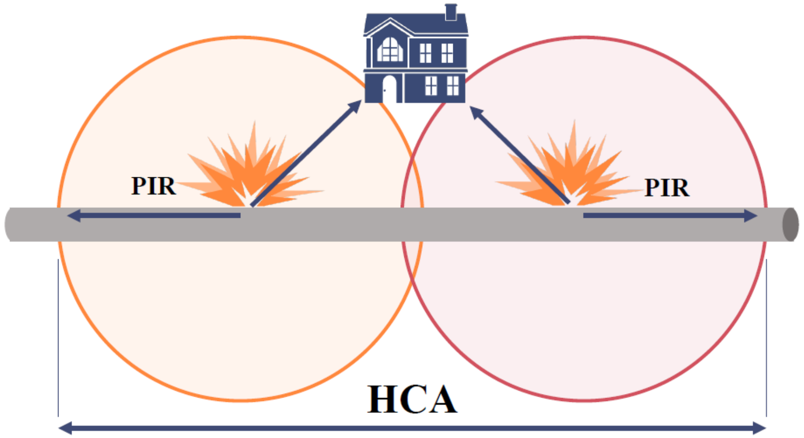
Product	PIR Formula
Ethylene	$r = 1.04 \cdot \sqrt{p \cdot d^2}$
Hydrogen	$r = 0.47 \cdot \sqrt{p \cdot d^2}$
Natural Gas (Lean)	$r = 0.69 \cdot \sqrt{p \cdot d^2}$
Natural Gas (Rich)	$r = 0.73 \cdot \sqrt{p \cdot d^2}$
Syngas	$r = 0.49 \cdot \sqrt{p \cdot d^2}$ Note 1

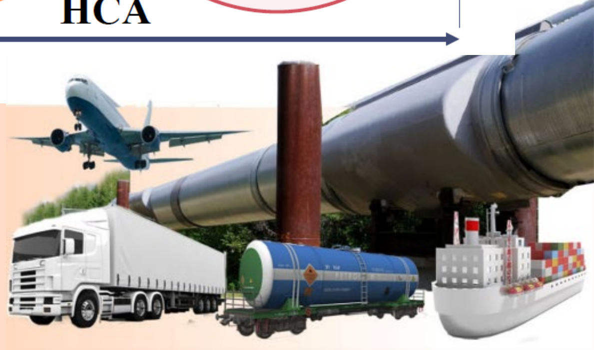
<u>Summary of Potential Impact Radius Formula</u>

Project Objective

- **Objective**: Develop a rapid, universally applicable tool to assess the consequences of accidental CO_2 dispersion from high-pressure pipelines and determine the PIR for CO_2 pipelines.

- **Potential Impact on Safety**: Using our tool to determine the PIR for CO_2 pipelines quickly, the risk of full pipeline ruptures can be thoroughly assessed during the planning stage and responders can quickly determine the emergency plan.





Challenges

- The release and dispersion of CO_2 from the high-pressure pipeline are very complex, as their calculation involves the pipeline characteristics, diameter, operating pressures, local geology/geography, and the weather.

- Specific challenges:
  1. How to establish the database with enough data to develop models?

  Solution: Develop **validated CFD models** for CO_2 dispersion over complex terrain types into the atmosphere and then perform all the simulations quickly to general data.

  2. How to develop the tool to determine PIR rapidly and reliably for CO_2 pipelines?

  Solution: Develop **machine learning models** based on the database created above.

Four Stages

Stage 1

Establish the CFD models of CO_2 release and dispersion from a high-pressure pipeline

Stage 2

Construct the database of CO_2 dispersion under different scenarios

Stage 3

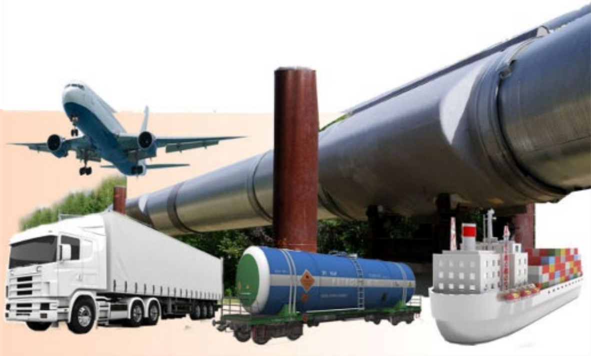
Perform QPCR analysis and identify the PIR for CO_2 pipelines

Stage 4

Develop a web-based tool to determine the PIR and evacuation time for the surrounding public

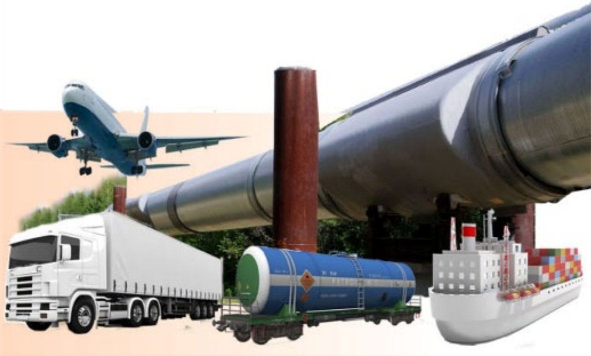
Stage 1: Establish CFD Models

- **Task 1.1:** Identify the appropriate physical models and numerical methods to describe the thermodynamic properties of CO_2.
- **Task 1.2:** Setup CFD models using ANSYS Fluent.
- **Task 1.3:** Perform CFD simulations of CO_2 dispersion and validate the results against full-scale CO_2 release experiments, such as CO2QUEST project, BP DF1 CO_2 dispersion experiments (DNV), CO2SafeArrest Joint Industry Project (JIP), or any data available by PHMSA.
- **Task 1.4:** Select the appropriate CFD model considering computing efficiency and accuracy.
- **Task 1.5:** Conduct a literature review about how PIR was addressed for natural gas pipelines.



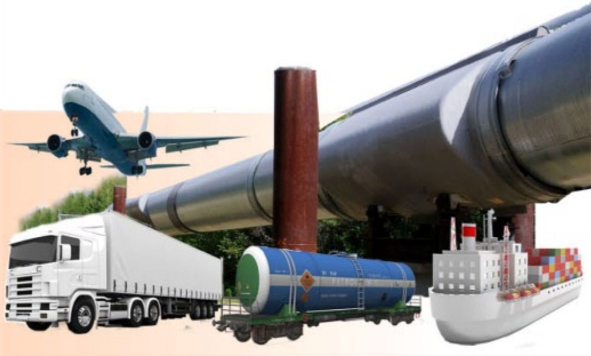
Stage 2: Construct Database

- **Task 2.1:** Conduct the literature review to identify common CO_2 pipeline operating conditions and define the appropriate dispersion parameters for CFD simulations.
- **Task 2.2:** Conduct risk assessment to identify the criteria for the areas with minor, medium, and severe health consequences from the released CO_2.
- **Task 2.3:** Perform CFD simulations at HPRC for all dispersion scenarios and construct the database for the PIR for CO 2 pipelines with different health consequences.
- **Task 2.4:** Construct a reliable database with pre validated, consistent dispersion data.



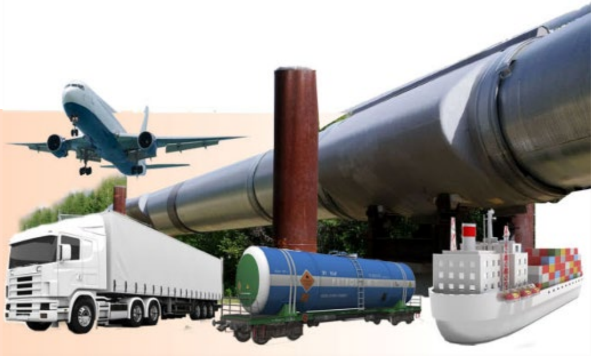
Stage 3: Perform QPCR Analysis

- **Task 3.1:** Find suitable descriptors as input variables to ensure the QPCR model's precision and practicality, including source property, criteria property, and physical property (e.g., the pipeline characteristics diameter; operating pressures; local geology/geography; the nonexplosive asphyxiant nature of the medium; the evacuation time for people in proximity to the pipeline; the weather).
- **Task 3.2:** Analyze the database to ensure its viability for machine learning analysis.
- **Task 3.3:** Generate scatter plot, histogram, and correlation matrices of QPCR model continuous variables to investigate the necessity of data transformation.
- **Task 3.4:** Build QPCR models using state of art machine learning techniques, such as support vector machine (SVM), random forest (RF), and XGBoost



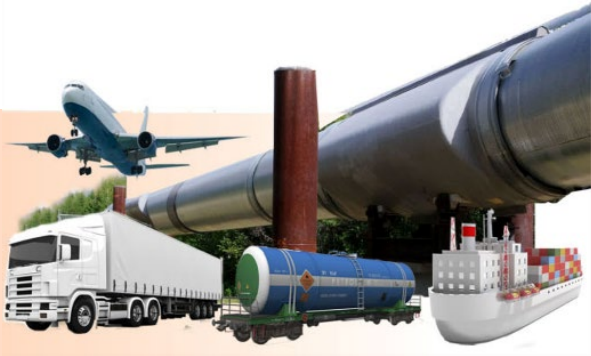
Stage 4: Develop Web-Based Tool

- **Task 4.1:** Determine the details of the front-end and back-end frameworks and technologies.
- **Task 4.2:** Build the prototype of the web-based tool (QPCR algorithm embedded) to determine the PIR for CO_2 pipelines.
- **Task 4.3:** Calculate the evacuation time based on the user inputs (e.g., source property, criteria property, and physical property) and PIR.
- **Task 4.4:** Host and launch the application on a web server.



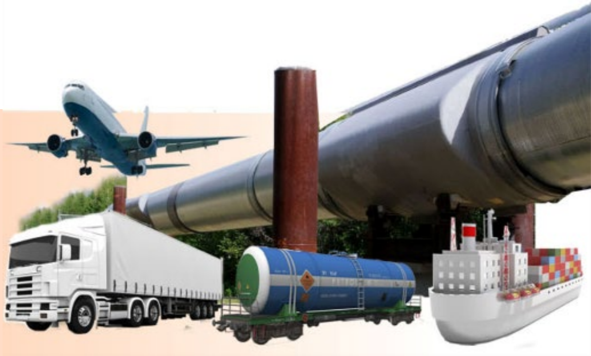
Project Deliverables

- **Stage 1: Establish the CFD models of CO_2 release and dispersion from a high-pressure pipeline**
  - **Deliverable 1a:** Summarize the physical models for CO_2 dispersion and the availability of CFD software that is applicable for CO_2 dispersion.
  - **Deliverable 1b:** Summarize the CFD simulation results and the comparison of their computing efficiency, as well as the existing literature about how PIR was addressed for natural gas pipelines and define the appropriate way of the PIR determination for CO_2 pipelines accuracy.
- **Stage 2: Construct the database of CO 2 dispersion under different scenarios**
  - **Deliverable 2a:** Summarize the common CO_2 pipeline operating conditions and the dispersion parameters determined for CFD simulations.
  - **Deliverable 2b:** Summarize the database for the PIR for CO_2 pipelines with different health consequences.



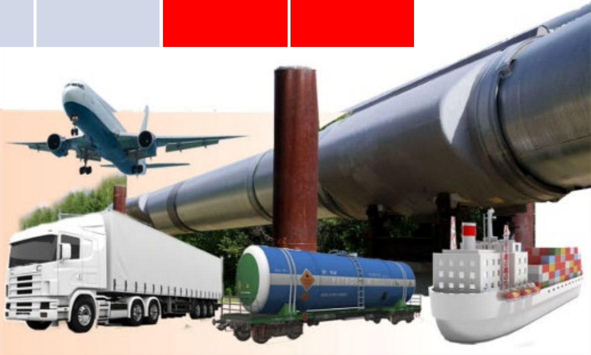
Project Deliverables

- **Stage 3: Perform QPCR analysis and identify the PIR for CO_2 pipelines**
  - **Deliverable 3a**: Summarize the database (from Stage 2) structure using scatter plot, histogram, and correlation matrices of QPCR model continuous variables.
  - **Deliverable 3b:** Results from finding the suitable descriptors, building the QPCR model, and evaluating the QPCR model by the R^2 and RMSE.
- **Stage 4: Develop a web-based tool to determine the PIR for CO_2 pipelines and evacuation time for the surrounding public**
  - **Deliverable 4a:** Summarize details of the front-end and back-end frameworks and technologies.
  - **Deliverable 4b**: Present the prototype of the web-based tool launch on a web server.
  - **Deliverable 4c**: Present the final results and submit the final report to PHMSA.



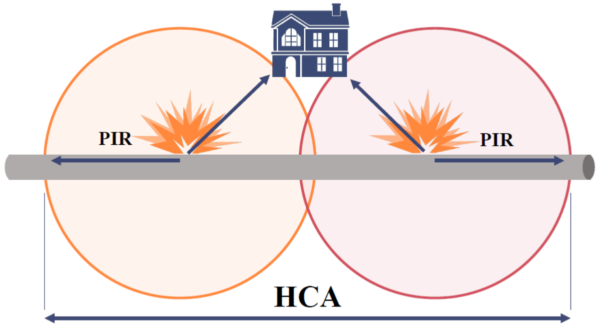
Project Timeline

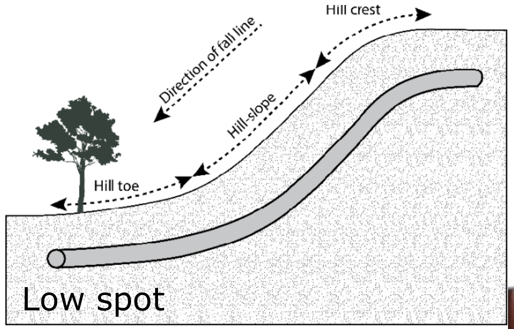
Task	Year 1				Year 2			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Establish the CFD models of CO_2 release and dispersion from a high-pressure pipeline	■	■	■					
Construct the database of CO_2 dispersion		■	■	■	■			
Perform QPCR analysis and identify the PIR for CO_2 pipelines					■	■	■	
Develop a web-based tool to determine the PIR for CO_2 pipelines and evacuation time form surrounding public							■	■



Key Takeaways & Next Steps

	PIR	Odorization
PHMSA Research Project	Determination of Potential Impact Radius for CO_2 Pipelines using Machine Learning Approach https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=987	Developing Design and Welding Requirements Including Material Testing and Qualification of New and Existing Pipelines for Transporting CO_2 https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=996
Issues	Significant CFD modeling required; more of a “zone” versus a PIR; CFD model may not cover all operational and route considerations.	Note: Natural gas is not odorized in transmission pipelines; atmospheric monitoring in low spots around CO_2 pipeline ROWs or odorization may be required.
Summary/ Next Steps	PIR issues to be generally covered in this PHMSA project.	Odorization issues addressed in this PHMSA project and one funded by PRCI.





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About Pipeline Research & Development

The mission of PHMSA's Pipeline Safety Research & Development Program is to sponsor projects focused on providing technical solutions that will improve pipeline safety, reduce the environmental impact of failures, and enhance the reliability of the Nation's pipeline transportation system.

The research program has the following objectives:

- Employ a coordinated and collaborative approach to address mutual pipeline challenges with a wide set of stakeholders.
- Help remove technical and sometimes regulatory barriers on a given challenge.
- Tell the research story by measuring our research results, outputs, and impacts.
- Promote transparency by posting online R&D program/project actions and products.

R&D Program Website: https://www.phmsa.dot.gov/research-and-development/pipeline/about-pipeline-research-development

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