PROTECTING PEOPLE AND PLACES FOR 50 YEARS HSE

Carbon dioxide and ammonia pipelines research

Simon Gant, Strategic Science Adviser for Net Zero, HSE

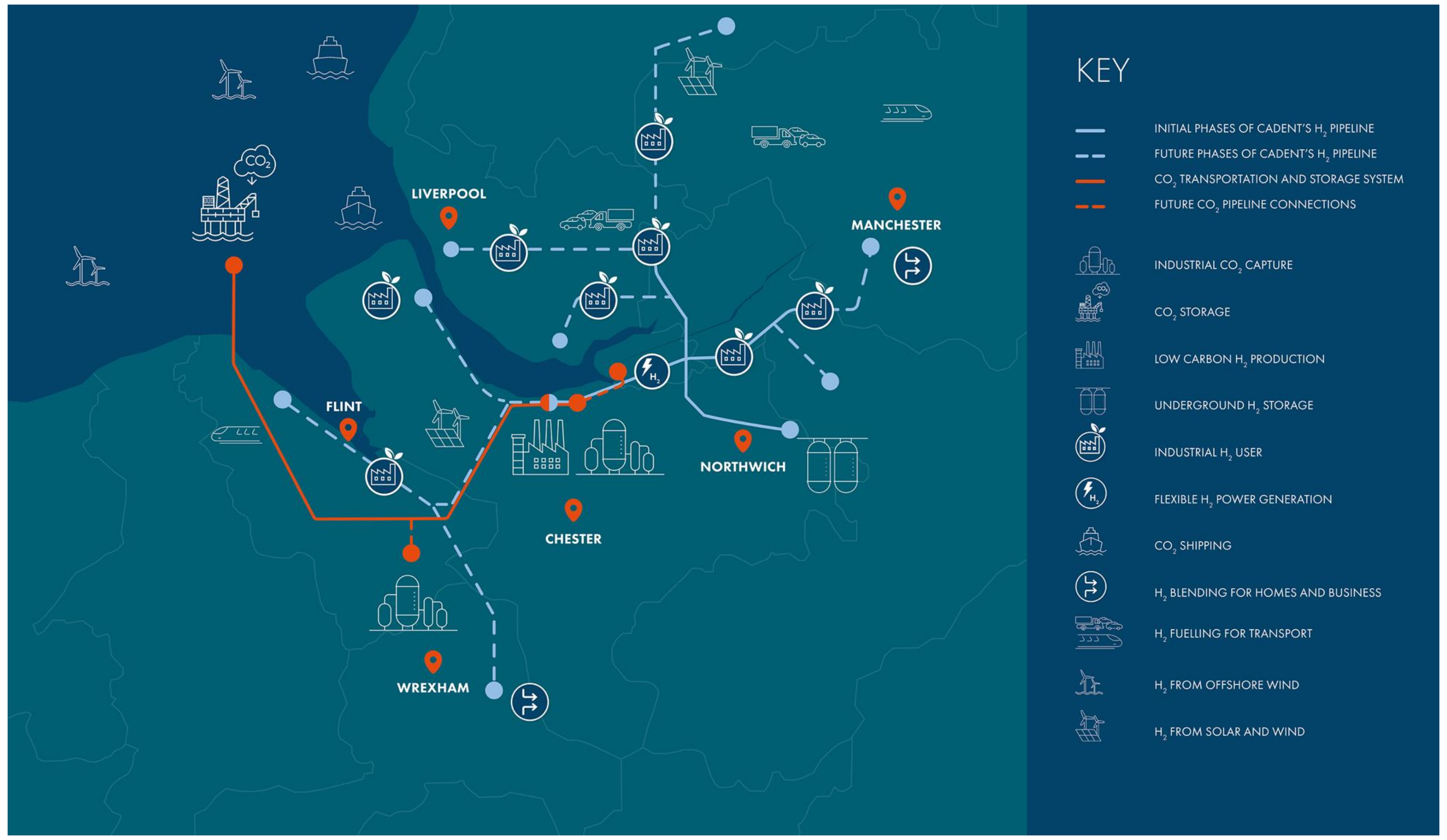
European Pipeline Authorities Meeting, Bergen, Norway, 21-22 May 2025

Outline

- Carbon dioxide pipelines
  - Planned CO_2 pipelines in the UK
  - Satartia incident
  - PHMSA public workshop and R&D forum
  - PHMSA draft rules
  - HSE research
  - Joint industry projects (Skylark, IntoCloud, PRCI etc.)

- Ammonia pipelines
  - Incidents
  - RIVM-HSE proposed project
  - Recent RIVM research
  - Other recent ammonia research activities

Planned CO_2 pipelines in the UK

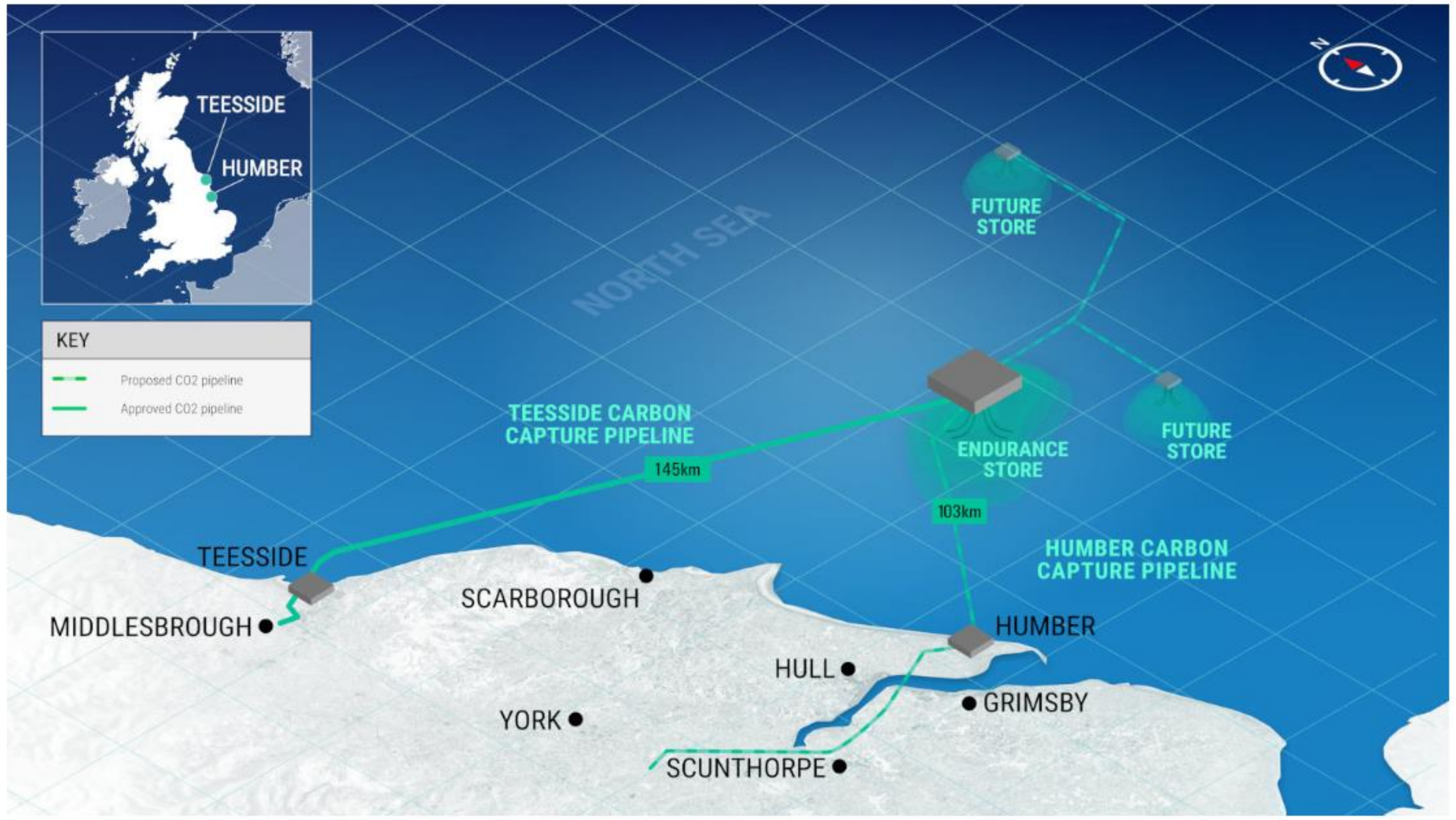


HyNet project https://hynet.co.uk

- Initially, gas-phase onshore/offshore CO_2 pipelines with sequestration in depleted natural gas field
- 40 miles of onshore pipeline, MAOP approx. 42 bar
- Later, transition to dense-phase CO_2 pipelines offshore – compression at the coast
- Pipelines: 20”, 24” and 36” diameter, mixture of repurposed and new
- New ENI offshore platform connected to several repurposed normally unmanned installations
- Capture plants: cement, refinery, blue hydrogen
- Planned to store 10 $MtCO_2$/yr by 2030

- Development Consent Order (planning permission) granted for HyNet CO_2 pipeline in March 2024 https://infrastructure.planninginspectorate.gov.uk/projects/Wales/HyNet-Carbon-Dioxide-Pipeline/

Planned CO_2 pipelines in the UK



East Coast Cluster project https://eastcoastcluster.co.uk

- Northern Endurance Partnership: BP, Equinor and TotalEnergies https://northernendurancepartnership.co.uk/
- March 2023: DESNZ Track 1 funding awarded
- Sept 2023: NSTA awarded further licenses to BP and Equinor for 1 GTe CO_2 storage
- March 2024: Development Consent Order granted for Teesside Carbon Capture Pipeline https://national-infrastructure-consenting.planninginspectorate.gov.uk/projects/EN010103
- 22” diameter onshore CO_2 gas-phase gathering pipelines for NZT Power, BOC and H2T capture plants
- Compression and 145 km 28” diameter offshore dense-phase CO_2 pipeline

- Humber pipeline: public consultation in Summer 2024, FEED and DCO application ongoing
- FID taken on Teesside pipeline in Dec 2024. Due to be operational by 2028

https://northernendurancepartnership.co.uk/wp-content/uploads/2025/04/SDS-NEP00-IR-REP-000-00001-Public-B02.pdf

Planned CO_2 pipelines in the UK

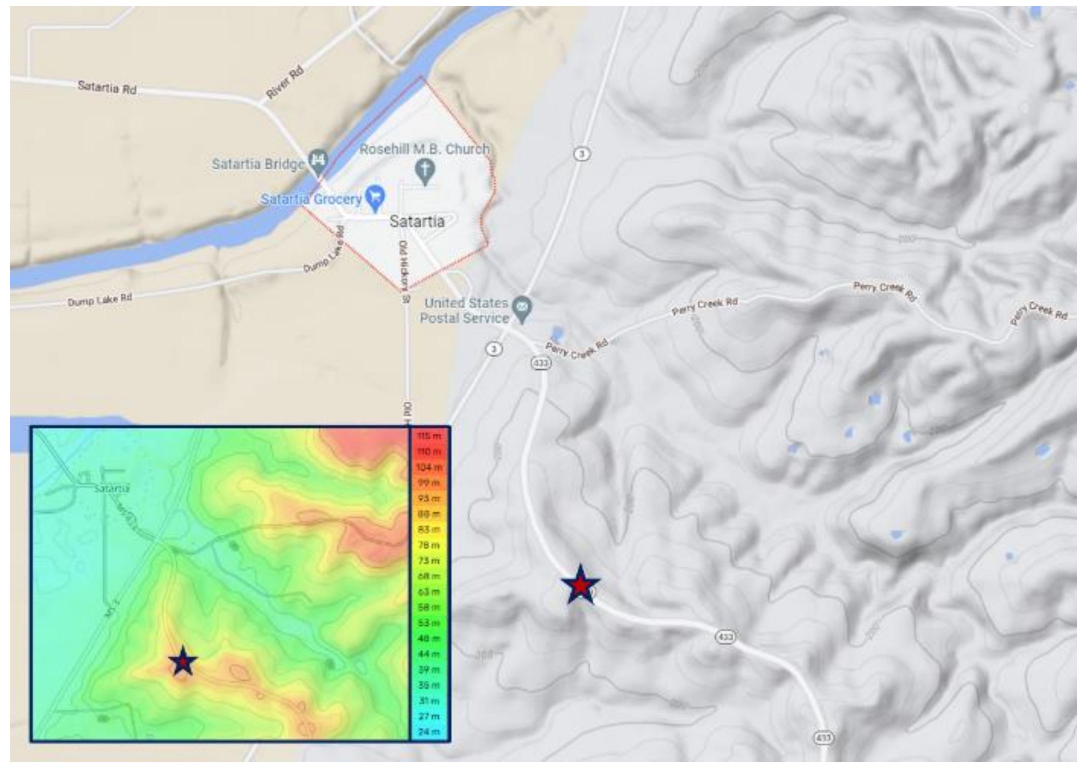
Viking CCS project https://www.vikingccs.co.uk/

- 55 km long 24” diameter onshore dense-phase CO_2 pipeline from Immingham to Theddlethorpe Gas Terminal https://pipeline.vikingccs.co.uk/
- DCO granted in April 2025 https://national-infrastructure-consenting.planninginspectorate.gov.uk/projects/EN070008
- FEED contract awarded to Technip in Jan 2024
- FID expected in Q1 2025

Satartia CO_2 pipeline incident

- Failure of Denbury 24-inch dense-phase CO_2 pipeline near Satartia, Mississippi due to landslide
- Full-bore failure at girth weld indicates weld was undermatching (yield strength < parent pipe)
- Dense CO_2 cloud rolled downhill and engulfed Satartia village, a mile away
- Approximately 200 people evacuated and 45 required hospital treatment
- Communication issues: local emergency responders were not informed by pipeline operator of the rupture and release of CO_2
- Denbury's risk assessment did not identify that a release could affect the nearby village of Satartia

Figure 6: Topographical Map Showing the Delhi Pipeline (Green) and Denbury's Buffer Zone (Red) on Either Side of the Pipeline and the Proximity to Satartia (Blue Star Indicates the Rupture Site)



Terrain map taken from Google Maps and contour map taken from topographic-map.com. Approximate location of release marked by a star.

Image sources: Yazoo County Emergency Management Agency/Rory Doyle for HuffPost and PHMSA

- https://www.huffingtonpost.co.uk/entry/gassing-satartia-mississippi-co2-pipeline_n_60ddea9fe4b0ddef8b0ddc8f
- https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2022-05/Failure%20Investigation%20Report%20-%20Denbury%20Gulf%20Coast%20Pipeline.pdf

See also Wilkowski *et al*. (2024) "Rupture proof CO_2 pipelines by design" IPC conference, Calgary, 2024, https://doi.org/10.1115/IPC2024-134007

PHMSA public meeting on CO_2 pipelines

- PHMSA held public meeting on CO_2 pipelines in Des Moines, Iowa on 31 May – 1 June 2023
  https://primis.phmsa.dot.gov/meetings/MtgHome.mtg?mtg=165

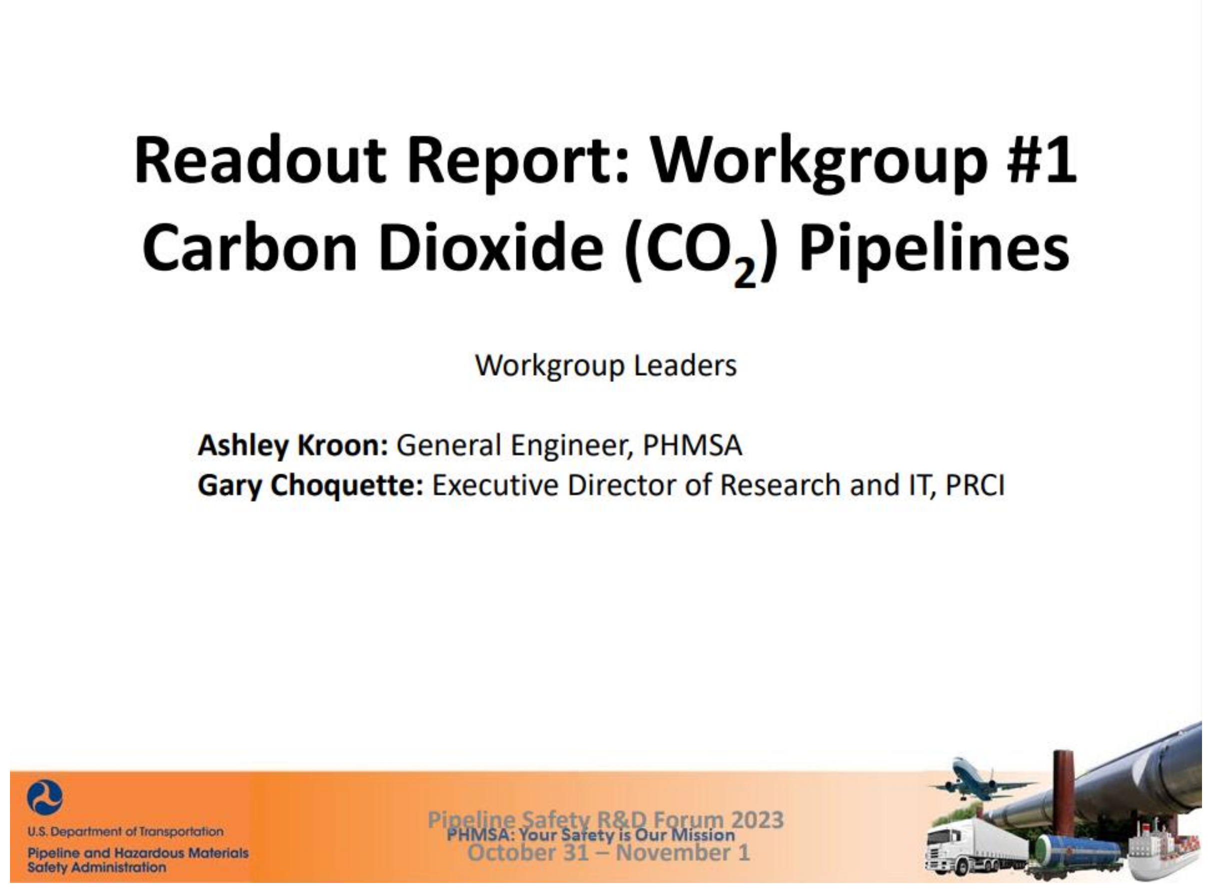
- Presentations by PHMSA, EPA, DOE, National Association of Pipeline Safety Representatives (NAPSR), Pipeline Safety Trust, Center for International Environmental Law, Science and Environmental Health Network, members of the public, API, HSE, CER etc.

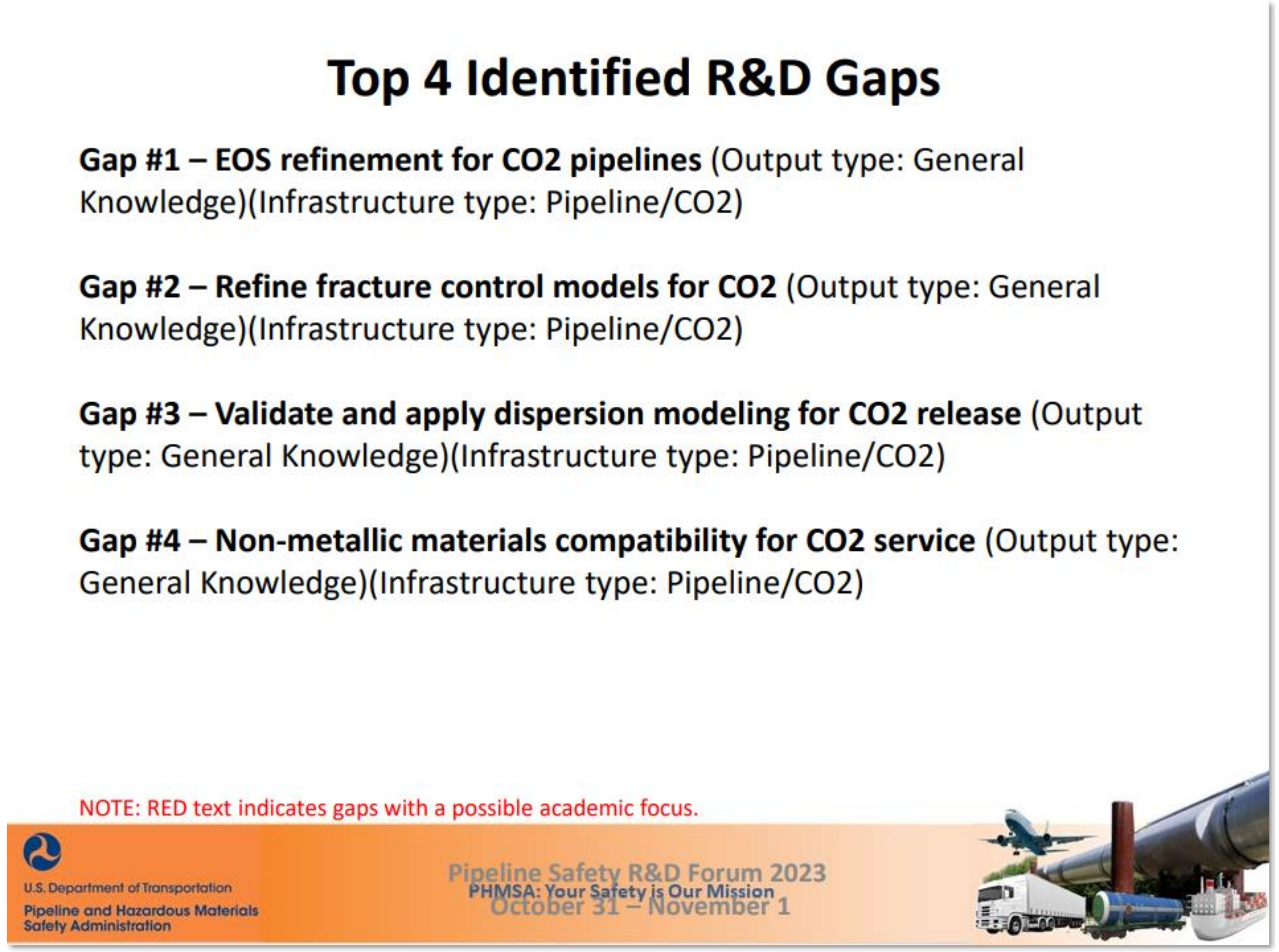
- Meeting discussed PHMSA's actions following the Satartia incident
  - https://www.phmsa.dot.gov/news/phmsa-announces-new-safety-measures-protect-americans-carbon-dioxide-pipeline-failures

- 116 formal comments received on Federal register
  - https://www.federalregister.gov/documents/2023/04/20/2023-08369/pipeline-safety-carbon-dioxide-pipeline-safety-public-meeting

PHMSA Pipeline Safety Research and Development Forum 2023

- PHMSA R&D forums are held every 2 years with public, government, and industry pipeline stakeholders to identify technology and knowledge gaps
- PHMSA uses this information to develop research solicitations
- Listing of PHMSA-funded research projects:
  https://primis.phmsa.dot.gov/matrix/
- Details of 2023 R&D Forum:
  https://primis-meetings.phmsa.dot.gov/archive/MtgHome.mtg@mtg=166.html





PHMSA Draft rulemaking on CO_2 pipelines, January 2025

PHMSA issued this Notice of Proposed Rulemaking on January 10, 2025, and it has been submitted to the Office of the Federal Register for publication. Although PHMSA has taken steps to ensure the accuracy of this version of the Notice of Proposed Rulemaking posted on the PHMSA website, and will post it in the docket (PHMSA-2022-0125) on the Regulations.gov website (www.regulations.gov), it is not the official version. Please refer to the official version in a forthcoming Federal Register publication, which will appear on the websites of each of the Federal Register (www.federalregister.gov) and the Government Printing Office (www.govinfo.gov). After publication in the Federal Register, this unofficial version will be removed from PHMSA's website and replaced with a link to the official version. PHMSA will also post the official version in the docket.

Billing Code: 4910-60-W

DEPARTMENT OF TRANSPORTATION

Pipeline and Hazardous Materials Safety Administration

49 CFR Parts 190, 195, 196, and 198

[Docket No. PHMSA-2022-0125]

RIN 2137-AF60

Pipeline Safety: Safety of Carbon Dioxide and Hazardous Liquid Pipelines

AGENCY: Pipeline and Hazardous Materials Safety Administration (PHMSA), Department of Transportation (DOT).

ACTION: Notice of proposed rulemaking (NPRM).

SUMMARY: PHMSA proposes revisions to the Pipeline Safety Regulations to include safety standards and reporting requirements for gas- and liquid-phase carbon dioxide pipelines. PHMSA proposes safety improvements for all carbon dioxide pipelines, including the establishment of an emergency planning zone for improved emergency response and public communications; more prescriptive fracture control requirements; explicit inclusion of carbon dioxide in the definition of a highly volatile liquid; specific requirements for vapor dispersion modeling; and conforming changes to operations, maintenance, and emergency manuals. PHMSA also proposes specific requirements applicable to both hazardous liquid and carbon dioxide pipelines, including enhanced right-of-way inspections to identify geologic hazards and mitigate those threats, and the use of fixed vapor detection and alarm systems at specific highly volatile liquid pipeline facilities. Additionally, PHMSA proposes changes to the conversion to service requirements affecting both hazardous liquid and carbon dioxide pipelines. On May 31

- Proposed emergency planning zone for CO_2 pipelines: default 2 miles wide on either side of the pipeline, unless otherwise defined by dispersion modelling
- Additional safety measures required within emergency planning zone
- Perform annual population density survey within zone for all places of residence, business or public assembly
- Distribute emergency response information to all within zone, including specific actions to be taken in the event of emergency
- Provide automatic notifications to the public within zone informing them when an emergency has occurred and what to do
- Operators to retain documentation on their CO_2 pipeline routing
- Fixed vapor detection and alarm systems on Highly Volatile Liquid pipelines (including CO_2 pipelines) at all above-ground installations (pump, compressor, meter, valve, PIG stations)
- Further requirements described in draft rule

https://www.phmsa.dot.gov/news/usdot-proposes-new-rule-strengthen-safety-requirements-carbon-dioxide-pipelines

https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2025-01/PHMSA%20Notice%20of%20Proposed%20Rulemaking%20for%20CO2%20Pipelines%20-%202137-AF60.pdf

https://pipelinepodcastnetwork.com/phmsa-co2-notice-of-preliminary-rule-making/

PHMSA-funded project on CO_2 dispersion modelling

PHMSA — Research & Development Program
Server Version: 3.02.00-rc.1 Server Time: 05/12/2025 12:39 PM UTC

Project Search

Modern Search
- Advanced Search...
- Historical Search...

RD Program
- MIS Home Page
- Public R&D Page
- Submit R&D Idea
- Final Reports
- Library

My Pages
- Questions and Comments
- Print-Friendly
- Log In...

Determination of Potential Impact Radius for CO2 Pipelines using Machine Learning Approach

Main Objective

The main objective of this project will be to establish a computational fluid dynamics (CFD) model to simulate the release and dispersion of supercritical CO2 from full pipeline ruptures, then use the simulation results to construct a database comprising CO2 dispersion data under different scenarios. The researcher will use the resulting scenario data in a machine learning analysis for predicting dispersion ranges and health consequences. Using the analysis results and existing literature, the researcher will develop a rapid, universally applicable tool to assess the consequences of accidental CO2 dispersion from high-pressure pipelines.

Public Abstract

Transport of CO2 via pipelines in a supercritical phase is more economic for a larger amount of CO2 over long distances. However, if the CO2 pipeline is accidentally ruptured, it can release a considerable amount of CO2 into the air that could pose harm to humans, especially in those areas that are characterized by a high population density. Accurate source modeling and dispersion modeling form the basis for accurately predicting the consequence. CFD models are becoming more popular to evaluate the release and subsequent dispersion of CO2 because they can fully take into account pipeline characteristics, operation conditions, local geology/geography, and the weather. In this project, we will first establish a CFD model to simulate the release and dispersion of supercritical CO2 from full pipeline ruptures with reasonable accuracy and acceptable computational cost. Then we will construct a database of CO2 dispersion under different scenarios along with some experimental data. Afterward, we will use the scenario and physical properties of CO2 as property descriptors and independent variables in machine learning-based quantitative property consequence relationship (QPCR) analysis for dispersion ranges prediction and health consequence. Being coupled with existing literature about how PIR was addressed for natural gas pipelines and evacuation time evaluation, we will perform risk assessment and develop a rapid, universally applicable tool to assess the consequences of accidental CO2 dispersion and determine the PIR for CO2 pipelines. This tool can be applied to assess the risk of CO2 pipelines during the planning stage and emergency responses.

Anticipated Results: A well-established CFD model for the release and dispersion of supercritical CO2 from pipeline ruptures, a database of CO2 dispersion scenarios, and a reliable and user-friendly machine learning web-based tool to determine the PIR for CO2 pipelines.

Potential Impact on Safety: Using our tool to determine the PIR for CO2 pipelines quickly, the risk of full pipeline ruptures can be thoroughly assessed during the planning stage and responders can quickly determine the emergency plan.

Fast Facts	
Research Award Recipient:	Texas A&M Engineering Experiment Station 400 Harvey Mitchell Parkway South Suite 300 College Station, TX 77845-4375
AOR/TTI:	Nusnin Akter, nusnin.akter2 @ dot.gov, 839-273-0528 Basim Bacenty, basim.bacenty @ dot.gov, 713-272-2838
Contract #:	693JK32250011CAAP
Project #:	987
Researcher Contact Info:	Dr. Sam Wang, Associate Professor 3122 TAMU, Texas A&M University, College Station, TX 77843 Phone: (979)845-9803; Fax: (979)845-6446; Email: qwang @ tamu.edu
Downloads of Project Reporting	
Since Jan 1, 2017	8741
Technology and Commercialization	
Technology Demonstrated?	TBD
Commercialized (in whole/part)?	TBD
Financial and Status Data	
Project Status:	Active
Start Fiscal Year:	2022 (09/26/2022)
End Fiscal Year:	2025 (09/25/2025)
PHMSA $$ Budgeted:	$279,754.00

QUARTERLY/ANNUAL STATUS REPORTS

Annual Report 2 updated on Feb 2025
ANNUAL_REPORT_2024_UPDATED_ON_FEB_2025.PDF (2,359,099 bytes) [VIEW] [DOWNLOAD/SAVE...]

Quarterly Report 1
QUARTERLY REPORT 1.PDF (638,133 bytes) [VIEW] [DOWNLOAD/SAVE...]

https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=987

Outline

- CO_2 pipelines
  - Planned CO_2 pipelines in the UK
  - Satartia incident
  - PHMSA public workshop and R&D forum
  - PHMSA draft rules
  - HSE research
  - Joint industry projects (Skylark, IntoCloud, PRCI etc.)
- Ammonia pipelines
  - Incidents
  - RIVM-HSE proposed project
  - Recent RIVM research
  - Other recent ammonia research activities

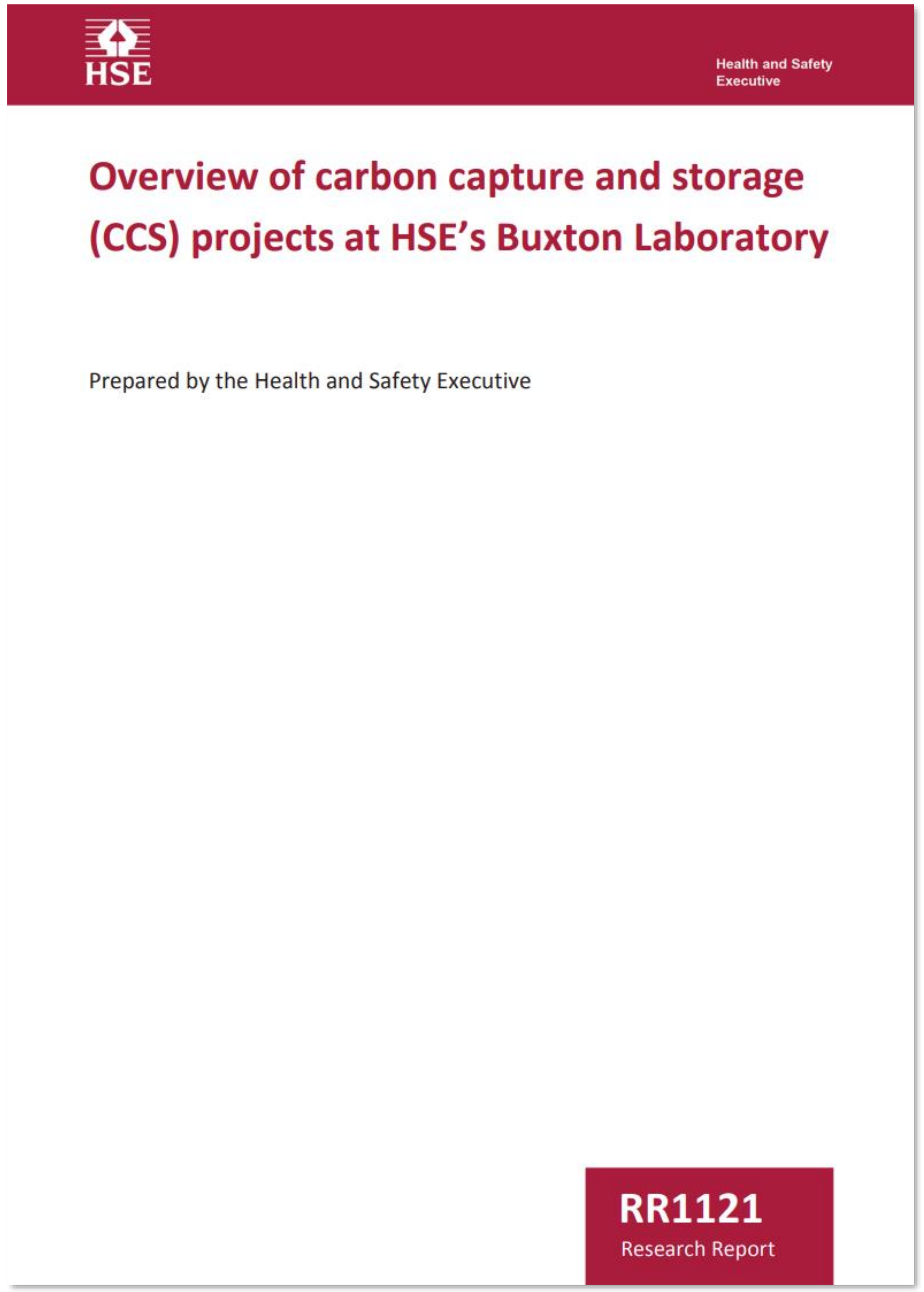
HSE research

Contents

https://ari.org.uk/source_documents/hse-areas-of-research-interest-2024.pdf

https://ari.org.uk/ https://int.octopus.ac/

Previous HSE research on CO_2 pipelines


HSE Health and Safety Executive

Overview of carbon capture and storage (CCS) projects at HSE's Buxton Laboratory

Prepared by the Health and Safety Executive

RR1121 Research Report

https://www.hse.gov.uk/research/rrhtm/rr1121.htm

CONTENTS

Ongoing HSE CCUS Research Project

- Task A1 – Oversight and technical coordination
- Task B1 – Develop internal CCUS training course
- Task B2 – Support to regulatory questions
- Task C1 – Collation of JIPs and international projects
- Task C2 – Steering Board engagement
- Task C3 – Review international lessons learned
- Task D1 – Review of industry models
- Task D2 – Update previous modelling
- Task D3 – Modelling offshore scenarios
- Task D4 – Storage thresholds for CO_2
- Task E1 – Understanding industry design
- Task E2 – Flow assurance and process safety
- Task E3 – Suitability of controls
- Task E4 – Understanding the standards landscape
- Task E5 – Definition of hazard and scenarios
- Task E6 – Mitigations and emergency response
- Task F1 – Materials challenges and interactions
- Task F2 – Fracture control
- Task F3 – Corrosion control
- Task F4 – Non-metallic materials and coatings
- Task F5 – Low temperature excursions
- Task G1 – Review of CO_2 toxic levels and dose
- Task G2 – Amines and health effects from the capture process

Ongoing HSE CCUS Research Project

- Task F2 – Fracture control
  - Review control of fracture initiation and propagation in pipelines
  - Identify unique pipeline challenges created by CO_2
  - Review approaches and guidelines for pipeline design for CO_2
  - Undertake some example analyses and investigate mitigation measures
- Task F3 – Corrosion control
  - Review current status of approaches for corrosion control (published research, guidance, standards, etc.)
  - Define the key material and component considerations for CO_2 pipelines and other components
- Task F5 – Low temperature excursions
  - Construct test facility at HSE Science and Research Centre in Buxton for impinging CO_2 jets onto pre-stressed steelwork to investigate cold embrittlement effects
  - Measure cooling effect on steel plates from exposure to impinging CO_2 jets
  - Conduct tests on specimens at different loadings, both with/without pre-formed defects
  - A range of barrier materials may also be tested

Ongoing HSE CCUS Research Project

- Task G1 – Review CO_2 toxic levels and dose
  - Revisit and publish a summary of HSE's assessment of the dangerous toxic load (SLOT and SLOD)
  - Review other published criteria on CO_2 toxicity
  - Review criteria for human impairment and possible impact on disorientation and means of escape
- Develop CO_2 pipeline risk assessment model for land-use planning
  - Extension of existing HSE natural gas pipeline risk assessment model (MISHAP)
  - Requires consideration of:
    - Fault trees
    - Failure rates
    - Fracture models
    - Release rate model
    - Dispersion model

Failure modes in PIPIN / MISHAP for land use planning: Initial overview of considerations for CO_2

PROTECTING PEOPLE AND PLACES FOR 50 YEARS HSE

Primary failure mode	Secondary failure mode	Currently in PIPIN?	Factors	Failure rate considerations; CO_2 case as compared to natural gas	Potential Effect
Ground movement	Landslides, earthquakes, heavy rains, operator error	Y	• Source of stress/strain unaffected by gas being transported • Pipe mechanical properties not affected • Likely to be location –sensitive • Common modes of failure include shell buckling, cross-sectional ovalisation and in extreme cases, tensile fracture (circumferentially)	• Cause of events should be unaffected. • Possibility of rupture from holes due to local cooling of metal in leak area due to J-T effect may increase failure frequency	Med
Mechanical failures	Construction faults	Y	• A function of the material and construction detail of the pipeline or its design • Generally independent of both the commodity being transported and the locality of the pipeline	• Cause of events should be unaffected. • Only in the event of an actual failure, depressurisation could lead to lower toughness: the likelihood of the event could be the same, but the consequence/ resultant leak area might be higher	Med
Corrosion	External corrosion	Y	• External corrosion is dependent on the type of soil in which the pipeline is located, the water levels, the pipeline material and age • Mitigated through physical corrosion protection such as coatings and the use of active corrosion prevention methods such as cathodic protection • Pressure fluctuations of the CO_2 could lead to low temperature transients of the coating	• Rates should be unaffected or possible slight increase • Pipes usually externally coated, and cathodic protection applied • Some references refer to coating disbonding due to temperature fluctuations from pressure changes, which could affect external corrosion	Med
	Internal corrosion	N	• Not currently included in natural gas model due to low water limits • Existing pipeline flow coatings are not recommended in BS ISO 27913 when repurposing to CO_2 due to debonding in pressure reduction scenarios in gas phase, and should be avoided in dense phase	• Corrosion rate potentially very high in CO_2 depending on composition • Unprotected regions around girth welds susceptible • Failure frequency potentially increases by a significant amount	High
Third party damage (TPA)	A gouge model that models the plastic collapse of the pipeline using either gouge data or dent-gouge data	Y	• YS and UTS form basis	• Provided there is no through-wall failure (J-T cooling), the failure frequency should be unaffected • However, possibility of rupture from holes due to local cooling of metal in leak area may increase failure frequency	Med
	A dent-gouge model that models failure of the pipeline by fracture	Y	• YS, UTS and fracture toughness form the basis	• Toughness issues from J-T cooling • Toughness may reduce, so failure frequency increase • Running fractures could become an issue in dense phase • Dense vs gas phase-different requirements	High
	A rupture model that models the likelihood of a leak leading to a rupture, resulting from either plastic collapse or fracture	Y	• YS, UTS and fracture toughness form the basis	• Toughness issues from J-T cooling • Toughness may reduce, so failure frequency increase • Running fractures could become an issue in dense phase • Dense vs gas phase-different requirements	High

Thoughts on “interim” CO_2 dispersion modelling

Possible CO_2 dispersion modelling methodologies that could be used during interim period, prior to conclusion of Skylark project

- 2 mile wide corridor either side of pipeline (default from PHMSA draft rule)
  - Takes into account CO_2 dispersion behaviour from Satartia incident
  - No account of hole size, pipeline diameter and pressure (gas/dense phase), meteorology etc.
- Integral model assuming flat terrain (Phast/Drift)
- Assessment of terrain along pipeline route
  - Use integral model for flat areas (criteria of “flat” to be defined?)
  - Apply extended cloud lengths for downslope areas (using scaling factors, e.g., from Satartia?)
  - Use CFD modelling in some high-priority areas?
- Use risk assessments undertaken by pipeline operator for routing purposes

Outline

- CO_2 pipelines
  - Planned CO_2 pipelines in the UK
  - Satartia incident
  - PHMSA public workshop and R&D forum
  - PHMSA draft rules
  - HSE research
  - Joint industry projects (Skylark, IntoCloud, PRCI etc.)
- Ammonia pipelines
  - Incidents
  - RIVM-HSE proposed project
  - Recent RIVM research

CCUS Joint Industry Projects

- SAFEN: failure rates for CCUS, hydrogen and ammonia
- SINTEF
  - Offshore large-scale subsea CO_2 releases
  - CO_2 EPOC: effect of CO_2 on polymeric materials
  - IntoCloud: venting of refrigerated CO_2
- DNV
  - Skylark: dispersion of CO_2 from pipeline releases
  - CO_2SafePipe: updating DNV-RP-F104
  - Materials in CO_2 wells
  - CO_2MET: CO_2 composition measurement
  - CO-CO_2 cracking in pipelines
  - CO_2 CFD simulation software
  - SubCO_2 Phase 3 – subsea CO_2 releases
  - CO_2 offshore injection into subsea reservoirs
- TWI
  - MASCO2T II: Materials assessment for CO_2 transport
  - Permeation of CO_2 through thermosets
- PRCI
  - CO_2 pipeline dispersion modelling

HSE participating in these JIPs

Skylark joint industry project: CO_2 dispersion in complex terrain

https://www.dnv.com/article/skylark-pioneering-excellence-in-co2-pipeline-safety-250648/

- Kick-off on 13 May 2025, 3-year duration
  1. CO_2 pipeline craters and source terms – DNV
  2. Wind-tunnel experiments – University of Arkansas
  3. Simple terrain dispersion experiments – DNV
  4. Complex terrain dispersion experiments – DNV
  5. Model validation – HSE
  6. Emergency response – NCEC
  7. Venting – DNV

Source of images: Allason D., Armstrong K., Barnett J., Cleaver P. and Halford A. "Behaviour of releases of carbon dioxide from pipelines and vents", Paper IPC2014-33384, Proc. 10th International Pipeline Conference IPC2014, Calgary, Alberta, 29 September – 3 October 2014, © Copyright National Grid / DNV / ASME

http://dx.doi.org/10.1016/j.ijggc.2015.04.001

Participation in Skylark modelling exercises

- Organisations who have expressed an interest so far:

1. Aker Solutions
2. Ambipar
3. Arup
4. AS Modelling & Data
5. Baker Risk
6. CERC
7. Eddistone consultancy
8. ESR Technology
9. Exponent
10. Fluidyn
11. Fraunhofer
12. Gexcon
13. Kent
14. Monaco Engineering Consultants
15. Ramboll
16. Riskaware
17. Rosen
18. RPS
19. Pace CCS
20. Petrofac
21. Sintef
22. Woods
23. Zelt (consultant for the Alberta Energy Regulator AER)
24. Met Office
25. Environment Agency
26. DSTL
27. INERIS (France)
28. EU Joint Research Centre, Ispra
29. Los Alamos National Lab (USA)

Universities of:

30. Leeds
31. Imperial College
32. Liverpool John Moores
33. Surrey
34. Texas A&M

- Participation of modellers to be approved by Skylark project steering board

University of Leeds

Proposed PhD project

Accelerated Fluid Dynamics of CO2 dense gas dispersion in complex terrain

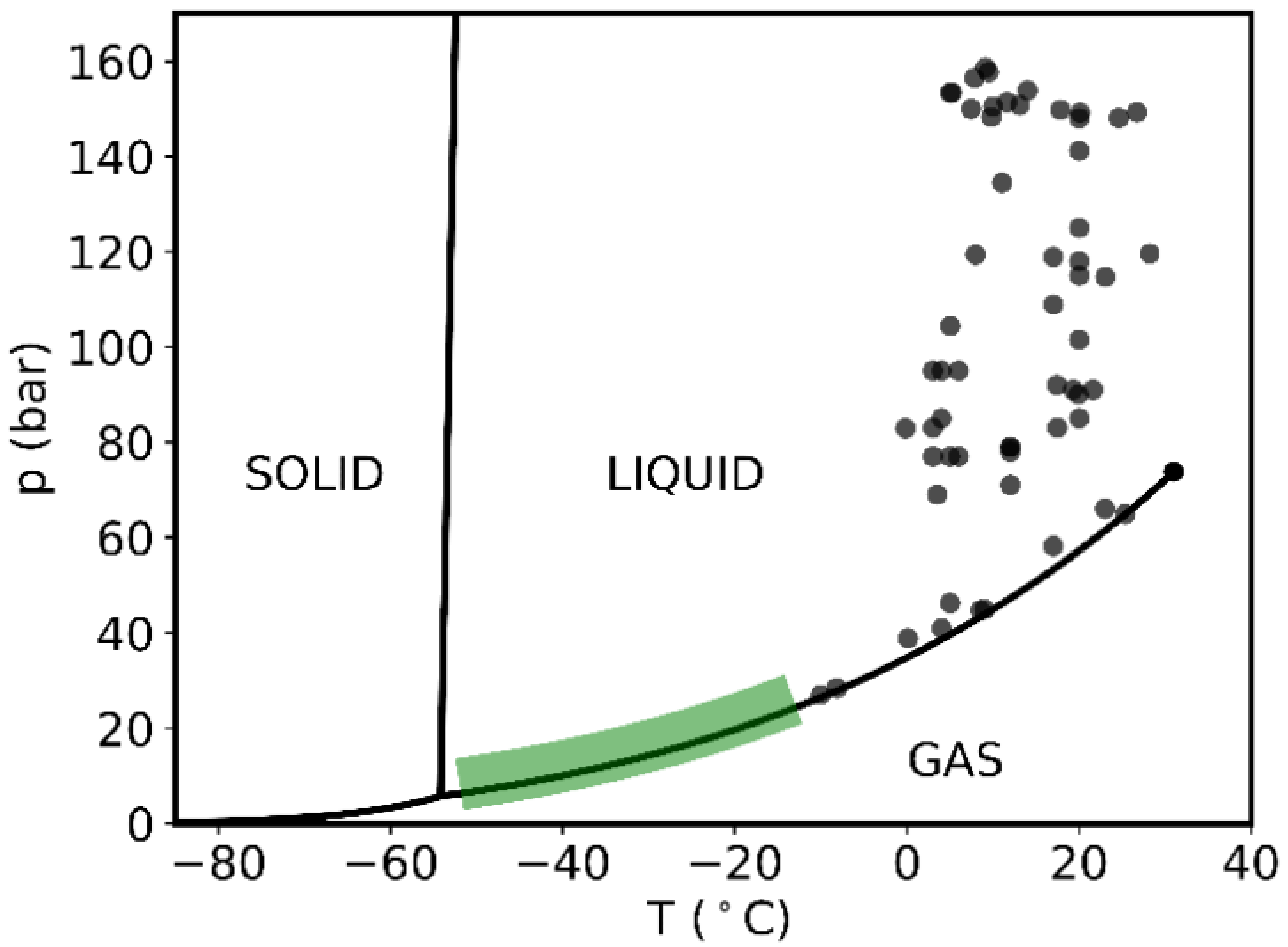
Academic lead: Dr Amirul Khan, School of Civil Engineering, a.khan@leeds.ac.uk
Industrial lead: Dr Simon Gant, Health and Safety Executive (HSE), simon.gant@hse.gov.uk
Co-supervisor(s):
Dr Andrew Ross, School of Earth and Environment, A.N.Ross@leeds.ac.uk, Dr Rory Hetherington, Health and Safety Executive (HSE), rory.hetherington@hse.gov.uk (External)
Project themes:
Clean Energy, Computational & Analytical Tools, Data-driven methods, Multiphysics & Complex Fluids

Carbon Capture and Storage (CCS) is recognised as a crucial element in reaching the target of Net Zero. To support this, an infrastructure of pipelines are required to transport liquid CO2. However, safe operation of pipelines relies on accurately predicting the consequences of a leak or rupture (e.g. 2020 Satartia pipeline release in Mississippi). Key factors in modelling pipeline releases, especially when a risk assessment is undertaken along the full length, include (i) the computational cost of a model and (ii) its capacity to account for complex terrain.

https://fluid-dynamics.leeds.ac.uk/projects/accelerated-fluid-dynamics-of-co2-dense-gas-dispersion-in-complex-terrain/

SINTEF IntoCloud joint industry project

- Leaks and dispersion from refrigerated CO_2 relevant to ship transport and intermediate storage
- Leakage and dispersion experiments
- Physics-based modeling and validation
- Benchmarking and industry cases
- 30 MNOK (€2.6M), duration: 2025 – 2029
- Partners: CLIMIT (40% funding), Equinor, Gassco, Open Grid Europe, Aker Carbon Capture, Aker Solutions, DNV, University of South-Eastern Norway
- Project leader: Hans Langva Skarsvåg (SINTEF)
- https://climit.no/en/project/intocloud/



Phase diagram for CO_2. Experimental data from previous dispersion experiments are marked. Typical shipping and intermediate storage conditions are marked in green.

Pipeline Research Council International (PRCI)

- HSE are members of PRCI Government engagement committee
- Project proposed by PRCI on CO_2 pipeline dispersion modelling
    1. Satartia incident (although, limited data available for modelling, may be omitted)
    2. Dense-phase onshore CO_2 pipeline release
    3. CO_2 vent release
- Project awarded funding in April 2025
- Led by Jeff Whitworth (PRCI) and David Burns (Enbridge)

Other CCS Joint Industry Projects

CO2SafePipe	To close knowledge gaps identified in the transportation of CO_2 in pipelines covering CO_2 in both gas phase and dense phase, including: 1. CO_2 stream composition and its effect on corrosion and materials 2. the risk of running ductile fracture The project will update Recommended Practice DNV-RP-104	https://www.dnv.com/article/design-and-operation-of-co2-pipelines-co2safepipe-240345/	2023-2024
Materials in CCS Wells	1. Identifying the role of key environmental factors on damage modes in Corrosion Resistant Alloys (CRAs) based on preliminary thermodynamic calculations. 2. Characterizing the performance of CRAs and establishing environmental limits for localized corrosion and SCC in CCS storage wells. 3. Creating a framework to translate qualification test observations into long-term performance predictions in service.	https://www.dnv.com/article/materials-performance-in-ccs-wells/	2023-2025
CO-CO_2 cracking in pipelines	1. Define limits on CO and oxidizers (O_2, NO_2) to prevent CO/CO_2 cracking 2. Identify metallurgical limits (yield strength/hardness) to mitigate CO/CO_2 cracking 3. Develop a qualification test methodology to screen line pipe steels and welds for susceptibility to CO/CO_2 cracking.	https://www.dnv.com/article/establishing-guidelines-to-avoid-co-co2-cracking-in-co2-pipelines-251263/	?
CO_2 CFD simulation software	Model development and validation of KFX including complex thermodynamics and heat transfer processes for release of liquid CO_2, including: dry ice formation, deposition of dry ice on the ground and in complex geometries, sublimation of dry ice, condensation of moisture in the surrounding air	https://www.dnv.com/article/co2-cfd-simulation-software-232808/	-2024
Offshore CO_2 good practice	Good Practice Guide for working on offshore oil and gas structures repurposed for CO_2 streams, including consideration of what action to be taken in the event that an evacuation proves necessary	Andy Brown proposed to Energy Institute in 2024	2024-

Other CCS Joint Industry Projects

SAFEN	Develop risk models for hydrogen, ammonia and CCS Share knowledge for development of best practices for safe design of technologies	https://www.safetec.no/en/news/safen-jip-ready-to-meet-new-challenges	Phase 2 2024-
Offshore Monitoring of Large-Scale Subsea Releases of CO_2	The project will collect observations from four releases from 300 meters depth, each lasting approximately 30 minutes Aim is to create an open curated dataset for public utilization	contact: Paal.Skjetne@sintef.no	2024-2025
CO_2 EPOC	Characterization and prediction of the CO_2 effect on polymeric materials within the CO_2 transport chain (pipelines and ships) in order to avoid leakage and failure	https://www.sintef.no/en/projects/2020/co2-epoc/	2020-2025
MASCO2T II	Materials Assessment for Supercritical CO_2 Transport 1.Generate corrosion data for candidate metallic materials in high pressure/supercritical CO_2, with varying types and concentrations of impurities 2.Establish a thorough knowledge of the impact of a range of environmental factors (such as pressure, temperature, fluid composition etc.) on (i) the corrosion behaviour of candidate metallic materials including welds, and (ii) the effect of stress on the environmental performance of candidate metallic materials and welds.	https://www.twi-global.com/media-and-events/press-releases/2023/join-our-new-supercritical-co2-transport-project	2023-2026
Permeation of CO_2 through thermosets	Combined Permeation of Pressurised CO_2 and Impurities through Thermosets 1. To establish the barrier performance of thermoset materials to CO_2 with associated impurities. 2. To establish if any transport of these impurity species causes ageing in the thermoset matrix.	https://www.twi-global.com/what-we-do/research-and-technology/research-programmes/joint-industry-projects#/	?

energy institute

PROTECTING PEOPLE AND PLACES FOR 50 YEARS HSE

Energy Institute: CCUS activities

- Recent and ongoing EI projects
  - Hazard analysis for onshore/offshore installations
  - Good plant design and operations
  - Running ductile fracture
  - Repurposing and design guidelines for carbon dioxide pipelines
  - Flow assurance and measurement
  - CO_2 impurities measurement
  - Material degradation, corrosion management and asset integrity
  - Interface between conventional power (thermal) generation and a CCUS plant
- Projects under development
  - Hazard identification and risk assessment for new and repurposed offshore structures used for CO_2 streams
  - CO_2 transportation and storage flexibility
  - Non-pipeline transport hubs
  - CO_2 subsurface storage
- Webinar “Good practice guide for CO_2 stream impurity measurement within CCS applications” 12 June 2025
- Joint HSE and Energy Institute workshop on CCUS research priorities planned in coming months

Reports now available from: https://www.energyinst.org/technical/publications/sectors/ccus

Regulators can access Energy Institute publications for free. Contact Mark Scanlon: mscanlon@energyinst.org

Outline

- Carbon dioxide pipelines
  - Planned CO_2 pipelines in the UK
  - Satartia incident
  - PHMSA public workshop and R&D forum
  - PHMSA draft rules
  - HSE research
  - Joint industry projects (Skylark, IntoCloud, PRCI etc.)

- Ammonia pipelines
  - RIVM-HSE proposed project
  - Incidents
  - Recent RIVM research
  - Other recent ammonia research activities

RIVM-HSE Concept for collaborative project on ammonia pipelines

- HSE has held discussions held over last year with Elin Bloem (RIVM) about scope for possible future project on ammonia pipelines (funding to be determined)
- Scope:
  - Current and future international plans for ammonia pipelines
  - Past international experience with operating ammonia pipelines
  - Relevant standards/guidelines/regulations on pipeline risk assessment, e.g. PD 8010, 49 CFR 195
  - Ammonia pipeline incidents ← Some info in next slides
  - Potential hazards of ammonia pipeline releases
    - Relevant physics
    - Modelling tools (PHAST, EFFECTS, FRED etc.)
    - Existing guidelines on effect distances
    - Run simulations of toxic dispersion and fireballs(?) for range of credible scenarios
    - Compare hazard distances to those for natural gas transmission pipelines
  - Failure rates and uncertainties in comparing risks
  - Emergency response
  - Public perception
  - Further research needs

If you are interested in this topic, please get in touch with Elin Bloem (elin.bloem@rivm.nl) or Simon Gant (simon.gant@hse.gov.uk)

McPherson, Kansas (1973) ammonia pipeline incident

- Since start of ammonia pipeline operation in 1968, 3 major leaks
- Third leak occurred at distance of 300 ft from pump station
- Ice storm caused power outage and pipeline shutdown
- Power restored and pumps activated but electrically-operated block valve failed to open, resulting in increased line pressure
- Pipeline failed at point of prior construction damage
- 5-10 mph winds blew dense cloud across highway at ground level
- Two vehicles drove into cloud, one stopped and driver escaped, the other crashed into ditch and driver escaped: two people hospitalised
- Sheriff evacuated nearest dwellings, 1 mile away

Ammonia Pipeline Maintenance and Repair

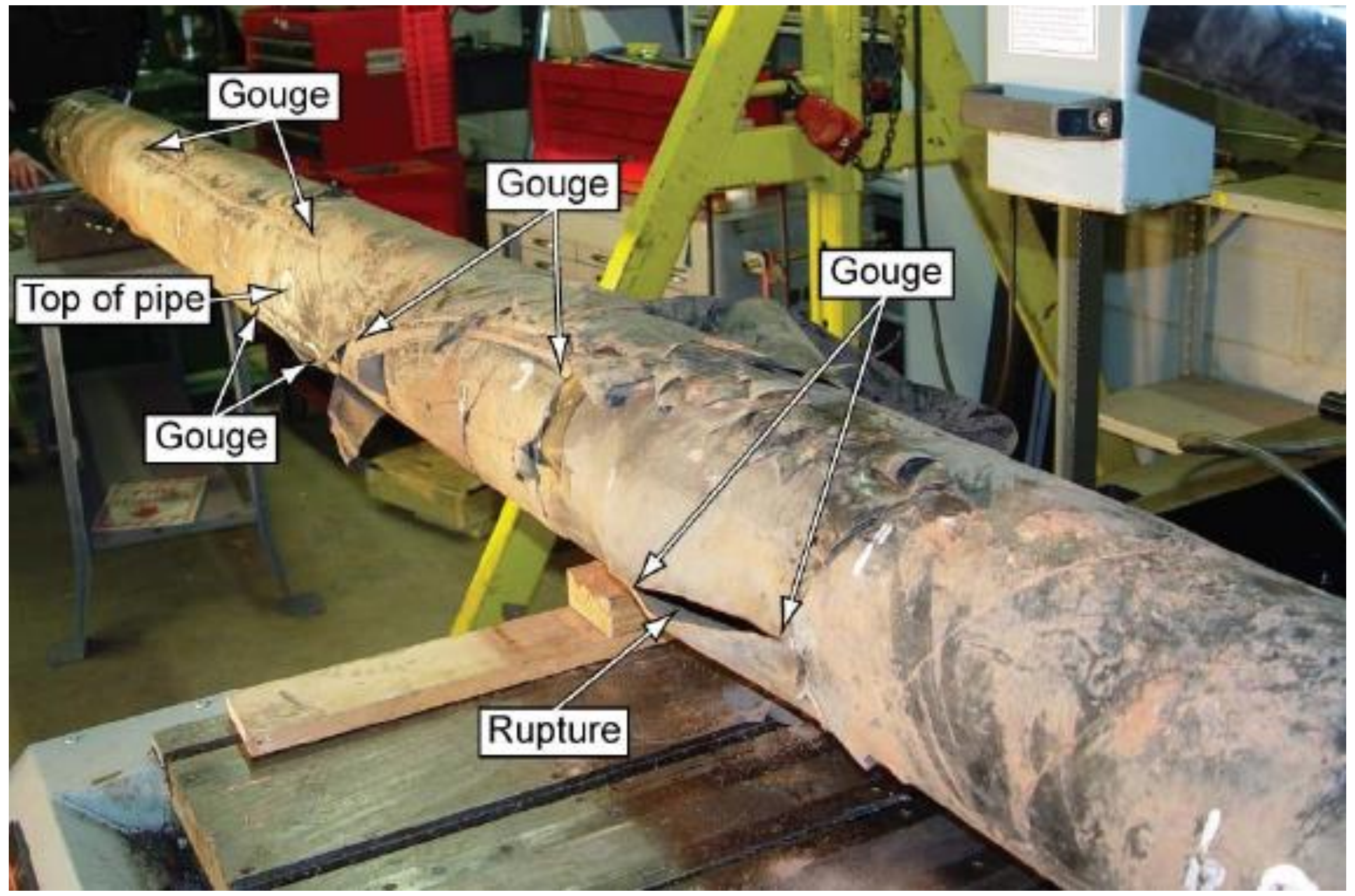
A case history of how one company with a 939-mile line maintains operations and the procedure it followed when a major leak problem occurred.

D.E. Luddeke
Mapco, Inc.
Tulsa, Okla.

https://appsparadeep.iffco.coop/CD_LIBRARY/technical/aiche%20papers%201956-2013/1974/Aiche-17-017.pdf

Kingman, Kansas (2004)

- 8-inch diameter Magellan pipeline ruptured and released 480 t of ammonia
- Visible vapour cloud 0.5 miles wide and 1.5 miles long
- Four families evacuated, no injuries
- Analysis showed pipeline rupture was caused by damage from digging equipment, either during construction or later agricultural activities



https://www.ntsb.gov/investigations/AccidentReports/Reports/PAB0702.pdf

Tampa Bay, Florida (2007)

- Teenager took 2 days to drill through steel wall of 6-inch diameter ammonia pipeline using a cordless drill
- Suffered burns from jetting ammonia, but fell or jumped into river and survived
- Public evacuated from ¼ to ½ mile radius
- Fortunately, pipeline was operating at half usual pressure due to maintenance

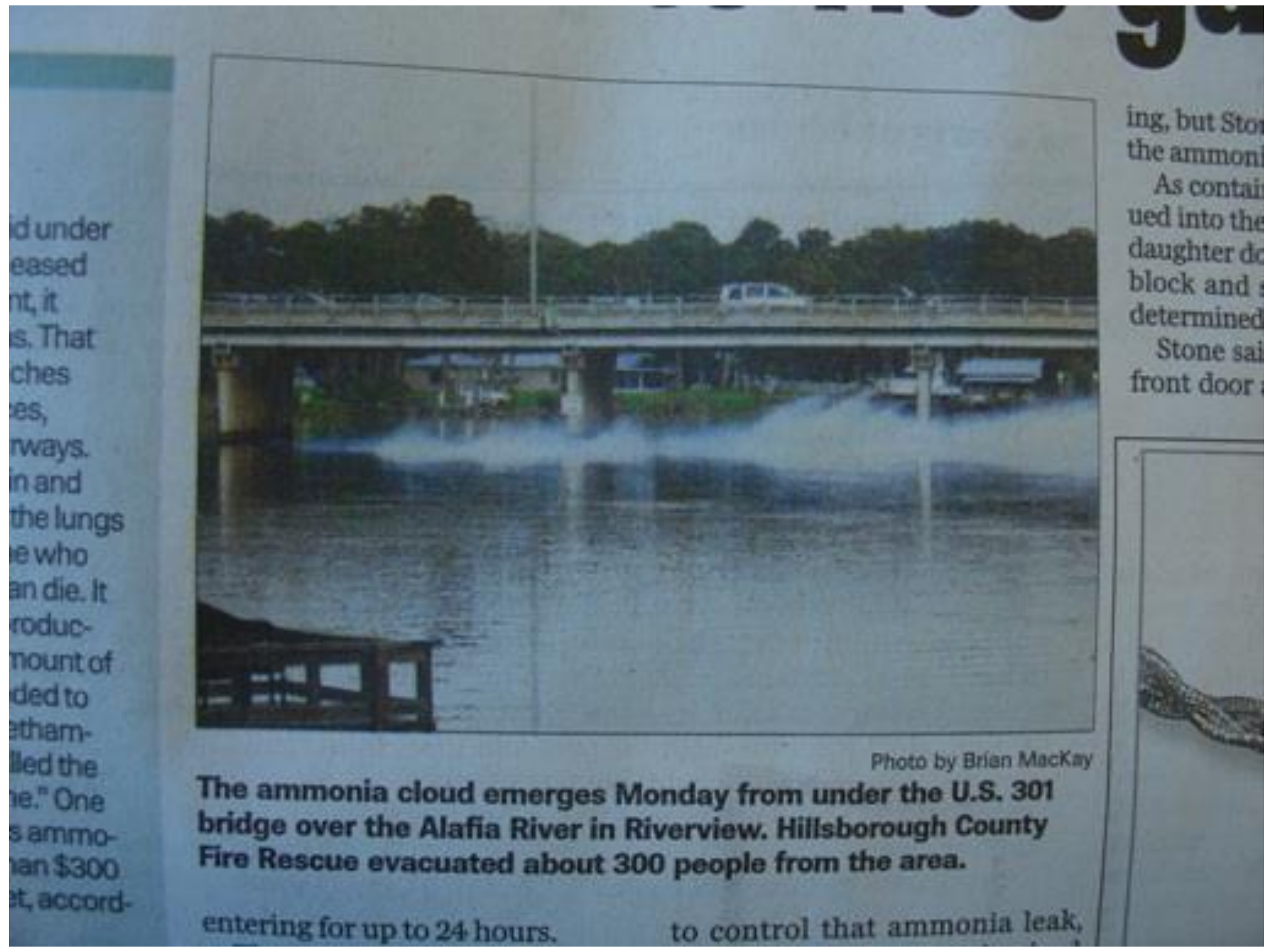


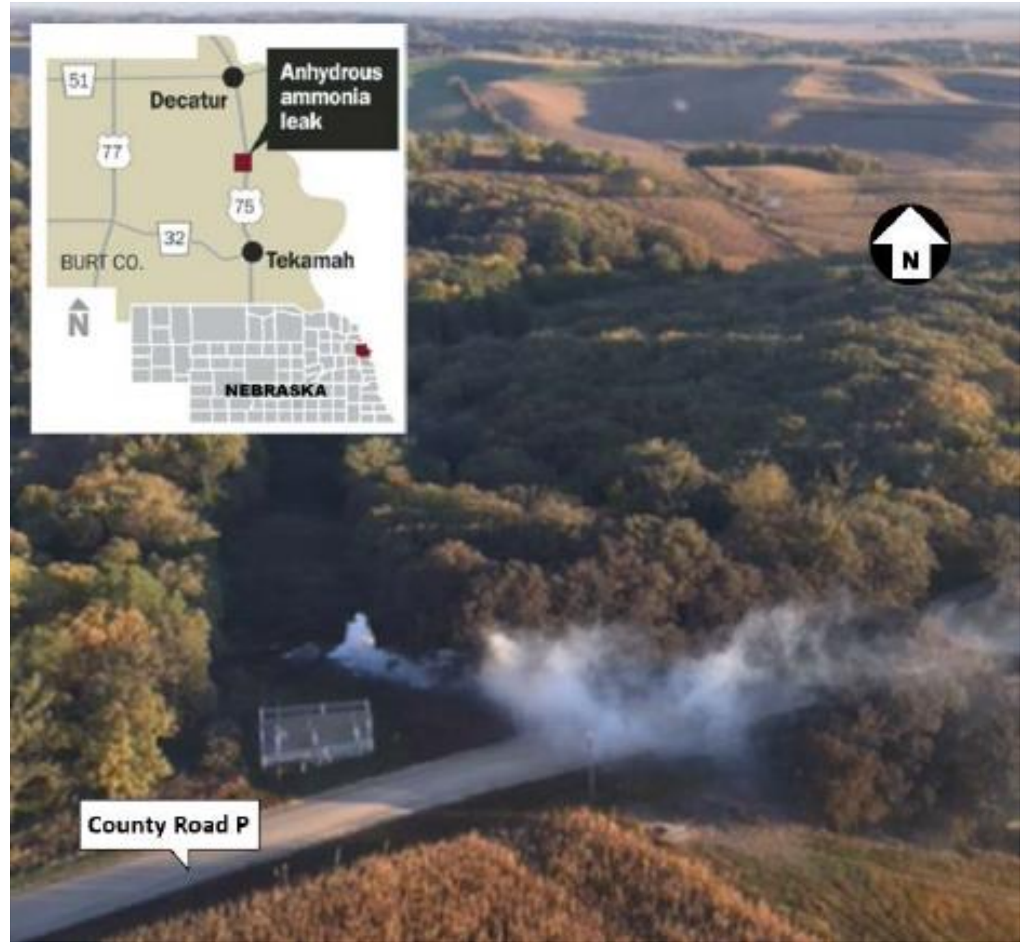
Photo by Brian MacKay

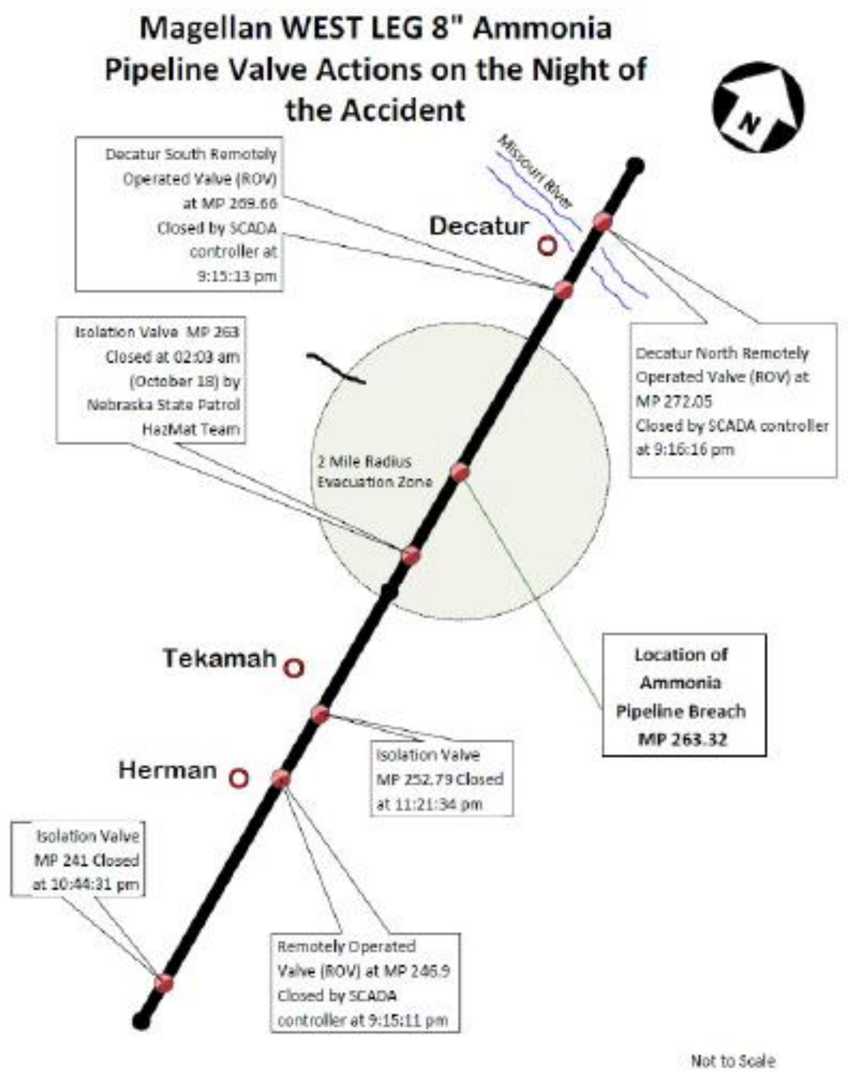
The ammonia cloud emerges Monday from under the U.S. 301 bridge over the Alafia River in Riverview. Hillsborough County Fire Rescue evacuated about 300 people from the area.

https://incidentnews.noaa.gov/incident/7711#!

Tekamah, Nebraska (2016)

- 8-inch diameter Magellan pipeline ruptured and released 260 t of ammonia
- 49 people evacuated, 1 death
- Several previous leaks in West leg of Magellan pipeline needed repairs: one in 1984, five between 1988 and 1990, three between 1993 and 1994
- Cause of 2016 incident: corrosion fatigue cracking of pipeline steel
- In 2019, Magellan announced they would decommission the 1,100-mile pipeline





https://www.ntsb.gov/investigations/AccidentReports/Reports/PAB2001.pdf

Chennai, India (2023)

- Release from 8-inch diameter flexible high-density-polyethylene ammonia pipeline running underwater from fertilizer plant at port near Chennai
- During pipeline pre-cooling process, pressure drop recorded in pipeline and gas bubbles observed 2 feet from shore
- Release occurred at night and cloud passed through nearby fishing village
- 52 people hospitalised

Residents from Periyakuppam fishing hamlet staging demonstration in front of Coramandel International Limited, Ennore on December 27, 2023 | Photo Credit: B. Jothi Ramalingam

https://www.thehindu.com/news/cities/chennai/many-hospitalised-as-ammonia-gas-leaks-out-at-an-industrial-unit-in-tamil-nadus-ennore/article67678852.ece

Recent RIVM research

Effect Modelling of Ammonia Pipeline Ruptures

Elin Bloem[1], Yannick Geertzema[1]

[1]Dutch National Institute for Public Health and the Environment

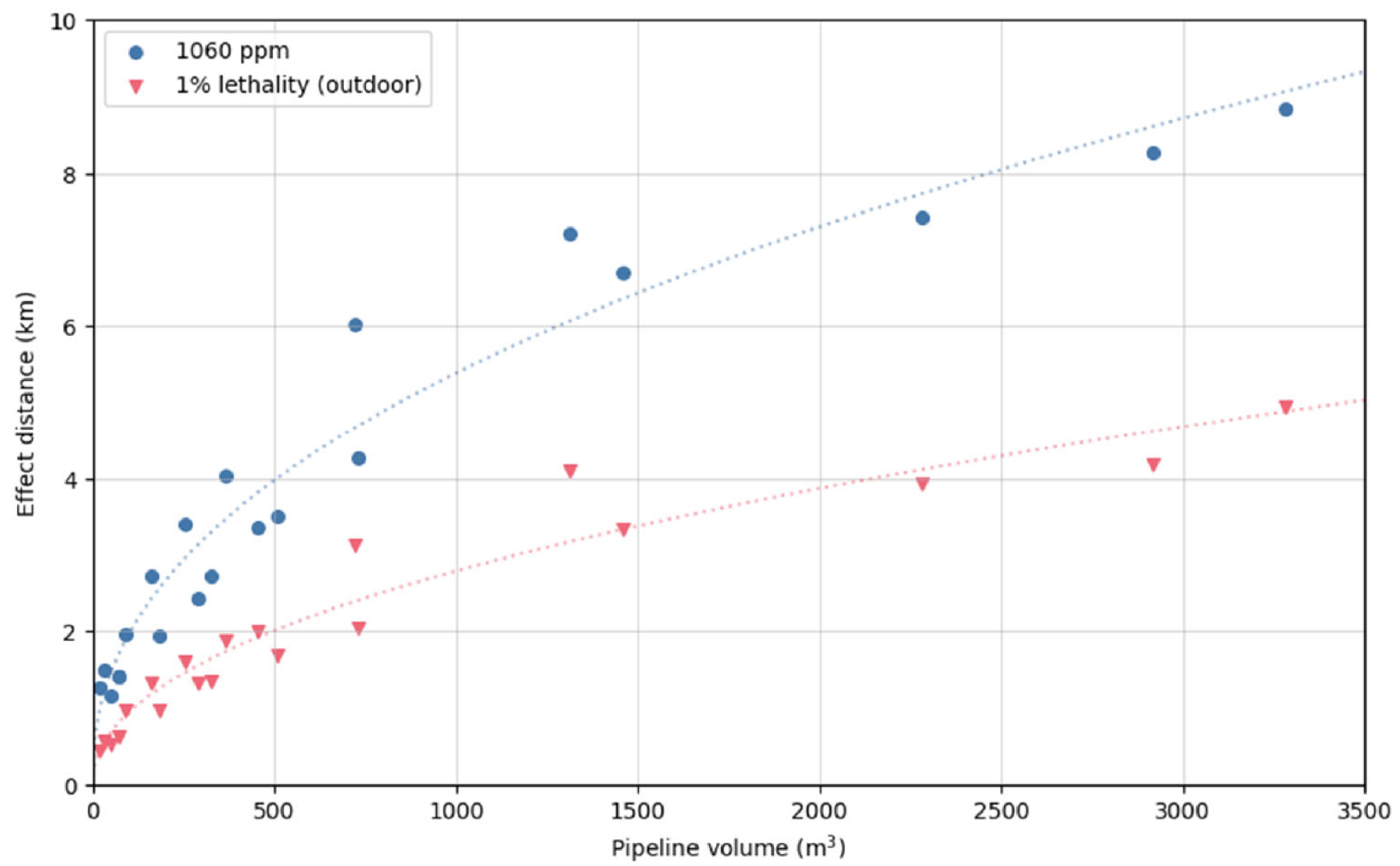
ptc 20TH PIPELINE TECHNOLOGY CONFERENCE
5–8 MAY 2025, BERLIN

Elin Bloem
elin.bloem@rivm.nl

Table 2: Parameters of the rupture scenario modelling

Parameter	Value
Material	Ammonia
Diameters	6, 8, 10, 12, 24, 30, and 36 inch
Length	50 km
Segment lengths	1, 5, and 10 km
Weather	F1.5, Soesterberg
Temperature	10 °C
Pressure	100 bar
Pipeline surrounding	Buried
Soil cover	1.75 meter
Valve closing time	65 seconds
Scenario duration	1800 seconds

Figure 1: Relation between pipeline volume and effect distances. The dotted lines are to guide the eye. For legibility, the volumes for the 30" and 36" 10 km pipelines (4600 and 6600 m3) are not included in this graph.



Atmospheric dispersion of pressure-liquefied ammonia: results from the Jack Rabbit III model inter-comparison exercise on Desert Tortoise and FLADIS

Simon Gant[1], Joseph Chang[2], Rory Hetherington[1], Steven Hanna[3], Gemma Tickle[4], Tom Spicer[5], Sun McMasters[6], Shannon Fox[6], Ron Meris[7], Scott Bradley[7], Sean Miner[7], Matthew King[7], Steven Simpson[7], Thomas Mazzola[8], Alison McGillivray[1], Harvey Tucker[1], Oscar Björnham[9], Bertrand Carissimo[10], Luciano Fabbri[11], Maureen Wood[11], Karim Habib[12], Mike Harper[13], Frank Hart[13], Thomas Vik[14], Anders Helgeland[14], Joel Howard[15], Lorenzo Mauri[16], Shona Mackie[16], Andreas Mack[16], Jean-Marc Lacome[17], Stephen Puttick[18], Adeel Ibrahim[18], Derek Miller[19], Seshu Dharmavaram[19], Amy Shen[19], Alyssa Cunningham[20], Desiree Beverly[20], Daniel M. O'Neal[20], Laurent Verdier[21], Stéphane Burkhart[21], Chris Dixon[22], Sandra Nilsen[23], Robert Bradley[24], Hans L. Skarsvåg[25], Eirik H. Fyhn[25] and Ailo Aasen[25]

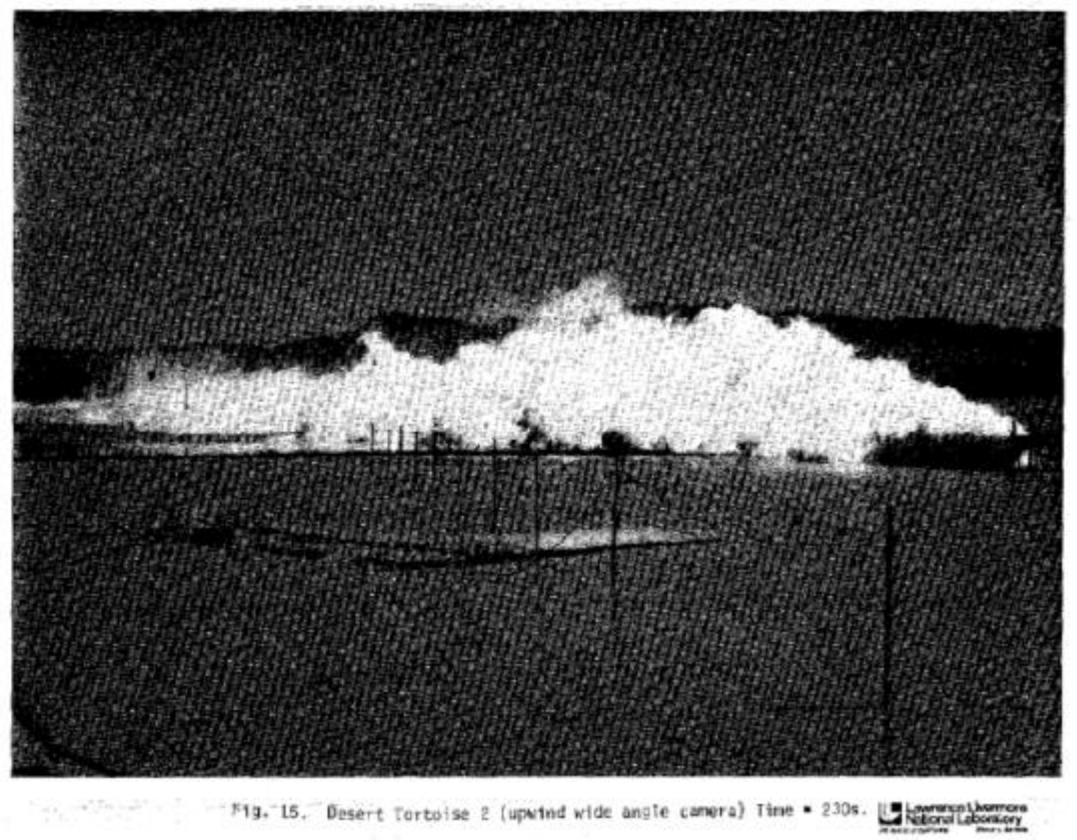
[1] Health and Safety Executive (HSE), Buxton, Derbyshire and Bootle, Merseyside, UK
[2] RAND Corporation, Arlington, Virginia, USA
[3] Hanna Consultants, Inc., Kennebunkport, Maine, USA
[4] GT Science and Software, Waverton, Cheshire, UK
[5] University of Arkansas, Fayetteville, Arkansas, USA
[6] Chemical Security Analysis Center (CSAC), Science and Technology Directorate (S&T), Department of Homeland Security (DHS), Aberdeen Proving Ground, Maryland, USA
[7] Defense Threat Reduction Agency (DTRA), Fort Belvoir, Virginia and Albuquerque, New Mexico, USA
[8] Systems Planning and Analysis, Inc. (SPA), Alexandria, Virginia, USA
[9] Swedish Defence Research Agency (FOI), Umeå, Sweden
[10] EDF and École des Ponts ParisTech, Paris, France
[11] European Joint Research Centre (JRC), Ispra, Italy
[12] Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin, Germany
[13] DNV Digital Solutions, Stockport, UK and Trondheim, Norway
[14] Norwegian Defence Research Establishment (FFI), Kjeller, Norway
[15] Defence Science and Technology Laboratory (DSTL), Porton Down, UK
[16] Gexcon, Bergen, Norway and Driebergen-Rijsenburg, Netherlands
[17] Institut National de l'Environnement Industriel et des Risques (INERIS), Verneuil-en-Halatte, France
[18] Syngenta, Huddersfield, Yorkshire, UK
[19] Air Products, Allentown, Pennsylvania, USA
[20] Naval Surface Warfare Center Indian Head Division (NSWC IHD), Indian Head, Maryland, USA
[21] Direction Générale de l'Armement (DGA), Paris, France
[22] Shell, London, UK
[23] Equinor, Norway
[24] Emergency Management (EM) Solutions, USA
[25] SINTEF Energy Research, Trondheim, Norway

Initial results presented at Harmo conference in 2022 https://harmo.org/conference.php?id=21
Journal paper currently in late draft stage

Jack Rabbit III ammonia dispersion modelling exercise

#	Organisation	Model	Model Type				Desert Tortoise			FLADIS		
			A	B	C	D	1	2	4	9	16	24
1	Air Products, USA	Ventjet		■			■	■	■	■	■	■
2	BAM, Germany	AUSTAL			■		■	■	■	■	■	■
3		VDI	■				■	■	■	■	■	■
4	CEREA (EDF/Ecole des Ponts), France	Code-Saturne v7.0				■					■	
5		Crunch v3.1		■			■	■	■			
6	DGA, France	PHAST v8.6		■			■	■	■	■	■	■
7		Code-Saturne v6.0				■				■	■	■
8	DNV, UK	PHAST v8.61		■			■	■	■	■	■	■
9	DSTL, UK	HPAC v6.5			■		■	■	■	■	■	■
10	DTRA, ABQ, USA	HPAC v6.7			■		■	■	■	■	■	■
11	EM Solutions, Inc., USA	ALOHA v5.4.7 Gaussian	■				■	■	■	■	■	■
12		ALOHA v5.4.7 Integral		■			■	■	■	■	■	■
13	Equinor, Norway	PHAST v8.6		■			■	■	■			
14	FFI, Norway	ARGOS v9.10			■		■	■	■	■	■	■
15	FOI, Sweden	PUMA			■		■	■	■	■	■	■
16	Gexcon, Netherlands	EFFECTS v11.4		■			■	■	■	■	■	■
17	Gexcon, Norway	FLACS				■	■	■	■	■	■	■
18	GT Science & Software	DRIFT v3.7.19		■			■	■	■	■	■	■
19	Hanna Consultants, USA	Britter & McQuaid WB	■				■	■	■			
20		Gaussian plume model	■							■	■	■
21	HSE, UK	DRIFT v3.7.19		■			■	■	■	■	■	■
22		PHAST v8.4		■			■	■	■	■	■	■
23	INERIS, France	FDS v6.7				■				■	■	■
24	JRC, Italy	ADAM v3.0		■			■	■	■	■	■	■
25	NSWC, USA	RAILCAR-ALOHA	■				■	■	■	■	■	■
26	Shell, UK	FRED 2022		■			■	■	■	■	■	■
27	SINTEF, Norway	OpenFOAM v2206				■	■	■	■	■	■	■
28	Syngenta, UK	PHAST v8.61		■			■	■	■	■	■	■

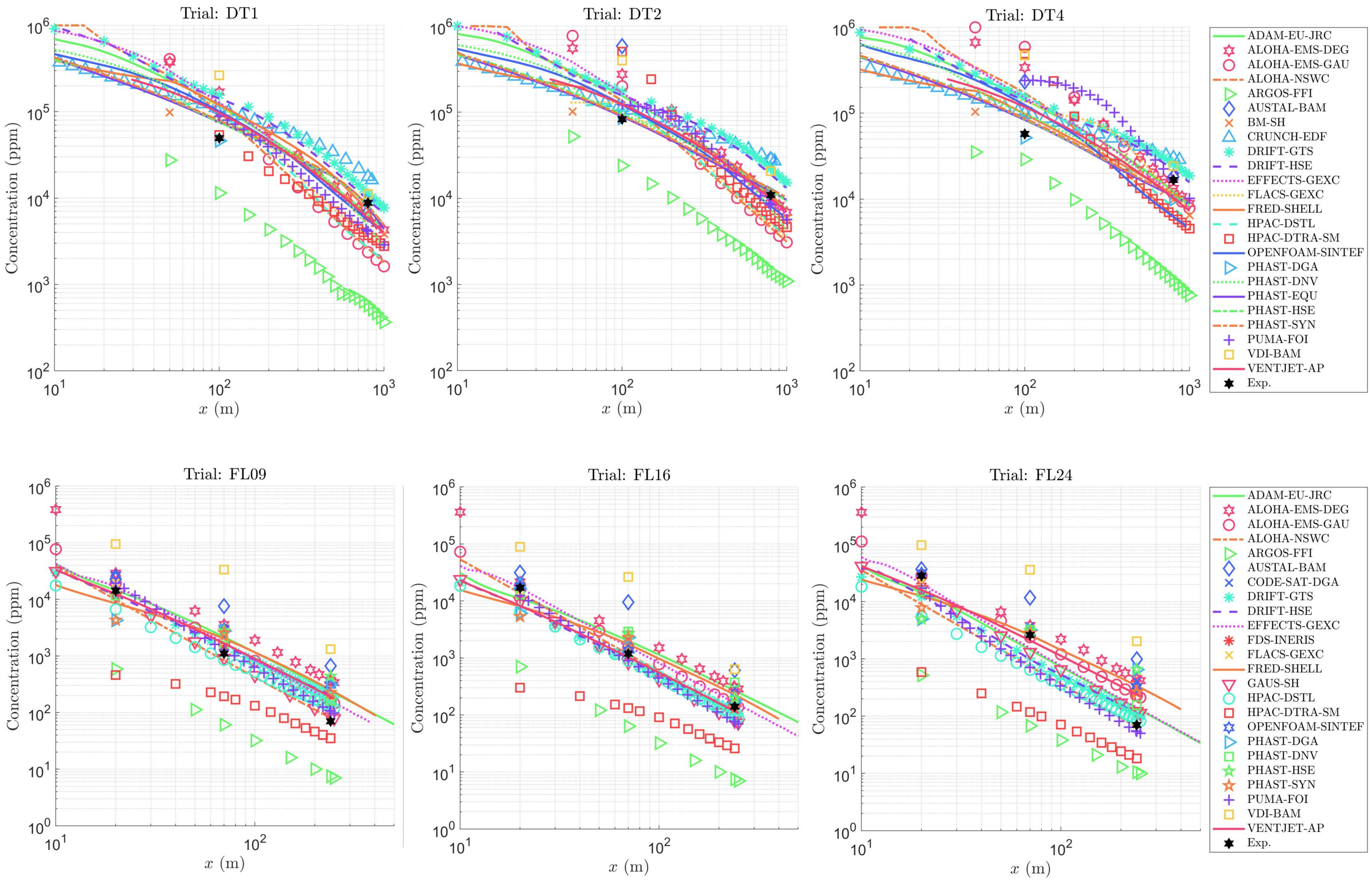
Note: Model Type: A = Empirically-based nomograms/Gaussian plume model; B = Integral model; C = Gaussian puff/Lagrangian model; D = CFD. Shading in the right six columns indicates model was run for that trial. See Glossary for the full names of the organisations and models.



Desert Tortoise ammonia release, Nevada, USA, 1983

FLADIS ammonia release, Sweden, 1993-1994

Jack Rabbit III ammonia dispersion modelling exercise



PROTECTING PEOPLE AND PLACES FOR 50 YEARS HSE

EU/OECD Joint Research Centre: hydrogen risks webinars

Moderator: Maureen Wood, EC-JRC-MAHB		Co-Moderator: Marie-Ange Baucher, OECD
09:00	**Introductory Session**	
	Welcome to the Webinar	Maureen Wood, EC-JRC and Eeva Leinala, OECD
	Introduction to the Programme	Maureen Wood, EC-JRC
	Session 1	
09:05	Need for closer cooperation between policy, industry and safety experts on ammonia and other hydrogen fuels	Ruta Baltause, EC DG ENER
	Discussion: If you would like to ask a question or comment, please use the Webex chat. Presenters should ideally plan for 20-25 minute presentations leaving time for discussion	
	Session 2	
09:50	Ammonia risks in the hydrogen fuel context	Lorenzo Van Wijk, EC-JRC-MAHB
10:00	Safe Ammonia handling – Challenges & Opportunities	Laurent Ruhlmann, Yara
10:20	Design principles for NH3 Fully Refrigerated Large Quantity Storage	Michel J Ruttens, Advario
10:40	PGS 12 Ammonia, New BAT document on ammonia storage in the Netherlands, Part 1	Jochem Langeveld, DCMR Environmental Service Rijnmond

WEBINAR
EU Technical Working Group for Seveso Inspections (TWG 2) and OECD Working Party on Chemical Accidents

Hydrogen Fuel Risks Webinar Part 4

Organised by the EC-Joint Research Centre with the TWG 2 and OECD
11 March 2025, 09:00– 13:30 CEST

11:10	PGS 12 Ammonia, New BAT document on ammonia storage in the Netherlands, Part 2	Jochem Langeveld, DCMR Environmental Service Rijnmond
11:20	Challenges and risks of ammonia storage in confined and geographically remote industrial precincts – an Australian perspective	Dannae Campbell, WorkSafe Paul Newell, WorkSafe, Queensland Steve Emery, WorkSafe, Western Australia
	Discussion: If you would like to ask a question or comment, please use the Webex chat. Presenters should ideally plan for 20-25 minute presentations leaving time for discussion	
	Session 3	
12:00	Decarbonized but Not De-Risked: The Case of Green Ammonia	Paolo Mocellin, University of Padua
12:20	Summary of research activities on ammonia safety at HSE	Simon Gant, Health and Safety Executive, UK
12:40	Fog formation and water-ammonia interactions: key physical mechanisms affecting ammonia risks	Hans Langva Skarsvåg, SINTEF, Norway

https://minerva.jrc.ec.europa.eu/EN/content/minerva/a065e0e1-9122-11ef-989f-0050563f0167/euoecd_hydrogen_fuel_risks_webinar_series

FABIG conference, London, 13-14 May 2025

Several ammonia presentations

- Challenges when designing and assessing the risks of ammonia plants Stian Bratsberg - Vysus Group
- Ammonia pipeline release modelling Paul Williamson - Thornton Tomasetti
- Bridging analytical models and CFD: Advancing ammonia spill dispersion predictions Filippo De Rosa - Monaco Engineering Solutions

Thank you

Any questions?

simon.gant@hse.gov.uk

- Disclaimer: the contents of this presentation, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy
- To review HSE areas of research interest, search here: https://ari.org.uk/ or https://int.octopus.ac/