2024 API PIPELINE CONFERENCE AND EXPO

PIPELINE, CONTROL ROOM AND CYBERNETICS

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Skylark CO_2 Dispersion Project

Simon Gant (Health and Safety Executive, UK)

API

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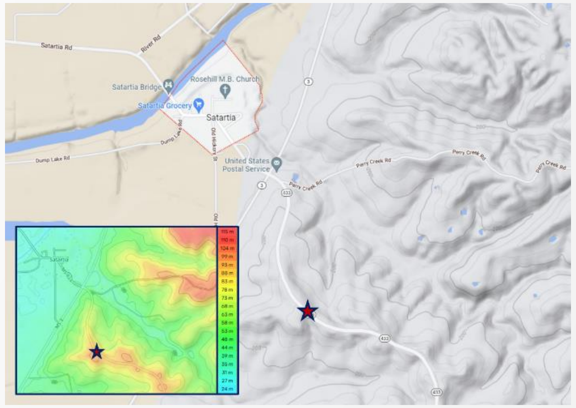
- Simon Gant, Zoe Chaplin and Rory Hetherington (Health and Safety Executive, UK)
- Daniel Allason, Karen Warhurst, Ann Halford, Mike Harper, Jan Stene and Gabriele Ferrara (DNV, UK)
- Tom Spicer (University of Arkansas, USA)
- Ed Sullivan (National Chemical Emergency Centre, UK)
- Justin Langridge and Matthew Hort (Met Office, UK)
- Steven Hanna (Hanna Consultants, USA)
- Joe Chang (RAND Corporation, USA)
- Gemma Tickle (GT Science and Software, UK)

Background: Satartia CO_2 pipeline incident, 2020

- Failure of Denbury 24-inch CO_2 pipeline near Satartia, Mississippi due to landslide
- 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

Knowledge gaps in CO_2 pipeline risk assessment

Moderate wind

Bent-over plume, no CO_2 re-entrainment

Light wind

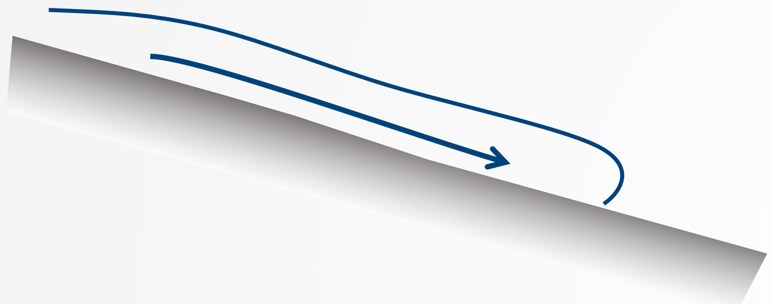
Plume fountain falls back on itself, CO_2 re-entrained, dense blanket formed

1. Questions:

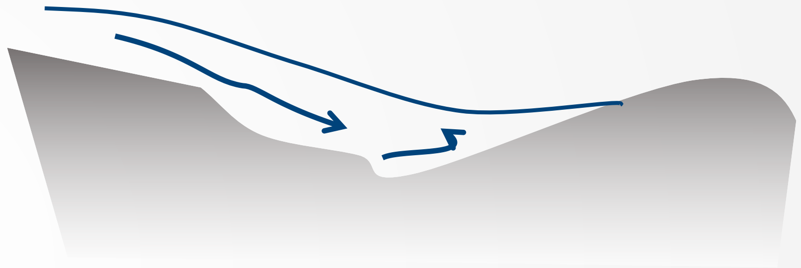
- Which set of conditions give rise to these two different source conditions (wind speed, release size etc.)?
- What are the characteristics of the dispersion source term (composition, flow rate, temperature etc.)?
- Experimental data is limited to just two COSHER tests (COOLTRANS data is currently unavailable)

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

Knowledge gaps in CO_2 pipeline risk assessment



Larger downslope dispersion distances?



Channelling effects in complex terrain, vapour hold-up in valleys

2. Questions:

- How confident are we in dispersion model predictions for dense-gas dispersion in complex/sloping terrain?
- Have the dispersion models been validated against reliable experimental data?
- Do any dispersion models exist that produce results quickly, i.e., within a few seconds (or minute at most) for use in risk assessment and emergency planning/response?

Knowledge gaps in CO_2 pipeline risk assessment

3. Are emergency responders sufficiently prepared to deal with possible incidents involving large CO_2 releases from CCS infrastructure?
   - Learning points from Satartia incident, e.g., vehicle engines stalling in CO_2-rich atmosphere: difficulties evacuating casualties (could electric vehicles be used?)
   - Similar approach could be adopted to the Jack Rabbit II chlorine dispersion experiments

     Work led by Andy Byrnes at Utah Valley University https://www.uvu.edu/es/jack-rabbit/

Related CO_2 knowledge gaps

4. Limited experimental data available for CO_2 venting and blowdown to validate dispersion models used for site risk assessments and permitting studies
   - Dense-phase CO_2 venting at pipeline pig traps
   - Gas-phase CO_2 venting at capture plants
   - Process upset leading to high oxygen levels in CO_2 stream
   - Loss of dehydration leading to high water levels in CO_2 stream
5. Uncertainties in venting strategies and consequences of major loss of containment of CO_2 on offshore platforms (including evacuation scenarios)
6. Useful to have further data on performance of CO_2 valves
   - Pressure safety valves on refrigerated liquid CO_2 storage vessels (e.g., 18 bar, -30 °C)
   - Pressure safety valves on high-pressure compression (dense-phase CO_2)
   - Pipeline emergency shutdown valves (dense-phase CO_2)
   - Valves to isolate flow of off-spec CO_2 from capture plants (e.g., 20-30 bar, ambient temp)

Proposed Skylark Joint Industry Project

- Work Package 0: Project Management – **DNV**
- Work Package 1: CO_2 pipeline craters and source terms – **DNV**
- Work Package 2: Wind-tunnel experiments – **University of Arkansas**
- Work Package 3: Simple terrain dispersion experiments – **DNV**
- Work Package 4: Complex terrain dispersion experiments – **DNV**
- Work Package 5: Model validation – **HSE**
- Work Package 6: Emergency response – **NCEC**
- Work Package 7: Venting – **DNV**

with support from the **Met Office** in the DNV field trials

Work Package 1: CO_2 pipeline craters and source terms

- Aim: to improve our understanding of source characteristics for CO_2 pipeline releases from craters, using field-scale experiments
- Review existing data for CO_2 pipeline craters, both punctures and ruptures (some data is not yet publicly available)
- Conduct pipeline rupture tests
  - Both gas-phase and dense-phase CO_2
  - 6-inch or 8-inch diameter buried pipelines
  - At least two soil types (e.g., clay/sandy)
  - Assess size/shape of craters produced in soil
  - Construct realistic-shaped metal crater
  - Perform further tests using metal crater with near-field instrumentation
  - Repeat tests: puncture tests, light and moderate wind speeds

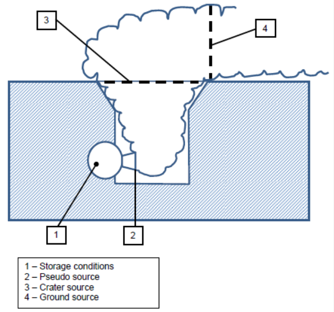


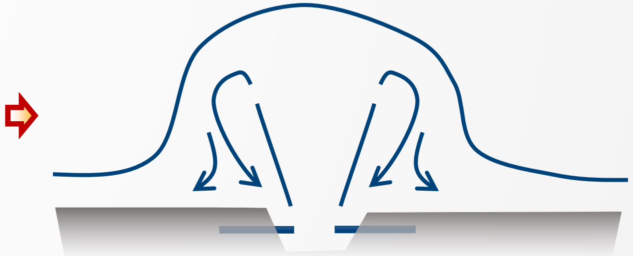
Figure 1 Puncture and crater sources

Work Package 2: Wind tunnel studies

- **Aim 1**: to conduct wind-tunnel experiments on crater source behaviour across a wide range of carefully-controlled conditions, with detailed measurements
- Variables: source area, initial jet velocity and density, wind speed
- Answer question: what are the criteria that control when the plume falls back onto the crater, producing re-entrainment and a source blanket?

When is it:

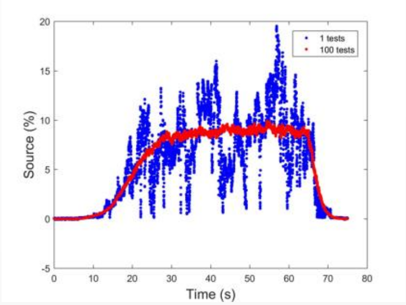
Or ?

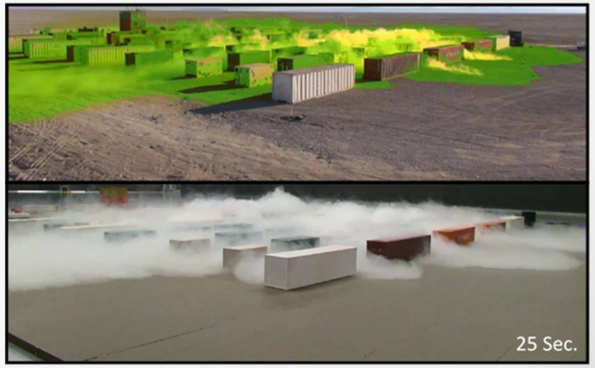


- **Aim 2**: to conduct wind-tunnel experiments on dense-gas dispersion in sloping terrain, comparing flat terrain to cases with uniform slopes in different directions with range of wind speeds
- **Aim 3**: to conduct wind-tunnel experiments to support complex terrain field trials

Work Package 2: Wind tunnel studies

- Chemical Hazards Research Center (CHRC), University of Arkansas
- Large ultra-low speed wind tunnel (larger than EPA, Hamburg and Surrey tunnels)
- 24 m long working section with a 6 m × 2.1 m cross section
- Capable of wind speeds as low as 0.3 m/s and still air experiments
- State of the art instruments for velocity and turbulence (LDV and PIV) and gas concentration (FID, PLIF, PID)
- Data from CHRC wind tunnel has previously used for:
  - PHMSA/NFPA model evaluation protocol for LNG siting applications
  - DNV Phast model development
  - Jack Rabbit II chlorine trials assessment





Work Package 3: Simple sloping terrain dispersion exps

- Aim: to conduct dense-gas dispersion experiments on “simple” uniform sloping terrain to provide data to validate dispersion models
- Idealised gaseous CO_2 source configuration to produce radially-spreading cloud, using a circular outlet similar to the Thorney Island dispersion trials
- Avoid modelling uncertainties associated with two-phase CO_2 release from crater
- Main focus of experiments is to understand effect of slope on dense gas behaviour

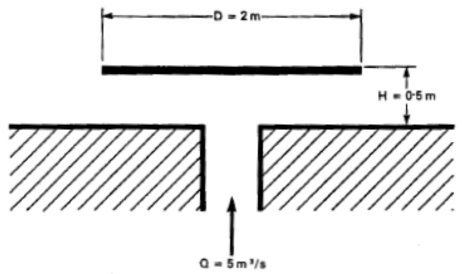


Fig.22.4 Geometry of ground-level source for continuous release experiments

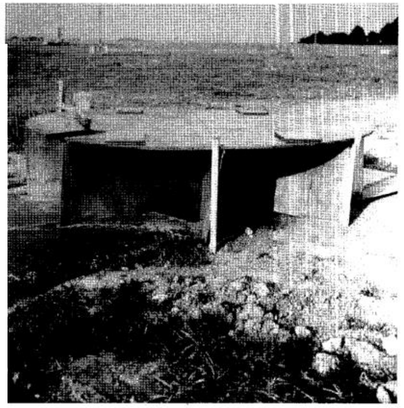
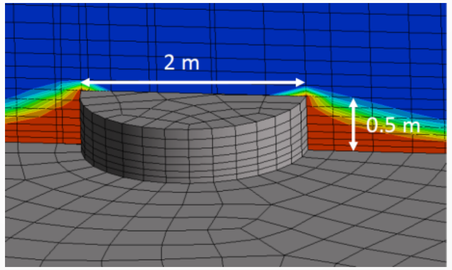
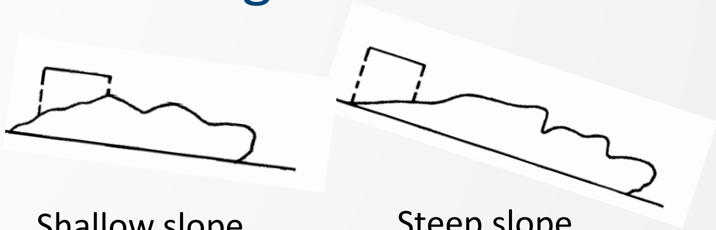


Fig. 22.2 Outlet from the gas supply duct at the release point



McQuaid & Roebuck (1985) Thorney Island
https://admlc.com/thorney-island/
CFD modelling
https://doi.org/10.1504/IJEP.2018.093026



Shallow slope

Steep slope

How does dispersion behaviour compare to flat terrain?

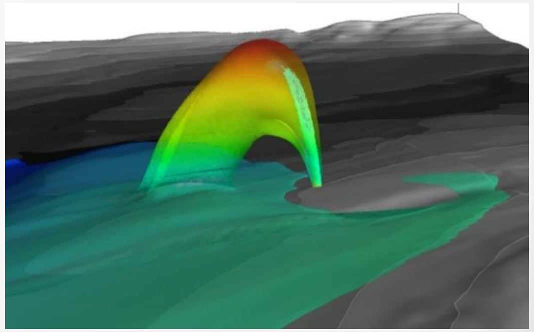
Work Package 4: Complex terrain dispersion exps

- **Aim**: to conduct series of CO_2 release experiments with complex terrain including valleys, hills, obstacles, changing roughness, buildings etc.
- DNV Spadeadam ideally suited to these tests, with multiple possible release locations and large exclusion distances
- Proposed to use mobile rig with 20 – 40 tonne CO_2 capacity with option to use preformed craters
- More challenging configurations for dispersion modelling
- Aim to answer practical questions:
  - How long does CO_2 persist in depressions?
  - What is the effect of obstacles (trees, hedgerows, buildings)?


~15m in 300m
~20m in 500m
~3m in 500m
DNV Spadeadam
DNV Spadeadam
~3m in 500m
~10m in 700m
DNV
Image © 2023 Getmapping plc
Image © 2023 Maxar Technologies
Google Earth
1186 m

Work Package 5: Model validation

- **Aim**: to test and validate dispersion models that can be used for CO_2 pipeline risk assessment and emergency planning/response
- Many international modelling teams and software developers are keen to test and validate their models against Skylark data (DNV, Gexcon, Kent, CERC, Met Office etc.)
- Opportunity to involve research groups who are developing rapid dispersion models (e.g., Texas A&M, Leeds University) to inform future commercial software development
- Aim to have an open and collaborative approach, like in Jack Rabbit projects
- Welcome input from government labs, industry, academia and consultants
- Aim to test spectrum of models, e.g., correlations, integral, Gaussian puff, shallow layer, machine learning, CFD
- Modellers given access to data in return for sharing results and collaborating
- Requests to join project approved by project steering committee
- Modelling exercises coordinated by HSE



Work Package 6: Emergency response

- **Aim**: to engage with emergency responders and make best use of the CO_2 dispersion trials: help to prepare responders to deal with possible CO_2 release incidents
- Identify knowledge gaps in emergency response, working with Hazmat teams, Fire and Rescue Services and other emergency responders
- Test gas sensors, breathing apparatus, PPE etc. used by responders in the trials?
- Test vehicles can be used to evacuate casualties? (learning from Satartia incident)
- Opportunity for emergency responders to witness trials and review video footage as learning and training exercise
- Work package led by UK National Chemical Emergency Centre (NCEC)



Work Package 7: Venting

- **Aim**: to assess if CO_2 vents could give rise to harmful concentrations downwind, near ground level
- Input from sponsors sought on defining range of conditions to be tested experimentally: vent diameter, temperature, pressure
- Planned to test:
  - Two vent diameters (up to 2" NB diameter pipes)
  - Dense, supercritical and gaseous CO_2
  - Repeated tests on three days (low, moderate and high winds)
- Measure outflow rate, vent conditions (pressure / temperature), CO_2 concentration near ground level, plume temperature, videos (normal, thermal, high-speed)
- Conducted alongside other work packages whilst rigs are available
- Interest in testing certain valve designs, following reports of some blowdown valves blocking in the open position due to solid CO_2?

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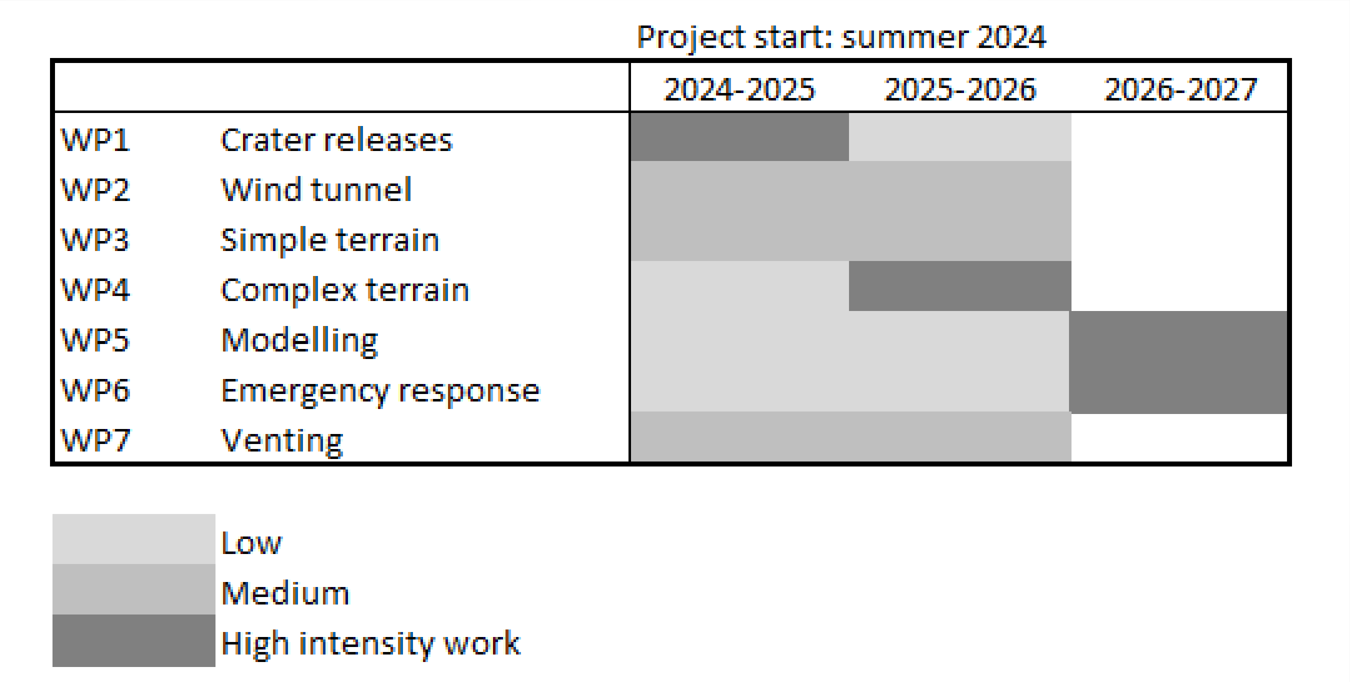
Work Package 0: Project Management

- **Project delivery team**
  - DNV (experiments): Dan Allason, Rob Crewe, Keith Armstrong
  - DNV (modelling): Ann Halford, Karen Warhurst, Mike Harper, Jan Stene and Gabriele Ferrara
  - HSE: Simon Gant, Zoe Chaplin and Rory Hetherington
  - University of Arkansas: Tom Spicer
  - NCEC: Ed Sullivan
  - Met Office: Matt Hort and Justin Langridge
  - External advisers: Steven Hanna (USA), Joe Chang (Rand Corporation), Gemma Tickle (UK)
- **Technical steering group**
  - Representative from each of the project sponsors (or their appointed technical consultant)
- **Modellers working group**
  - Representative from each of the modelling teams contributing and analysing results
- **Emergency response working group**

Timeline (approximate)



Costs

- Summary of costs (approx. estimate, non-binding)
  - DNV
  - HSE
  - University of Arkansas
  - NCEC
  - Met Office
  - External advisors

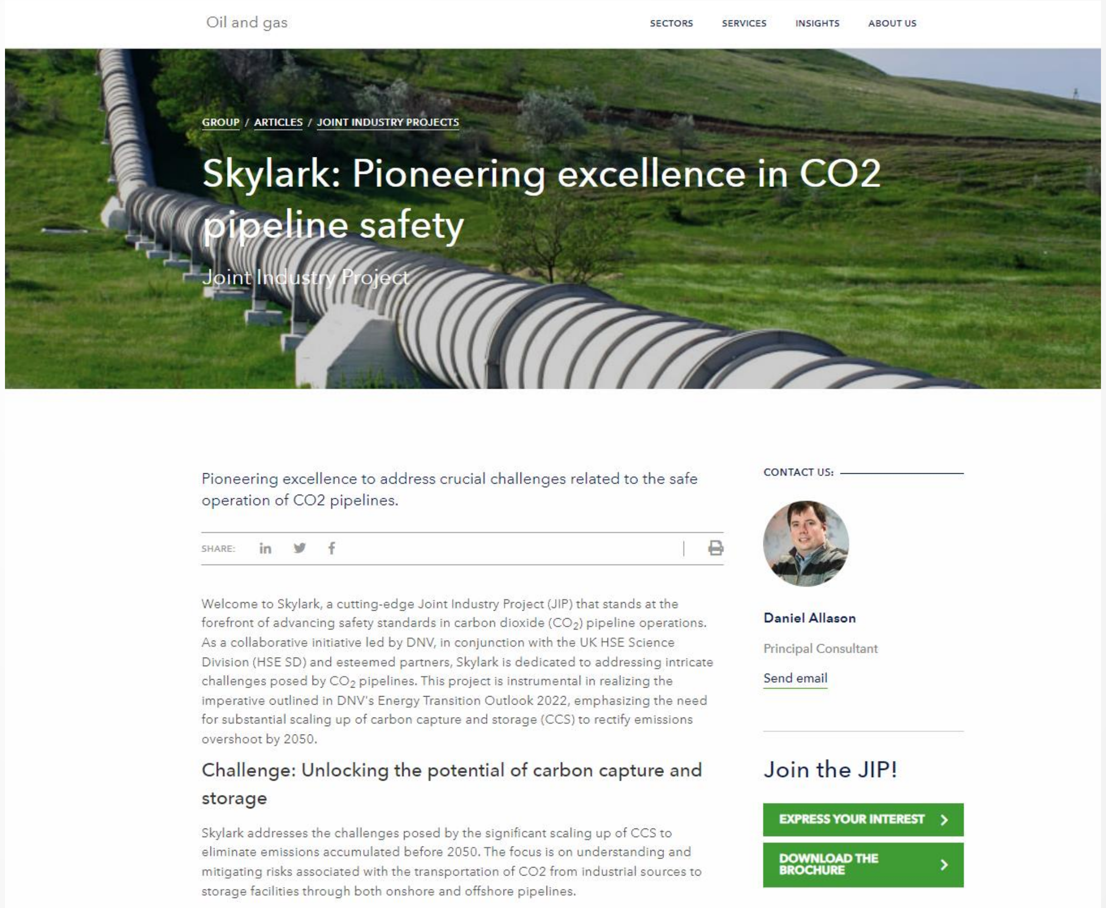
  Total cost, approximately £10m ($12m)
- Department of Energy Security and Net Zero (UK Government) contribution: circa £5m ($6m)
- Ideally, around ten sponsors: £0.5m ($0.6m) per sponsor, spread over 3 years
- If you are interested in sponsoring Skylark, please contact: Daniel.Allason@dnv.com

Feedback

- Current plans have been developed following discussions at several meetings
    - 7 March 2023: ADMLC webinar “Dense-gas dispersion modelling in complex terrain, with a focus on carbon dioxide pipelines”
    - 8-11 May 2023: Presentation on “Knowledge gaps in the risk assessment of hydrogen and carbon dioxide pipelines", 18th Pipeline Technology Conference, Berlin, Germany
    - 20 – 22 June 2023: Presentation at George Mason University (GMU) Conference on Atmospheric Transport and Dispersion Modeling
    - 6 July 2023: UKCCSRC webinar on “Regulating UK CCS deployment: experience to date and research needs”
    - 31 August 2023: Presentation on the proposed Skylark trials at the CCSA Health and Safety Task Sub-Group meeting
    - 6 October 2023: Skylark project meeting at DNV Spadeadam and online
    - 31 Oct – 1 Nov 2023: Presentation and participation in a panel discussion on CO_2 pipelines at the PHMSA Pipeline Safety Research and Development Forum , Arlington, Virginia, USA
    - 27 November 2023: CCSA Health and Safety Task Sub-Group meeting on CO_2 venting
- Keen to have wider engagement with CCS industry, regulators and other stakeholders
- Feedback welcome

Skylark project website

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



Thank you

- Contact: simon.gant@hse.gov.uk , daniel.allason@dnv.com
- 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

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Why the name Skylark?

Historical dispersion trials

- Avocet: LNG
- Burro: LNG
- Coyote: LNG
- Desert Tortoise: ammonia
- Eagle: nitrogen tetroxide
- Falcon: LNG
- Goldfish: hydrogen fluoride
- Kit fox: carbon dioxide
- Jack Rabbit: chlorine and ammonia
- Red Squirrel: ammonia
- Skylark: carbon dioxide

https://www.birdguides.com/gallery/birds/alauda-arvensis/1003602/