PROTECTING PEOPLE
AND PLACES

HSE

Carbon Capture Utilisation and Storage (CCUS): Knowledge gaps and ongoing UK activities

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PHMSA Pipeline Safety Research and Development Forum, Arlington, Virginia, USA

31st October 2023

Overview

- Quick introduction to HSE
- Ongoing CCUS infrastructure projects in the UK
- Scientific knowledge gaps
  - Historical perspective
  - Remaining gaps
- Ongoing/proposed joint industry projects
- Summary

PROTECTING PEOPLE AND PLACES

HSE

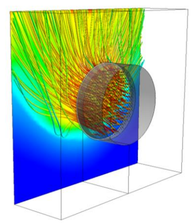
Introduction to HSE

- HSE is the UK regulator for workplace health and safety
  - Includes onshore/offshore pipelines, chemical/oil/gas infrastructure, offshore platforms etc.
  - Activities: evidence gathering, policy development, consultation, regulation, incident investigation, enforcement
  - HSE acts as an enabling regulator, supporting the introduction of new technologies
  - 2,400 total staff
  - £230M ($280M) budget: 60% from Government, 40% from external income

- HSE Science and Research Centre, Buxton, UK
  - 400 staff, 550 acre test site
  - Scientific support to HSE and other Government departments
  - “Shared research” or joint-industry projects co-funded by HSE
  - Bespoke consultancy on a commercial basis

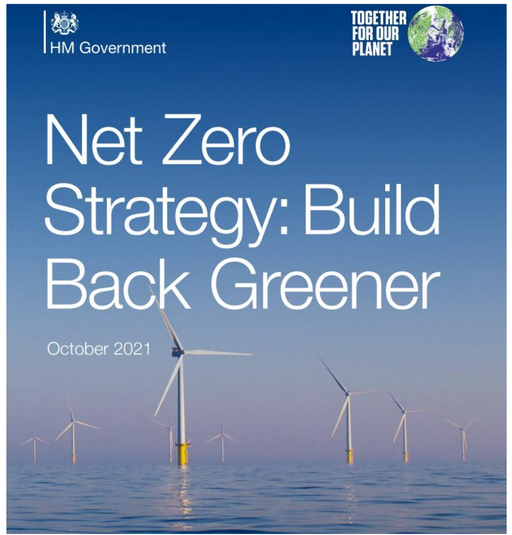






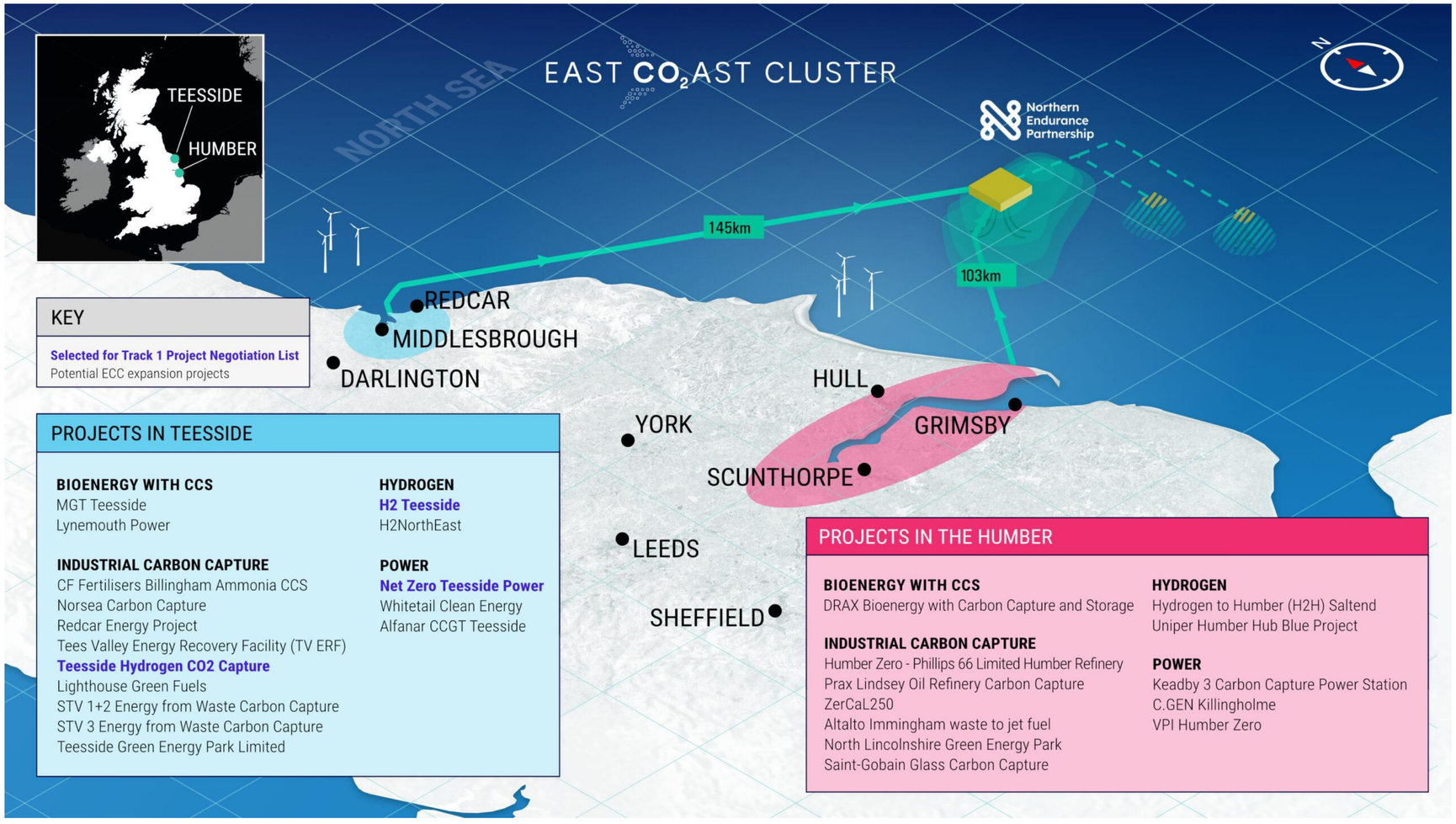
UK CCUS Infrastructure Projects

- **October 2021**: UK Government Net Zero Strategy published[1] with target of four CCUS clusters capturing 20-30 $MtCO_2$ by 2030
- **November 2021**: HyNet and East Coast Cluster selected as Track 1 projects by UK Government
- **March 2023**: UK Government Spring Budget announcement of £20 billion for CCUS over next 20 years
- **July 2023**: UK Government consultation concluded that Track 2 projects will be Acorn and Viking CCS



[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

East Coast Cluster



NEP Partners: BP, Equinor and TotalEnergies

Onshore gas and dense-phase CO_2 pipelines

Two new offshore dense-phase CO_2 pipelines: 16-24 inch diameter

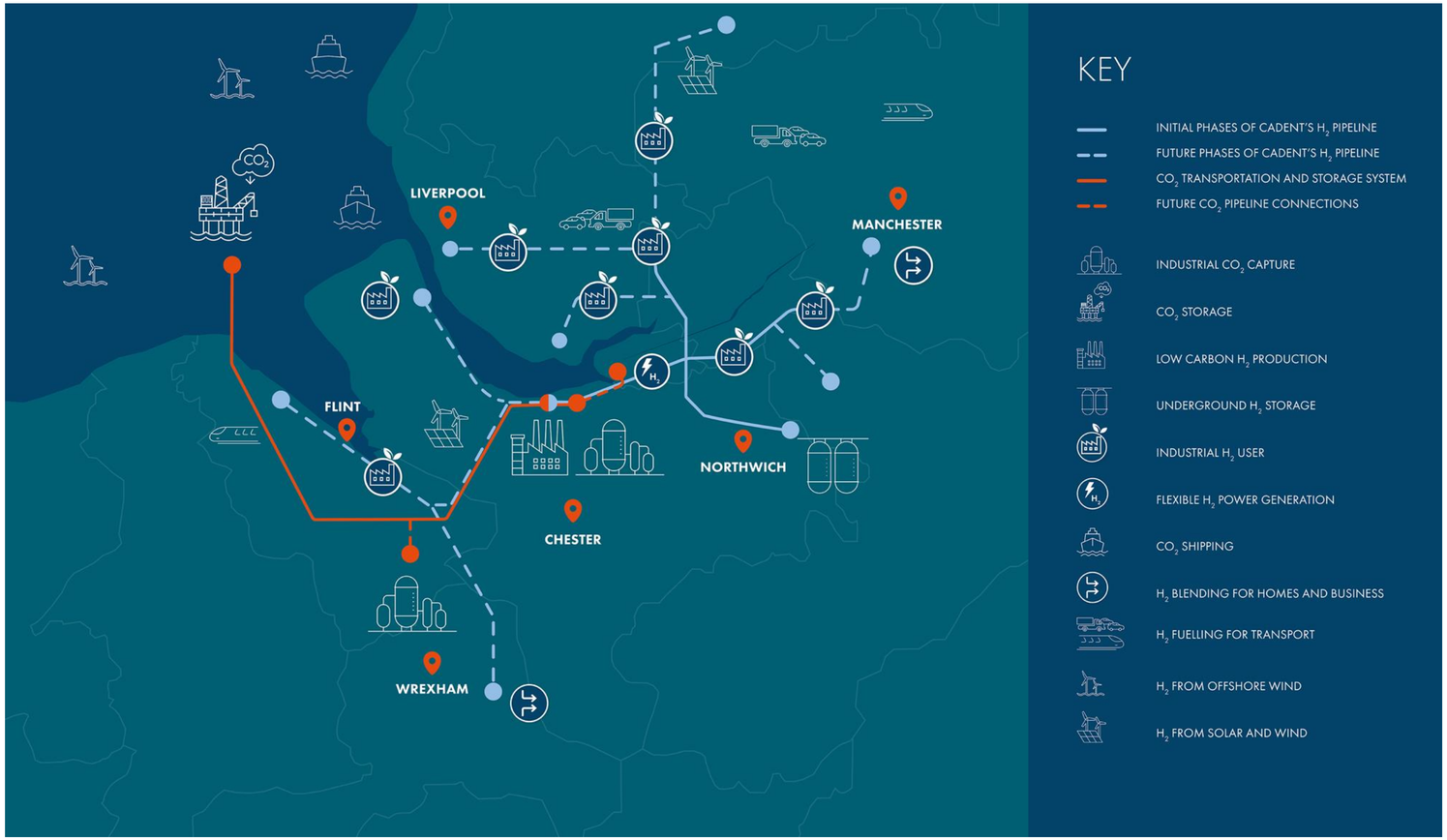
March 2023: Funding awarded for three Track 1 capture plants

Sept 2023: NSTA awarded further licenses to BP and Equinor for 1 GTe CO_2 storage

Due to be operational by 2027

https://eastcoastcluster.co.uk

HyNet



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 approximately 42 bar

Later, transition to dense-phase CO_2 pipelines offshore – compression at the coast

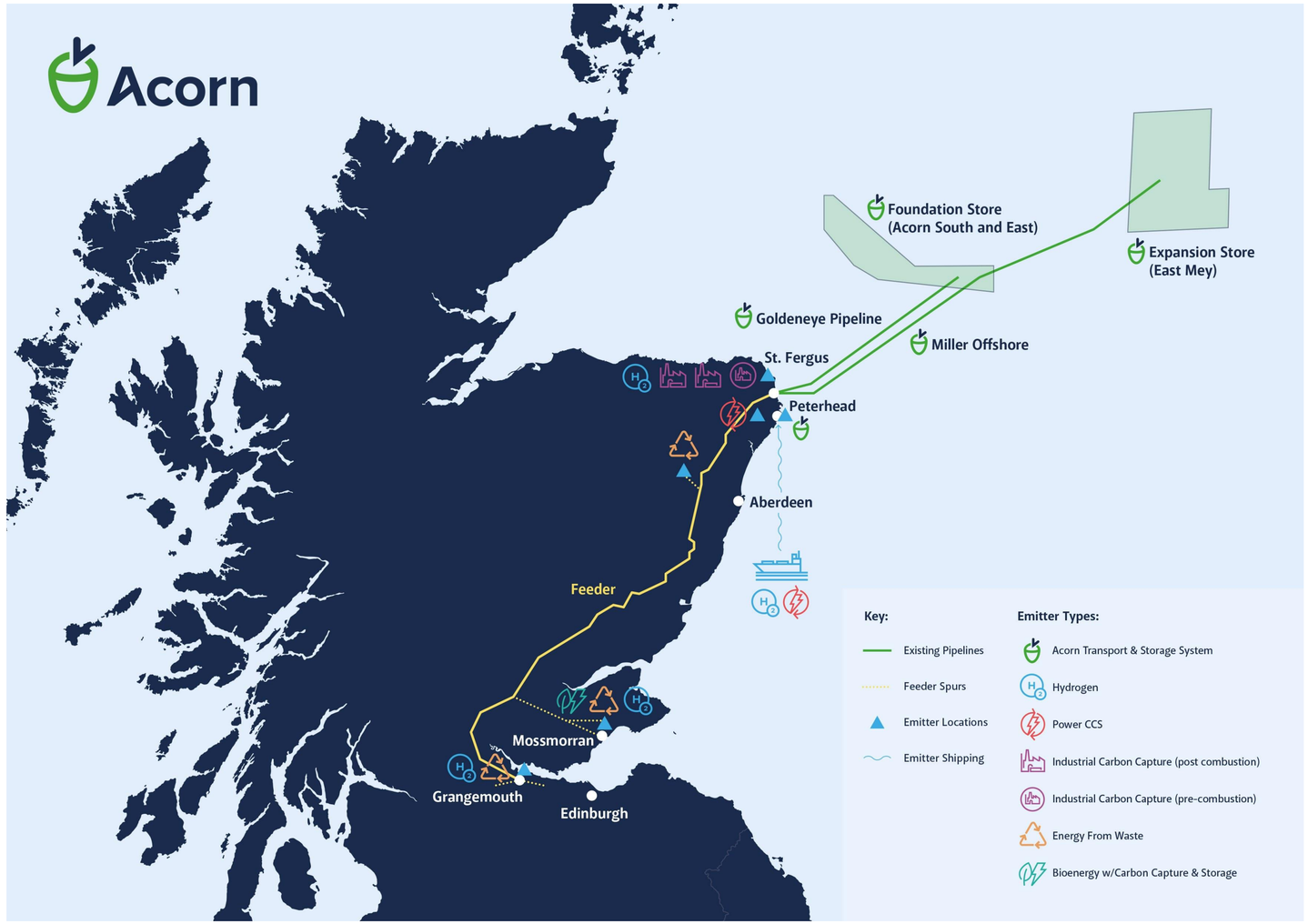
Pipelines: 20”, 24” and 36” diameter, mixture of repurposed and new

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

Acorn



https://www.theacornproject.uk/

Partners: Shell, Harbour Energy, Storegga and North Sea Midstream Partners

Capture plants: St Fergus gas complex, SSE and Equinor Peterhead power station, INEOS Grangemouth blue hydrogen plant, ExxonMobil/Shell's Mossmorran facilities

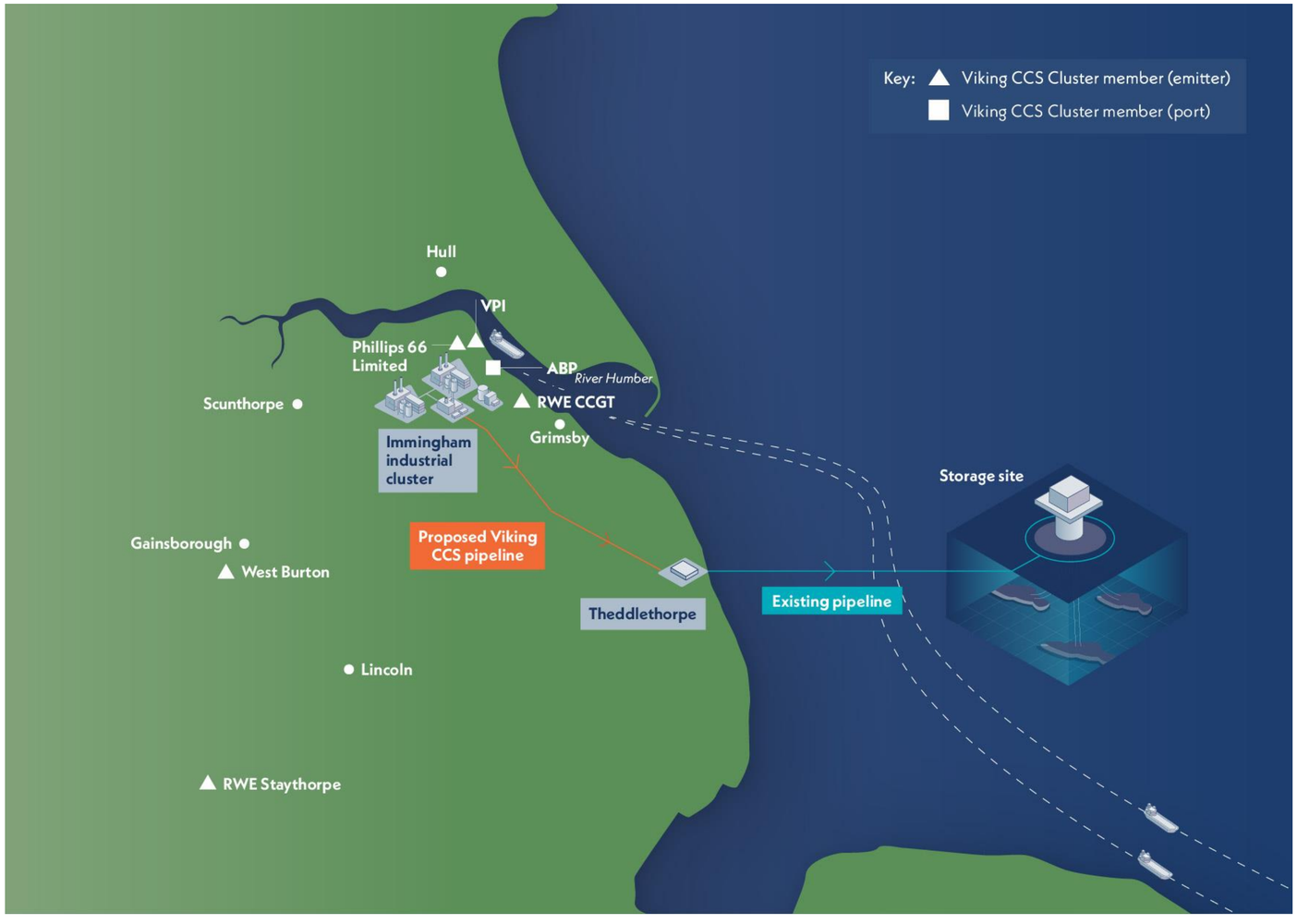
Repurposing of onshore Feeder 10 natural gas pipeline for CO_2 transport

Repurposing of existing Goldeneye, Miller or Atlantic pipelines for CO_2 transport

Final investment decision in 2024

Planned to store at least 5Mt/yr of CO_2 by 2030

Viking CCS



Partners: BP and Harbour Energy

Onshore: new 30 mile dense-phase CO_2 pipeline

Offshore: repurposing existing 70 mile offshore pipeline and new 10 mile spur line

Final investment decision in 2024

Planned to store at least 10Mt/yr of CO_2 by 2030

https://www.vikingccs.co.uk/

Initial CCUS safety concerns

IChemE SYMPOSIUM SERIES NO. 153

HAZARDS FROM HIGH PRESSURE CARBON DIOXIDE RELEASES DURING CARBON DIOXIDE SEQUESTRATION PROCESSES†

Stephen Connolly[1] and Laurence Cusco[2]

12th International Symposium on Loss Prevention and Safety Promotion in the Process Industries, Loss Prevention 2007, Edinburgh, UK, 22 - 24 May, 2007

https://www.icheme.org/media/17864/cusco_connolly_2007_hazards_from_co2.pdf

Uncertainties:

- Dispersion modelling of (liquid/solid + gas) CO_2 jet releases: how does it behave? Can we predict extent of hazardous zones?
- Implications of severe Joule-Thomson cooling (embrittlement?)
- Solid CO_2 implications for blowdown (blocking valves?)
- Solid CO_2 particles scouring and erosion (jet cleaning and cutting)
- Solid CO_2 deposition as dry-ice bank (prolonged sublimation)
- Running ductile crack propagation along dense-phase CO_2 pipelines
- Equation of state for CO_2 + impurities for flow assurance modelling
- Corrosion issues: CO_2 + water = carbonic acid, effects of other impurities

Remaining CO_2 knowledge gaps

- Fracture propagation
  - Brittle fracture due to cooling of CO_2 release that changes the fracture behaviour of steel from ductile to brittle: growth of small punctures into ruptures?
  - Long-running ductile fractures for supercritical CO_2 due to net decompression speed of the fluid < fracture propagation speed along the pipe
  - Difficult to determine requirements, particularly if impurities are present
  - More work done on dense-phase than gaseous; therefore, less certainty in fracture arrest requirements for gaseous CO_2
  - Recent publications on running ductile fractures:
    - Skarsvåg *et al*. (2023) “Towards an engineering tool for the prediction of running ductile fractures in CO_2 pipelines” Process Safety and Environmental Protection 171 (2023) 667–679. https://doi.org/10.1016/j.psep.2023.01.054
    - Cosham *et al*. (2022) “The decompressed stress level in dense phase carbon dioxide full-scale fracture propagation tests”. Proceedings of the 14th International Pipeline Conference IPC2022, 26-30 Sept 2022, Calgary, Canada
  - Revision of guidance in DNV-RP-F104 and ISO 27913 (TC/265)?
  - Further CO_2 pipeline rupture experiments to inform guidance?

Remaining CO_2 knowledge gaps

- Fracture tests
  - Uncertainty around suitability of Charpy impact test and Drop-Weight Tear Test (DWTT) to predict fracture resistance

- Corrosion highly dependent on presence of free water
  - If water present, other impurities (NOx, SOx) can increase likelihood of corrosion
  - What to do in case of process upset (e.g., CO_2 composition outside specification)?
  - Inspection and maintenance regimes?

Remaining CO_2 knowledge gaps

- Venting
  - Dry-ice possible for both gas and dense-phase CO_2 releases
  - Reported that dry-ice has blocked pipeline valves in their open position
  - What valves and/or operating procedures should be used?
  - Venting on offshore platforms: downwards from underside of platform?

- Pipeline risk assessment
  - Terrain effects: heavier-than-air CO_2 cloud flowing downhill, collecting in low areas
  - Issues with dispersion models used for risk assessment and emergency planning
    - Crater source: uncertainty (correlations based on just two experiments)
    - Need to develop fast-running dispersion models that can simulate terrain effects
  - Need experimental data to develop, test and validate these models

Remaining CO_2 knowledge gaps

- Offshore risk assessment
  - Consequences of subsea CO_2 pipeline release or well blowout
    - How much CO_2 is absorbed into the water column?
    - Characteristics of rising plume and zone affected on sea surface
- Emergency Response
  - Onshore: learning lessons from Satartia Incident
    - e.g., use of electric vehicles to evacuate casualties?
    - Coordination between pipeline operators and emergency services
  - Offshore
    - Potential impact of dense CO_2 clouds on floating support vessels, ingress of CO_2 into lifeboats
    - Detection and emergency control systems on platforms handling both hydrocarbons and CO_2

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Skylark CO_2 Joint Industry Project

- Aims
  - To undertake dispersion experiments on CO_2 pipeline releases and venting, including releases from craters and dispersion in sloping/complex terrain
  - To run joint collaborative model validation exercises
  - To improve emergency preparedness and support first responders
- Work Packages
  - CO_2 pipeline craters and source terms – **DNV**
  - Wind-tunnel experiments – **University of Arkansas**
  - Simple terrain dispersion experiments – **DNV**
  - Complex terrain dispersion experiments – **DNV**
  - Model inter-comparison and validation – **HSE**
  - Emergency response – **NCEC**
  - Venting – **DNV**

UNIVERSITY OF ARKANSAS COLLEGE OF ENGINEERING

DNV

HSE

Met Office

NCEC RICARDO

Cost: approximately $12m
(support of $6m from UK Government)
Timeline: start in summer 2024 for 3 years
Contacts: simon.gant@hse.gov.uk
daniel.allason@dnv.com

SubCO$_2$ DNV Joint Industry Project

- Aims: to improve our understanding of subsea dense-phase CO_2 releases
- Experiments planned at 40 m water depth in sea loch at Fort William, Scotland
- Dense-phase releases of 20-40 tonnes CO_2 through submerged pipeline
- Partners invited to join the JIP at an introductory meeting held in Sept 2023

Background – previous phases

- Underwater CO_2 Releases have been done at depths of 3 meters (Phase 1) and 10 meters (Phase 2) in 2016.
- Releases at a depth of 40 meters (Phase 3) are proposed.

Phase 1 – 3 meters

Phase 2 – 10 meters

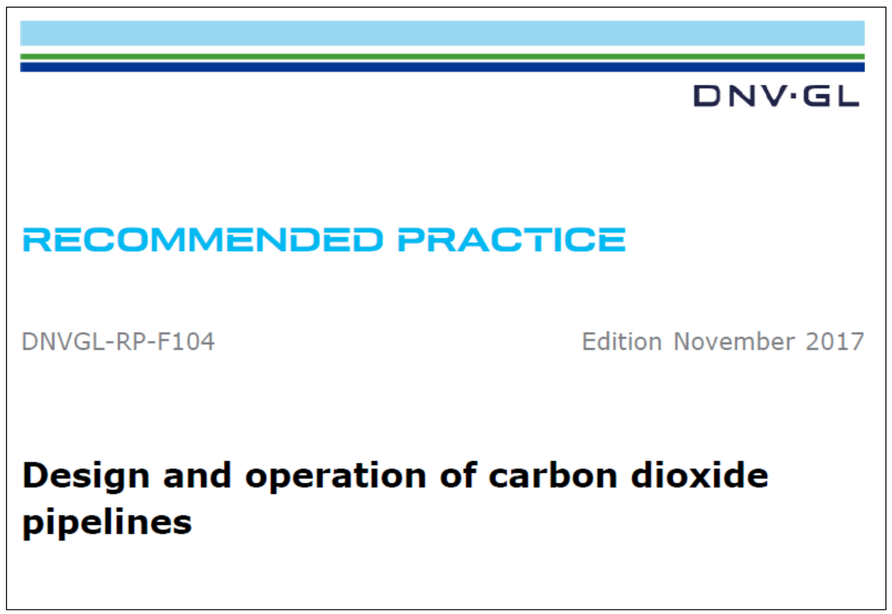
5 DNV ©

Contact: andy.cummings@dnv.com

DNV

CO_2SafePipe DNV Joint Industry Project

- Aims
  - To close knowledge gaps identified in the transportation of CO_2 in pipelines
  - Includes consideration of both gas and dense phase CO_2
  - Assess the effect of CO_2 stream composition on corrosion and materials, and the risk of running ductile fracture
  - Update the recommended practice DNV-RP-F104



https://www.dnv.com/article/design-and-operation-of-co2-pipelines-co2safepipe-240345

Summary

- CO_2 pipeline knowledge gaps
  - Limited operational experience compared to natural gas pipelines
  - Issues are common internationally: benefits in working collaboratively
  - Some work underway and/or proposed to address the gaps
  - We would be interested to hear about any other work aimed at filling these gaps

- Are cautious approaches necessary in the short term?
  - Do we need clarity on this interim guidance?

- Further details of Skylark JIP provided in breakout session

Thank you for listening

- Contact: simon.gant@hse.gov.uk, zoe.chaplin@hse.gov.uk

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