RESEARCH AND GUIDANCE FROM HSE

Carbon Capture and Storage (CCS): Scientific knowledge gaps and regulation

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Health and Safety Executive (HSE)

UKCCSRC webinar on “Regulating UK CCS deployment – experience to date and research needs”, 6 July 2023

Research - HSE funded to provide evidence which underpins its policy and regulatory activities
Guidance - freely available to help people comply with health and safety law

Overview

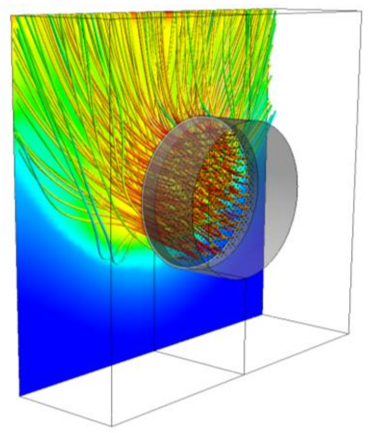
- Quick introduction to HSE
- Scientific knowledge gaps
  - Historical perspective
  - Remaining gaps
  - Proposed CO_2 dispersion project
  - Some key standards and recommended practice
- Regulation
  - Regulatory framework: onshore, offshore
- Summary

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 (€260M) 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

Initial 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

- Failure rates
  - 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?
  - Fracture propagation
    - Brittle fractures due to rapid cooling of CO_2 on decompression that changes fracture behaviour of steel from ductile to brittle
    - Long-running ductile fractures for supercritical CO_2 due to net decompression speed of the fluid < fracture propagation speed along the pipe

Remaining CO_2 knowledge gaps

- Fracture arrest
  - 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
  - Existing methods to predict crack arrest in natural gas pipelines (Battelle Two Curve Method) are not conservative for dense-phase CO_2
- Fracture tests
  - Uncertainty around suitability of Charpy impact test and Drop-Weight Tear Test (DWTT) to determine fracture resistance

Remaining CO_2 knowledge gaps

- Fracture arrest
  - 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?
  - Further CO_2 pipeline rupture experiments to inform guidance?

Remaining CO_2 knowledge gaps

- Dry-ice formation
  - Dry-ice possible for both gaseous and dense-phase releases
  - Reported to have blocked pipeline valves in their open position
  - Could dry-ice block parts of the pipeline and/or valves?
  - What valves and/or operating procedures should be used?

- Terrain effects
  - CO_2 cloud denser than air so affected by gravity
  - CO_2 cloud will tend to follow local terrain, accumulating in dips and hollows

Remaining CO_2 knowledge gaps

- Terrain effects (continued)
  - Satartia CO_2 dense-phase pipeline incident demonstrated that toxic hazard could extend large distances from a pipeline (~ 1 mile?)
  - Fast-running dispersion models (e.g., Phast) unable to simulate effects of sloping terrain
  - CFD models can in principle simulate terrain, but require long computer run times: impractical for assessing risks of long pipelines
  - For both CFD and fast dispersion models: lack of experimental data to validate models for dense-gas dispersion in sloping terrain. Can we trust the model predictions?

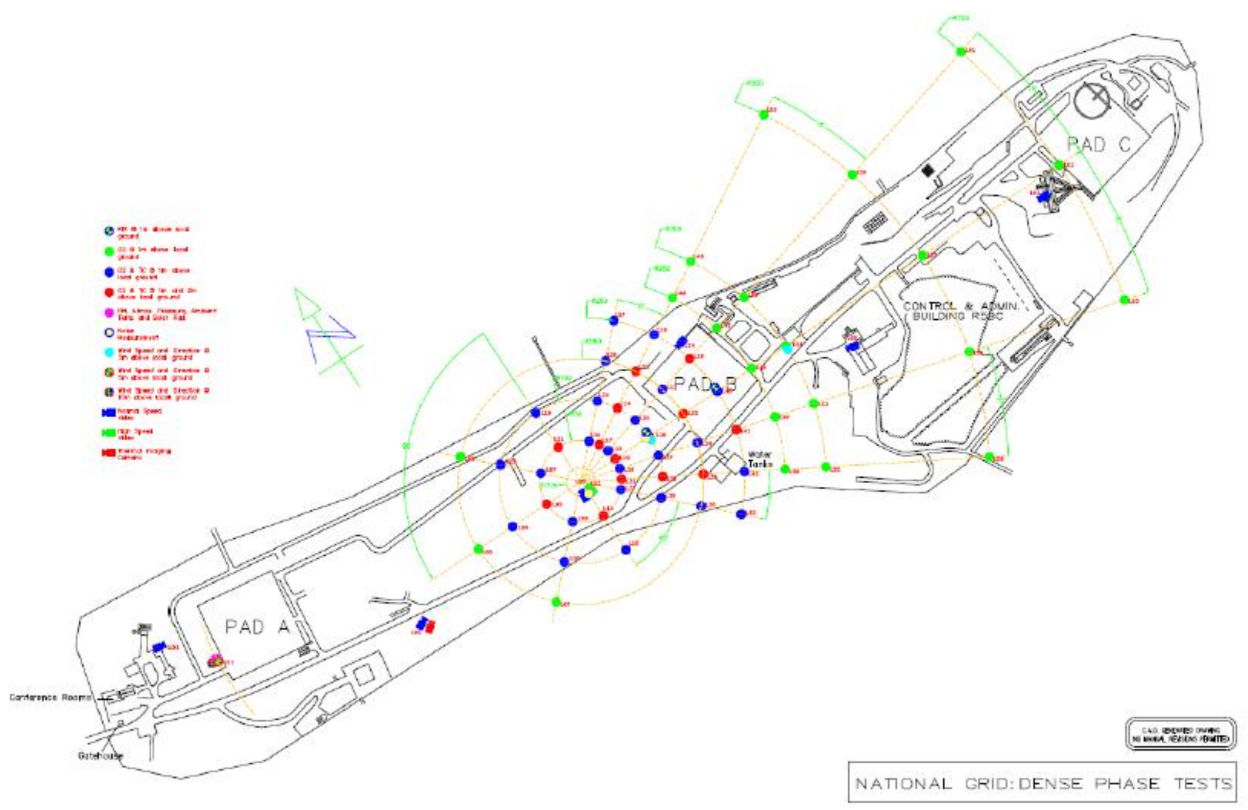
Proposed future Joint-Industry Project on CO_2 dispersion

- Aims:
  - To undertake field-scale experiments on dispersion of CO_2 from pipeline releases in sloping/complex terrain, to provide data for model validation
  - To develop and validate fast-running dispersion models that can be used for pipeline risk assessment and emergency planning/response
  - To improve our understanding of CO_2 pipeline risks

- Four work packages:
  1. CO_2 pipeline craters and source terms
  2. Simple terrain dispersion experiments
  3. Complex terrain dispersion experiments
  4. Model development and validation

Proposed future Joint-Industry Project on CO_2 dispersion

- Proposed to use complementary capabilities of two UK test sites:
  - DNV Spadeadam: previous experience with CO2 pipeline puncture/rupture tests, remote location, complex terrain
  - DSTL Porton Down: atmospheric dispersion test site (e.g., Picknett trials), two large open grassland bowls several hundred metres across (steep and shallow uniform slopes)
- Aim to have open and collaborative approach to model development and testing, similar to the Jack Rabbit project



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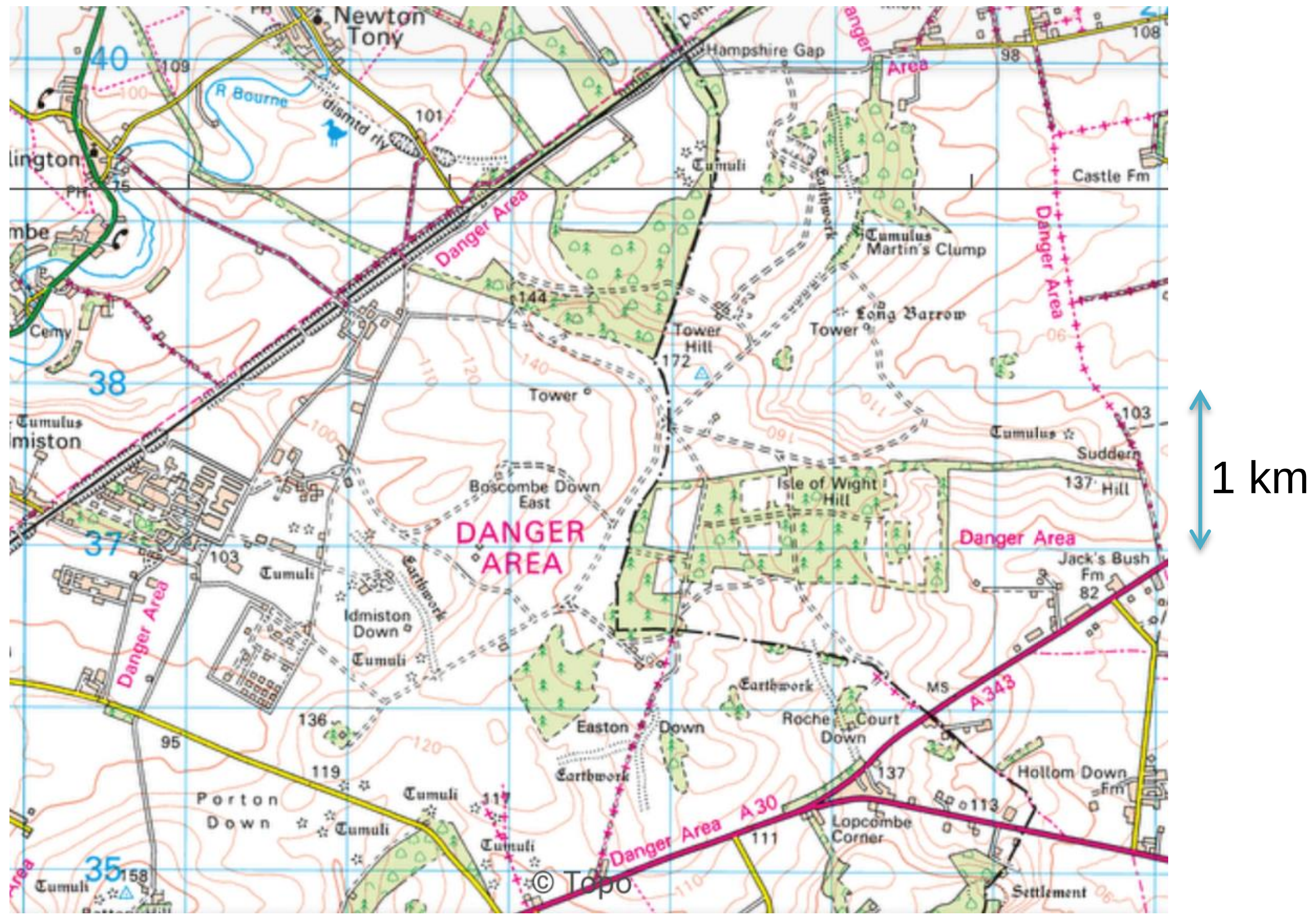

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Some key standards and recommended practice

- ISO Technical Committee ISO/TC 265 “Carbon dioxide capture, transportation, and geological storage”

Filter : ☐ Published ☑ Under development ☐ Withdrawn ☐ Deleted   Search in the list

Standard and/or project under the direct responsibility of ISO/TC 265 Secretariat (7)	Stage	ICS
ISO/CD 27913 Carbon dioxide capture, transportation and geological storage — Pipeline transportation systems	30.20	13.020.40
ISO/AWI 27914 Carbon dioxide capture, transportation and geological storage — Geological storage	20.00	
ISO/AWI TR 27925 Flow Assurance	20.00	
ISO/AWI TR 27926 Carbon dioxide enhanced oil recovery (CO2-EOR) - Transitioning from EOR to storage	20.00	
ISO/AWI 27927 Carbon dioxide capture, transportation and geological storage — Key performance parameters and characterization methods of absorption liquids for post-combustion CO2 capture	20.00	
ISO/AWI 27928 Carbon dioxide capture, transportation and geological storage — Performance evaluation methods for CO2 capture plants connected with CO2 intensive plants	20.00	
ISO/AWI TR 27929 Transportation of CO2 by ship	20.00	

Some key standards and recommended practice

energy INSTITUTE

TECHNICAL GUIDANCE ON HAZARD ANALYSIS FOR ONSHORE CARBON CAPTURE INSTALLATIONS AND ONSHORE PIPELINES

A guidance document

1st edition

September 2010

GOOD PLANT DESIGN AND OPERATION FOR ONSHORE CARBON CAPTURE INSTALLATIONS AND ONSHORE PIPELINES

A Recommended Practice Guidance Document

First edition

September 2010

CCSa Carbon Capture & Storage Association

GLOBAL CCS INSTITUTE

Currently being revised

https://publishing.energyinst.org/topics/process-safety/risk-assessment/technical-guidance-on-hazard-analysis-for-onshore-carbon-capture-installations-and-onshore-pipelines

https://publishing.energyinst.org/topics/process-safety/risk-assessment/good-plant-design-and-operation-for-onshore-carbon-capture-installations-and-onshore-pipelines

Some key standards and recommended practice

DNV·GL

RECOMMENDED PRACTICE

DNVGL-RP-F104 Edition November 2017

Design and operation of carbon dioxide pipelines

- Previous version: DNVGL-RP-J202, Edition July 2017
- DNV CO2SafePipe JIP?

Some key standards and recommended practice

- BS PD 8010 – Pipeline systems

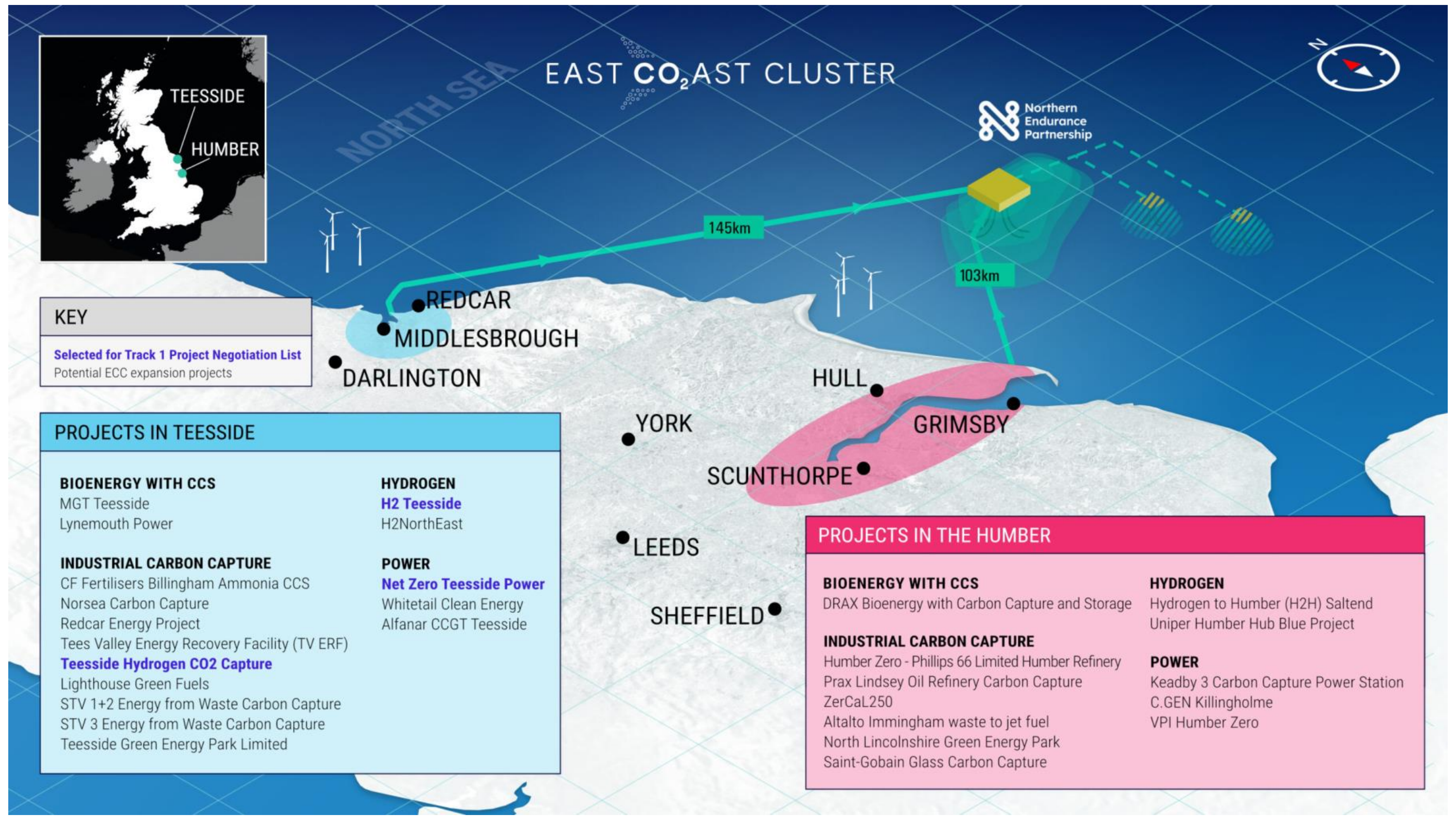
- Pipeline Research Council International (PRCI) due to publish review of CO_2 pipeline operational practice in Summer 2023
  - Work led by RINA

Conclusions

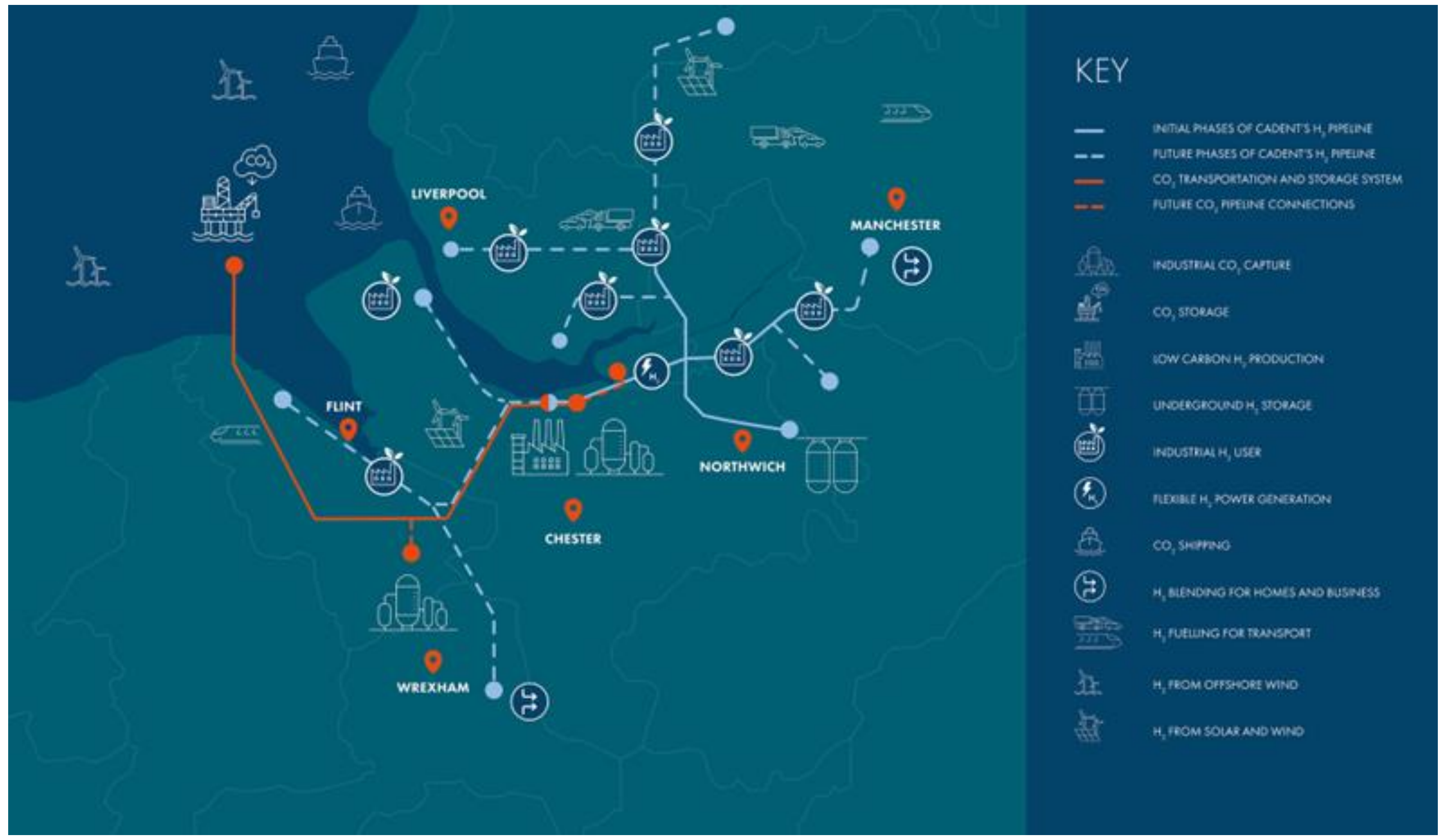
- Knowledge gaps exist for CO_2 pipelines
  - Therefore: uncertainties in risk predictions
- Limited operational experience to fill the gaps
- Issues are international: benefits in working collaboratively
- Some work underway to address the gaps
- We would be interested to hear about any work aimed at filling these gaps
- Conservative approaches necessary in the short term?
- Please contact us if you are interested in participating in the proposed JIP on dispersion of CO_2 in complex terrain

Regulating CCS deployment

- The Health and Safety Executive is responsible for regulating the health and safety of carbon capture, usage and storage (CCUS) operations, both on and offshore.



https://eastcoastcluster.co.uk/



https://hynet.co.uk/about/

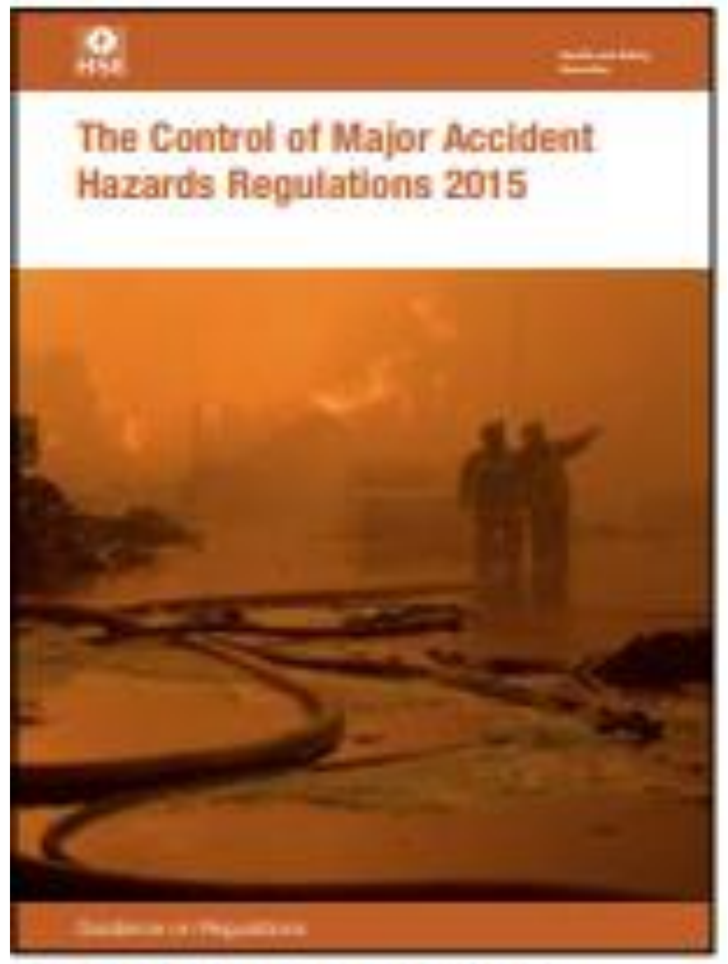
Existing regulatory framework

- **Health & Safety at Work etc Act 1974**
- The Health and Safety at Work etc Act 1974 is the primary piece of legislation covering occupational health and safety in Great Britain. It's sometimes referred to as HSWA, the HSW Act, the 1974 Act or HASAWA.
- It sets out the general duties which:
- employers have towards employees and members of the public
- employees have to themselves and to each other
- certain self-employed have towards themselves and others

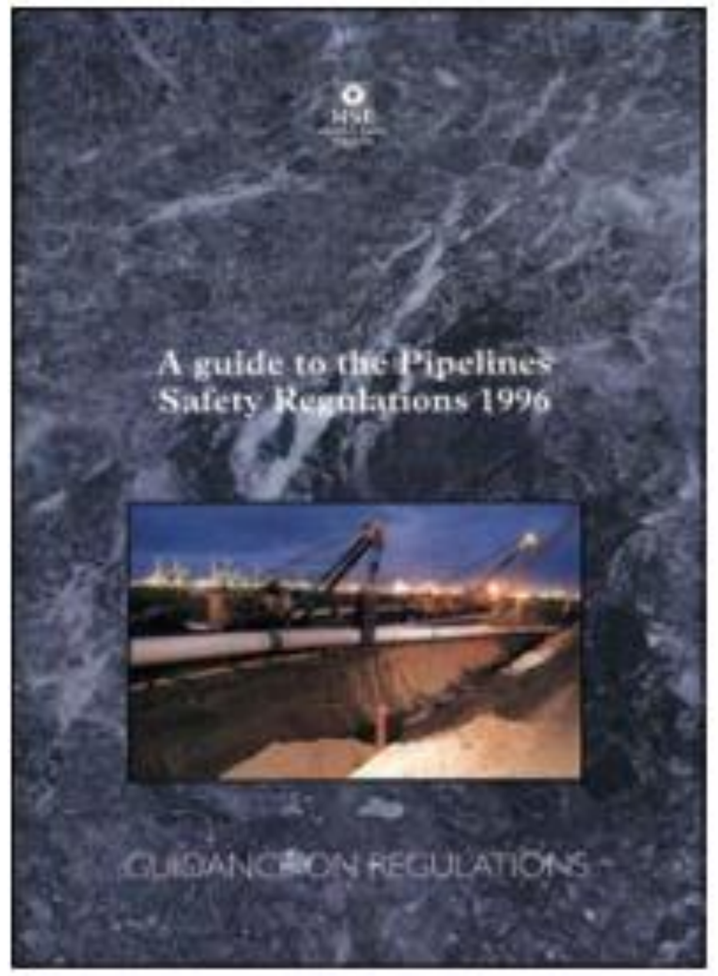
- Number of Statutory Instruments (SI). Regulations covering design, construction, operation, maintenance etc under the umbrella of the Act.

Onshore

- Control of Major Accident Hazards (COMAH) Regulations 2015
- Pipeline Safety Regulations (PSR) 1996



L111 (Third edition) Published 2015

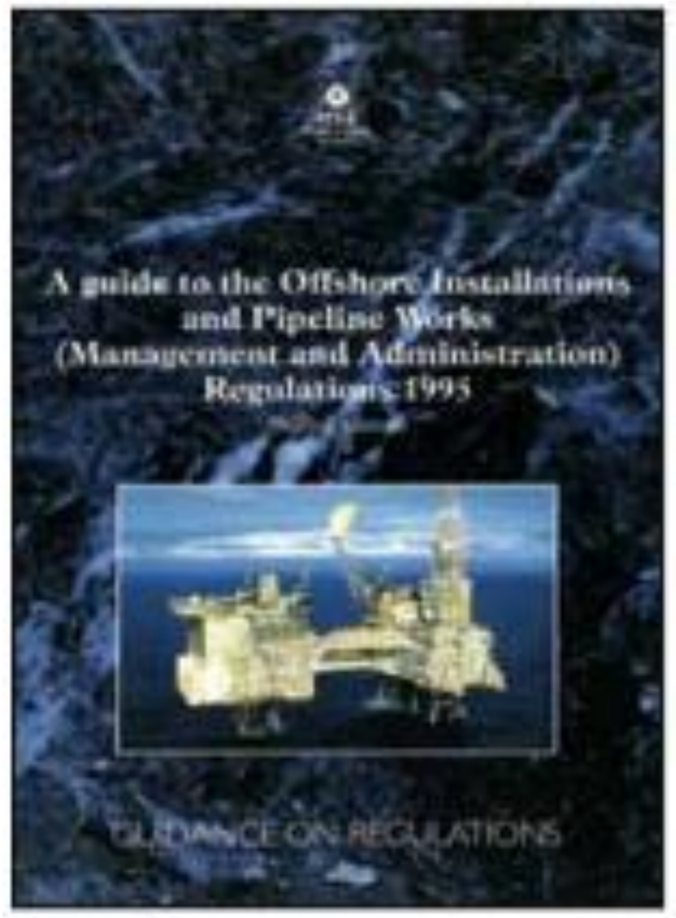


L82 (First edition, published 1996)

Offshore

- The Offshore Installations (Offshore Safety Directive)(Safety Case etc) Regulations 2015
- The Offshore Installations and Pipeline Works (Management and Administration) Regulations 1995 (MAR)

L154 (First edition)
Published 2015



L70, (Second edition, published 2002)

Regulatory challenges

- HSE is working to understand the health and safety risks associated with CCUS operations, including CO_2 in its different phases.

- HSE's regulatory assessment indicates that existing offshore legislation may apply to the transport and sequestration of CO_2 offshore, however the exact arrangements of the operation may impact on how the regulations apply. HSE is considering potential regulatory amendments to clarify the application to CO_2 operations offshore.

Thank you for listening

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