# Health and Safety Executive

- Aim of HSE involvement in UKCCSRC meetings, 31 Jan – 3 Feb 2022
  - To re-engage with the CCUS research community
  - To understand what research has been ongoing on CCUS in the last 5 years
  - To see whether previously identified safety-related knowledge gaps have been filled
  - To identify any other safety-related issues across the full chain (capture, transport, utilization/storage) with which HSE should engage
- Presentation by Trevor Sexty (HSE) at CCSA on 16 Sept 2021 on “Regulation of transport and underground storage of carbon dioxide” – available on request
- Contact details:
  - Simon Gant: simon.gant@hse.gov.uk
  - Catherine Spriggs: catherine.spriggs@hse.gov.uk
  - Adam Chisholm: adam.chisholm@hse.gov.uk


© Crown Copyright HSE 2022

RESEARCH AND GUIDANCE FROM HSE

# Overview of Previous CCUS Research and Remaining Knowledge Gaps

Simon Gant and Catherine Spriggs

## UKCCSRC Industry and policy led ‘what are our research needs’ workshop on Environmental impacts (including Health and Safety), 1 February 2022

**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

# Initial safety concerns

IChemE SYMPOSIUM SERIES NO. 153

© 2007 Crown Copyright

**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 $CO_2$ pipelines
- Equation of state for $CO_2$ + impurities for flow assurance modelling
- Corrosion issues



© Crown Copyright HSE 2022

# Carbon dioxide incidents

- Onshore well-head blowout in Hungary, 1998
- 207 bar release of $CO_2$ and $H_2S$
- 5,000 people evacuated, no significant injuries or fatalities
- Solid $CO_2$ snow bank 1.5 – 2 metres thick, -30 °C near release point

https://publishing.energyinst.org/__data/assets/file/0006/71394/Guidance-on-HA-for-onshore-CCS-installations-WEB-VERSION.pdf

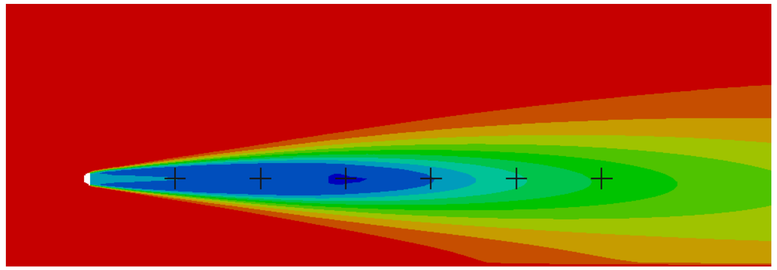


© Crown Copyright HSE 2022

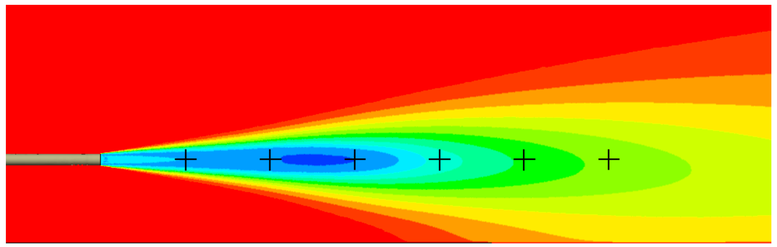
# CCS research over the period from 2007 - 2017

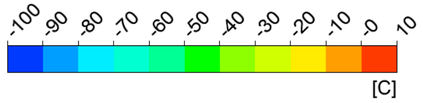
Experiments (DNV)

OpenFOAM (Shell)



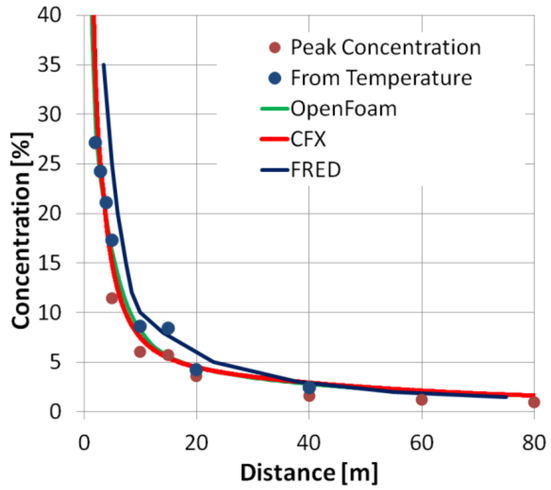
CFX (HSL)

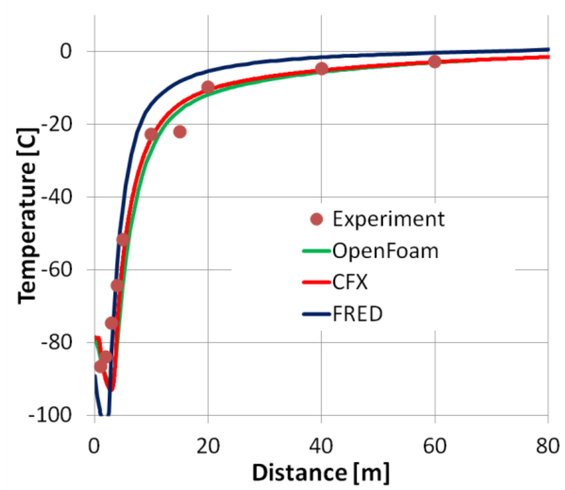





Images copyright Shell / DNV

Dense-phase $CO_2$ jet experiments at DNV Spadeadam funded by Shell




Dixon C.M., Gant S.E., Obiorah C. and Bilio M. "*Validation of dispersion models for high pressure carbon dioxide releases*" IChemE Hazards XXIII Conference, Southport, UK, 12-15 November 2012



© Crown Copyright HSE 2022

# CCS research over the period from 2007 - 2017

COOLTRANS
Research Programme

Proceedings of the 2014 10th International Pipeline Conference
IPC2014
September 29 - October 3, 2014, Calgary, Alberta, Canada

IPC2014-33370

## THE COOLTRANS RESEARCH PROGRAMME – LEARNING FOR THE DESIGN OF $CO_2$ PIPELINES

**Julian Barnett**
National Grid Carbon
Solihull, UK

**Russell Cooper**
National Grid Carbon
Solihull, UK

## Crater size and its influence on releases of CO2 from buried pipelines

by Philip Cleaver[1], Ann Halford[1], Karen Warhurst[1], and Julian Barnett[2]
1 GL Noble Denton, Loughborough, UK
2 National Grid Carbon, Warwick, UK

4th International Forum on the Transportation of CO2 by Pipeline

Hilton Gateshead-Newcastle Hotel, Gateshead, UK
19-20 June, 2013

© Crown Copyright HSE 2022

Proceedings of the 2016 11th International Pipeline Conference
IPC2016
September 26-30, 2016, Calgary, Alberta, Canada

IPC2016-64456

## ANALYSIS OF A DENSE PHASE CARBON DIOXIDE FULL-SCALE FRACTURE PROPAGATION TEST IN 24 INCH DIAMETER PIPE

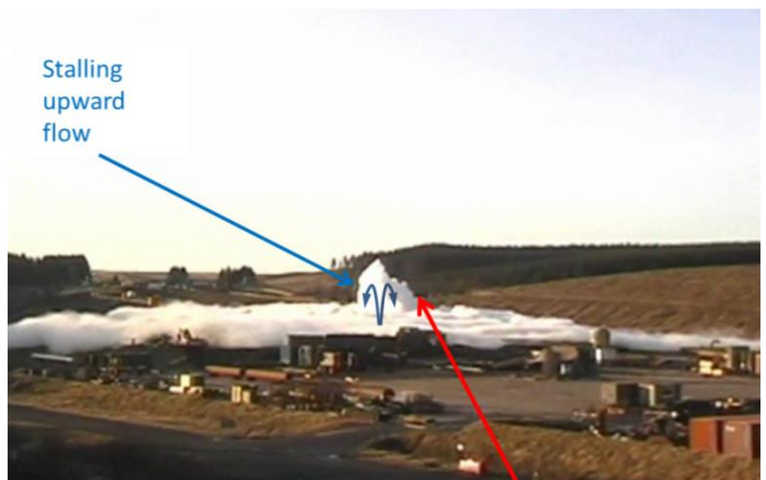
**Andrew Cosham**
Ninth Planet Engineering
Newcastle upon Tyne, UK

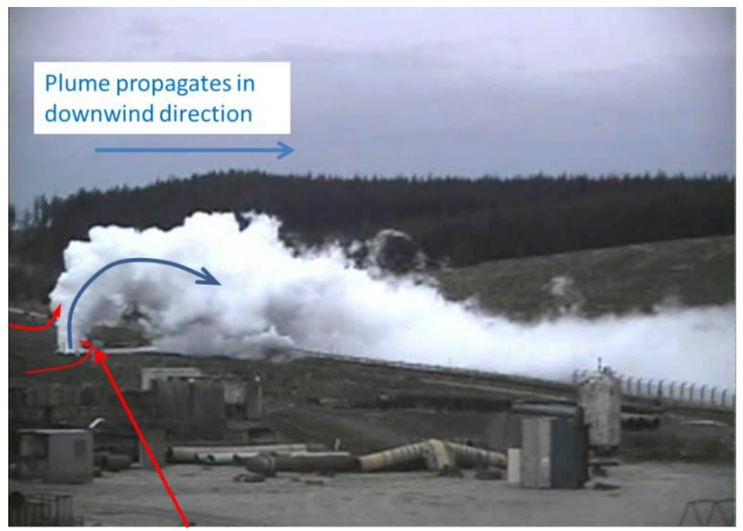
**David G Jones**
Pipeline Integrity Engineers
Newcastle upon Tyne, UK

**Keith Armstrong**
DNV GL
Spadeadam Test & Research Centre, UK

**Daniel Allason**
DNV GL
Spadeadam Test & Research Centre, UK

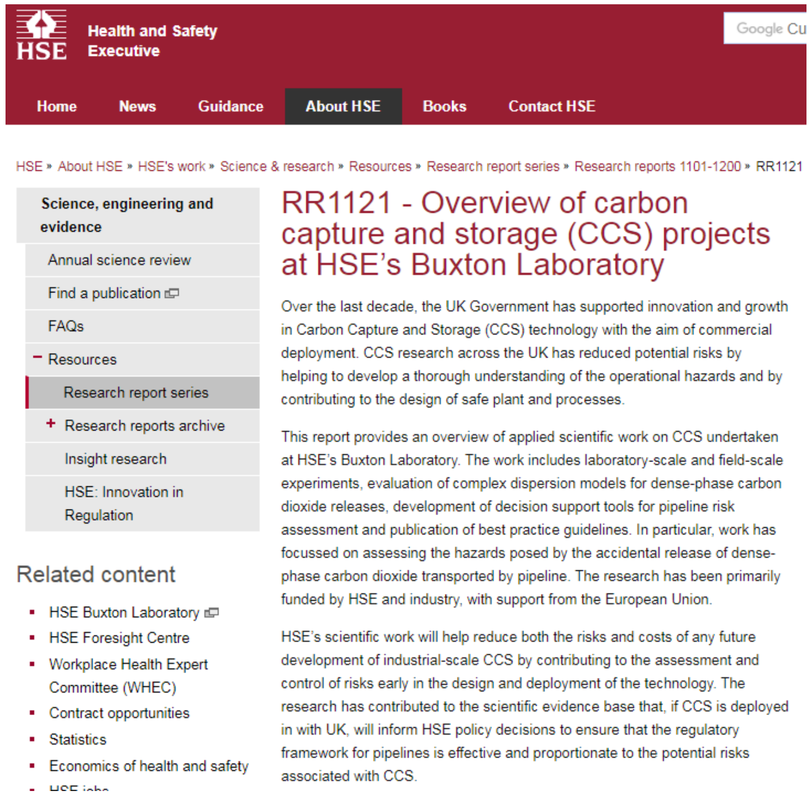
**Julian Barnett**
National Grid
Solihull, UK




Images copyright National Grid / DNVGL

# CCS research over the period from 2007 - 2017



Health and Safety Executive

Google Cu

Home | News | Guidance | About HSE | Books | Contact HSE

HSE » About HSE » HSE's work » Science & research » Resources » Research report series » Research reports 1101-1200 » RR1121

Science, engineering and evidence
- Annual science review
- Find a publication
- FAQs
- − Resources
  - Research report series
  - + Research reports archive
  - Insight research
  - HSE: Innovation in Regulation

Related content
- HSE Buxton Laboratory
- HSE Foresight Centre
- Workplace Health Expert Committee (WHEC)
- Contract opportunities
- Statistics
- Economics of health and safety

## RR1121 - Overview of carbon capture and storage (CCS) projects at HSE's Buxton Laboratory

Over the last decade, the UK Government has supported innovation and growth in Carbon Capture and Storage (CCS) technology with the aim of commercial deployment. CCS research across the UK has reduced potential risks by helping to develop a thorough understanding of the operational hazards and by contributing to the design of safe plant and processes.

This report provides an overview of applied scientific work on CCS undertaken at HSE's Buxton Laboratory. The work includes laboratory-scale and field-scale experiments, evaluation of complex dispersion models for dense-phase carbon dioxide releases, development of decision support tools for pipeline risk assessment and publication of best practice guidelines. In particular, work has focussed on assessing the hazards posed by the accidental release of dense-phase carbon dioxide transported by pipeline. The research has been primarily funded by HSE and industry, with support from the European Union.

HSE's scientific work will help reduce both the risks and costs of any future development of industrial-scale CCS by contributing to the assessment and control of risks early in the design and deployment of the technology. The research has contributed to the scientific evidence base that, if CCS is deployed in with UK, will inform HSE policy decisions to ensure that the regulatory framework for pipelines is effective and proportionate to the potential risks associated with CCS.

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

## CONTENTS


1 INTRODUCTION ..... 1

2 HSE RESEARCH PROJECTS ..... 2
2.1 Assessment of the major hazard potential of $CO_2$ ..... 2
2.2 Comparison of risks from $CO_2$ and natural gas pipelines ..... 4
2.3 Concentration fluctuations and toxic load ..... 6
2.4 Sensitivity analysis of $CO_2$ jet dispersion models ..... 7
2.5 Validation of CFD dispersion models with Shell ..... 9
2.6 Integral modelling of $CO_2$ pipeline outflow and dispersion ..... 10
2.7 Flammability of hydrocarbon and $CO_2$ mixtures ..... 11
2.8 Experimental work at HSL ..... 13

3 $CO_2$PIPEHAZ ..... 18
3.1 Objectives ..... 18
3.2 Partners ..... 18
3.3 Dispersion modelling ..... 19
3.4 Decision support ..... 20
3.5 Conclusions ..... 21
3.6 Impact ..... 22

4 COOLTRANS ..... 23
4.1 Background ..... 23
4.2 Partners ..... 23
4.3 Objectives ..... 24
4.4 Model Evaluation Protocol (MEP) ..... 24
4.5 Conclusions ..... 25
4.6 Impact ..... 25

5 CO2PIPETRANS ..... 26
5.1 Background ..... 26
5.2 Participants ..... 26
5.3 Methodology ..... 26
5.4 JIP progress ..... 27
5.5 HSE and HSL involvement ..... 27
5.6 Impact ..... 27

6 SHERPA CONSULTING REPORT ON $CO_2$ PIPELINES ..... 28

7 IEA GHG REPORT ..... 29
7.1 Background ..... 29
7.2 Objectives ..... 29
7.3 Methodology ..... 29
7.4 Conclusions ..... 29

8 DECATUR PROJECT ..... 31
8.1 Background ..... 31
8.2 Objectives ..... 31

9 PROGRESSIVE ENERGY PROJECT ..... 32
9.1 Background ..... 32
9.2 Objectives ..... 32
9.3 Methodology ..... 32
9.4 Conclusions ..... 32
9.5 Impact ..... 32

10 RWE-NPOWER PROJECT ..... 33
10.1 Background ..... 33
10.2 Objectives ..... 33
10.3 Methodology ..... 33
10.4 Conclusions ..... 33

11 CONCLUSIONS ..... 34

12 REFERENCES ..... 35




© Crown Copyright HSE 2022

# Remaining Knowledge Gaps?

- Capture plant
  - Do we understand the risks from toxic amines, nitrosamines etc.?
- Pipeline design
  - Is there a validated model for predicting running ductile crack propagation along $CO_2$ pipelines that can be used to specify material toughness and/or crack arrester requirements?
  - Do we understand corrosion regimes (e.g. non-dry $CO_2$ streams from different sources, process-upset conditions)? – lessons from Gorgon project

Proceedings of the 2020 13th International Pipeline Conference
IPC2020
September 28-30, 2020, Virtual, Online

**AN EMPIRICAL FRACTURE CONTROL MODEL FOR DENSE-PHASE CO2 CARRYING PIPELINES**

Guillaume Michal [1], Erling Østsby [2], Bradley J. Davis [1], Sigbjorn Røneid [2], Cheng Lu [1]

[1] University of Wollongong, Wollongong, Australia
[2] DNVGL, Høvik, Norway

IPC2020-9421



© Crown Copyright HSE 2022

# Remaining Knowledge Gaps?

- Pipeline risk assessment
  - Pipeline failure rates: need for modifications to fracture mechanics model in pipeline risk assessment models?
  - Need to develop a fast method for $CO_2$ dispersion modelling incorporating terrain effects on along pipeline route (as a screening tool)?
  - Need to develop a toxic risk methodology that takes into account sublimating solids (only for dense-phase pipelines, but just being used offshore)?

- Ship transport and subsea $CO_2$ pipelines
  - For transport of UK $CO_2$ to Norwegian “Northern Lights” project?
  - Do we understand impact of $CO_2$ releases onto water – no freely available data (recent DNV SUB CO2 JIP experiments)
  - Potential for RPTs following release from ship or failure of loading arms?


© Crown Copyright HSE 2022

# Remaining Knowledge Gaps?

- What lessons have been learnt from recent experience?
  - CCS and carbon dioxide pipeline incidents

    "While workers did a controlled blow-down to remove any remaining $CO_2$ from the section, a valve froze in the open position due to internal ice formation and gas poured out"
    https://www.huffingtonpost.co.uk/entry/gassing-satartia-mississippi-co2-pipeline_n_60ddea9fe4b0ddef8b0ddc8f
  - Operational experience, e.g., Boundary Dam, Gorgon, Sleipner, Snøhvit, USA EOR pipelines – can we share good practice, info on near misses etc.?

- Current status of industrial/academic research on CCUS safety
  - HSE has not been engaged with CCUS community since 2017, but some research has been ongoing. What have been the recent findings on safety-related issues?


© Crown Copyright HSE 2022

# Acknowledgements

## Thank you – any comments or questions?


- Sincere thanks to Shell, National Grid, DNV and the Energy Institute for permission to use images, and thanks to Adam Bannister, Zoe Chaplin, Mike Wardman and Catherine Spriggs (HSE) for useful contributions to these slides.


- 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.


- Contact: simon.gant@hse.gov.uk




© Crown Copyright HSE 2022