PROTECTING PEOPLE AND PLACES FOR 50 YEARS HSE

# CCUS research activities at HSE

Simon Gant, Strategic Science Adviser for Net Zero

Joint HSE – Energy Institute workshop, London, 1 July 2025

# Outline

- Background to HSE research on CCUS, starting in 2007
- HSE Strategy and “Areas of Research Interest”
- Ongoing CCUS research activities in HSE Science Division
- CCUS Joint Industry Projects
- Some potential CCUS research questions

# Previous research on CCUS at HSE

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

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

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

# Previous research on CCUS at HSE (published in 2017)

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://webarchive.nationalarchives.gov.uk/ukgwa/20241208032528/https://www.hse.gov.uk/research/rrhtm/rr1121.htm

# HSE website



https://www.hse.gov.uk/carboncapture/carbondioxide.htm

## General hazards of Carbon Dioxide

For over a century $CO_2$ has been recognised as a workplace hazard at high concentrations. However, $CO_2$ is naturally present in the air we breathe at a concentration of about 0.037% and is not harmful to health at low concentrations. At room temperature and atmospheric pressure $CO_2$ is a colourless and odourless gas and, because of this, people are unable to see it or smell it at elevated concentrations. $CO_2$ is not flammable and will not support combustion. As the concentration $CO_2$ in air rises it can cause headaches, dizziness, confusion and loss of consciousness. Since $CO_2$ is heavier than air, fatalities from asphyxiation have occurred when, at high concentrations, it has entered confined spaces such as tanks, sumps or cellars and displaced Oxygen. It is also possible for $CO_2$ to accumulate in trenches or depressions outside following leaks and this is more likely to occur following a pressurised release where the released $CO_2$ is colder than the surrounding air.

In GB, CO2 is classed as a 'substance hazardous to health' under the Control of Substances Hazardous to Health Regulations 2002 (COSHH). The HSE publication 'EH40/2005 Workplace exposure limits' provides workplace exposure limits (WELs) for $CO_2$. WELs are limits to airborne concentrations of hazardous substances in the workplace and are set in order to help protect the health of workers. Workplace exposure is calculated by taking an average over a specified period of time. The WELs for $CO_2$ are:

- Long-term exposure limit (8-hr reference period) of 5000 ppm
- Short-term exposure limit (15 minute reference period) of 15000 ppm

### Related content

- The health and safety risks and regulatory strategy related to energy developments
- Emerging Energy Technologies Programme: Background Report
- Assessment of the major hazard potential of carbon dioxide ($CO_2$) (PDF)
- Chemical manufacture and storage website
- Planning applications for NSIP consultation with HSE
- Scottish Government - Energy Consents
- Pipelines website
- Offshore website
- COSHH
- COMAH

# HSE’s Areas of Research Interest


## Contents



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

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

# HSE's Areas of Research Interest

**Question 1: How can it be ensured that GB's evolving industrial landscape and the built environment doesn't lead to a higher likelihood of major health and safety incidents?**

- What are the significant hazards and risks associated with the deployment and scale-up of new and emerging technologies for Net Zero, such as Carbon Capture Usage and Storage (CCUS) and hydrogen?
- How HSE ensures that dutyholders in new industries such as CCUS, hydrogen, alternative liquid fuels and energy storage, design with safety and health considerations in mind?
- What are the appropriate controls and mitigations that need to be built into new carbon capture infrastructure?
- How do operational fusion power plants compare in risk profile to more traditional industrial installations?
- How can the integrity and safety of industrial assets be ensured across their lifecycle?

**Question 2: What evidence is needed to inform how we regulate future technological developments, and the emergence of new industrial sectors to optimise safety in design and operation?**

- What evidence is needed to enable the safe and rapid introduction of new and emerging technologies, the use of novel materials and new manufacturing processes in, for example, energy.
- What evidence is needed to ensure that technological advancements serve to maintain or improve existing levels of safety and health and do not present additional risks (either immediate or latent)?
- What other new or emerging innovations might have implications for the safety of building users that merit further consideration, e.g. Artificial Intelligence?

**Question 3: To what extent can the experience, knowledge, and lessons learned from traditional industries be applied to new and emerging technologies in the energy transition with a view to improving health and safety outcomes?**

- What can be learned from the deployment and scale-up of more mature industries that will help the management of safety outcomes for the emergence of new technologies?
- What are the opportunities and associated benefits of transferring relevant knowledge and skills from hydrocarbon technologies to operators of new and emerging technologies in the energy transition and how might this be best achieved?
- What methods and information are needed to learn from early adopters of new technologies globally, including understanding health and safety failures?
- How can designers, consultants and manufacturers contribute to incorporating improvements in occupational health and safety when considering design of new technologies?

**Question 4: What risks are associated with the shift towards a decentralised energy landscape, and how might this impact health and safety outcomes?**

- What are the risks associated with the new energy landscape and how could they be best controlled? What new hazards arise from how new energy systems are integrated and controlled? Do co-located technologies pose new hazards and risks?
- What are the human factors and their potential impacts in the safe and effective operation of a new energy system and how can they be effectively understood?
- What are the health and safety challenges associated with growing industries including the retrofitting of domestic and commercial buildings; climate adaptation, installation of low carbon heat solutions and installation of electrical infrastructure for electric vehicles?

**Question 5: How is climate change currently affecting the health and safety of workers, building users and communities, and what methods can be employed to best assess its evolving impact on the healthy and safe operation of residential and industrial assets?**

- To what extent is climate change affecting health and safety of workers and communities and how is this expected to change over time?
- What is the effect of climate change on the safe operation of industrial assets and what are the best methods to determine the effect?
- What are the main health and safety challenges related to maintenance and repair of ageing low carbon energy infrastructure, such as offshore wind turbines?
- What are the safety implications of widespread adoption (including retrofitting) across the built environment from low carbon heat solutions including the impact of non-fossil fuel heating and storage systems and the impact of heat pumps on noise/acoustic performance standards and legionella control?




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# 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

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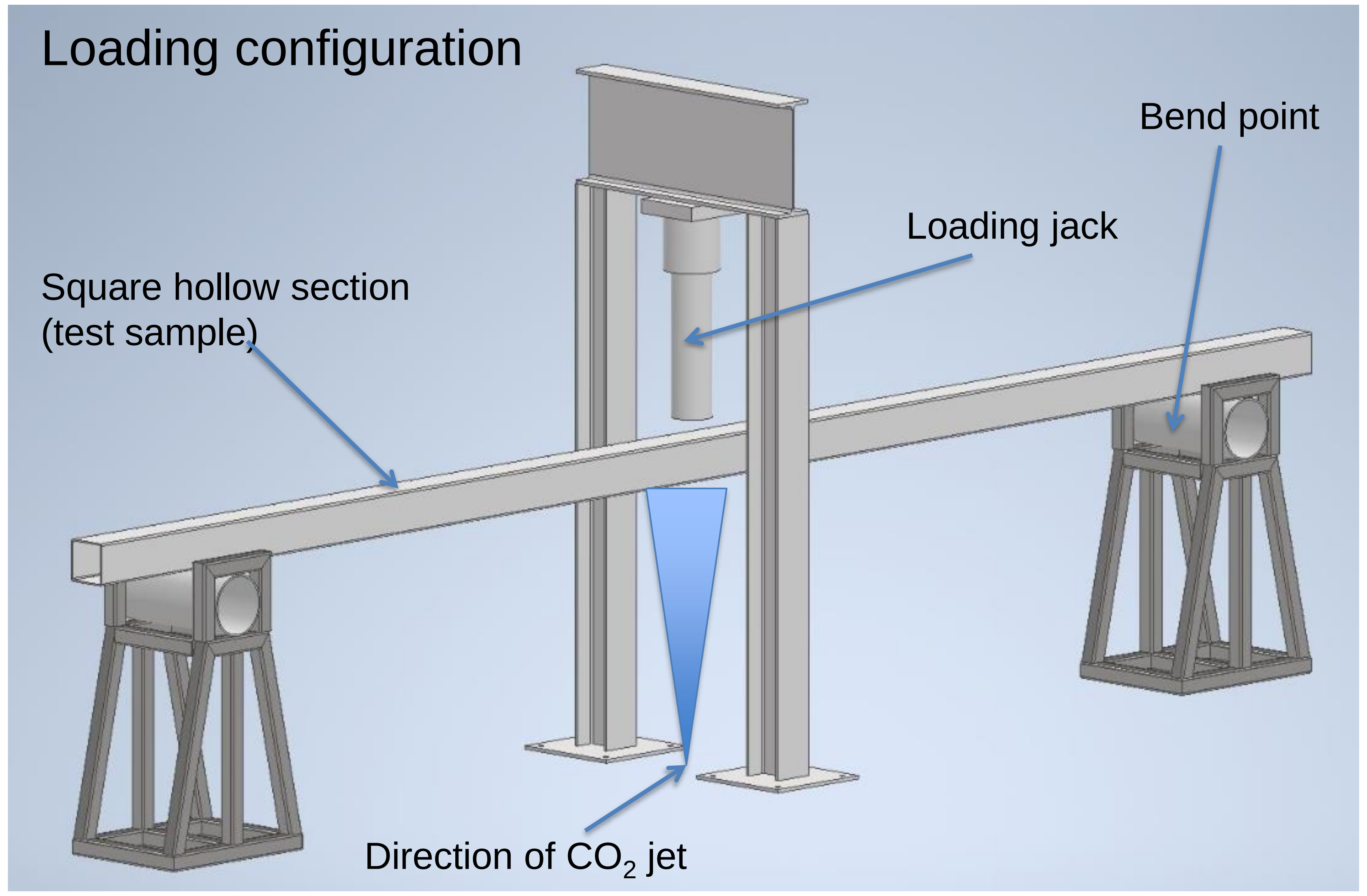
# CCUS research

- Task F5 – Low temperature excursions
  - Investigate risk of structural failure from impinging $CO_2$ jets onto steelwork
  - Potential rapid cooling to -78°C or below, reducing steelwork temperature below design temperature and potentially below the DBTT (Ductile Brittle Transition Temperature)
  - Typically, offshore steels toughness tested at -20°C
  - HSE project activities:
    - Review BS 7910 fitness for service evaluation method
    - Review historical data for offshore steelwork
    - Construct test facility for impinging $CO_2$ jets onto pre-stressed steelwork to investigate cold embrittlement effects

- Three-point bend test
- Steel hollow section
- With / without artificial defect
- Statically loaded to % SMYS
- $CO_2$ release at different distances/durations
- Tests scheduled for summer 2025



# CCUS research

- 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

**Table 1. Summary of key data supporting the DTL assessment**

| $\%CO_2$ | Exposure duration | Effects | Reference |
|---|---|---|---|
| 27.9 | 25 sec | Onset of unconsciousness, muscle spasms | Committee on Aviation Toxicology, 1953 |
| 17 | 35 sec | Onset of unconsciousness | Committee on Aviation Toxicology, 1953 |
| 10, with 21% $O_2$ | 15-22 min, following a 40-90 min exposure to 7% | Restlessness, confusion, progressive listlessness | Brackett et al, 1965 |
| 7.5 | 15 min | Shortness of breath, headache, vertigo, sweating, numbness, increased motor activity, loss of control over limbs due to overactivity, visual colour distortions, loss of balance, irritation and disorientation. | Schaefer, 1963 |
| 7, with 21% $O_2$ | 40-90 min | Heavy breathing, mild headache, burning of eyes ($O_2$ concentration maintained at 21%) | Brackett et al, 1965 |
| 6 | 5-8 min | Reversible changes in visual intensity discrimination | Gellhorn, 1936 |
| 6 | 16 min | Increased respiration rate, dyspnoea, headache, sweating | White et al, 1952 |
| 6 | 6-8 min | Minor ECG changes | Okajima and Simonson, 1962 |
| 3.5-6 | 6-10 min | Reversible changes in auditory threshold | Gellhorn and Spiesman, 1934, 1936 |
| 5.4 | 15 min | No clinical signs of symptoms. Flicker fusion frequency decreased indicating some CNS depression | Schaefer, 1963 |
| 4 | 14 days | No adverse effects on neurobehavioural test performance | Storm and Gianetta, 1974 |
| 3.9 | 30 min | Headache during heavy exercise | Menn et al. 1970 |
| 3.5 | 60 min | Increased cerebral blood flow, slight dyspnoea | Patterson et al, 1955 |
| 2.8 | 30 min | Intercostal pain, dyspnoea during heavy exercise | Menn et al, 1970 |
| 2.5 | 60 min or 21 days | Mild headaches, awareness of increased respiratory effort during heavy exercise | Sinclair et al, 1971 |

Summary of HSE's Dangerous Toxic Load assessment for $CO_2$ (SLOT-SLOD criteria) available on request

# Other ongoing HSE work on CCUS

- Development of $CO_2$ pipeline risk assessment model for land-use planning
  - Extension of existing HSE natural gas pipeline risk assessment model
  - Requires revised failure rates, fault trees, fracture, release rate and dispersion models

- Skylark $CO_2$ dispersion in complex terrain project (kick-off on 13 May 2025)
  - $CO_2$ pipeline craters and source terms
  - Simple and complex terrain (wind tunnel and field experiments)
  - Dispersion model validation
  - Emergency response
  - Venting

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

# 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 $CO_2$ venting
- DNV
  - $CO_2$SafePipe updating $CO_2$ pipeline guidance
  - Materials in $CO_2$ wells
  - $CO_2$MET quality monitoring ($CO_2$ composition measurement)
  - CO-$CO_2$ cracking in pipelines
  - $CO_2$ CFD simulation software
  - Sub$CO_2$ 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
- NZTC
  - Qualification of SSSV for injection of $CO_2$

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**HSE participating in these JIPs**

# Some potential CCUS research questions

- Consequences of bulk $CO_2$ storage vessel failure (cold BLEVE): rainout of dry-ice?
- $CO_2$ pipeline leaks: potential for enlargement of punctures into ruptures by progressive brittle fracture around the release point. Is brittle fracture mitigated by warm pre-stressing?
- Review of operating procedures and safety measures: purging, venting, inspection, repairs, heaters/vaporisers, $CO_2$ solid blockages (lessons learnt from operations?)
- $CO_2$ venting strategies offshore: from the underside of platforms?
- Detection and emergency control systems on platforms handling hydrocarbons and $CO_2$?
- Impact of dense $CO_2$ clouds on floating support vessels and ingress of $CO_2$ into lifeboats?
- Wells: impact of $CO_2$ impurities on casing cements, risks associated with varying injection rates, $CO_2$ phase change in wells, salt precipitation and hydrates?

This list is not extensive

# Thank you

# Any questions?

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