PROTECTING PEOPLE AND PLACES FOR 50 YEARS HSE

Net Zero Science Roadmap

An initial look

Simon Gant – Strategic Science Adviser for Net Zero, Science Division
Catherine Spriggs – Net Zero Programme Manager, Engagement & Policy Division

Science and Technical Advisory Committee (STAC) meeting, Energy Institute, London, UK
26 November 2024

Outline

- Context: UK Government's mission and HSE's role
- HSE's areas of research interest
- Process for identifying research needs
- Current status of HSE science on Net Zero
- The journey ahead
  - Ongoing work and projects under discussion
  - Knowledge gaps
- Final thoughts

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UK Government's mission for Net Zero

- Quadruple offshore wind with an ambition of 55 GW by 2030
- Pioneer floating offshore wind, by fast-tracking at least 5 GW of capacity
- More than triple solar power to 50 GW
- More than double our onshore wind capacity to 35 GW
- Get new nuclear projects at Hinkley and Sizewell over the line, extending the lifetime of existing plants, and backing new nuclear including Small Modular Reactors
- Invest in carbon capture and storage, hydrogen, and long-term energy storage to ensure that there is sufficient zero mission back-up power and storage for extended periods without wind or sun, while maintaining a strategic reserve of backup gas power stations to guarantee security of supply
- Double the government's target on green hydrogen, with 10 GW of production for use particularly in flexible power generation, storage, and industry like green steel
- Unleash marine and tidal power

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HSE's role as a regulator

- Aims
  - To prevent workplace death, injury or ill health
- Approach
  - Provide advice, information and guidance
  - Raise awareness in workplaces by influencing and engaging
  - Operate permissioning and licensing activities in major hazard industries
  - Carry out targeted inspections and investigations
  - Take enforcement action to prevent harm and hold those who break the law to account

https://www.hse.gov.uk/enforce/our-role-as-regulator.htm

https://www.hse.gov.uk/aboutus/assets/docs/hse-business-plan.pdf

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HSE's Strategic Objectives 2022-2032

Protecting people and places

1. Reduce work-related ill health, with a specific focus on mental health and stress
2. Increase and maintain trust to ensure people feel safe where they live, where they work and, in their environment
3. Enable industry to innovate safely to prevent major incidents, supporting the move towards net zero
4. Maintain Great Britain's record as one of the safest countries to work in
5. Ensure HSE is a great place to work, and we attract and retain exceptional people

https://www.hse.gov.uk/enforce/our-role-as-regulator.htm

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HSE's Areas of Research Interest

Contents

https://www.hse.gov.uk/research/content/hse-areas-of-research-interest.pdf

https://ari.org.uk/

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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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https://www.hse.gov.uk/research/content/hse-areas-of-research-interest.pdf

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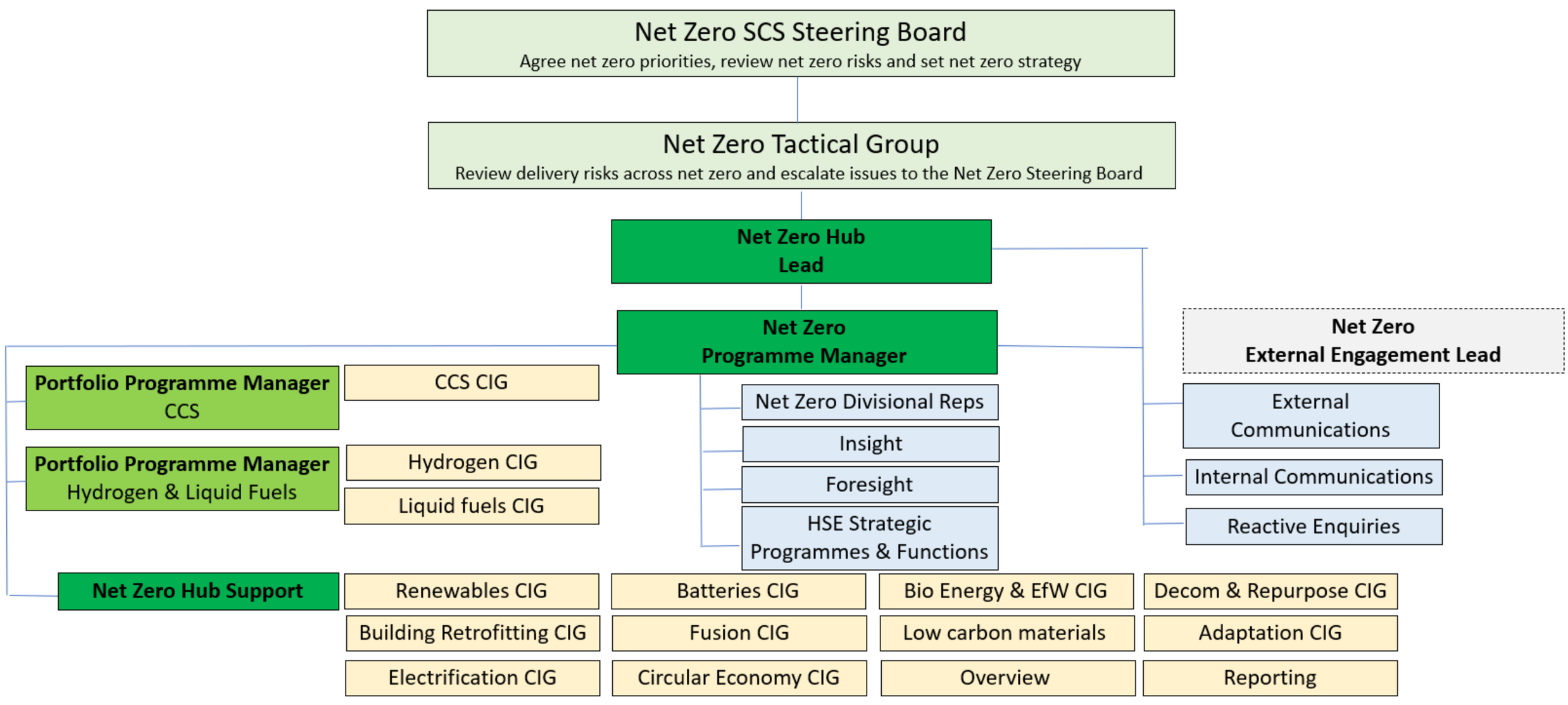
Process for identifying research needs

HSE's Net Zero Hub



CIG = Common Interest Group, comprising relevant experts from regulation, policy and science divisions of HSE

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Process for identifying research needs

Contributions to HSE's Net Zero Hub common interest groups

- Regulatory inspectors
  - Inputs based on inspections, incident investigations, review of COMAH Safety Reports, Offshore Safety Cases, etc.

- HSE policy specialists
  - Inputs based on discussions with other Government departments and consideration of the need for potential regulatory policy changes

- HSE scientists, engineers and analysts
  - Findings from ongoing HSE research, reviews of scientific publications, involvement in committees developing standards and guidelines, discussions with peers at conferences, workshops, etc.

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Process for identifying research needs

Engagement with industry, consultants, regulators, other Government departments and academia at events, such as:

- HSE Safe Net Zero conferences
  - Save the date: 11-12 March 2025, Edinburgh
- IChemE Hazards conferences
- AIChE Global Congress on Process Safety
- EU Loss Prevention and Safe Promotion in the Process Industries
- IMechE conferences on Net Zero topics
- Fire and Blast Information Group (FABIG) meetings
- UK Explosion Liaison Group meetings
- UKCCSRC events
- USA PHMSA and American Petroleum Institute conferences
- EU/OECD Working Party on Chemical Accidents events
- Energy Institute events

etc.

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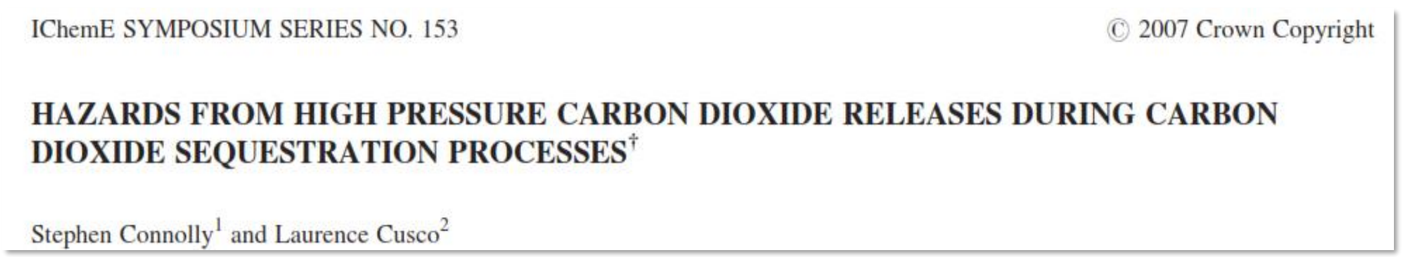
Current status of HSE science on Net Zero

- HSE has undertaken research on hydrogen, CCUS and other Net Zero topics for more than 20 years
- Working collaboratively to identify potential safety issues and help to prioritise research activities
- Examples include:
  - HSE input to HySafe research priorities workshops

    https://hysafe.info/activities/research-priorities-workshops/
  - HSE input to IChemE and UKCCSRC events, e.g.:



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

Stephen Connolly[1] and Laurence Cusco[2]

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

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Current status of HSE science on Net Zero

Examples of HSE publications on hydrogen safety

- RR1133 – Maintaining the integrity of process plant susceptible to high temperature hydrogen attack. Part 1: analysis of non-destructive testing techniques
- RR1134 – Maintaining the integrity of process plant susceptible to high temperature hydrogen attack. Part 2: factors affecting carbon steels
- RR1169 – Hydrogen in the natural gas distribution network: Preliminary analysis of gas release and dispersion behaviour
- RR715 – Installation permitting guidance for hydrogen and fuel cell stationary applications: UK version
- RR1047 – Injecting hydrogen into the gas network – a literature search
- RR769 – Hazards of liquid hydrogen: position paper
- RR985 – Modelling of liquid hydrogen spills
- RR986 – Releases of unignited liquid hydrogen
- RR987 – Ignited releases of liquid hydrogen
- RR1159 – Hydrogen research priorities workshop
- RR615 – Spontaneous ignition of hydrogen: Literature review

https://www.hse.gov.uk/research/rrhtm/index.htm

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Current status of HSE science on Net Zero

- The following slides provide a summary of ongoing research projects at HSE on the topics of:
  - Hydrogen
  - CCUS
  - Ammonia
  - Batteries
  - Renewables

- Also, Joint Industry Projects (JIPs) on these topics led by other organisations

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Current hydrogen projects at HSE

- Hydrogen safety training courses
- Liquid hydrogen safety guidebook
- Land, sea and port integration (hydrogen highway)
- Hydrogen burner experiments for food production
- Hydrogen compatibility of components in the gas network
- Hydrogen blends in the gas network
- Zero emissions for sustainable aircraft
- Aircraft liquid hydrogen container lab tests
- Gaseous hydrogen aircraft fuel sub-system testing
- Cold hydrogen combustion tests for aircraft applications

List of projects continued on next slide…

Key:	Externally-funded	Shared research (part-funded) by HSE	DESNZ funded	Internally-funded by HSE

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Current hydrogen projects at HSE

- Hydrogen heating programme
- MultHyFuel safety of hydrogen at multifuel refuelling stations
- ELVHYS liquid hydrogen in transfer operations for mobile applications
- High-pressure hydrogen jets in enclosed spaces
- Develop risk assessment model for hydrogen pipelines
- Review risk assessment models for LUP/COMAH sites
- Facility for materials testing in hydrogen atmospheres
- Review of hydrogen leakage in isolated vessels and pipes

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Details of some example projects given in the next slides

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ELVHYS

Enhancing safety of liquid and vaporised hydrogen transfer technologies in public areas for mobile applications

Funding: 2.0 M€

Duration: 2023-2026

Coordinator: NTNU

Partners:

Website

Objective: provide indications on inherently safer and efficient cryogenic hydrogen technologies and protocols in mobile applications by proposing innovative safety strategies including selection of effective safety barriers and hazard zoning strategies, which are the results of a detailed risk analysis.

NTNU role: coordinator, consequence analysis, risk analysis

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ELVHYS

Expected outcomes & objectives

1. Detailed risk analysis for LH2 transferring operations for mobile applications (ships, trucks, stationary tanks) fillings
2. Generic hazard distances for LH2 transferring operations in the different applications, also addressing SimOps
3. Guidelines for design of LH2 transferring facilities
4. Consensual loading procedures for LH2 transferring operations
5. Provide inputs for developing Standards, Technical Specifications, or Technical Reports at the international level

Co-funded by the European Union
Clean Hydrogen Partnership
UK Research and Innovation

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Risk assessment model for hydrogen pipelines

- Objectives: Review HSE's pipeline risk assessment methodology to determine its suitability for hydrogen, and update it if needed, considering:
  - Failure rate model, pipeline release rate model, event trees, ignition model, fire and explosion model
- Motivation: Provision of HSE's statutory land-use planning advice to local planning authorities on the risks associated with major accident hazard pipelines (as described in the Pipeline Safety Regulations, 1996)
- Timeline of HSE research project: 2023 – 2025
- Ongoing work:
  - Method developed to modify the material fracture toughness in air for hydrogen service
  - Is delayed ignition credible? If so, this will require HSE to incorporate a vapour cloud explosion model. Awaiting findings from hydrogen rupture tests at DNV Spadeadam
- Key milestones
  - 125 km high pressure HyNet North West hydrogen pipeline currently in pre-application stage, application is expected in 2025

    https://national-infrastructure-consenting.planninginspectorate.gov.uk/projects/EN060006
- Further info on MISHAP model https://www.hse.gov.uk/Research/rrhtm/rr1040.htm

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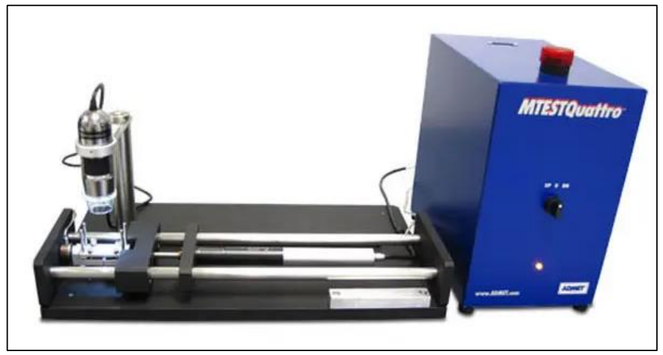
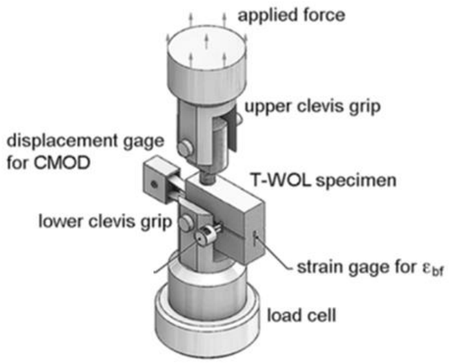
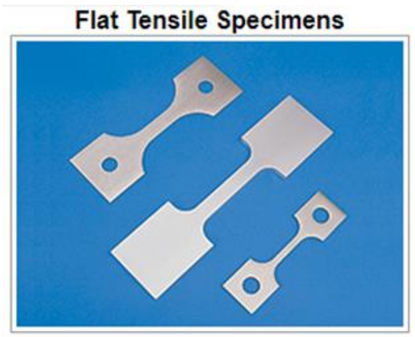
Facility for materials testing in hydrogen atmospheres

- HSE is investing in a new hydrogen materials testing facility at its Science and Research Centre in Buxton
- Aim to conduct long-term exposure tests of materials (~years) in gaseous hydrogen up to 10 bar
- Testing methods:
  - In-situ micro tensile testing
  - Ex-situ tensile testing
  - Ex-situ impact testing
- Testing of metals, polymers and elastomers
- Four vessels acquired; setup ongoing
- Due to be operational in 2025





https://www.admet.com/products/micro-testers/expert-4000/



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Joint Industry Projects: hydrogen

- SAFEN failure rate and ignition models for Net Zero
- Energy Institute
  - Hy2402/3 hydrogen separation distances

HSE currently involved

- DNV
  - Materials qualification for underground hydrogen storage
  - Hydrogen salt cavern storage
  - Integrity management of hydrogen pipelines
  - Hydrogen CFD simulation software

HSE seeking to join

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CFD = Computational Fluid Dynamics

Current CCUS projects at HSE

- Skylark CO_2 project
  - Dispersion experiments: CO_2 pipeline releases in complex terrain and CO_2 venting
  - Validation of pipeline source and dispersion models
  - Emergency response

List of projects continued on next slide…

Key:	Externally-funded	Shared research (part-funded) by HSE	DESNZ funded	Internally-funded by HSE

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Current CCUS projects at HSE

- Develop risk assessment model for CO_2 pipelines
- CCUS research programme
  - Map industrial plans for CCUS
  - Identify potential hazards
  - Review human harm criteria for CCUS applications
  - Review capability and validation of current risk assessment models
  - Reviewing materials issues: corrosion, ductile/brittle fracture
  - Updating HSE's previous CO_2 pipeline risk comparison
  - Modelling of CO_2 storage risk thresholds

Key:	Externally-funded	Shared research (part-funded) by HSE	DESNZ funded	Internally-funded by HSE

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Joint Industry Projects: CCUS

- SAFEN failure rate and ignition models for Net Zero – HSE currently involved
- SINTEF
  - Offshore large-scale subsea CO_2 releases
  - CO_2 EPOC: effect of CO_2 on polymeric materials
- TWI
  - MASCO2T II: Materials assessment for CO_2 transport
  - Permeation of CO_2 through thermosets
- DNV
  - CO2SafePipe updating CO_2 pipeline guidance
  - Materials in CO_2 wells
  - CO-CO_2 cracking in pipelines
  - CO_2 CFD simulation software
  - CO_2 fluid compositions and CO_2 quality monitoring
- Energy Institute
  - Good practice guide for CO_2 applications offshore
  - Corrosion management and asset integrity for CCUS

HSE seeking to join

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Current ammonia projects at HSE

- ARISE ammonia spill experiments at sea
  - Led by INERIS and CEDRE
- Jack Rabbit III ammonia trials and model validation
  - Led by USA Depts of Homeland Security and Defense

Joint Industry Projects: ammonia

- SINTEF
  - SafeAm: ammonia spills onto water
- Energy Institute
  - Hy2307: use of ammonia and methanol as maritime transport fuels

HSE currently involved in both projects on advisory boards

Key: Externally-funded | Shared research (part-funded) by HSE | DESNZ funded | Internally-funded by HSE

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Current battery projects at HSE

- Recycling of electric vehicle batteries
- Battery monitoring in tunnels
- Battery vent gases
- Large-scale battery fires
- Stand-off distances and building response

Key:	Externally-funded	Shared research (part-funded) by HSE	DESNZ funded	Internally-funded by HSE

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Current renewables projects

- There are no HSE wind/solar research projects ongoing at HSE

- DNV is leading JIPs on:
  - FLOW: Concrete substructures for floating wind
  - Floating substations
  - Anchor/foundations for floating wind
  - Mooring and dynamic cable design for floating wind
  - Transportation and installation techniques for floating wind
  - Behaviour of laterally-loaded monopiles and jackets
  - Design requirements for cable protection systems
  - Subsea flexible pipe technology
  - SIMFAT: SIMulataneous load processes in FATigue estimates
  - Cyber security for offshore wind

https://www.dnv.com/group/joint-industry-projects-categories/

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HSE future projects on hydrogen (2025 – onwards)

- Hydrogen safety training courses
- ELVHYS liquid hydrogen in transfer operations (2023-2026)
- High-pressure hydrogen jets in enclosed spaces (2024-2027)
  - PhD project with Edinburgh University
- Develop risk assessment model for hydrogen pipelines (2023-2025)
  - Data available from DNV hydrogen pipeline rupture experiments?
- Review risk assessment models for LUP/COMAH sites (2023-ongoing)
  - Data from Air Products LH2 vessel release experiments?
- Facility for materials testing in hydrogen atmospheres (2024-ongoing)
  - Currently in construction/commissioning phase
- Review of hydrogen leakage in isolated vessels and pipes (2024-2025)
  - Literature review started
  - Potentially, some HSE experiments in 2025

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HSE future projects on CCUS (2025 – onwards)

- Skylark CO_2 project (2025 – 2028)
- Development of fast model for CO_2 dispersion in complex terrain
- Development of risk assessment model for CO_2 pipelines
- CCUS research programme
  - Map industrial plans for CCUS
  - Identify potential hazards
  - Review human harm criteria for CCUS applications
  - Review capability and validation of current risk assessment models
  - Reviewing materials issues: corrosion, ductile/brittle fracture
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Knowledge gaps: hydrogen

- Hazardous area classification for hydrogen (discussions ongoing in HSE)
  - Zone of “negligible extent” criteria
  - Appropriate hole sizes for area classification
  - Selection of hydrogen lower flammable limit value (4% or 8% v/v ?)
  - Buoyancy-induced ventilation in enclosures (produced by hydrogen cloud)
- Mapping of hydrogen regulations, standards and good practice guidelines
  - Led by Energy Institute?
  - Application or sector specific?
- Review of issues relating to sub-COMAH hydrogen installations
- Electrolyser safety issues
- Lessons learnt from operational experience of hydrogen equipment and hydrogen incidents

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Knowledge gaps: CCUS

- Brittle fracture due to CO_2 jet impingement following loss of containment on offshore platforms
  - Potential for enlargement of punctures into ruptures by progressive brittle fracture around the release point
  - Is brittle fracture mitigated by warm pre-stressing?
- Running ductile fractures in dense-phase CO_2 pipelines due to net decompression speed of the fluid < fracture propagation speed
- CO_2 venting strategies offshore: from the underside of platforms?
- Detection and emergency control systems on platforms handling both hydrocarbons and CO_2
- Potential impact of dense CO_2 clouds on floating support vessels and ingress of CO_2 into lifeboats
- Consequences of subsea CO_2 pipeline release or well blowout
- Learning from operational experience of CCUS plants

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Knowledge gaps: CCUS

- Design standards for CCUS, e.g., seal integrity, vent design, valves considering thermal expansion, compressor operation/redundancy
- Corrosion control
  - Reactions between impurities present in CO_2 stream
  - Online monitoring of CO_2 impurities
  - Guidance on inspection methods and frequency
  - Mitigation options
- Potential for rapid phase transition of liquid to gaseous CO_2 following spills of liquid CO_2 onto water (e.g., in ship transport applications)
- Consequences of bulk CO_2 storage vessel failure
- Review of operating procedures and safety measures: purging, venting, inspection, repairs, heaters/vaporisers, CO_2 solids blockages
- Wells: impact of CO_2 impurities on casing cements, risks associated with varying injection rates, CO_2 phase change in wells, salt precipitation, hydrates, vibrations/seismic activity, microbial activity

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Training

- Should HSE widen the scope of its training courses to cover more aspects of Net Zero safety?
  - Hydrogen, CCUS, ammonia, batteries, renewables etc.
  - Building on success of existing HSE hydrogen training courses
  - Potential partnerships between HSE and other organisations? e.g., Energy Institute, DNV, Ricardo, Wood

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Final thoughts

- Plans will evolve over the coming months and years
  - Plans presented here will be discussed in HSE and with other organisations in coming months, and may change
  - In addition to strategic plans, there will probably be urgent requests for research to support HSE regulatory inspectors
- Open to suggestions of other knowledge gaps
- Keen to learn about research findings that close gaps
- HSE is interested in participating in joint industry projects
- Collaboration is key to achieving Net Zero

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Thank you

simon.gant@hse.gov.uk

catherine.spriggs@hse.gov.uk

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- To review HSE areas of research interest, search here: https://ari.org.uk/

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