RESEARCH AND GUIDANCE FROM HSE

Hydrogen, ammonia and CCUS risks

Recent research findings and knowledge gaps

Simon Gant, HSE Science Division

32nd Meeting of the OECD Working Party on Chemical Accidents, “Challenges and issues arising from decarbonisation and the energy transition”, Wednesday 26 October 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

Outline

- Hydrogen
  - Gas distribution and transmission network
  - Cryogenic liquid hydrogen
  - Transport-related studies

- Ammonia
  - Green energy vector and shipping fuel context
  - Jack Rabbit III international collaborative project

- Carbon capture, utilisation and storage
  - Satartia CO_2 pipeline incident
  - Knowledge gaps in pipeline risk assessment and releases of CO_2 onto water

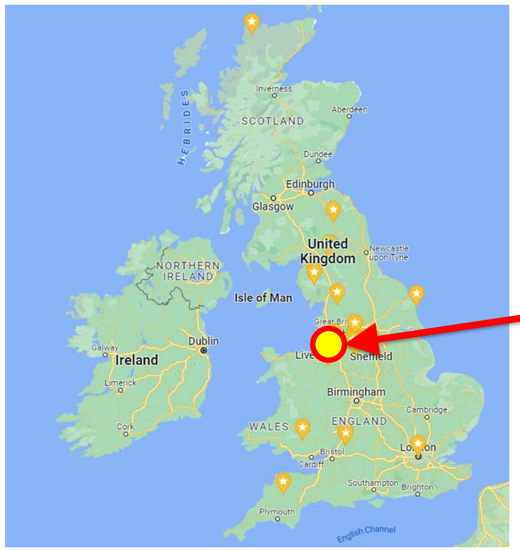
Hydrogen

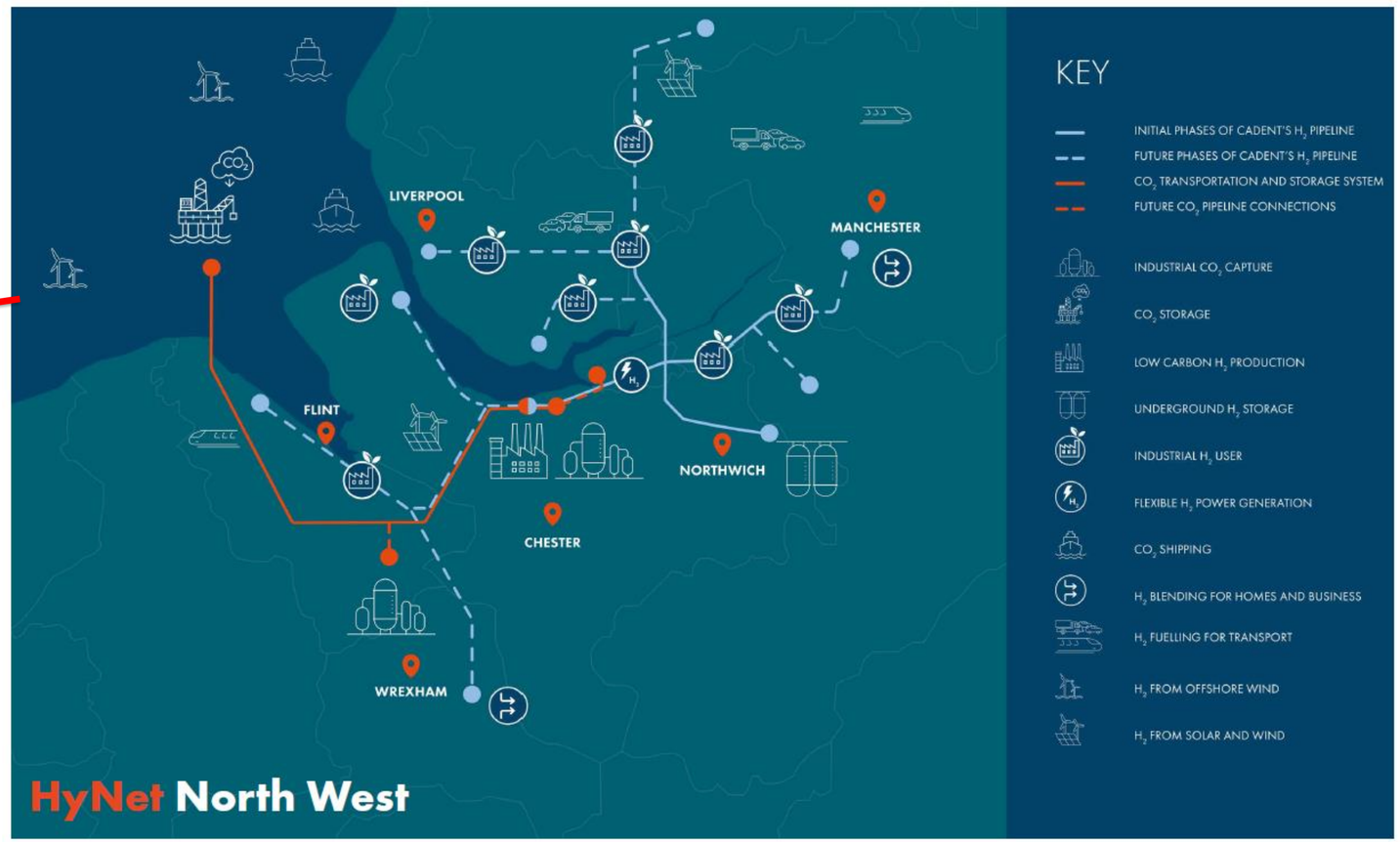
- Net Zero 2050 : UK Government announced Ten Point plan[1] in November 2020
- Two regional hydrogen and CCUS clusters funded by UK Government
  1. **HyNet** https://hynet.co.uk
  2. **East Coast Cluster** https://eastcoastcluster.co.uk
  - Aim to be operational by mid-2020s, storing 20-30 $MtCO_2$/year by 2030 = 8-12 million cars emissions
  - Further hydrogen and CCS cluster projects seeking track 2 funding, decision in Q2 2023
- Hydrogen for heating
  - 2023: Neighbourhood trial (https://www.h100fife.co.uk/)
  - 2025: Village trial
  - By 2030: Town trial
  - Targets of 5 GW of low carbon hydrogen production and 10 Mt carbon capture by 2030
  - Working towards cross-government policy decision on hydrogen heating in 2026
- Other Net Zero ambitions
  - Offshore wind, nuclear, zero-emission vehicles/planes/ships, greener buildings, protecting environment, green finance and innovation

[1] https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

HyNet North West

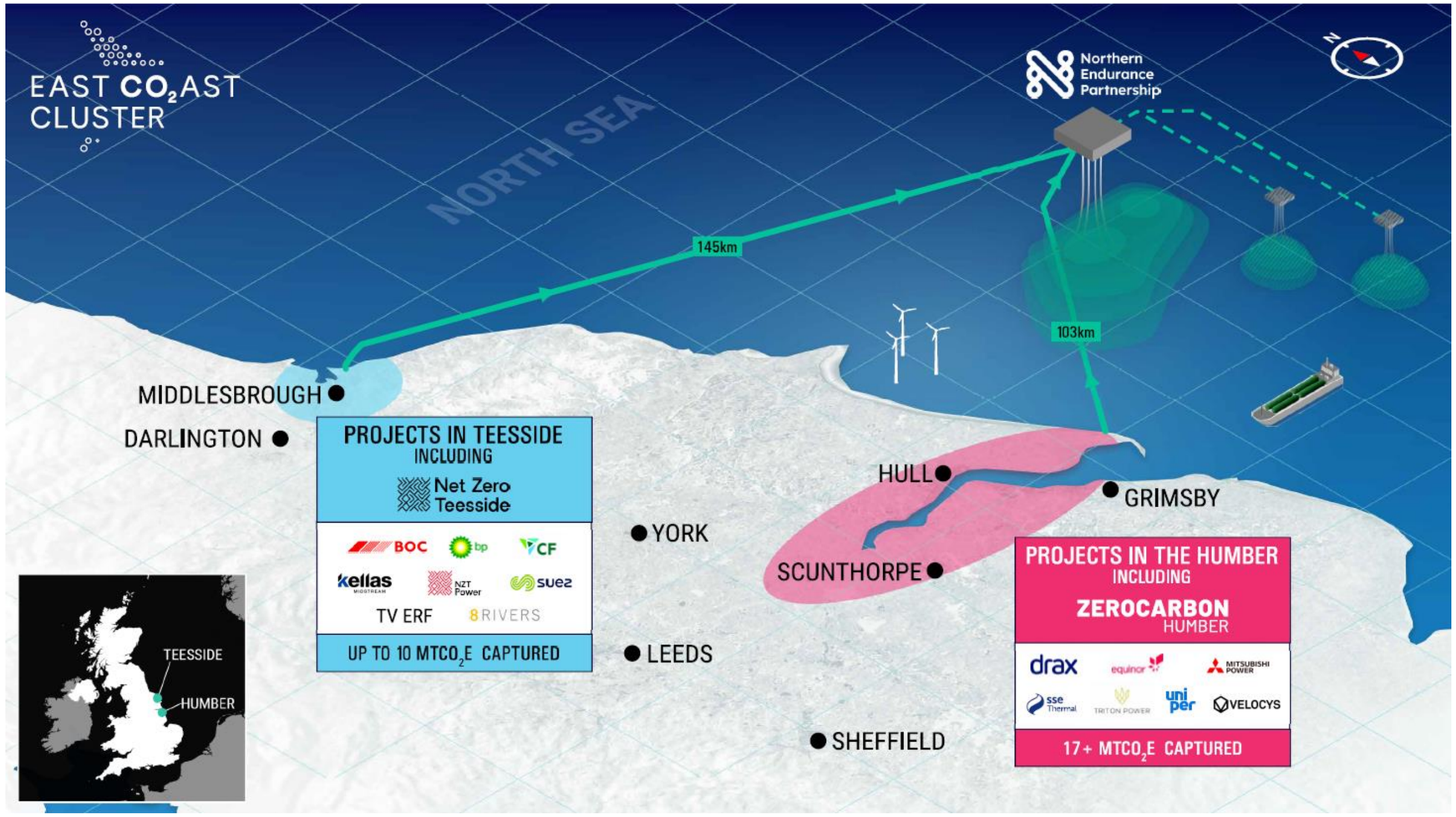
- New hydrogen and CCUS cluster in the Liverpool regional area





https://hynethub.co.uk/CMS/uploadpdfs/1644235772.pdf

Hydrogen and CCUS: East Coast Cluster



netzeroteesside.co.uk

zerocarbonhumber.co.uk

Topics covered in HSE's ongoing review of evidence

Assessing the impact of hydrogen on the British transmission and distribution pipeline network, including above ground installations

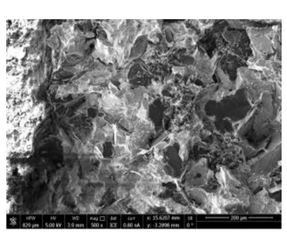
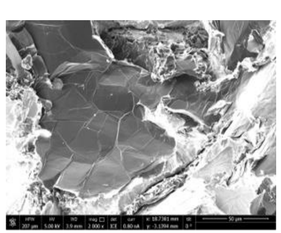
- **Materials performance**
  - Effect of hydrogen embrittlement and fatigue on design, construction, operation and maintenance
- **Risk assessment**
  - Change in failure frequencies, leakage, gas migration, dispersion, accumulation, ignition potential, fire and explosion effects, hazardous area classification
- **Operational procedures**
  - Pipeline purging, venting, inspection, maintenance, leak detection, repair
- **Equipment**
  - Gas detectors, regulators, heat exchangers, meters, kiosks, PPE, software
- **Training and Regulation**

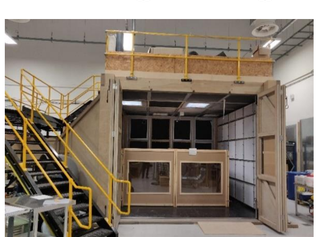
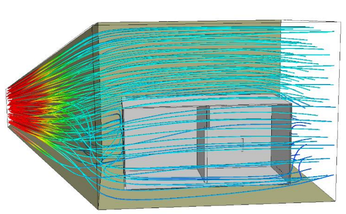
Ongoing hydrogen research projects

HyDeploy

https://hydeploy.co.uk/

- **Blend of 20% hydrogen in natural gas**
- Scientific analysis and experiments to support QRA for 20% blend
- Community trials at Keele University and Winlaton village ongoing (668 homes)

h21

https://h21.green/

- **Repurposing of existing natural gas distribution network for 100% hydrogen**
- Leakage tests on recovered assets, gas migration through soil, dispersion, accumulation, ignition, fires, explosion severity, QRA, operational procedures



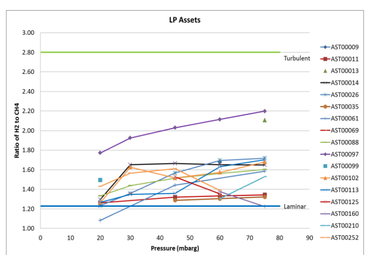
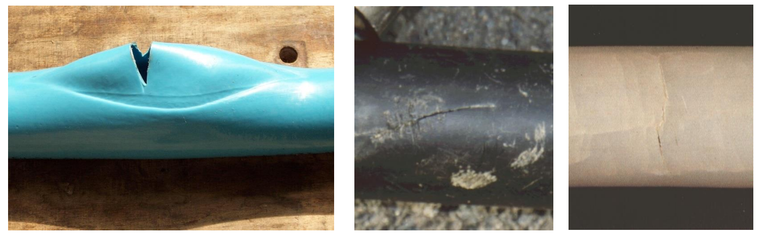


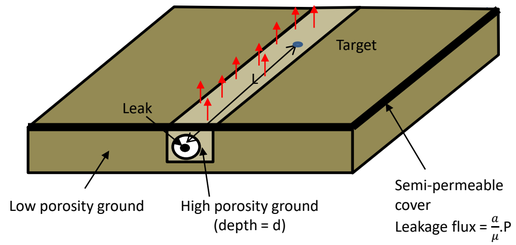
Image of H21 test site at Spadeadam courtesy of DNV (© DNV, 2021)

Ongoing hydrogen projects

https://www.sgn.co.uk/H100Fife

- **100% hydrogen in a new gas distribution network**
- Testing of PE pipe, experiments and analysis to support QRA
- Community trials in Scotland (300 homes) planned for 2023





FutureGrid

https://www.nationalgrid.com/FutureGrid

- **Repurposing of existing national gas transmission network for hydrogen**
- Analysis of 2% and 20% hydrogen blends plus 100% hydrogen
- Tests on different types, sizes, material grades of NTS assets, permeation, pipe coating and CP testing, fatigue, flange tests, leakage, rupture tests
- Phase 1: construction of hydrogen test facility at DNV Spadeadam using assets retrieved from the UK gas transmission network
- Build started in April 2021, testing to start in October 2022

Ongoing hydrogen projects

Hy4Heat

https://www.hy4heat.info/

- Hydrogen in residential and commercial buildings and gas appliances
  - Focus on downstream of the emergency control valve
  - Gas quality, metering, appliances, purging, tightness testing, trials
  - Two demonstration hydrogen homes

https://www.businessgreen.com/news/4034556/green-gas-uk-hydrogen-homes-open-public

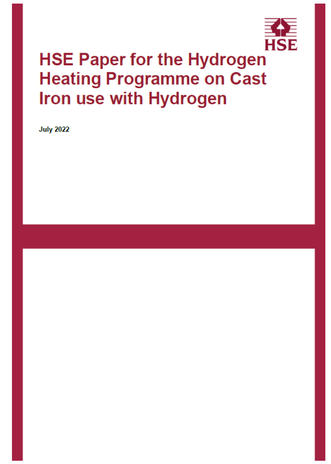
LTS Futures

https://www.sgn.co.uk/about-us/future-of-gas/hydrogen/lts-futures

- Hydrogen in the Local Transmission System (7 to 60+ bar)
  - New 3-year project starting in 2022
  - Live trial design (Granton to Grangemouth pipeline)
  - Lab material testing
  - Offsite testing (at the DNV Spadeadam facility)
  - Live trial (repurposing trial and demonstration including uprating)
  - QRA, Case for safety
  - Knowledge dissemination

Hydrogen for Heating: Knowledge Gaps

- Suitability of cast iron for hydrogen
  - HSE policy (July 2022): cast iron not acceptable for long term transportation of hydrogen
  - However, around 15% of GB houses are within 150 m of cast iron pipe mains
  - Tests ongoing at Sandia and Manchester University funded by HyBlend, H-Mat, HyDeploy



- Hydrogen gas explosions in buildings
  - Previous explosion research does not take into account pressure-relief and venting due to failure of building fabric (doors, windows, brick walls etc.)
  - Research project and new experiments planned at DNV Spadeadam

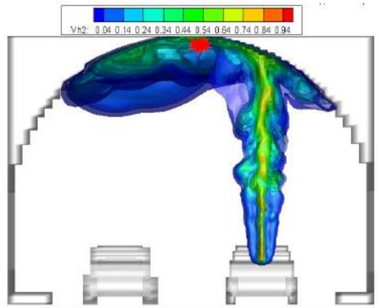
- Delayed ignition of hydrogen gas releases from pipelines
  - Scenario: pipeline rupture followed by delay of a few seconds before hydrogen gas cloud ignites
  - Limited experimental evidence shows significant overpressures for hydrogen (whereas no significant pressure for natural gas)
  - Further tests planned at DNV Spadeadam to feed into pipeline risk assessment and industry guidance

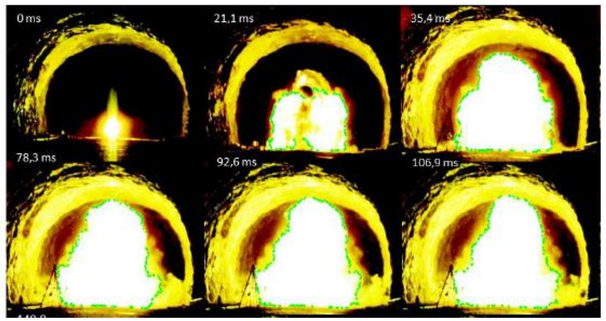
Cryogenic Liquid Hydrogen

- PreslHy (www.preslhy.eu) 2018-2021
  - Prenormative research for safe use of liquid hydrogen
  - Experiments: LH2 jets, electrostatics, ignition, jet/pool fires
- SH2IFT https://www.sintef.no/projectweb/sh2ift/ 2019-2022
  - Experiments: BLEVE, LH2 spills on water, impinging jet fires
- Remaining knowledge gaps
  - Dispersion behaviour, DDT, condensed-phase LH2 explosions, physics/scaling of BLEVEs, performance of passive fire protection
  - Waterborne spills: will LH2 ship loading-arm releases self-ignite?
- Future projects
  - ELVHYS and SH2IFT-2 from 2021/2 onwards

Hydrogen: further transport-related studies

- HyTunnel (www.hytunnel.net) 2019-2022
  - Hydrogen fires and explosions in tunnels from vehicle releases
  - Explosion prevention and mitigation, emergency response actions





- MultHyFuel (www.multhyfuel.eu) 2021-2023
  - Safety and permitting of hydrogen at multi-fuel retail sites
  - Review of permitting requirements and risk assessment
  - Experiments and modelling of high-pressure hydrogen releases

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Green and Blue Ammonia

- Ammonia as an hydrogen energy carrier and shipping fuel

'More than 85% of export-oriented low-carbon hydrogen projects plan to ship ammonia, not H2'

Green NH3 is emerging as the hydrogen carrier of choice, but it's not without its challenges, writes Noel Tomnay, global head of hydrogen consulting at energy analyst Wood Mackenzie

https://www.rechargenews.com

'Shipping green hydrogen to the EU will be too expensive, but importing green ammonia would be cheaper than producing it locally'

High shipping costs rule out importing low-cost H2 from places such as Chile and Australia, but the opposite is true for hydrogen derivatives, says think-tank report

	Hydrogen	Ammonia
Boiling point	-253°C	-33°C
Energy density[3] (cryogenic liquid)	9 MJ/litre	16 MJ/litre

MISSION INNOVATION BEYOND 2020

Challenges and opportunities

A paper by the MI Secretariat on the clean energy innovation landscape for input into discussions about the role and priorities of Mission Innovation beyond 2020

Shipping is likely to favour direct drop-in alternatives for existing engines, with hydrogen (e.g. stored in liquid organic hydrogen carriers) and ammonia likely to dominate in the long-term.[58]

Department for Transport

Clean Maritime Plan

maritime 2050 NAVIGATING THE FUTURE

- Under the assumptions made in the research, ammonia is estimated to be more cost-effective than methanol or hydrogen for most ship types.

AIR PRODUCTS

Gas Supply

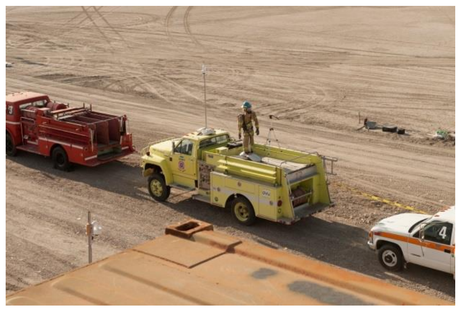
05/26/2022 | LEHIGH VALLEY, PA; MUSCAT, OMAN; AND RIYADH, KINGDOM OF SAUDI ARABIA

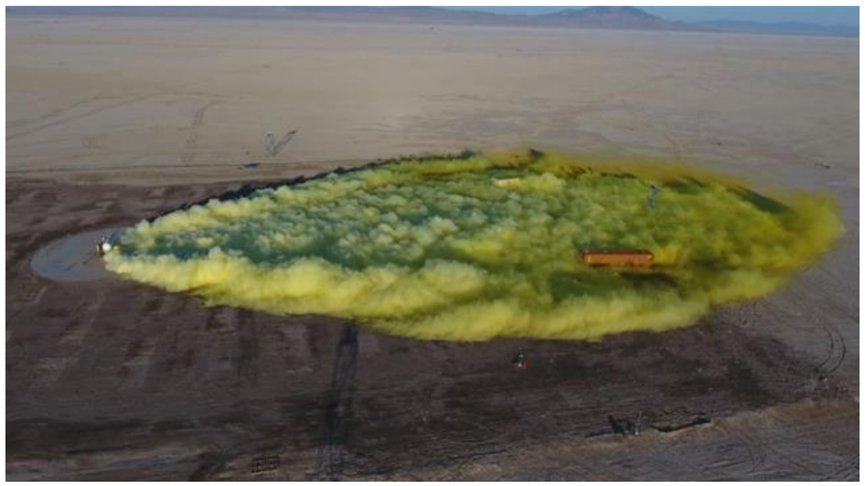
Air Products, OQ and ACWA Power Sign Joint Development Agreement Toward World-Scale Green Hydrogen-Based Ammonia Production Facility in Oman

mix in 2050, depending on decarbonization scenario. It is hard to identify clear winners among the many different fuel options across all scenarios, but ammonia (electro-based and 'blue') and bio-based methanol are the most promising carbon-neutral fuels in the long run.

Jack Rabbit III: Ammonia release experiments

- Follow-on from Jack Rabbit I and II projects, led by the US Department of Homeland Security and Department of Defense
- Aim: to conduct large-scale anhydrous ammonia release experiments, fill critical hazard prediction data gaps and inform emergency responders
- International collaboration: initial modelling exercise with 21 participants from USA, UK and Europe conducted in 2021-2022, experiments in planning stage





For further information, see: https://www.uvu.edu/es/jack-rabbit/

Images of Jack Rabbit II chlorine field trials at Dugway Proving Ground and wind tunnel / laboratory studies © DHS S&T CSAC and Arkansas University

Knowledge Gaps in Ammonia and other TICs

- USA , UK and European collaborative scientific knowledge gaps exercises conducted in 2020 on modelling of toxic industrial chemical releases published jointly:
  - Hanna S., Mazzola T., Chang J., Spicer T., Gant S.E. and Batt R. "Gaps in Toxic Industrial Chemical (TIC) model systems: improvements and changes over past ten years", Process Safety Progress, June 2021, http://dx.doi.org/10.1002/prs.12289
  - Topics covered: definition of scenarios, source models, dispersion (dense gas in low wind speeds, transition to passive dispersion, obstacles and terrain, meteorology, infiltration into buildings, dry deposition and chemical reactivity), health effects

- Ammonia as a marine fuel – bunkering, safety and release simulations
  - Report by Nanyang Technical University (NTU), Singapore, Oct 2022
  - Findings: 3% lethality reaches 1.3km in ship-to-ship transfer, 400m in shore-to-ship transfer
  - Knowledge gaps: experimental validation of models, performance of mitigation systems
  - https://www.ammoniaenergy.org/articles/key-singaporean-safety-study-releases-report

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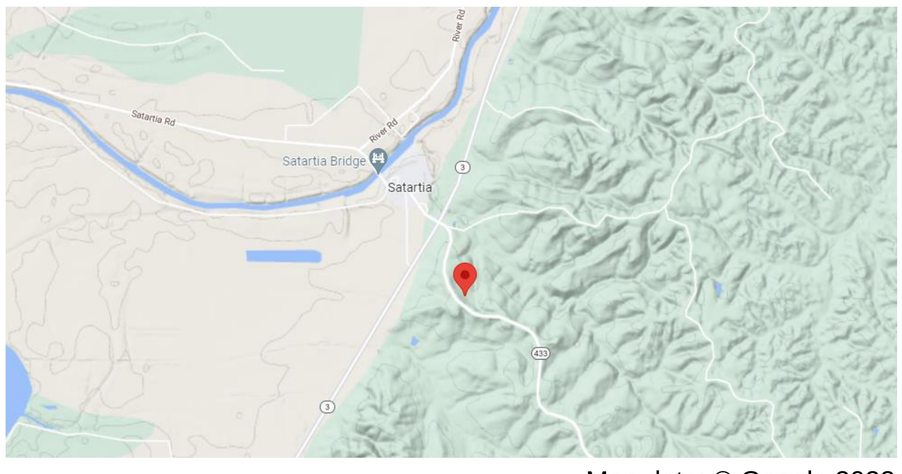
Satartia, Mississippi, CO_2 pipeline incident, Feb 2020

- Landslide ruptured 24-inch diameter, 97 bar dense-phase CO_2 pipeline
- Release was located approximately 1 mile from village of Satartia
- Local emergency responders not informed by pipeline operator (Denbury) of the pipeline rupture and release of CO_2
- Denbury's risk assessment did not identify that a release could affect the population of Satartia
- Approximately 200 residents evacuated, 46 casualties
- Terrain influenced the direction of the hazardous cloud

Figure 6: Topographical Map Showing the Delhi Pipeline (Green) and Denbury's Buffer Zone (Red) on Either Side of the Pipeline and the Proximity to Satartia (Blue Star Indicates the Rupture Site)



Map data: © Google 2022

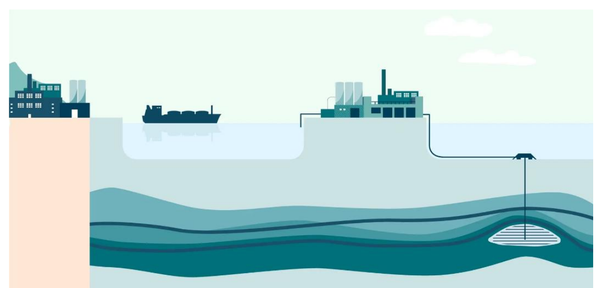
Images © PHMSA: https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2022-05/Failure%20Investigation%20Report%20-%20Denbury%20Gulf%20Coast%20Pipeline.pdf

CCUS Knowledge Gaps

- Pipeline design
  - Understanding of running ductile crack propagation along CO_2 pipelines that can be used to specify material toughness and/or crack arrester requirements

- Pipeline risk assessment
  - Pipeline failure rates: need for modifications to fracture mechanics model in pipeline risk assessment models for CO_2 properties
  - Need to develop a fast method for modelling CO_2 dense-gas dispersion, incorporating terrain effects on along pipeline route

- Ship transport of CO_2 and subsea CO_2 pipelines
  - E.g. for transport of UK CO_2 to Norwegian “Northern Lights” project
  - Do we understand behaviour of CO_2 releases onto water?



https://www.equinor.com/energy/northern-lights

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- 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

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