Industrial Decarbonisation Frontiers Report

Hydrogen Transport and Storage

Since its launch in 2021, the Industrial Decarbonisation Research and Innovation Centre (IDRIC) has funded 100 projects, investigating and addressing the key dimensions of the whole system of industrial decarbonisation. This work has generated a vast body of knowledge, offering critical insights into the challenges we face in decarbonising and into the solutions – technical, economic and social – that are emerging. The *Frontiers Reports* series brings together all these insights to share with our industry and policy stakeholders.

Each report synthesises key findings from multiple projects conducted on a closely related theme, providing a comprehensive perspective on a specific aspect of industrial decarbonisation. Far more than simply research summaries, these reports translate academic insights into practical, evidence-based recommendations for our stakeholders. These recommendations are shaped by the expertise and evidence gathered by our research teams and are designed to support decision-makers in advancing their net-zero goals.

The *Frontiers Reports* are anticipated to serve as catalysts for meaningful discussions between academia, industry, and policymakers on the most viable paths forward. We welcome constructive debate and are eager to support the implementation of recommendations that best align with our stakeholders' priorities and goals towards net zero.

This report brings together all IDRIC's research on Hydrogen Transport and Storage.

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Executive summary

As hydrogen demand is expected to grow significantly, delivering large-scale, efficient and safe transport and storage systems is vital to the UK's net-zero ambitions. This report synthesises IDRIC's research on hydrogen transport and storage and explores the technical, environmental and safety considerations associated with scaling hydrogen infrastructure. It provides recommendations for industry and policymakers to strategically plan and develop the necessary infrastructure for a future hydrogen economy.

Key findings

Geological reservoir suitability for hydrogen storage
Whilst salt caverns are the most technically mature and operationally reliable storage option, porous rock formations – such as depleted gas fields and saline aquifers – offer large-scale potential. Laboratory studies on porous rock samples from two major UK aquifers showed no notable changes in rock structure or chemical composition after hydrogen exposure under high temperature and pressure.

Strategic gaps in capacity and infrastructure
The UK's current hydrogen storage capacity is far below the projected capacity requirements for 2050. IDRIC research highlights a significant infrastructure gap – particularly for clusters lacking salt formations – and reinforces the need for urgent innovation and government backing to scale alternative solutions like lined rock caverns and porous rock systems.

Hydrogen transport and storage systems

- **Efficiency**
  Compressing hydrogen requires more energy than natural gas requires, but pipeline delivery remains efficient, especially for networks under 500 km. Liquefaction and long-distance trucking represent the least efficient options in the value chain.
- **Environmental impacts**
  There are major knowledge gaps in life cycle assessments (LCAs) for hydrogen storage and transport, limiting insight into long-term environmental trade-offs. Fugitive hydrogen emissions during storage and transmission remain underexplored.
- **Safety**
  Hydrogen's unique properties, such as high flammability, diffusivity and pressure demands require adapted safety regulations. Existing gas infrastructure may be repurposed for hydrogen blends, but new builds are preferred for 100% hydrogen.

Recommendations to industry

Strategically plan geological storage
Target salt cavern development near clusters like Teesside and Humberside for high-purity hydrogen storage. Explore porous rock or offshore storage options in regions without halite formations.

Ensure material and geological compatibility
Prioritise rock types with low reactive mineral content to minimise gas loss or contamination risks. Storage infrastructure, including well casings and cap rocks, must be designed to withstand degradation from hydrogen exposure.

Further accelerate cluster-level coordination and policy development
Align demand profiles, timelines and infrastructure planning across producers, carriers and offtakers. Support business models that reflect shared investment needs.

Promote knowledge sharing and collaboration for storage decision-making
Collaborate with academia to jointly develop modelling tools, digital platforms and pilot projects that reduce risk and support strategic investment.

Collaborate on safe system design
Work with research bodies to apply hydrogen-specific safety standards and minimise on-site hazards, particularly at refuelling and distribution hubs. Research institutions can support the development of safety cases for blended and 100% hydrogen networks.

Recommendations to policymakers

Accelerate R&D and demonstration through public-private collaboration
Fund regionally tailored pilot projects for low-TRL geological storage options, coordinated with devolved governments and local industry needs.

Develop robust and inclusive regulatory frameworks
Update national regulations governing large-scale geological hydrogen storage and develop new safety frameworks to address hydrogen-specific risks.

Enable strategic planning through data and mapping
Support national and regional geological surveys – onshore and offshore – to identify viable storage sites, especially in regions lacking salt caverns.

Integrate storage into national energy strategies
Embed geological hydrogen storage – both salt cavern and porous rock – into national hydrogen and energy transition strategies. This includes setting clear capacity targets, timelines and investment priorities.

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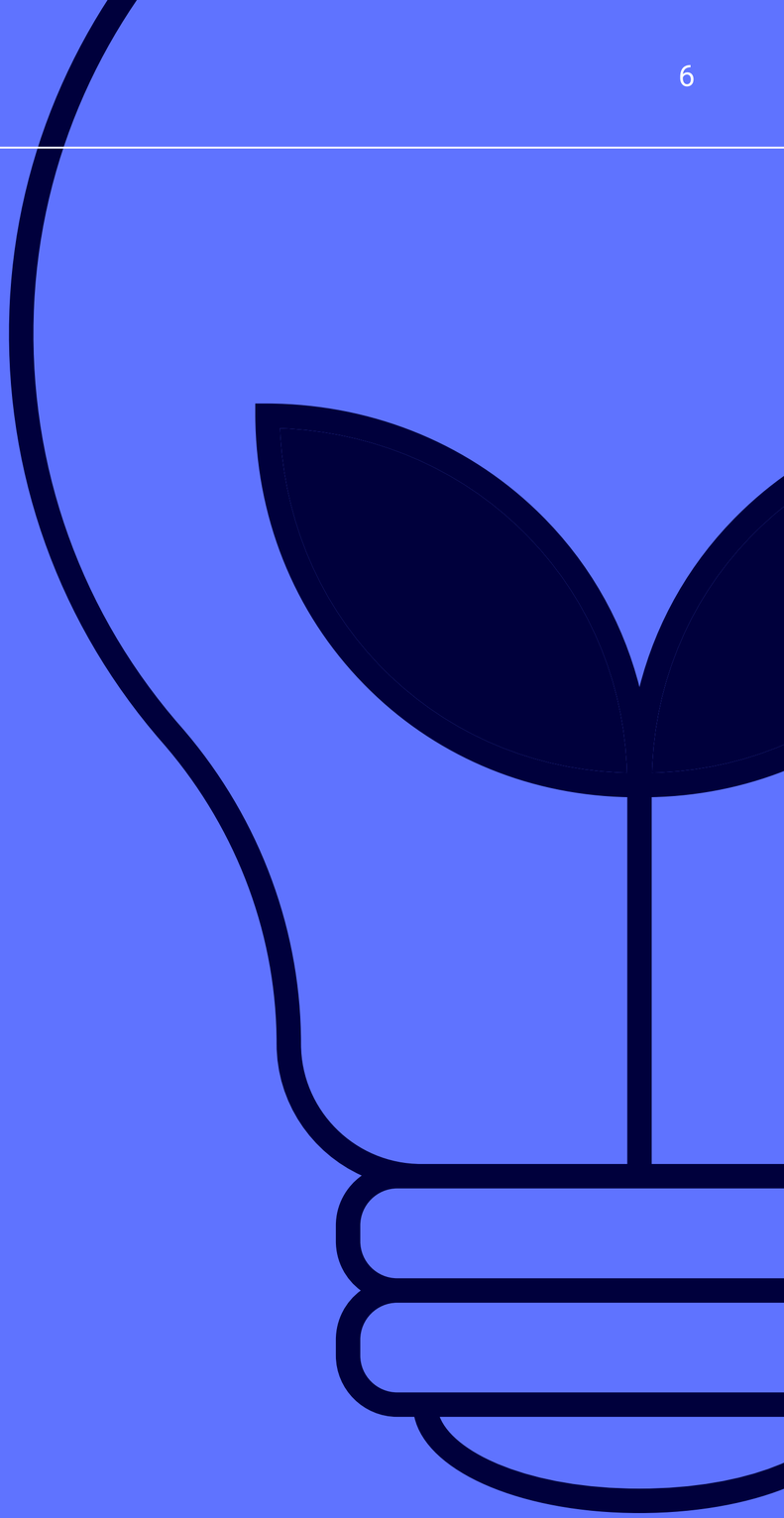
Introduction

Hydrogen is a key enabler for the industrial transition to net zero – particularly for many high-temperature and hard to decarbonise applications in industry – as well as an enabler for flexible response within a power system heavily reliant on renewable energy. The UK Industrial Decarbonisation Cluster Plans all indicate the urgent need to address the distribution of very large quantities of hydrogen to support the anticipated demand for decarbonisation.
This also comes with a requirement for hydrogen storage at a scale well beyond the capacity in use for current industrial applications.



At present, the transportation of hydrogen in the UK is dominated by road distribution of compressed hydrogen cylinders and trailers. The most common means of hydrogen storage is in above ground metallic or composite compressed cylinders, with a modest amount of liquid hydrogen storage to suit specific applications. However, there are a small number of existing local hydrogen pipelines servicing industrial customers in some of the UK's industrial clusters, and larger-scale underground storage of hydrogen has been in operation since the early 1970s in former brine caverns in the Saltholme Brinefield in Teesside.

Whilst the hydrogen industry is well established in the UK, major increases are required in the volume of hydrogen transported and stored to meet the anticipated demand that will, in turn, enable industrial decarbonisation and support the energy network in the UK. The UK Government's own analysis indicates a hydrogen supply equivalent to 250-460TWh will be necessary by 2050 to satisfy the demands needed to reach net zero, equivalent to 20-35% of UK final energy consumption.[1] This compares with an estimated current UK demand for hydrogen of approximately 27TWh[2] primarily used as an industrial feedstock. At this proposed scale of hydrogen demand, with a significant proportion of the hydrogen produced from renewable electricity – and with highly variable industrial load profiles – there is a clear necessity for substantial hydrogen storage. In addition to larger 'blue' hydrogen plants (reformers with carbon capture) located adjacent to coastal industrial demand, there is also likely to be multiple hydrogen generation sites, often located some distance from industrial offtakers. This necessitates the development of wide-scale hydrogen distribution at a scale well beyond the current position.

For more information about advances in the generation of hydrogen, please read IDRIC's Frontiers Report on Hydrogen Generation.

Hydrogen pipeline development

Distribution

Each of the UK's industrial clusters have developed plans for hydrogen pipeline distribution to link clean hydrogen production with industrial offtakers within region.[3] These planned hydrogen networks go well beyond the current hydrogen distribution pipelines within each cluster; largely based on co-location of hydrogen production with an industrial feedstock demand. Repurposing the UK's natural gas distribution network for hydrogen or hydrogen blends presents both opportunities and challenges. Studies indicate that materials used in the existing distribution infrastructure, such as iron and polyethylene, must be assessed for hydrogen compatibility, given the potential for embrittlement and leakage issues.[4] Research on the feasibility of blending hydrogen with natural gas suggests that moderate blending ratios can be accommodated without significant retrofitting, but transitioning to 100% hydrogen would require substantial modifications.[5] Additionally, regulatory and commercial barriers must be addressed to facilitate large-scale repurposing efforts.[6] These studies provide critical insights into the potential pathways and technical adaptations required for a hydrogen-compatible gas distribution system in the UK.

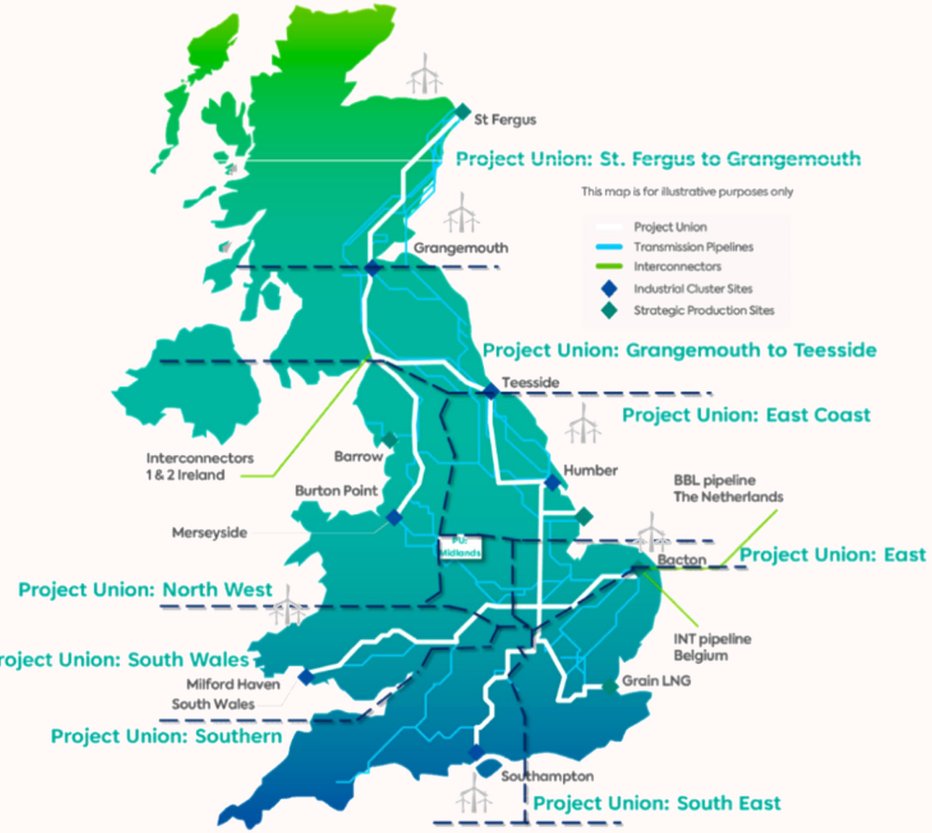


Figure 1

Illustrative map showing the ambitions for a UK hydrogen transmission network under Project Union (taken directly from National Gas website, "Project Union").

Transmission

Ultimately, each of these regional hydrogen distribution pipelines are intended to link to a national hydrogen transmission backbone, to be developed by Project Union. This major infrastructure project led by National Gas Transmission (NGT), aims by the mid-2030s to establish connection between key hydrogen production sites, industrial clusters and storage facilities, supplying major industries and power generation directly and via Gas Distribution Networks (GDNs).[7]

Hydrogen storage need

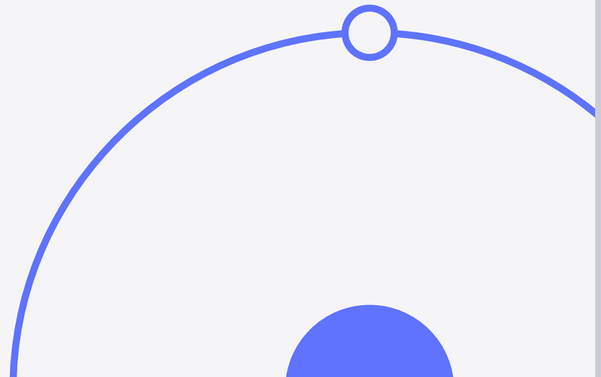
As with many forward projections supporting decarbonisation, there are a range of scenario-based estimates of future hydrogen storage need. It is also difficult to separate the requirement solely for industrial decarbonisation from that required for the energy system as a whole. Based on the previous National Grid Energy Scenarios, a 2021 analysis by Centrica indicated a hydrogen storage capacity requirement of 10-40TWh by 2050 to enable net zero.[8] However, as identified by IDRIC project MIP 3.2, other studies have suggested significantly higher hydrogen storage capacity requirements based on domestic heating requirement, including Moulli-Castillo (77.9TWh)[9] and Scafidi (150TWh).[10] By comparison, the UK currently has 1.5 billion cubic meters, equivalent to 145TWh of underground natural gas storage in salt caverns and depleted reservoirs.[11] Recent studies have tended to increase the estimate of hydrogen demand to achieve net zero. This includes the assessment of industrial hydrogen requirement identified by each of the Industrial Cluster Plans, and from the CCC's estimation of hydrogen required to balance the future energy system. Government decisions on domestic and commercial heating by hydrogen will impact total hydrogen demand significantly. Because of the seasonality of heating demand, this will also have a major consequence for the total amount of hydrogen storage required in the UK. What is clear is that the UK will need to make rapid progress on the development of new hydrogen storage or risk the country's progress to net zero.

Hydrogen storage in salt caverns

The UK has significant potential for hydrogen storage in underground salt caverns, particularly in regions with thick, high-purity halite formations. These salt caverns are created through solution mining, where water dissolves salt layers, forming stable underground voids. These caverns naturally seal due to salt's self-healing nature, minimizing leakage. Designed to handle high pressures, they can efficiently store natural gas or hydrogen. Onshore, key locations include the Cheshire Basin, Yorkshire, Teesside and parts of the Wessex Basin, while offshore sites like the East Irish Sea Basin and Southern North Sea also show promise. Research suggests Somerset and the Bristol Channel (where it meets the Irish Sea) could support salt cavern development, though depth, thickness and halite purity are key considerations for suitability. The Mercia Mudstone Group (Cheshire Basin, Worcestershire, East Midlands, Somerset) and Zechstein Group formations (East Yorkshire, County Durham, Cleveland Basin) provide ideal storage conditions due to their impermeability and self-sealing properties. Salt caverns enable rapid hydrogen injection and withdrawal, making them crucial for grid balancing and energy security. Ongoing studies, including those by the British Geological Survey, support their feasibility, particularly as the UK transitions to a low-carbon hydrogen economy. However, further site-specific assessments are needed.

Hydrogen storage in porous rocks

Hydrogen storage in porous rocks is a promising approach to support industrial decarbonisation by providing large-scale, underground storage alternatives to surface tanks and engineered salt caverns. While salt caverns are already used for gas storage, their distribution is geographically limited, necessitating the exploration of porous media such as saline aquifers and depleted hydrocarbon reservoirs. However, hydrogen's behaviour in porous rock formations remains largely untested, with concerns related to potential geochemical reactions, microbial activity and long-term containment. The technology readiness level (TRL) for porous rock hydrogen storage remains low (TRL 2-4), making experimental studies essential to proving feasibility, addressing safety concerns and building investor confidence. By developing a deeper understanding of how hydrogen interacts with rock formations, research will contribute to efforts to integrate hydrogen storage into the energy supply chain.



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Research findings

The IDRIC programme has addressed several of the most important technical, environmental and regulatory challenges associated with the large-scale transportation and long-term geological storage of hydrogen.

Seven IDRIC projects contributed to this report. They are referred to by their project IDs throughout.
→ See further information.

Project ID	Project name
MIP 3.2	Hydrogen storage and transport networks for net-zero industrial clusters
MIP 7.1a	Evaluating the energy balance and efficiency of the large-scale deployment of a hydrogen energy system
MIP 7.1b	Environmental impacts of the large-scale deployment of a hydrogen energy system
MIP 7.1c	Guidance on the development of a safety case for the hydrogen value-chain
MIP 7.4	Enabling hydrogen storage near industrial clusters
MIP 7.8	Enabling hydrogen storage near industrial clusters (Phase 2): Enhancing confidence in porous rock storage
FF 4-6	Assessing regional demand for geological H_2 Storage: Building a strategic case for investment in the East Coast Cluster

Findings from IDRIC's projects MIP 3.2, MIP 7.1a–c, MIP 7.4, MIP 7.8 and FF 4-6 underscore the scale of the challenge and the urgent need to develop a diversified and robust UK hydrogen storage and distribution network as a key enabler of industrial decarbonisation and a future clean energy economy. Collectively, the projects inform future development pathways for hydrogen transportation infrastructure in the UK and the opportunities and challenges of geological hydrogen storage.

Geological reservoir suitability for hydrogen storage

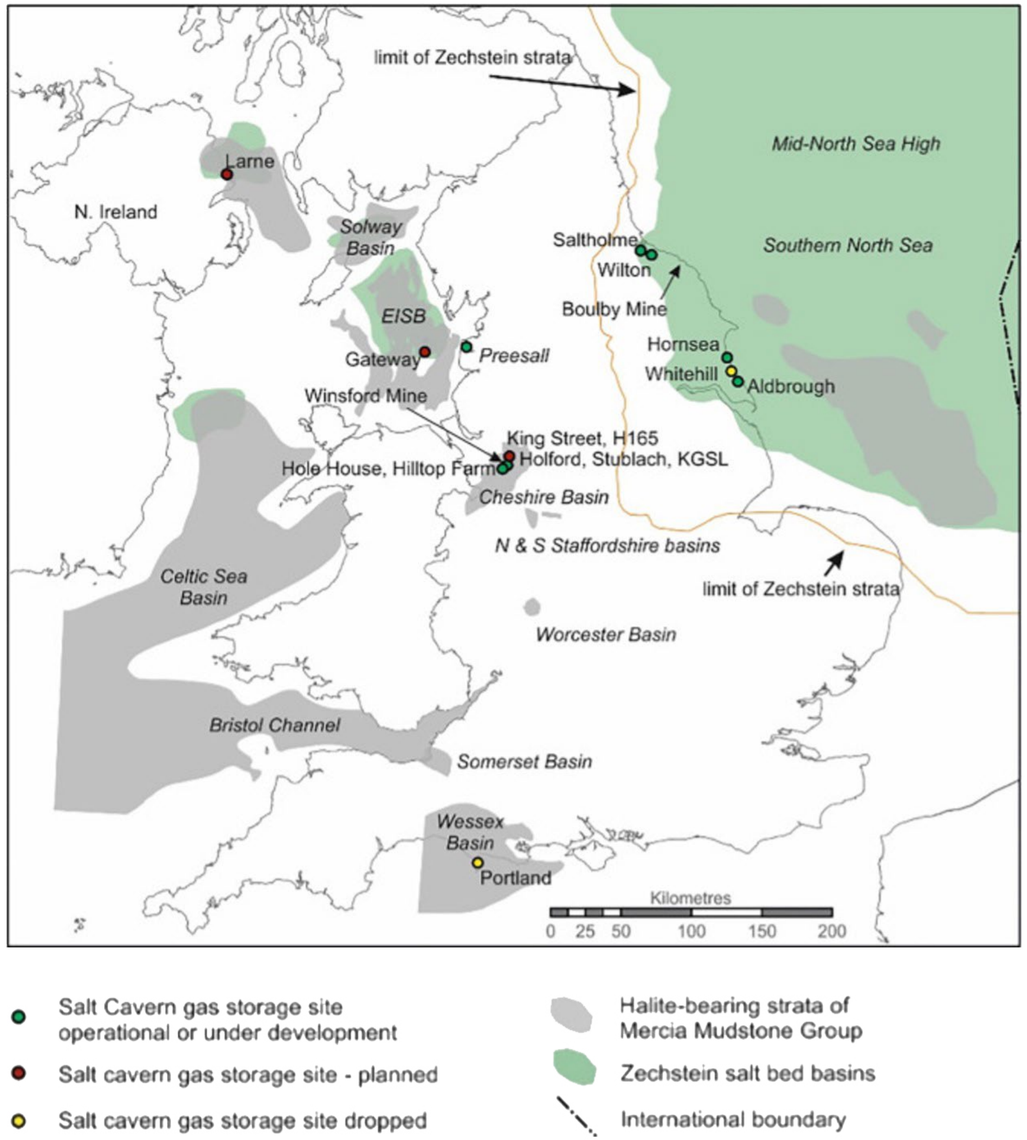
Salt caverns

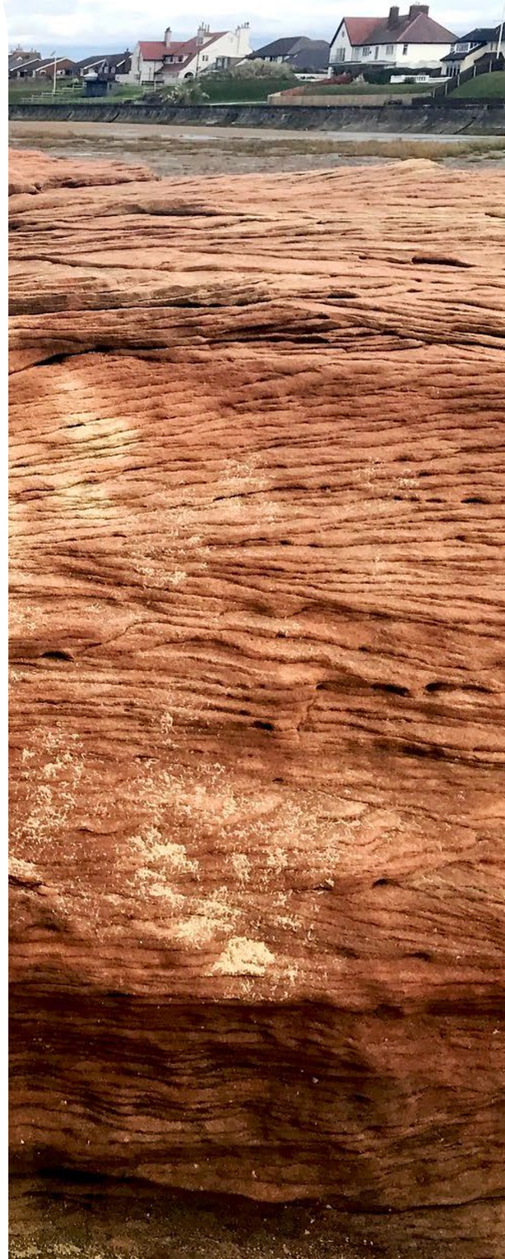
Salt caverns remain the most mature and technically achievable option for large-scale hydrogen storage in the UK, having been used for this purpose since the mid-20th century. Their key advantages include excellent sealing integrity due to halite's low permeability, minimal cushion gas requirements, high charge/discharge rates and limited microbial or geochemical reactivity that helps maintain hydrogen gas purity. Projects MIP 3.2, MIP 7.4 and MIP 7.8 each highlight the operational resilience of salt caverns, which can support repeated hydrogen injection and withdrawal cycles at high pressures.

Existing cavern sites in Cheshire and Teesside and halite-bearing strata in the Wessex Basin both align well with the spatial needs of key industrial clusters (Figure 2). However, the industrial clusters regions in South Wales and Grangemouth lack nearby halite formations, limiting onshore development and posing a significant challenge for regional hydrogen storage. Offshore caverns may serve these clusters, but they introduce added complexity, including brine management during cavern creation and structural stability concerns. Significant investment and robust regulatory frameworks will be required to scale up salt cavern usage.

Figure 2

Map showing UK salt caverns at different stages of planning and development [MIP 3.2].





Porous rock formations

IDRIC projects MIP 3.2 and MIP 7.4 identify depleted hydrocarbon reservoirs and saline aquifers as promising long-term alternatives, offering capacity well in excess of demand. Depleted gas fields are particularly attractive due to existing infrastructure and well-characterised geologies. Although no operational projects have yet stored pure hydrogen in saline aquifers, historical use of porous media for town gas suggests feasibility.[1] Successful deployment, however, depends on caprock integrity, recovery efficiency and gas-mineral-microbe interactions.

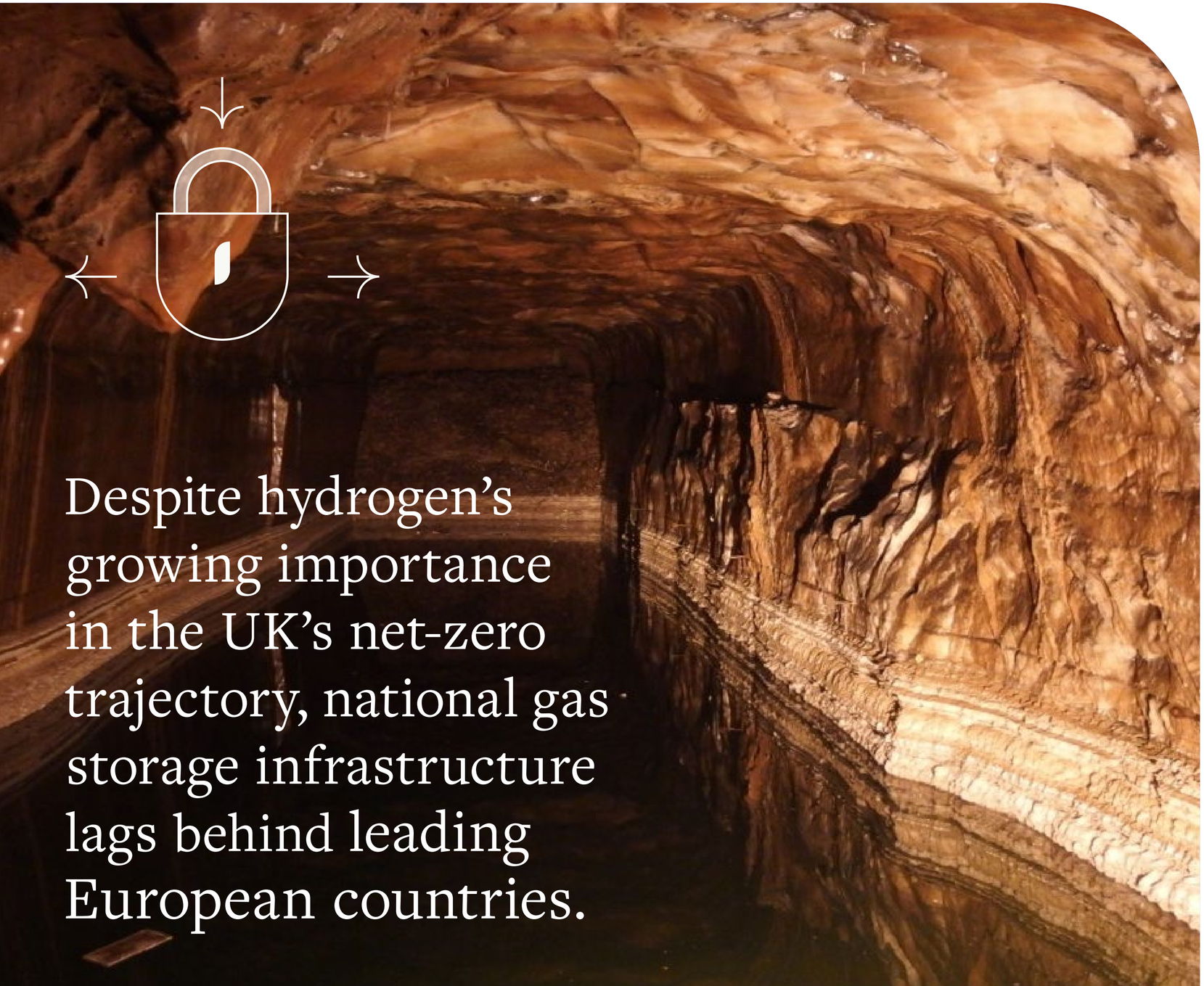
While hydrogen storage in porous rocks is not yet commercially used, concerns over containment and contamination persist due to possible geochemical and microbial reactions enhanced by the presence of hydrogen. To address this, project MIP 7.4 studied hydrogen behaviour in porous rock samples, with focus on two major UK aquifers: the Triassic Sherwood Sandstone and Cretaceous Lower Greensand, as shown in Figure 3.

The study revealed no significant alterations in rock structure or chemical composition after hydrogen exposure under high temperature and pressure conditions. Minor changes detected could stem from the limitations of the analytical methods used. Additionally, aspects of the experimental setup itself may have contributed to these observed variations. Although no major changes were found in the tested samples, rocks with different mineral compositions – such as those containing sulphate minerals or pyrite – may still be susceptible to geochemical reactions or microbial activity triggered by hydrogen.

A GIS-based national mapping exercise identified natural closures (geological structures which create natural traps for fluids) within the Sherwood and Lower Greensand aquifers, categorised by depth. This initial assessment highlighted potential hydrogen storage targets in regions such as the English Midlands and Wessex Basin. However, volumetric calculations and fault analyses were not included at this stage.

Figure 3

National-scale assessment of areas of geology that may be suitable for hydrogen storage in porous rocks [MIP 7.4].



Despite hydrogen's growing importance in the UK's net-zero trajectory, national gas storage infrastructure lags behind leading European countries.

Strategic gaps in capacity and infrastructure

Project MIP 3.2 notes that despite hydrogen's growing importance in the UK's net-zero trajectory, national gas storage infrastructure lags behind leading European countries. The UK has six operational onshore salt caverns for natural gas storage (11 TWh capacity) and two onshore depleted gas fields (4 TWh). As indicated above, 2050 storage demand forecasts for hydrogen vary widely — from 10 TWh for heating alone, to theoretical upper bounds of 2661. 9 TWh for gas field storage. HyUSPRe estimates porous media could provide 44 TWh of capacity (rising to 63 TWh with cavern expansion), while the UK Continental Shelf may offer up to 9100 TWh when combining gas fields and saline aquifers – though the latter figure is highly uncertain.

Project FF 4-6 also warns of a significant mismatch between anticipated near-term hydrogen storage needs and current UK capacity. The storage demand of the East Coast Cluster by 2035 is projected at 2–18 TWh. However, current operational hydrogen storage capacity stands at just 0.025 TWh (Teesside's Saltholme Brinefield), with an additional 1.5 TWh under development (HyKeuper and Aldbrough). FF 4-6 revises earlier estimates of onshore UK salt cavern potential from down to ~25 TWh, citing land use restrictions, salt deposit heterogeneity and limiting geological features.

The findings reinforce the need for urgent innovation and government backing to scale alternative solutions, such as lined rock caverns and porous rock systems. These technologies remain at lower technology readiness levels and require targeted funding under mechanisms like the Hydrogen Storage Business Model. Project FF 4-6's dissemination efforts have already influenced policy by elevating storage as a priority area within decarbonisation planning.

Hydrogen transport and storage systems — Efficiency, environmental impacts and safety

Energy efficiency

Project MIP 7.1a assessed hydrogen distribution via road trailer, rail, ships and pipelines. The work found that compressing hydrogen requires more energy than for natural gas, but pipeline delivery remains efficient, especially for networks under 500 km. Hydrogen's lower density results in over three times the volumetric flow rate compared to methane, leading to ~50% higher pressure drops. Newly constructed hydrogen pipelines are expected to mitigate this via design optimisations. Local networks (<100 km) exhibit negligible efficiency losses. Hydrogen pipeline transport can benefit from "line pack" in a similar way to natural gas, allowing temporary storage and flow regulation; however, due to hydrogen's lower energy density and higher diffusivity, the line pack capacity is reduced, offering more limited buffering potential compared to natural gas.

Project MIP 7.1a also compared multiple storage types: pressurised tanks (350 barg), pipeline storage (20 barg over normal), geological formations (150 barg) and cryogenic systems (−252°C). Geological and pipeline storage show block efficiencies exceeding 99%, outperforming cryogenic storage. Liquefaction and long-distance trucking represent the least efficient options in the value chain.

Environmental impact analysis

Project MIP 7.1b identifies major knowledge gaps in life cycle assessments for hydrogen storage. While emissions and space use are sometimes included, most studies lack disaggregated analysis of individual storage stages, limiting insight into long-term environmental trade-offs. Fugitive hydrogen emissions during storage and transmission – despite hydrogen's indirect greenhouse gas potential – remain underexplored, indicating a clear research need.

As with storage, transmission stages suffer from incomplete environmental profiling. The literature review in project MIP 7.1b showed emissions to air as the most documented aspect, but detailed evaluations of the transmission process are scarce. Fugitive emissions again represent a blind spot, particularly for pipeline transport of liquefied hydrogen.

Safety and regulation

Project MIP 7.1c emphasised the importance of adapting safety regulations for hydrogen's unique properties, such as high flammability, diffusivity and pressure demands. Existing gas infrastructure may be repurposed for hydrogen blends and low and medium pressure distribution of 100% hydrogen, although new builds or lining are preferred for higher pressure hydrogen transmission. Projects like HyNet and HyTechnical are investigating overpressures, venting risks and fire dynamics. Findings show hydrogen fires result in slightly reduced Building Proximity Distances compared to natural gas but still necessitate rigorous planning and further study.

Project MIP 7.1c reviewed storage modalities (compressed, liquid, liquid organic hydrogen carriers (LOHC) and ammonia) from a safety and compliance perspective. It recommends minimising hazardous material onsite through frequent offloading or derivative production (e.g., methanol). Cryogenic storage vessels fall under specific regulatory scrutiny. Projects like H2H Humber serve as case studies for bulk onshore storage, illustrating emerging regulatory pathways.

Hydrogen's unique properties, such as high flammability, diffusivity and pressure demands require adapted safety regulations.

Recommendations to industry

Based in IDRIC's research into hydrogen transportation and storage, we make the following recommendations to industry to support their decarbonisation through a transition to hydrogen.

Key recommendations

1 **Strategically plan geological storage**
Target salt cavern development near clusters like Teesside and Humberside for high-purity hydrogen storage. Explore porous rock or offshore storage options in regions without halite formations.

2 **Ensure material and geological compatibility**
Prioritise rock types with low reactive mineral content to minimise gas loss or contamination risks. Storage infrastructure, including well casings and cap rocks, must be designed to withstand degradation from hydrogen exposure.

3 **Further accelerate cluster-level coordination and policy development**
Align demand profiles, timelines and infrastructure planning across producers, carriers and offtakers. Support business models that reflect shared investment needs.

4 **Collaborate on safe system design**
Work with research bodies to apply hydrogen-specific safety standards and minimise on-site hazards, particularly at refuelling and distribution hubs. Research institutions can support the development of safety cases for blended and 100% hydrogen networks.

Strategically plan geological storage

Industrial clusters like Teesside, Humberside and Merseyside are **well positioned to take advantage of existing or potential salt cavern infrastructure** for high-purity hydrogen storage.

Industry support is important in exploring viable UK geological formations for salt cavern development, such as the Fordon Evaporite Formation, Northwich Halite Member and Dorset Halite Member.

Industries would benefit from exploring both salt cavern and porous rock storage options to enhance flexibility and supply chain resilience

For **industrial clusters without nearby salt cavern access** – such as the Black Country, South Wales and Grangemouth – **porous rock formations could offer alternative storage options** (e.g. Sherwood Sandstone and Lower Greensand).

Cluster development linked with offshore wind development should consider **co-locating hydrogen production and storage using depleted offshore gas reservoirs** to enable integrated, low-carbon energy systems.

Ensure material and geological compatibility

Industrial engagement with geological hydrogen storage projects is recommended to **prioritise rock types with low reactive mineral content to minimise risks of gas loss or contamination**. Design of storage infrastructure must **consider potential material degradation from hydrogen exposure**, especially in well casings and cap rocks.

Where possible, **sectors requiring pure hydrogen, are recommended to prioritise salt cavern storage for its ability to maintain gas purity**. Industries blending hydrogen with natural gas or with **more flexible purity needs should assess the viability of porous media storage**.

The support of industrial clusters is necessary in developing pilot projects to test hydrogen storage performance in real-world conditions and validate long-term stability.

Further accelerate cluster-level coordination and policy development

Industrial clusters should **continue to refine hydrogen demand profiles, timelines and geographic needs** to align storage and distribution planning.

Further **collaboration, coordination and planning is needed between producers, carriers and offtakers** to overcome investment hesitancy and establish regional storage infrastructure. This includes advocating for business models that reflect this interdependence.

Promote knowledge sharing and collaboration for storage decision-making

Research institutions and academic partners should **actively promote knowledge-sharing to bridge the gap between hydrogen production and storage**, while fostering partnerships with industry and government to **co-develop technologies and secure joint funding opportunities.**

Research organisations can support industry by curating and expanding access to digital platforms such as the Hydrogen Knowledge Centre, and by developing tools that assess geological storage potential and guide strategic investment decisions across the hydrogen value chain.

Academic and **research partners can help de-risk hydrogen storage initiatives by contributing advanced modelling capabilities and technical expertise in areas such as reservoir simulation, wellbore integrity and geological characterisation** – especially by collaborating with the oil and gas sector.

Collaborate on safe system design

We recommend **industry and research organisations work together to apply inherently safe design principles** that minimise hazardous substances on-site – particularly at distribution hubs – and explore options such as frequent transport or alternative storage methods to remain below COMAH thresholds.

Joint efforts can **ensure that hydrogen infrastructure, including pipelines and refuelling stations, complies with relevant codes and standards** (e.g. BS EN 60079-10, PD CLC/TR 50404:2003, BCGA Codes of Practice), incorporating hydrogen's unique properties and addressing risks related to co-location and hazardous area classification.

Research institutions can assist industry in developing robust safety cases for both blended and 100% hydrogen networks, guided by frameworks like the demonstrator project HyDeploy and Gas Safety (Management) Regulations (GS(M)R), and in conducting comprehensive risk assessments to address major accident hazards across industrial and community applications.

Collaborative initiatives **focussing on ensuring compliance** with cryogenic storage standards and promoting proactive safety practices, such as **notifying local fire authorities** – even below regulatory thresholds – **can strengthen emergency response readiness.**

Research institutions can support the development of safety cases for blended and 100% hydrogen networks.

Recommendations to policymakers

Based in IDRIC's research into hydrogen transportation and storage, we make the following recommendations to policymaker to enable industrial decarbonisation through a transition to hydrogen.

Key recommendations

1 **Accelerate R&D and demonstration through public–private collaboration**
Fund regionally tailored pilot projects for low-TRL geological storage options, coordinated with devolved governments and local industry needs.

2 **Develop robust and inclusive regulatory frameworks**
Update national regulations governing large-scale geological hydrogen storage and develop new safety frameworks to address hydrogen-specific risks.

3 **Enable strategic planning through data and mapping**
Support national and regional geological surveys – onshore and offshore – to identify viable storage sites, especially in regions lacking salt caverns.

4 **Integrate storage into national energy strategies**
Embed geological hydrogen storage – both salt cavern and porous rock – into national hydrogen and energy transition strategies. This includes setting clear capacity targets, timelines and investment priorities.

Accelerate R&D and demonstration through public-private collaboration

We recommend the UK Government **scales up support for collaborative research and demonstration projects that advance geological hydrogen storage technologies** – particularly porous rock and alternative options like lined rock caverns – which currently remain at low technology readiness levels.

Coordinating these efforts with research institutions, industry stakeholders and devolved administrations can ensure that pilot projects reflect regional needs and infrastructure contexts. Devolved administrations can support this effort by providing region-specific grants, aligning R&D initiatives with local decarbonisation goals.

Enable strategic planning through data and mapping

We recommend UK Government and Devolved administrations **support national and regional-scale geological surveys**, including for offshore saline aquifers, to **improve understanding of the UK's underground hydrogen storage potential**. These surveys will help de-risk investment by providing industry with high-resolution data for site selection and infrastructure development.

This is especially important where salt cavern storage is not available. Identifying viable porous rock formations will be critical for unlocking the hydrogen potential of these regions, particularly given their high renewable energy generation capacity.

Local authorities can use this data to inform spatial planning decisions and align hydrogen storage infrastructure with industrial development, grid access and transport corridors.

Develop robust and inclusive regulatory frameworks

UK Government are recommended to **clarify and update national regulations governing large-scale geological hydrogen storage.** This includes **extending the scope of existing regulations** such as the Gas Safety (Management) Regulations (GS(M)R) to address hydrogen blends and **developing new frameworks to manage the unique risks of hydrogen**, such as its high diffusivity and potential for material embrittlement. **Devolved administrations are recommended to work in parallel to ensure regulatory clarity.**

Local councils, as Hazardous Substances Authorities (HSAs), have a **crucial role in guiding developers through the planning process** under The Planning (Hazardous Substances) Regulations 2015. They **need to be equipped to evaluate regional safety and land-use implications of underground hydrogen storage.**

Collaborative input from academia and industry is essential to **ensure that emerging regulations are grounded in the latest scientific knowledge**, including lessons from CO_2 and methane storage, and that they support both safety and innovation.

Integrate storage into national energy strategies

Government is recommended to embed geological hydrogen storage – both salt cavern and porous rock – **into national hydrogen and energy transition strategies**. This includes setting clear capacity targets, timelines and investment priorities, particularly for supporting decarbonisation in industrial clusters and the heating sector.

Moving forward

This section outlines the most pressing further research required to accelerate industrial decarbonisation and the establishment of a thriving hydrogen economy.

Advance subsurface storage science and engineering

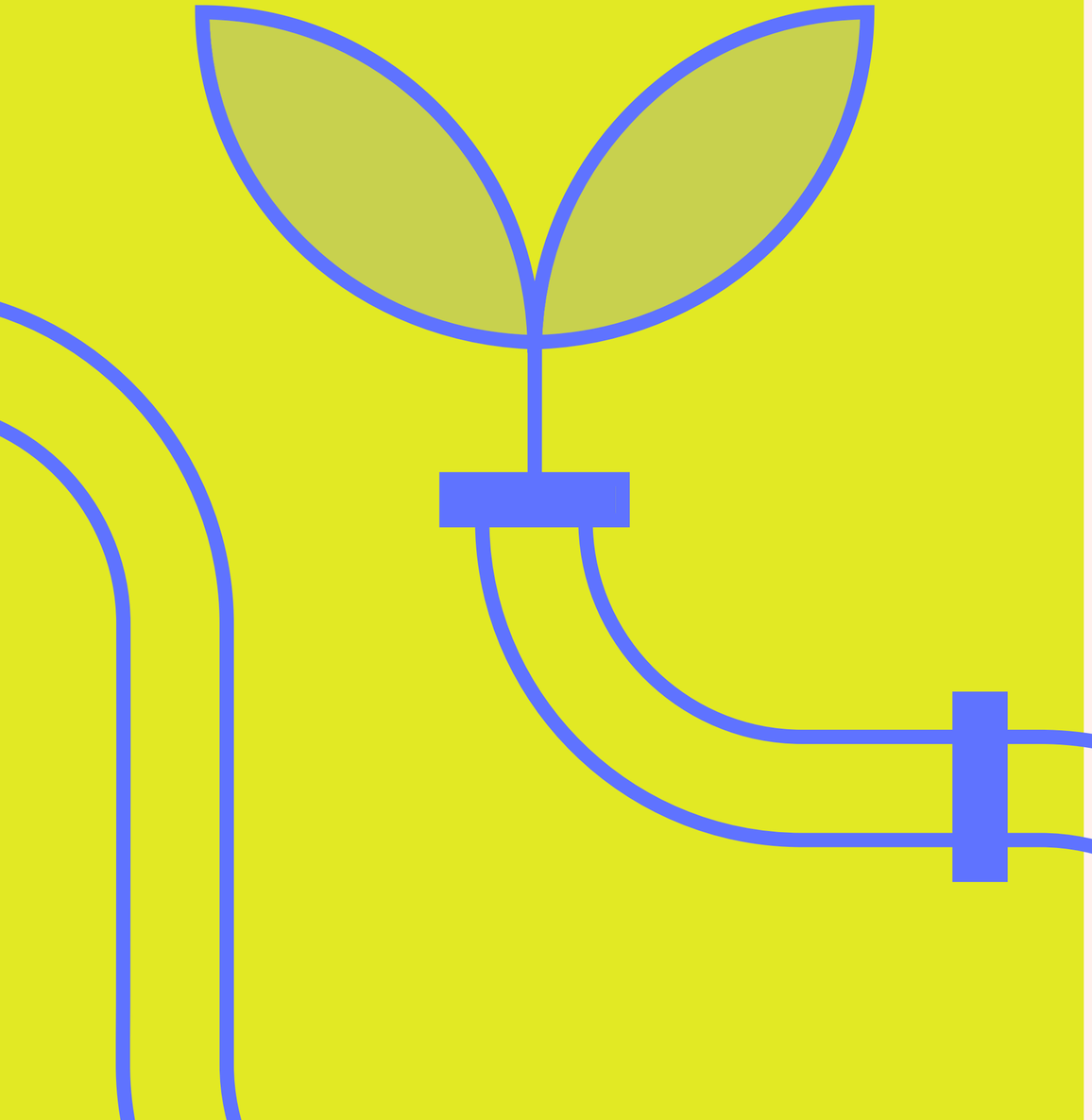
- Prioritise saline aquifer research by enhancing geological characterisation, integrating seismic and petrophysical data, and improving reservoir simulation to assess long-term storage potential for hydrogen.
- Investigate key subsurface challenges, including hydrogen leakage, gas-rock interactions, caprock integrity and microbial activity, to ensure containment and gas quality in porous media.
- Conduct site-specific studies using in-situ pressure, temperature and groundwater conditions — especially in formations with reactive minerals like pyrite or anhydrite — to evaluate geochemical and microbial stability.
- Evaluate cushion gas optimisation, exploring different gases and pressure regimes to enhance efficiency and reduce operational costs.

Bridge lab research and real-world deployment

- Scale up from lab to field through pilot-scale hydrogen injection trials and long-duration experiments to validate storage behaviour under realistic operational conditions.
- Develop predictive modelling tools to simulate hydrogen injection, withdrawal and retention in porous media, supporting better design and operational decision-making.
- Refine site selection methodologies by incorporating small-scale structural features, overburden integrity and depth thresholds based on technical and economic feasibility.

Support infrastructure integration and operational feasibility

- Research cavern optimisation for integration with industrial hubs, particularly in areas where salt formations exist, to expand strategic hydrogen storage networks.
- Assess the impact of historic extraction practices, such as fracking, on caprock sealing capacity, especially when repurposing depleted hydrocarbon fields for hydrogen storage.
- Investigate synergies with other subsurface technologies — including compressed air energy storage (CAES) and carbon capture and storage (CCS) — to enable multi-functional, resilient underground energy systems.



Strengthen environmental and safety assessments

- Expand environmental research into emissions, by-products (e.g., brine), noise and thermal radiation associated with hydrogen storage and distribution, especially under high-pressure conditions.
- Conduct life cycle assessments (LCAs) comparing hydrogen with alternative low-carbon fuels like sustainable aviation fuel (SAF) and ammonia, including their storage and transport impacts.
- Investigate the environmental footprint of different hydrogen production methods (e.g., electrolysis, pyrolysis, gasification) and electricity sources, considering implications for storage requirements and sustainability.
- Engage industry to validate LCA data sets, ensuring assessments of hydrogen storage and distribution reflect real-world operations and improve comparison reliability.

Modernise standards and operational protocols

- Support IGEM and other standards bodies in updating existing gas infrastructure standards (TD/3, TD/4, TD/13) to reflect the unique properties and behaviours of hydrogen.
- Develop operational procedures and live working practices for hydrogen distribution networks to support safe, real-time maintenance and control of storage and transmission systems.

Align innovation with market and workforce needs

- Conduct techno-economic comparisons of hydrogen storage technologies — including repurposing of existing and development of new salt caverns, depleted reservoirs and saline aquifers — to guide investment and policy priorities.
- Study future hydrogen market dynamics to understand sector-specific demand and inform infrastructure roll-out strategies across different regions and industries.
- Use research insights to shape training programs, supporting the development of a skilled workforce for emerging hydrogen storage and industrial decarbonisation roles.

Contributing projects

IDRIC projects included in this report

IDRIC ran three complementary strands of projects:

1 In-depth research projects embedded within nine Multidisciplinary Integrated Programmes (MIPs), each programme tackling a key challenge or pathway for industrial decarbonisation;

2 Shorter-term Flexible Fund (FF) projects designed to rapidly address emerging or urgent opportunities identified directly by industrial clusters;

3 Impact Accelerator (IA) projects aimed at maximising the impact of existing IDRIC projects.

Projects discussed within the report are referred to by their project ID.

◔ — Principal investigator

Project ID	Project name	Researchers	
MIP 3.2	Hydrogen storage and transport networks for net-zero industrial clusters	Mercedes Maroto-Valer ◔, John Andresen, Omid Shahrokhi, Amir Jahanbakhsh, Johnson Jimba, Sean Higgins	Heriot-Watt University
MIP 7.1a	Evaluating the energy balance and efficiency of the large-scale deployment of a hydrogen energy system	Martin Maeso ◔, Mark Scanlon, Toni Needham, Amaia O'Reilly	Energy Institute
MIP 7.1b	Environmental impacts of the large-scale deployment of a hydrogen energy system	Martin Maeso ◔, Mark Scanlon, Toni Needham, Amaia O'Reilly	Energy Institute
MIP 7.1c	Guidance on the development of a safety case for the hydrogen value-chain	Martin Maeso ◔, Mark Scanlon, Toni Needham, Amaia O'Reilly	Energy Institute
MIP 7.4	Enabling hydrogen storage near industrial clusters	Ed Hough ◔, Simon Gregory, Richard Haslam, Simon Kemp, Chris Rochelle, Jeremy Rushton	British Geological Survey
		Kevin Taylor, Lin Ma	University of Manchester
MIP 7.8	Enabling hydrogen storage near industrial clusters (Phase 2): Enhancing confidence in porous rock storage	Lin Ma ◔, Kevin Taylor, Jianpeng Wang	University of Manchester
		Ed Hough, Christopher Rochelle	British Geological Survey
		John Andresen, Omid Shahrokhi	Heriot Watt University
FF 4-6	Assessing regional demand for geological H_2 Storage: Building a strategic case for investment in the East Coast Cluster	Katriona Edlmann ◔, John Low, Henry Williams, Tim Armitage, James Todd	University of Edinburgh

Project ID	Project name	Outputs	
MIP 3.2	Hydrogen storage and transport networks for net-zero industrial clusters	Underground hydrogen storage	Journal
		A review of analogue case studies relevant to large-scale underground hydrogen storage	
		Enabling hydrogen storage near industrial clusters: Phase I and II	Webinar
MIP 7.1	Evaluating the energy balance and efficiency of the large-scale deployment of a hydrogen energy system	Review of directives/regulations relevant to the safe and environmentally compliant production, transportation, and storage of hydrogen — Executive summary	Report
		Application of life cycle assessment methodology to the understanding of the energy balance and efficiency of hydrogen value chain building blocks — Executive summary	
MIP 7.4	Enabling hydrogen storage near industrial clusters	Hydrogen storage in porous media	Report
		Hydrogen-induced mineral alteration: A review in the context of underground hydrogen storage (UHS) in saline aquifers	Journal
		Enabling hydrogen storage near industrial clusters: Phase I and II	Webinar
		Enabling hydrogen storage near industrial clusters: Enhancing confidence in porous rocks	
MIP 7.8	Enabling hydrogen storage near industrial clusters (Phase 2): Enhancing confidence in porous rock storage	Underground hydrogen storage, the key to a green and sustainable future	Blog
		Subsurface Solutions: Geological reservoirs for hydrogen storage	
		Geologist's view	
		Hydrogen-induced mineral alteration: A review in the context of underground hydrogen storage (UHS) in saline aquifers	Journal
		Time-lapse 3D imaging and modelling of acid-rock interactions within a mudstone: Implications for cap-rock behaviour during carbon storage	
		Enabling hydrogen storage near industrial clusters: Phase I and II	Webinar
		Enabling hydrogen storage near industrial clusters: enhancing confidence in porous rocks	

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