CSIRO

Australia's National Science Agency

Hydrogen RD&D Collaboration Opportunities: United Kingdom

As at 27 September 2022

Australian Government

Department of Climate Change, Energy, the Environment and Water

MISSION INNOVATION

CATALYSING CLEAN ENERGY SOLUTIONS FOR ALL

Citation

Benedicte Delaval, Trevor Rapson, Raghav Sharma, Will Hugh-Jones, Erin McClure, Max Temminghoff, Vivek Srinivasan (2022) Hydrogen RD&D Collaboration Opportunities. CSIRO, Australia

Copyright

Disclaimer

Acknowledgments

CSIRO acknowledges the Traditional Owners of the lands that we live and work on across Australia and pays its respect to Elders past and present. CSIRO recognises that Aboriginal and Torres Strait Islander peoples have made and will continue to make extraordinary contributions to all aspects of Australian life including culture, economy and science.

We are grateful for the time and input of the stakeholders from industry, government, academia who were consulted throughout this project and across the report series. In particular, the CSIRO project team would like to thank:

- Colleagues at CSIRO, members of the Australian Hydrogen Research Network (AHRN) and staff at the Department of Industry, Science, Energy and Resources (DISER), DFAT, Austrade who provided invaluable contributions to the report.
- CSIRO's Intellectual Property team and IP Australia who contributed the hydrogen patent analytics used in this series of reports: Greg Maloney (CSIRO), Catriona Shaw (IP Australia), Pushpika Wijesinghe (IP Australia).
- CSIRO's Science Impact & Policy team who contributed the hydrogen research publication analysis used in this series of reports: Tadro Abbott (CSIRO)
- The project Working Group who provided valuable feedback throughout the course of the project: Ben Aldham (CSIRO), Linda Stalker (CSIRO), Craig Buckley (Curtin University), Amalia Pearson (DISER).
- The CSIRO-DISER Hydrogen RD&D International Collaboration Program leadership team who provided oversight and guidance throughout the project: James Hetherington (DISER), Amalia Pearson (DISER), Patrick Hartley (CSIRO), Vicky Au (CSIRO), Dan O'Sullivan (CSIRO).

Finally, we would like to thank the following organisations and individuals for their time and feedback on this country report:

CSIRO: Amelia Fyfield, Doki Yamaguchi, Greg Maloney, Joel Sarout, Nawshad Haque**,** Sebastian Charnock, Yuko Wakamatsu, Yunxia Yang**.**

AHRN: Andrew Dicks (Griffith University, AHRN Convenor), Peter Grubnic (Future Fuels CRC), Peter Majewski (University of South Australia).

International Stakeholders:
UK Hydrogen Fuel Cell Association (UK HFCA), United Kingdom
University of Chester, United Kingdom
UCL Energy Institute, UK
Department for Business, Energy and Industrial Strategy (BEIS)

Contents

Executive Summary: United Kingdom

The United Kingdom (UK) has identified hydrogen as critical to achieving net-zero emissions. This report aims to enhance country-to-country engagement by providing stakeholders with an overview of the UK's hydrogen priorities and R&I ecosystem. It presents an overview the hydrogen R&D landscape in the UK, starting from the national strategy level, down to activity in specific technology areas. It also includes a publication and intellectual property (IP) scan, identifying key stakeholders in the UK that are actively undertaking hydrogen RD&D, both at the early research and commercialisation stages.

The UK's hydrogen strategy

The UK Hydrogen Strategy is a roadmap of future policies, reports, infrastructure plans, and feasibility studies detailing how the government will deliver on its ambitions. The UK has identified four key drivers for their hydrogen strategy: emissions reductions and decarbonisation, economic growth, energy security, and energy efficiency. The UK has also noted that recovery from the COVID-19 pandemic represents a unique opportunity to invest in emerging green and low-carbon technologies to address these drivers. Further, within the *UK Hydrogen Strategy*, it is stated that the UK's strategic hydrogen priorities centre around the ambition to become a global leader in hydrogen production, storage, and utilisation technologies via a 'whole-system' approach. The UK also identified that scaling up of technologies and the development of regulatory and market frameworks as important focus areas to support this ambition.

In acknowledging the importance of private sector investment in research, development and innovation, the UK has developed several initiatives to promote and direct private investment into hydrogen technologies, for example though its *Sector Development Action Plan*. To deliver further clarity on the direction of travel of UK hydrogen policy across the value chain and support effective collaboration between government and industry, the UK published a Hydrogen Strategy update to the market in July 2022, providing an accessible summary of government policy developments and schemes since the launch of the UK Hydrogen Strategy. This supporting environment for the private sector is further strengthened by the UK Government's development of a Hydrogen Business Model, which will incentivise both production and use of low carbon hydrogen through the provision of ongoing revenue support; and underpinned by a wider UK Innovation Strategy and collaborative engagements with industry, including via the Hydrogen Advisory Council.

The UK's targets and RD&D priorities

The UK's Hydrogen Strategy set out the UK's hydrogen ambitions, including an ambition for 5GW of low carbon hydrogen production capacity by 2030. This was doubled in the British Energy Security Strategy, to up to 10GW of low carbon hydrogen production capacity by 2030, with at least half of this coming from electrolytic hydrogen. The UK Government has put research, innovation and 'learning by doing' at the heart of its approach to achieving these ambitions, in line with the 2020s Roadmap set out in the UK Hydrogen Strategy. Acknowledging the iterative process by which current technology is de-risked whilst next generation technology is developed, the UK is taking a whole-system approach to R&I during the 2020s.

To achieve these goals, the UK is investing in RD&D in a variety of areas.

Figure 1: The UK's RD&D priorities

Production
Electrolysis: renewable
Fossil fuel conversion: CCS, methane pyrolysis, autothermal methane reforming
Biomass and waste conversion
Thermal water splitting
Electrolysis: nuclear

Storage and distribution
Compression and liquefaction: pipelines, underground storage
Chemical: ammonia, physisorption
Other: tank lorries and tube trailers

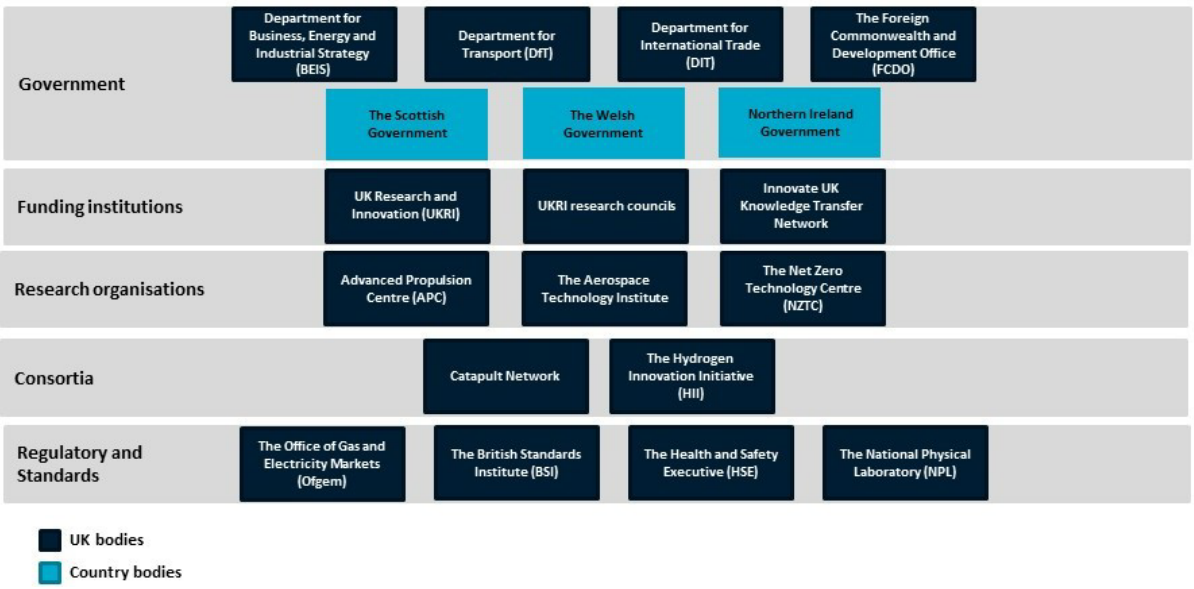
Utilisation
Gas blending: pipelines
Transport: fuel cells, refuelling stations,
Electricity generation: hydrogen turbines, fuel cells
Industrial processes: steel processing, synthetic fuels, methanol

Cross-cutting
Regulations, standards and safety
Skills
Technoeconomic analysis and modelling
Business models and market frameworks

The UK's domestic hydrogen landscape

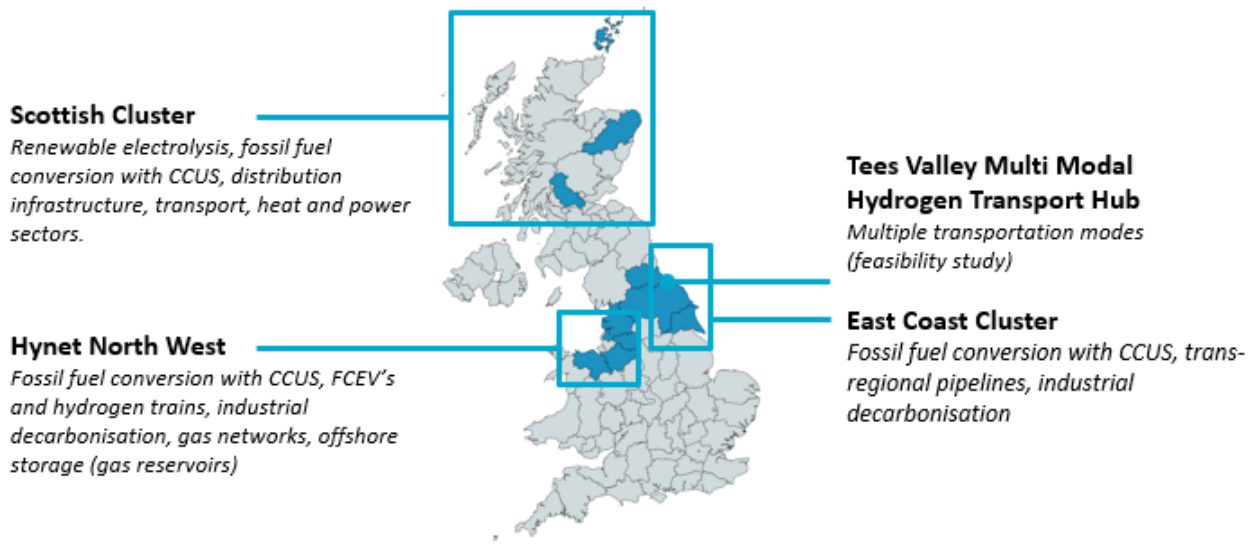
The Department for Business, Energy and Industrial Strategy (BEIS) leads on UK hydrogen policy and is responsible for providing strategic direction, policy implementation and funding for hydrogen R&I. The UK public sector hydrogen research and innovation ecosystem is vibrant, with a number of public and publicly-backed organisations possessing unique capabilities, expertise, know-how, testing facilities, and available funding, which together play an integral part in the UK's hydrogen R&I ecosystem supporting hydrogen R&I across the hydrogen value chain and along Technology Readiness Levels (TRLs). While public funding for hydrogen and the wider UK decarbonisation strategy is administered by BEIS, the Department for Transport (DfT) leads on and funds transport-related hydrogen policy and is responsible for road, rail, maritime, and aviation policy and infrastructure.

Figure 2: The UK's hydrogen RD&D ecosystem



Industry, academia and government are collaborating to bring about hydrogen clusters (also known as hydrogen valleys or ecosystems). These are hydrogen value chain demonstrations and pilot projects that cut across sector applications. As part of the UK's *Ten Point Plan*, the UK Government is planning to establish 2 industrial clusters (known as SuperPlaces), which integrate renewables, CCUS and hydrogen by the mid-2020s and 4 by 2030. Further, the UK Government's Industrial Strategy includes the Industrial Clusters Mission which aims to establish a net-zero carbon industrial cluster by 2040 and at least one low-carbon cluster by 2030. The five major clusters of integrated hydrogen value chain activity in the UK are:

Figure 3: The UK's hydrogen clusters



IP and publications scan

Several universities, public research institutions and private companies are highly active in early-stage hydrogen research and late-stage technology commercialisation. This is reflected in hydrogen research publication output and patent output data.

Table 1: Top organisations active in early-stage and late-stage hydrogen RD&D

Rank	Top organisations (Research publication output)	Top organisations (Hydrogen patent output)
1	Imperial College London	Johnson Matthey
2	University College London	Intelligent Energy
3	University of Cambridge	CompactGTL
4	University of Oxford	Rolls Royce
5	University of Manchester	H2GO Power

International collaboration

The UK has signalled a strong intention to collaborate on hydrogen RD&D, with a particular focus on supporting domestic industry, accelerating the development and commercialisation of hydrogen technologies, de-risking and driving investment, and establishing cross-cutting mechanisms to facilitate the development of a hydrogen economy.

The UK drives hydrogen innovation through multilateral partnerships and engagement with international forums and multilateral organisations and committees. Examples include the Clean Energy Ministerial, the International Partnership for Hydrogen and Fuel Cells in the Economy, and the Mission innovation Clean Hydrogen Mission, which is co-led by the UK, US, Chile, European Commission, and Australia. In particular, the UK has committed to using its global leadership roles – such as its 2021 G7 Presidency and co-Presidency of COP26 – to strengthen these efforts and facilitate greater coordination and progress with respect to hydrogen innovation across various areas, including technical innovation and policy development.

The UK also recognises bilateral partnership as an effective and equally important means to drive hydrogen innovation, particularly between its North Sea and European counterparts. The UK Hydrogen Strategy emphasises that the UK is open to further bilateral partnerships and that the UK will be open to 'more specific and in-depth collaboration' where strategic hydrogen priorities, interests and/or challenges align.

A number of domestic RD&D funding mechanisms allow the leading UK participants to collaborate with international partners. Examples include the hydrogen competitions supported by BEIS Net Zero Innovation Portfolio, and the Engineering and Physical Sciences Research Council funding. The UK has also established funds for international RD&D collaboration, such as the Fund for International Collaboration (FIC).

Activity levels for hydrogen and net-zero initiatives is high. While effort has been made to capture major announcements and key information as at 27 September 2022, the content is intended to provide a starting point for informing international engagement, particularly when used in conjunction with other reports in the series, and is non-exhaustive.

1 Country Analysis: United Kingdom

1.1 Introduction

The UK is a global leader in hydrogen technologies, with a strong track record in hydrogen research, development and demonstration (RD&D). The UK recognises the importance of low-carbon[1] hydrogen as a versatile replacement for high-carbon fuels to drive economic growth, energy security, and emissions reductions. The UK intends to capitalise on its geological, infrastructure, and technical know-how strengths to become a global leader in hydrogen. It has a strong history of collaboration between government, industry and innovators to tackle climate change and grow its economy. The UK's tech-neutral approach for hydrogen production capitalises on its potential to produce large quantities of both electrolytic 'green' and CCUS-enabled 'blue' hydrogen, alongside other potential production routes.

The UK Hydrogen Strategy, published in August 2021, takes a holistic approach to developing a thriving UK hydrogen sector, and sets out expectations for the evolution and scale up of the hydrogen economy over the 2020s and early 2030s through a comprehensive roadmap. The Strategy combines near term pace and action with long-term direction to unlock the innovation and investment critical to meeting the UK's ambitions, including the UK's legally binding commitment to achieving net zero by 2050. The UK has continued to set out new policy and funding for hydrogen across the value chain since publication of the UK Hydrogen Strategy, most notably through its Net Zero Strategy in October 2021 and the British Energy Security Strategy in April 2022. The UK's Net Zero Research and Innovation Framework was published alongside the UK Net Zero Strategy and provides further detail on the hydrogen-specific research and innovation required to deliver on the Net Zero Strategy.

The *Hydrogen RD&D Collaboration Opportunities: United Kingdom* report presents an overview of the hydrogen RD&D landscape in the UK, starting from the national strategy level, down to activity in specific hydrogen technology areas.

1.2 The United Kingdom's hydrogen drivers, strategy and RD&D priorities

1.2.1 The United Kingdom's key drivers

Taken together, four key drivers cut across the UK's Hydrogen Strategy and supporting policy package: emissions reductions and decarbonisation; economic growth; energy security; and energy efficiency. The UK has also noted the unique opportunity investment in emerging green and low-carbon technologies presents to successfully recovering from the COVID-19 pandemic. In pursuing its ambition to become a global leader in hydrogen production, storage, and utilisation technologies via a 'whole-system' approach, the UK also identified the scale up of technologies and development of regulatory and market frameworks as important focus areas.

[1] The UK refers to low-carbon hydrogen and clean hydrogen as hydrogen that is produced from low-carbon sources such as renewables, fossil fuel conversion with CCUS, nuclear and biomass. It is worth noting that the UK's Department for Business, Energy & Industry has acknowledged the need for a low-carbon hydrogen standard and is currently assessing potential avenues for its establishment. See BEIS (2021) Closed Consultation: Designing a low carbon hydrogen standard https://www.gov.uk/government/consultations/designing-a-uk-low-carbon-hydrogen-standard

1.2.2 United Kingdom's strategic priorities for hydrogen

Low carbon hydrogen is set to play a critical role in UK's energy system by supporting both UK's energy independence and its carbon reduction targets. The UK has set out a 'whole-system' approach to accelerating its hydrogen economy, placing a focus on both scaling up hydrogen technologies and developing the necessary regulatory and market frameworks to support this transition. The points below summarise the UK's strategic priorities for hydrogen across the value chain. The latest progress and development on each of those areas in the UK can be found in the UK Government's recently published Hydrogen Strategy Market Update (July 2022):

- **Production**: The UK's recently published Energy Security Strategy doubled the UK's ambition to up to 10GW of low carbon production capacity by 2030, subject to affordability and value for money, with at least half of this coming from electrolytic hydrogen. The UK also has an interim aim of up to 1GW of electrolytic hydrogen and up to 1GW of CCUS – enabled hydrogen operational or in construction by 2025.

  While the initial scale-up of hydrogen production output is expected to be from electrolytic hydrogen and steam methane reformation (SMR) with carbon capture, other hydrogen production methods could also play a role in the country's future energy mix.[2] In July 2022 the UK published a Hydrogen Strategy Update to Market[3] which included an annex providing more of the Government's thinking on the role of different hydrogen production technologies in meeting the UK's ambitions, along with consideration of potential wider environmental impacts.

  The UK Government expects that increasing the production ambition could mobilise over GBP 9 billion of private investment (an increase of GBP 5 billion relative to 5GW ambition) and support over 12,000 jobs by 2030, ensuring reliable, secure energy while maintaining progress towards UK's legally binding targets under the Climate Change Act.[4] It is expected that the UK's existing large-scale offshore wind infrastructure will support electrolytic production of hydrogen. For hydrogen produced from fossil fuels with CCUS, the UK intends to develop industrial clusters (also known as SuperPlaces,[5] which integrate production, distribution, storage and utilisation) as significant potential demand centres. Beyond the 2030s, as the hydrogen economy expands and demand grows, the UK will consider a wider range of production technologies including hydrogen from nuclear, using low carbon heat and power from small modular and advanced modular reactors, as well as bio-hydrogen with CCUS.

- **Storage and distribution***:* Hydrogen networks will have to grow and diversify considerably over the 2020s to enable the UK to meet its 2030 ambition and prepare for CB6. As set out in the UK's Hydrogen Strategy, towards 2035 the UK aims to progressively develop regional or national-scale storage and distribution networks which are integrated with electricity, CCUS, and gas networks.

  The UK Government expects growth to be driven by production and demand, which in turn will impact the shape and location of the network, and whether it evolves into a national system or a number of regionally-based networks.

[2] HM Government (2021) UK Hydrogen Strategy. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

[3] Hydrogen strategy update to the market, July 2022 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1092555/hydrogen-strategy-update-to-the-market-july-2022.pdf

[4] Hydrogen investor roadmap https://www.gov.uk/government/publications/hydrogen-investor-roadmap-leading-the-way-to-net-zero

[5] HM Government (2020) The Ten Point Plan for a Green Industrial Revolution. https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

A number of policy decisions are planned for this decade which will influence how hydrogen networks will develop and be operated in the UK. The two most notable ones are strategic decisions on blending hydrogen into the gas grid, and whether hydrogen will be used for decarbonising heat.

The UK Government is aiming to reach a policy decision in 2023 on whether to allow blending of up to 20% hydrogen (by volume) into GB gas distribution networks, subject to the outcomes from ongoing economic and safety assessments and wider strategic considerations.

Strategic decisions on the role of hydrogen for decarbonising heat are planned for 2026. The UK Government is working with industry, regulators and others to deliver a range of research, development and testing projects to assess the feasibility, costs and benefits of using 100% hydrogen for heating, to inform the 2026 decision. This includes trialling a hydrogen neighbourhood by 2023, hydrogen village by 2025 and potential pilot hydrogen town by 2030.

These strategic decisions notwithstanding, the UK Government is prioritising the development of hydrogen transport and storage infrastructure, placing a focus on supporting research, development, and testing projects to explore development of hydrogen network infrastructure. For example, it is supporting the Whitelee Green Hydrogen for Glasgow project, the UK's largest power to hydrogen energy storage project.

Additionally, National Grid's 'Project Union' is exploring the development of a hydrogen 'backbone' in the UK to connect strategic hydrogen production centres with storage and demand. The project looks to repurpose the existing National Transmission System (NTS) in a phased approach to create a 2,000km hydrogen network for the UK. It could increase system resilience while simultaneously reducing the need for additional production or storage facilities.[6] The UK is evaluating several hydrogen storage mechanisms – including traditional specialist tanks and storage vessels – as well as more novel methods, including hydrogen carriers (ammonia, liquid organic hydrogen carriers (such as toluene), cryogenic liquid, substances such as metal hydrides) and underground salt cavern storage and depleted gas fields.[7] The HySecure project is currently demonstrating the feasibility of grid-scale hydrogen storage in a salt cavern in North West England.[8]

In the British Energy Security Strategy, the UK Government committed to designing, by 2025, new business models dedicated to supporting the development of hydrogen transport and storage infrastructure. The intention is that these business models will provide investors and developers with the reassurance needed to bring forward the T&S infrastructure required to meet UK Hydrogen Strategy ambitions.

To progress that design commitment, in August the UK Government published a consultation looking at options for progressing hydrogen transport and storage infrastructure across the UK, including potential design options for the business models. More widely, the UK Government is also prioritising reviewing hydrogen T&S infrastructure requirements in the 2020s and beyond. It intends to publish a consultancy study commissioned to understand T&S requirements up to 2035 and beyond later this year.

[6] National Grid (2021) Making plans for a hydrogen 'backbone' across Britain https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/042921-interview-uks-national-grid-looks-to-prove-case-for-hydrogen-blending

[7] HM Government (2021) UK Hydrogen Strategy.
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

[8] Inovyn and Storenergy (2019) Project HySecure – Phase 1 Summary Sept 2019
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/866376/Phase_1_-_Inovyn_-_HySecure.pdf

- **Utilisation:** The UK Government is prioritising unlocking the use of low carbon hydrogen to deliver against many of the outcomes set out in its Hydrogen Strategy, including decarbonising existing UK hydrogen production and use, establishing end-to-end systems with a diverse range of end users, and supporting emissions reductions under CB4 and 5.

  The use of hydrogen is expected to develop over the 2020s in the UK, with early demonstration in industry, heat and power and limited use in transportation. These are expected to develop into a wider range of uses across multiple sectors by the late 2020s and mid-2030s. By 2035, the UK aims to utilise hydrogen across various industry sectors and end-use applications. This may include household heating, transportation (heavy vehicles, rail, shipping, aviation, passenger and commercial fuel cell vehicles supported by refuelling networks), electricity generation, metals manufacturing (such as steel) and industry (e.g. fuel and feedstock).

  The UK Government is prioritising engaging industry and wider stakeholders, and supporting innovation, demonstration projects and trials to ensure the use of hydrogen will increasingly decarbonise heavy industry and provide greener, flexible energy across power, transport and potentially heat, through the 2020s and beyond. It continues to build evidence and develop policy, including initially focusing on areas such as fuel switching in large 'anchor sites' in industrial clusters. The UK aims to facilitate the deployment of CCUS in four major industrial clusters by 2030, aiming to build two of these by 2020s and to build the world's first net zero industrial cluster by 2040.

  The potential for electrolytic hydrogen in power applications is also being explored. Engagement with industry has demonstrated that the power sector has the potential to deliver a pipeline of both new and refurbished power projects that could provide a significant source of hydrogen demand and aid the development of the hydrogen economy, with indication that 100% capable hydrogen firing generation equipment should be available on the open market by 2030.

  Cross-government work also continues to facilitate early rollout of hydrogen in transport applications such as buses, as well as accelerating research, trials and demonstration of hydrogen use in heavy goods vehicles (HGVs), maritime and aviation, and in an integrated manner through the Tees Valley multi-modal Hydrogen Transport Hub.

  Launched in 2021, the Tees Valley Multi-Modal Hydrogen Transport Hub is the UK's first Hydrogen Transport Hub, bringing together industry and academia, delivering pilot trials on hydrogen propulsion technologies across different transport modes. While not an industrial cluster, the Tees Valley Multi-Modal Hydrogen Transport Hub is stimulating a critical mass of supply (refuelling infrastructure) and demand (vehicles and vessels) to demonstrate the commercial viability of hydrogen transport and explore where it works well across transport modes. The UK is aiming for the region to become a global leader in industrial research on the use of hydrogen as a fuel, as well as research and development hub for hydrogen transport, attracting hundreds of jobs and boosting the local economy in the process. The hub is expected to be fully operational by 2025.[9]

  The Government is working with industry, regulators and others to deliver a range of research, development and testing projects to assess the feasibility, costs and benefits of using 100% hydrogen for heating, ahead of a strategic decision in 2026 on the role of hydrogen in decarbonising heat. Priorities in this area includes supporting industry to deliver a neighbourhood trial of hydrogen for heating (SGN's H100 Fife project in Levenmouth, Scotland), with the trial due to commence in 2023 and involve around 300 homes. This project has also received GBP 6.9 million of funding from the Scottish Government. This will pave the way to a further hydrogen village by 2025 and potential pilot

[9] HM Government (2021) Tees Valley Multi-Modal Hydrogen Transport Hub Masterplan https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/969468/tees-valley-multi-modal-hydrogen-transport-hub-masterplan.pdf

hydrogen town trials by 2030 – which the Government committed to in its Ten Point Plan. Government is also prioritising work to assess and develop the role of gas blending and hydrogen storage in balancing supply and demand in the early development of the market.

Further detail on these priorities, and supporting policy and market frameworks, are outlined in sector-specific strategies that relate to hydrogen. These include the *Transport Decarbonisation Plan* which sets the strategy to decarbonise all forms of transport in the UK, with a particular focus on rail, maritime, aviation and heavy road freight. This will be achieved by investing in R&D aligned with the UK's *Hydrogen Strategy*. The UK invested GBP 3 million in 2021 to establish a multi-modal hydrogen transport hub in Tees Valley (north of England) which seeks to explore the use of hydrogen across transport modes. The Heat and Buildings Strategy sets the context for decarbonising heat in buildings and supporting homeowners to transition to low-carbon heating solutions. It commits to a number of large-scale hydrogen trials and to making a decision by 2026 as to whether hydrogen will be used to decarbonise heat in buildings.[10] The latest progress across all of the relevant policy areas for UK hydrogen can be found in the Hydrogen Strategy Market Update.[11]

Private hydrogen funding in the UK

Acknowledging the importance of private investment in hydrogen research, development, and innovation - particularly when unlocking commercialisation, the UK Government has developed multiple initiatives to promote and direct private investment in hydrogen. Some major examples include:

- **Hydrogen Investment Package**: Unveiling investments for energy technologies of the future, the UK Government announced a GBP 375 million package of support for innovative energy technologies that will boost UK energy security, provide cheap, clean energy to homes and businesses and create thousands of jobs. This support is intended to unlock investment and opportunities in hydrogen, advanced nuclear and carbon capture, usage and storage (CCUS). This includes the opening of the GBP 240 million Net Zero Hydrogen Fund to support the production of hydrogen as a clean, low-cost energy technology and a further GBP 5 million towards research into carbon capture.
- **The Hydrogen Investor Roadmap**: This roadmap summarises the UK government's policies designed to support the development of a thriving UK low-carbon economy and showcases the investment opportunities across the hydrogen value chain. The Roadmap mentioned up to 20GW of potential low carbon hydrogen capacity out to 2037 and highlighted a sample of projects in a map to show the geographical spread of hydrogen production in the UK.
- **UK Public Sector Support for Hydrogen R&I**: is a brochure providing an overview of the key players and latest available support across the UK public sector research and innovation ecosystem.
- **Hydrogen Business Model**: this revenue support mechanism is currently under development and aims to overcome the cost gap between low-carbon hydrogen and other higher carbon fuels and to support several hydrogen production routes. The business model is intended to apply across different production technologies, including renewables and fossil fuel conversion with CCUS. Through the Hydrogen Business Model, the UK Government aims to bring forward significant private investments in new low carbon hydrogen production, with government providing an initial GBP 100 million in revenue support funded by the Industrial Decarbonisation and Hydrogen Revenue Support (IDHRS) scheme.

[10] HM Government (2021) Heat and Buildings Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1044598/6.7408_BEIS_Clean_Heat_Heat___Buildings_Strategy_Stage_2_v5_WEB.pdf

[11] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1092555/hydrogen-strategy-update-to-the-market-july-2022.pdf

- **Renewable Transport Fuel Obligation (RTFO)**: The RTFO is a DfT scheme which stimulates the supply of eligible transport fuels through a system of tradable Renewable Transport Fuel Certificates (RTFCs). Because hydrogen fuel is classified as a 'development' fuel under the RTFO, its production is incentivised with higher buy-out value certificates compared to more established renewable fuels. Both BEIS and DfT continue to work together on development of this strategy and associated research workstreams to understand implications for UK hydrogen production and specific technologies.
- **UK Innovation Strategy**: The Innovation Strategy outlines the UK Government's approach to innovation and how public and private sector investment in research and innovation can be facilitated. The Innovation Strategy summarises the UK's innovation funding system and outlines the various public funding support mechanisms and programs available through UK Research and Innovation (UKRI), Innovate UK, the British Business Bank, ministerial departments, and the Office for Investment.[12]
- **UK Infrastructure Bank**: The scope of the UK Infrastructure Bank will be expanded to provide the market with the necessary leadership to develop new low-carbon technologies, and will seek to facilitate private finance and secure GBP 40 billion to accelerate technology development.[13]

United Kingdom's hydrogen targets

The UK's Hydrogen Strategy set out the UK's hydrogen ambitions, including an ambition for 5GW of low carbon hydrogen production capacity by 2030. This was doubled in the British Energy Security Strategy, to up to 10GW of low carbon hydrogen production capacity by 2030, with at least half of this coming from electrolytic hydrogen. The UK Government has put research, innovation and 'learning by doing' at the heart of its approach to achieving these ambitions, in line with the 2020s Roadmap set out in the UK Hydrogen Strategy. Acknowledging the iterative process by which current technology is de-risked whilst next generation technology is developed, the UK is taking a whole-system approach to R&I during the 2020s.

The UK is already trialling how hydrogen can be integrated into current energy systems and testing its many potential applications in projects across the value chain. It is also the second most active supporter of hydrogen and fuel cell research in Europe. The importance of R&I in developing the hydrogen economy and capturing economic potential for the UK is highlighted in the UK Hydrogen Sector Development Action Plan, published in July 2022.

There is a strong recognition that the UK R&I ecosystem will be central to developing the hydrogen technologies necessary to reach Net Zero. The UK Government's Net Zero Innovation Framework, published in 2021, identifies the main net zero R&I challenges for the UK over the next 5 to 10 years and serves as a guide to the research and technologies needed to reach net zero by 2050, including hydrogen.[14] The framework emphasises the importance of pursuing a whole system, evidence-based approach to R&I and provides information for businesses and academics working on net zero related research.

The UK's Innovation Strategy sets out that the Government continues to be committed to increasing direct public expenditure on research and innovation to GBP 22bn per year and a key part of this will be net zero related, including hydrogen.

---

[12] BEIS (2021) UK Innovation Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009577/uk-innovation-strategy.pdf

[13] BEIS (2021) Net Zero Strategy; Build Back Greener
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

[14] Refer to Figure 15 in the UK Net Zero Innovation Framework https://www.gov.uk/government/publications/net-zero-research-and-innovation-framework

Hydrogen strategies in Wales, Scotland and Northern Ireland

The focus of this report is on hydrogen initiatives and policy established by the UK Government. The UK Parliament retains the exclusive power to legislate on reserved matters and develop policy with respect to energy across England, Scotland, Wales and Northern Ireland. The UK Government is working with devolved administrations, including England, Scotland, Wales and Northern Ireland, across all levels to ensure the *UK Hydrogen Strategy* can be consistently implemented.[15] The Scottish Government, Welsh Government and Northern Ireland Executive have each developed country-specific hydrogen policies or action statements which set their own ambitions and complement the *UK Hydrogen Strategy* and its implementation.

- **Wales:** In December 2020, the Welsh Government commissioned the baseline report entitled *Hydrogen development in Wales*,[16] which evaluates the feasibility of and a potential pathway to establish a hydrogen sector in Wales. In 2021, and following consultations, the Welsh Government released the *Consultation Document: a pathway and next steps for developing the hydrogen sector in Wales*, which outlined a roadmap and actions for developing the hydrogen energy sector in Wales.[17] Key recommendations included establishing a 10MW+ renewable hydrogen production site by 2023/24, deploying 200 hydrogen bus FCEVs, establishing Wales as an early market for commercial FCEVs, scoping large-scale hydrogen production sites and supporting industrial decarbonisation through R&D initiatives.[18]
- **Scotland:** In November 2021, the Scottish Government published a *Draft Hydrogen Action Plan*, setting out a strong strategic approach to the development of the hydrogen economy in Scotland over the course of the next five years. The *Draft Hydrogen Action Plan* details how Scotland's hydrogen ambitions will be achieved, including through new funding mechanisms, establishing cross-cutting capabilities, and facilitating the development of a domestic market.[19] The *Draft Hydrogen Action Plan* was informed by the *Hydrogen Policy Statement*, published in December 2020. *The Hydrogen Policy Statement* articulated Scotland's ambition to generate 5GW of renewable and/or low-carbon hydrogen by 2030 and 25 GW by 2045 and committed GBP100 million in funding to accelerate the growth of the hydrogen economy in Scotland over the next five years.[20] The Final Hydrogen Action Plan will be published in late 2022.[21]

[15] HM Government (2021) Net Zero Strategy: Build Back Greener < https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf>

[16] Dolman M, Nock W and King S (2021) Hydrogen development in Wales: Baselining report into hydrogen activities and expertise in Wales. Element Energy. https://gov.wales/sites/default/files/consultations/2021-01/baselining-report-hydrogen-development-in-wales.pdf

[17] Welsh Government (2021) Consultation Document: a pathway and next steps for developing the hydrogen energy sector in Wales https://gov.wales/sites/default/files/consultations/2021-01/hydrogen-in-wales-consultation.pdf

[18] Welsh Government (2021) Consultation Document: a pathway and next steps for developing the hydrogen energy sector in Wales https://gov.wales/sites/default/files/consultations/2021-01/hydrogen-in-wales-consultation.pdf

[19] Scottish Government (2021) Draft Hydrogen Action Plan https://www.gov.scot/publications/draft-hydrogen-action-plan/documents/

[20] Scottish Government (2020) Scottish Government Hydrogen Policy Statement https://www.gov.scot/binaries/content/documents/govscot/publications/speech-statement/2020/12/scottish-government-hydrogen-policy-statement/documents/scottish-government-hydrogen-policy-statement/scottish-government-hydrogen-policy-statement/govscot%3Adocument/scottish-government-hydrogen-policy-statement.pdf

[21] Scottish Government (2020) Scottish Government Hydrogen Policy Statement https://www.gov.scot/binaries/content/documents/govscot/publications/speech-statement/2020/12/scottish-government-hydrogen-policy-statement/documents/scottish-government-hydrogen-policy-statement/scottish-government-hydrogen-policy-statement/govscot%3Adocument/scottish-government-hydrogen-policy-statement.pdf

- **Northern Ireland:** In December 2021, the Northern Ireland Executive published the *Path to Net Zero Energy Strategy,*[22] which targets a 56% reduction in energy-related carbon emissions on 1990 levels by 2030. The strategy identified that establishing a hydrogen economy and facilitating hydrogen end-use applications (particularly in the transport sector) will be necessary to achieve these ambitions.[23] In January 2022, the Executive released the *Energy Strategy for Northern Ireland Path to Net Zero Action Plan 2022* which examined concrete actions to establish a hydrogen economy, including the creation of a GBP 10 million Green Innovation Challenge Fund, RD&D initiatives and the development of a 'Hydrogen Centre of Excellence' to be located at the Advanced Manufacturing Innovation Centre.[24] In addition, in March 2022, the Executive launched the GBP 4.5 million Green Innovation Challenge Fund – pilot which can support early hydrogen R&D projects. That same month, the Executive also opened the new Hydrogen Training Academy at Ballymena with operational training with Wrightbus, safety training from HySAFER (Ulster University) & advanced manufacturing O&M from QUB AMIC.

1.2.3 United Kingdom's hydrogen RD&D priorities

The UK *Net-Zero Research and Innovation Framework*[25] has identified the UK's hydrogen research and innovation needs in the short-, medium- and long-term.[26] These have been collated in Table 2 below, for more detail please refer to the original report.

Table 2: United Kingdom's RD&D priorities

Supply chain area	Sub-technology areas	UK's key RD&D priorities
Production	Fossil fuel conversion with CCUS	Demonstrate hydrogen production using next generation methane reforming technology coupled with CCUS (2020-2030). Research and development to further drive down emissions from hydrogen production (2020-2030s and beyond).
	Renewable electrolysis	Till 2030, demonstrate hydrogen production via electrolysis, initially 10s MW scale at different sites & develop next generation electrolysers / advanced manufacturing methods to drive costs and efficiency Beyond 2030, deployment at scale to increase efficiency and reduce costs of production.
	Emerging hydrogen production technologies	From 2020-2030, development of lower TRL and novel production technologies. This includes high temperature nuclear electrolysis, thermochemical water splitting, and methane pyrolysis. Pending R&D, demonstration and commercial-scale hydrogen produced from advanced nuclear may begin in 2030.

[22] Northern Ireland Executive (2021) The Path to Net Zero Strategy https://www.economy-ni.gov.uk/sites/default/files/publications/economy/Energy-Strategy-for-Northern-Ireland-path-to-net-zero.pdf

[23] Northern Ireland Executive (2021) Energy Strategy for Northern Ireland https://www.economy-ni.gov.uk/sites/default/files/publications/economy/Energy-Strategy-for-Northern-Ireland-path-to-net-zero.pdf

[24] Northern Ireland Executive (2021) Energy Strategy for Northern Ireland Action Plan 2022 https://www.economy-ni.gov.uk/sites/default/files/publications/economy/energy-strategy-path-to-net-zero-action-plan.pdf

Supply chain area	Sub-technology areas	UK's key RD&D priorities
		From 2025, develop alternative ammonia production processes to improve or replace the Haber-Bosch process.
Storage and distribution		Research and innovation to improve the efficiency and costs of hydrogen distribution (2025-2030). Understand and model the needs of hydrogen grid transmission. Develop infrastructure and technologies for international transport and improve integration of different hydrogen networks (2022-2030). Demonstrate longer distance hydrogen transmission - scaling up to international transport in 2030s. From 2020-2025, assess the impact of hydrogen on materials for storage and supply and identify options / solutions. Identify the optimal storage solutions across the hydrogen system, including developing novel short term, transportable and large-scale solutions. Enable efficient use of short- and longer-term storage options, including assessing the need for underground storage.
	Ammonia	From 2020-2030, increase the efficiency of ammonia storage and cracking.
	Solid storage	From 2020-2030, develop solid storage systems such as solid phase absorbent technologies.
Utilisation	Power generation	From 2020-2030, explore the role of stationary fuel cells in applications such as decentralised power, industrial combined heat and power and heat networks. Develop and demonstrate large centralised hydrogen fuelled power generation options, such as hydrogen turbines, in the 2020s.
Cross-cutting	Use of hydrogen at the system level	Analysis of hydrogen at the whole system level. Enable ecosystems for hydrogen research and innovation. Align production and demand. Address safety questions and incorporate safety by design into hydrogen technologies. Research and innovation to enable supply chain development across the value chain and address technology barriers. Research and innovation to optimise integration into the electricity / energy system.
	Environmental and societal impact assessment	Assess environmental impact of a hydrogen economy (by 2025) and mitigate against impacts (on-going) Address new questions as technologies are developed and deployed Understand and forecast impact of hydrogen on international markets Understand and address acceptance barriers

1.3 The United Kingdom's hydrogen RD&D ecosystem

1.3.1 Public bodies and policy ecosystem

Overview of United Kingdom's STI policy landscape

The UK traditionally has a top-down approach to science, technology and innovation (STI) policy in which various government agencies establish priorities and identify, draft and then implement policies. However, the UK has commenced reform to the STI ecosystem to foster an open policy-making process, which streamlines collaboration between government, private sector and research institutions to enhance STI capability and commercialisation.[27] It is hoped this new approach will allow companies, research institutions, financial institutions and government agencies to exchange ideas and formulate policy in a more streamlined and participative manner.[28] The *UK Research and Development Roadmap* (*R&D Roadmap*)[29] and the *UK Innovation Strategy* (*Innovation Strategy*) are guiding this broad reform.[30]

The *UK Innovation Strategy* and the *UK R&D Roadmap* include the creation of 'Innovation Missions' to focus R&D and innovation efforts.[31] The Innovation Missions aim to strengthen collaboration across sectors, combining the insight from government, academia and industry in order to accelerate the commercialisation of technologies necessary to achieve the UK's net-zero targets.[32] The Innovation Missions will coordinate policy across sectors and support the allocation of funding.[33] Whilst yet to be confirmed, it is expected that an 'energy and environmental technologies mission' (or similar) will be announced.

On 21 June 2021, then Prime Minister Boris Johnson announced the creation of two new STI policy organisations: the Office for Science and Technology Strategy (OSTS) and a National Science and Technology Council (NSTC) to support the new STI focus.[34] The OSTS, based in the Cabinet Office, will coordinate policy initiatives across the UK Government to ensure the UK has the necessary STI capabilities. In particular, the OSTS will identify and accelerate the UK's STI priorities and identify key R&D focus areas.

---

[27] HM Government (2020) UK Research and Development Roadmap
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/896799/UK_Research_and_Development_Roadmap.pdf

[28] BEIS (2021) UK Innovation Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009577/uk-innovation-strategy.pdf

[29] HM Government (2020) UK Research and Development Roadmap
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/896799/UK_Research_and_Development_Roadmap.pdf

[30] HM Government (2021) UK Innovation Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009577/uk-innovation-strategy.pdf

[31] BEIS (2021) Innovation Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009577/uk-innovation-strategy.pdf;
HM Government (2020) UK Research and Development Roadmap
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/896799/UK_Research_and_Development_Roadmap.pdf

[32] BEIS (2021) Innovation Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009577/uk-innovation-strategy.pdf

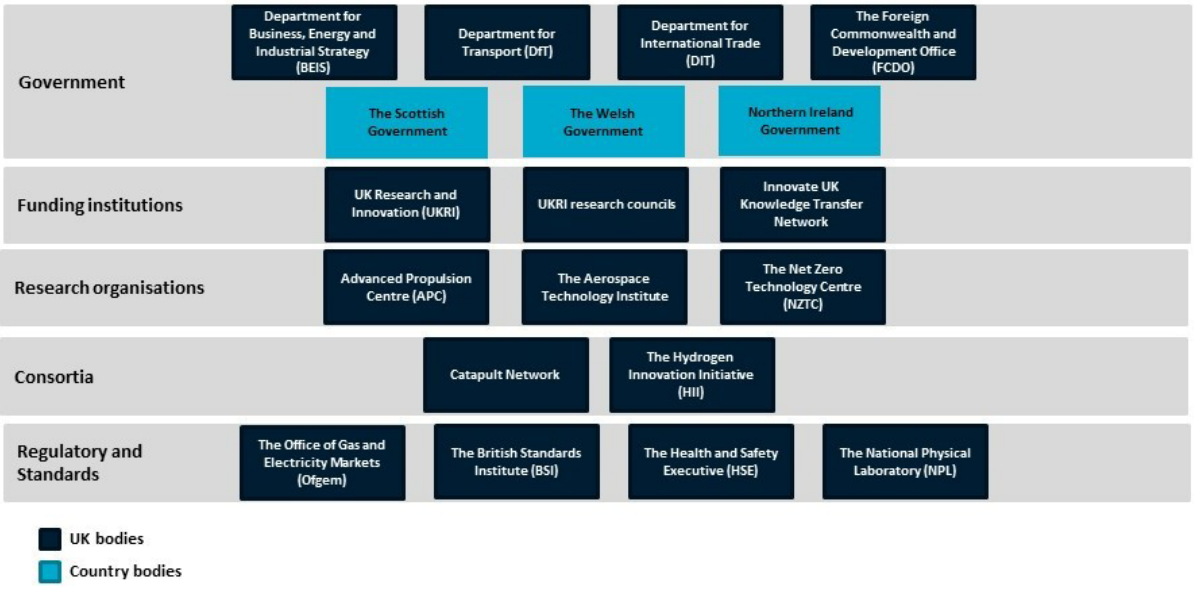
[33] BEIS (2021) Innovation Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009577/uk-innovation-strategy.pdf

[34] HM Government (2021) Prime Minister sets out plans to realise and maximise the opportunities of scientific and technological breakthroughs
https://www.gov.uk/government/news/prime-minister-sets-out-plans-to-realise-and-maximise-the-opportunities-of-scientific-and-technological-breakthroughs

The NSTC, which will be chaired by the Prime Minister, will establish the strategic direction on the use of science and technology to address key challenges.[35]

In the UK, RD&D occurs across private industry, research and public sector organisations. Both the *UK R&D Roadmap* and the *UK Innovation Strategy* seek to increase collaboration and align RD&D priorities across these stakeholders. In July 2022, the UK Government published a brochure focussing on UK Public Sector Support for hydrogen research and innovation (R&I), which set out an overview of the key bodies supporting public sector hydrogen R&I in the UK and this ecosystem is summarised in Figure 4.[36]

Figure 4: Summary of the United Kingdom's hydrogen policy ecosystem



Further information regarding the UK's top research institutions in hydrogen are outlined in *Section 1.6 Data insights: The United Kingdom's hydrogen RD&D activity.*

Public Sector support for UK hydrogen RD&D

In 2020 the UK Government committed to increase total and private investment in R&D to GBP 22 billion per year by 2024, and public investment to 2.4% of GDP by 2027.[37] Between 2021 and 2022 the UK plans to invest GBP 14.6 billion on science and technology R&D. In November 2020, the UK Government also committed to a further GBP 1 billion investment in UKRI and National academy funded research by 2024.[38]

The UK has committed significant funding to drive forward the growth of low-carbon hydrogen. Details of these, and how they help to support strategic hydrogen and R&I objectives, are set out in the UK's Hydrogen Investor Roadmap.[39]

---

[35] HM Government (2021) Prime Minister sets out plans to realise and maximise the opportunities of scientific and technological breakthroughs. Press Release https://www.gov.uk/government/news/prime-minister-sets-out-plans-to-realise-and-maximise-the-opportunities-of-scientific-and-technological-breakthroughs

[36] UK public sector support for hydrogen research and innovation https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1092352/hydrogen-research-investment-brochure.pdf

[37] HM Government (2020) The Ten Point Plan For A Green Industrial Revolution https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution

[38] BEIS (2021) Net Zero Strategy: Build Back Greener https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

[39] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1067408/hydrogen-investor-roadmap.pdf

The wider UK public sector hydrogen research and innovation ecosystem is vibrant, with a number of public and publicly-backed organisations possessing unique capabilities, expertise, know-how, testing facilities, and available funding. Collectively, they support UK hydrogen R&I across the whole value chain and technology readiness levels (TRLs), from discovery and applied research to innovation, demonstration and deployment. It is vast, and to make it easier to navigate, the UK Government recently published a brochure (UK Public Sector Support for Hydrogen Research and Innovation) outlining its major stakeholders, the support they can offer for UK hydrogen R&I, and how to contact them.[40]

Additionally, the UK has several advocacy groups and public-private consortia that operate within the hydrogen space for example UKERC, ARIA, etc. Research groups include the UK Hydrogen and Fuel Cell Association (UK HFCA) and the Hydrogen and Fuel Cell SUPERGEN Hub (H2FC SUPERGEN) supported by the EPSRC, to name just a few.

Table 3: Summary of key public bodies (not exhaustive)

Body	Role in RD&D Ecosystem
BEIS *Department for Business, Energy and Industrial Strategy*	The majority of public funding for hydrogen, and for the UK's decarbonisation, is administered by The Department for Business, Energy and Industrial Strategy (BEIS). BEIS leads on UK hydrogen policy and is responsible for providing strategic direction, policy implementation and funding for hydrogen R&I. It plays a key part in the UK Government's Net Zero Innovation Board, which provides strategic direction on net zero R&I across government departments. BEIS also works alongside industry and academia via the BEIS Hydrogen Advisory Council (HAC), which supports the implementation of the UK's hydrogen strategy. Public funding for hydrogen R&I is largely made available through the BEIS-administered GBP 1 billion Net Zero Innovation Portfolio, which funds a number of hydrogen-related commercialisation programmes including the GBP 60 million Low Carbon Hydrogen Supply 2 Competition. BEIS also supports commercial deployment of hydrogen production through its recent launch of the GBP 240 million Net Zero Hydrogen Fund and by designing a Hydrogen Business Model (a revenue support mechanism designed to overcome one of the key barriers to deploying low carbon hydrogen: the higher cost of low carbon hydrogen compared to high carbon counterfactual fuels).
HAC *Hydrogen Advisory Council*	Hydrogen Advisory Council (HAC) identifies and promotes concrete actions required to enable the supply and deployment of low carbon hydrogen at scale for use across the energy system, addressing near-term challenges and maximising opportunities for UK business. The Council is a joint government-industry forum – members include representatives from across the hydrogen sector, UK Research and Innovation (UKRI, the UK's national funding agency investing in science and research in the UK), and other government departments including the Department for Transport and HM Treasury.
UKRI *UK Research and Innovation*	Public funding for hydrogen R&I comes largely from UK Research and Innovation (UKRI, which is funded through BEIS), notably from its Innovate UK and EPSRC arms. The UKRI can enable funding for international collaborators across science and technology R&D, for example through its GBP 160 million Fund for International Collaboration (FIC).
Department for Transport (DfT)	While public funding for hydrogen and the wider UK decarbonisation strategy is administered by BEIS, the Department for Transport (DfT) leads on and funds transport-related hydrogen policy and has responsibility for road, rail, maritime, and aviation policy and infrastructure.

[40] https://www.gov.uk/government/publications/uk-public-sector-support-for-hydrogen-research-and-innovation

Body	Role in RD&D Ecosystem
	DfT administers the Renewable Transport Fuel Obligation (RTFO), which supports the UK Government's policy on decarbonising transport by encouraging the production and use of renewable fuels that do not damage the environment.
Other Government Departments	The Department for International Trade (DIT) is responsible for securing and retaining inward investment, and securing international trade agreements between the UK and foreign countries, including on hydrogen R&I. The Foreign, Commonwealth and Development Office (FCDO), responsible for pursuing the UK's national interests, safeguarding the UK's security, defending UK values and tackling global challenges, works with BEIS to stimulate international R&I through jointly funding the UK Science and Innovation (SIN) Network.

1.3.2 Hydrogen consortia

Table 4: Hydrogen consortia

Consortium	Description
UK HFCA *UK Hydrogen and Fuel Cell Association*	The UK HFCA is a private body which seeks to advocate for, and advance, policies and research to support hydrogen energy and fuel cell research, development and procurement.[41] Executive members include Air Products, Anglo American, AVL, Baker Botts, OC, Burges Salmon, Ceres, Conrad Energy, CPH_2, ITM Power, Johnson Matthey, Ingersoll Rand and Statkraft.[42]
North-West Hydrogen Alliance	The North-West Hydrogen Alliance aims to support the development of a hydrogen-based economy, particularly in the North-West of the UK. It will do this by bringing together stakeholders and developing business cases for government funding. [43]
H2FC SUPERGEN *The Hydrogen and Fuel Cell Research Hub*	The Hydrogen and Fuel Cell Research Hub (H2FC SUPERGEN) is funded by the Research Council's UK Energy Programme. The H2FC SUPERGEN Hub was established to conduct research and address key challenges within the hydrogen and fuel cell sector, with the aim of developing cost-effective low-carbon technologies. [44]
Wales Hydrogen Trade Association (H2Wales)	Launched in 2020, H2Wales aims to accelerate the development of Wales' hydrogen economy. This includes: representing the fuel cell and hydrogen industry at the government and industry levels; promoting innovation; facilitating funding for hydrogen projects; influencing policy; and developing partnerships with other hydrogen-related associations and industry bodies. [45]
Hydrogen NI	Hydrogen NI is a peak hydrogen industry body in Northern Ireland. Hydrogen NI's role is to represent the views of its members through ministerial and government engagement, to

[41] UK HFCA (2021) Aims. UK Hydrogen and Fuel Cell Association. http://www.ukhfca.co.uk/about/aims/

[42] UK HFCA (2021) UK Hydrogen and Fuel Cell Association http://www.ukhfca.co.uk/

[43] North West Hydrogen Alliance (2021) About us https://www.nwhydrogenalliance.co.uk/about-us/

[44] H@FC SUPERGEN (2021) About H2FC SUPERGEN http://www.h2fcsupergen.com/about/

[45] HyCymru Wales Hydrogen Trade Association (2020) About Us. https://hydrogenh2.cymru/about-us/

Consortium	Description
	support effective policy making with the view to scale-up Northern Ireland's hydrogen economy. [46]
Scottish Hydrogen and Fuel Cell Association	The Scottish Hydrogen and Fuel Cell Association promotes and facilitates the development of Scottish expertise and research in fuel cells and hydrogen technologies. The Scottish Hydrogen and Fuel Cell Association brings together research institutions, consultants, power generation companies and other industry bodies. [47]

1.3.3 Funding mechanisms

Overview of the United Kingdom's hydrogen public budget allocations

In 2020 the UK Government committed to increase total and private investment in R&D to GBP 22 billion per year by 2024, and public investment to 2.4% of GDP by 2027.[48] Between 2021 and 2022 the UK plans to invest GBP 14.6 billion on science and technology R&D. In November 2020, the UK Government also committed to a further GBP 1 billion investment in UKRI and National academy funded research by 2024. [49]

The UK has committed significant funding to drive forward the growth of low-carbon hydrogen. The UK Government's policy announcements on a GBP 240m Net Zero Hydrogen Fund to support deployment, a business model to ensure long-term revenue support, and a Low-Carbon Hydrogen Standard are aimed at enabling market access and developing a thriving hydrogen economy in the UK. The UK has recognised that increased funding is necessary to demonstrate and accelerate the commercialisation of these technologies.[50] Some of these measures are outlined in Table 5. The table shows a mix of hydrogen-specific funding mechanisms and technology-agnostic funds that seek to achieve the UK's broader decarbonisation goals. The majority of public funding for hydrogen, and for the UK's decarbonisation strategy, is administered by BEIS, which leads on UK hydrogen policy and is responsible for providing strategic direction, policy implementation and funding for hydrogen R&I.

Table 5: Key public hydrogen funding mechanisms (list is not exhaustive)

Funding arrangement	Description	Budget / duration / provider	International eligibility to participate
NZHF *Net Zero Hydrogen Fund*	The GBP 240 million Net Zero Hydrogen Fund, funding low carbon hydrogen production projects, with the aim of awarding funding from the end	GBP 240 million 2022 - 2025 Provider: BEIS	Potentially. Eligibility criteria requires projects to be based in the UK. [51]

[46] Hydrogen NI (2021) About Us https://www.hydrogen-ni.com/

[47] Scottish Hydrogen and Fuel Cell Association (2020) About http://www.shfca.org.uk/

[48] HM Government (2020) The Ten Point Plan For A Green Industrial Revolution <https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution>.

[49] BEIS (2021) Net Zero Strategy: Build Back Greener https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf.

[50] HM Government (2021) UK Net Zero Research and Innovation Framework < https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1030656/uk-net-zero-research-innovation-framework.pdf>

[51] BEIS (2021) Designing the Net Zero Hydrogen Fund – Consultation. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011468/Designing_the_Net_Zero_Hydrogen_Fund.pdf

Funding arrangement	Description	Budget / duration / provider	International eligibility to participate
	of 2022. This will advance the government's ambition to have up to 2GW of low-carbon hydrogen production capacity by 2025 and up to 10GW installed by 2030.		
Carbon Capture and Storage Infrastructure Fund	GBP 1 billion was allocated to the Carbon Capture and Storage Infrastructure Fund (CIF) in November 2020. The CIF will fund capital expenditure on industrial carbon capture projects and transport and storage networks.	GBP 1 billion 2020 – 2030 (approx.) Provider: BEIS	No.
Scottish Hydrogen Innovation Scheme[52]	In June 2022, the Scottish Government launched the Scottish Hydrogen Innovation Scheme, the first tranche of the Emerging Energy Technologies Fund (EETF). The Hydrogen Innovation Scheme will support innovative renewable hydrogen production, storage and distribution solutions as well as the development of test and demonstration facilities in Scotland.	The Hydrogen Innovation Scheme is a GBP 10 million capital funding stream of the GBP 100 million Emerging Energy Technologies Fund, to be delivered between 2022-2026. Provider: Scottish Government	Projects applying to the Hydrogen Innovation Scheme can work with international partners, but over 50% of the funded project work (by value) must be conducted in Scotland. Projects relating to physical demonstrators must be based in Scotland.[53] Further details on the wider EETF Fund will be provided at launch.
Scottish Industrial Energy Transformation Fund	The SIETF incentivises investment in industrial energy efficiency or decarbonisation through methods such as switching to lower carbon-intensive fuels at industrial manufacturing sites across Scotland, with an emphasis on our energy-intensive sectors. This is done through providing capital support for deployment projects and providing support for feasibility and engineering studies.	GBP 34 million 2020 – 2026 Provider: Scottish Government	Potentially. Eligibility criteria requires projects to be based in Scotland

[52] Scottish Government (2021) Draft Hydrogen Action Plan https://www.gov.scot/publications/draft-hydrogen-action-plan/

[53] Emerging Energy Technologies Fund - Hydrogen Innovation Scheme: form and guidance - gov.scot (www.gov.scot)

Funding arrangement	Description	Budget / duration / provider	International eligibility to participate
RSE Scotland-Germany Hydrogen Research Scheme	The RSE Scheme is funded by the Scottish Government to facilitate international collaboration and enhance hydrogen-related research which supports Scotland's policy objectives. [54] Key research themes include research aimed at: [55] • optimising the production of renewable hydrogen to reduce costs; • enabling and optimising medium- to long- term hydrogen storage; and • enabling cost-effective distribution solutions.	GBP 10,000 to 30,000 per project. Ongoing (for 12-month projects). 2022-2023 Provider: Scottish Government	Closed.
Research Wales Innovation Fund	The Research Wales Innovation Fund provides funding to Welsh higher education institutions to facilitate stronger collaboration with industry and business. Three-year research strategies are developed which outline research focus areas and establish commercialisation targets. [56]	Hydrogen-specific funding unknown. 2021 – ongoing Provider: BEIS	Yes. Direct access to funding is restricted to Welsh higher institutions. However, foreign researchers and industry may collaborate on projects.
Low Carbon Hydrogen Supply Competition 2	Funding has been allocated to research and projects which seek to accelerate the development of innovative low-carbon hydrogen supply solutions prior to commercialisation. The competition is delivered via two streams; stream one is for market entry projects and stream two is for more mature projects which can scale up hydrogen use	GBP 60 million 2021 – 2025 Provider: BEIS The UK Government has recently awarded contracts for 23 feasibility studies and 5 demonstration projects under the GBP 60 million Net Zero Innovation	Potentially. Standard BEIS procurement eligibility rules apply. Consortia are encouraged to apply, however country

[54] The Royal Society of Edinburgh (2021) RSE Scotland-Germany Hydrogen Research Scheme < https://rse.org.uk/funding-collaboration/award/rse-scotland-germany-hydrogen-research-scheme/#:~:text=The%20new%20RSE%20Scotland%2DGermany,inform%20Scottish%20Government%20policy%20objectives.>

[55] The Royal Society of Edinburgh (2021) RSE Scotland-Germany Hydrogen Research Scheme < https://rse.org.uk/funding-collaboration/award/rse-scotland-germany-hydrogen-research-scheme/#:~:text=The%20new%20RSE%20Scotland%2DGermany,inform%20Scottish%20Government%20policy%20objectives.>

[56] BEIS (2021) UK Innovation Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1009577/uk-innovation-strategy.pdf

Funding arrangement	Description	Budget / duration / provider	International eligibility to participate
	and act as a project pipeline for the NZHF. The Low Carbon Hydrogen Supply competitions are part of a broader Net Zero Innovation Portfolio, an GBP 1 billion fund which provides funding across a range of low carbon technologies and systems. [57]	Portfolio (NZIP) Low Carbon Hydrogen Supply 2 programme, which funds innovative projects relating to the supply of hydrogen.	requirements are not specified. [58]
EIP and NZIP Industrial Fuel Switching Competitions	Part of the BEIS Energy Innovation Programme as IFS then IFS2 in NZIP. Funding is allocated to support development of fuel switching and fuel switch enabling technologies, including hydrogen, for UK industry.	GBP 20 million 2021 – 2025 Provider: BEIS	Yes. International partners can collaborate, however the project must be led by a UK-based entity and at least 50% of project must be conducted in the UK. [59]
NZIP Industrial Hydrogen Accelerator Innovation programme	The Industrial Hydrogen Accelerator (IHA) competition supports projects generating evidence on end-to-end industrial fuel switching to hydrogen. It covers the full technology chain, from hydrogen generation and delivery infrastructure through to industrial end-use, including the integration of the components in a single project. It forms part of the wider NZIP portfolio.[60]	GBP 26 million 2022 – 2025 Innovation funding up to GBP 10 million / project for demonstrations and up to GBP 400,000 per project for feasibility studies.	A minimum of 50% of the work by value must be conducted in the UK.
NZIP Longer Duration Energy Storage Demonstration Competition	Fund of approximately GBP 67 million to accelerate commercialisation of first-of-a-kind longer duration energy storage. Stream one of the competition is for demonstrations of technologies at TRL 6/7, and stream two is for	GBP 67 million 2021 – 2025 Provider: BEIS	Yes. However, there are comprehensive eligibility criteria (which differ between the two streams). Funding is restricted to

[57] BEIS (2021) Net Zero Innovation Portfolio https://www.gov.uk/government/collections/net-zero-innovation-portfolio#hydrogen

[58] BEIS (2021) Low Carbon Hydrogen Supply 2 Competition: Stream 1 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1004563/low-hydro-stream-1-guidance.pdf

[59] BEIS (2021) Net Zero Innovation Portfolio: Industrial Fuel Switching competition – Phase 1 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1031688/ifs-guidance.pdf

[60] https://www.gov.uk/government/publications/industrial-hydrogen-accelerator-programme

Funding arrangement	Description	Budget / duration / provider	International eligibility to participate
	prototype demonstrations at technologies at TRL 4/5. The competition has relevance to hydrogen through its funding of Power-to-X technologies.		projects which support the UK Electricity Grid.
NZIP Green Distilleries Fund	The aim of this funding program is to support the decarbonisation of distilleries. Funding is to be allocated for a range of decarbonisation solutions including electrification, hydrogen, and biomass and waste. 9 out of the 17 feasibility studies currently funded are for low-carbon hydrogen-related projects.	GBP 10 million 2020 – 2023 Provider: BEIS	A minimum of 50% of the work by value must be conducted in the UK.
NZIP Red Diesel Replacement Competition	Fund for researching alternatives for diesel to power construction and mining machinery. The aim is to promote alternative fuels, including hydrogen fuel cells.	GBP 40 million 2021 – 2025 Provider: BEIS	Yes. International partners can collaborate, however the project must be led by a UK-based entity and at least 50% of project must be conducted in the UK.
Industrial Decarbonisation Challenge Fund	This fund supports the development of low-carbon technologies, including CCUS and hydrogen fuel switching, particularly projects at the Front End Engineering Design (FEED) phase. Out of the GBP 171 million allocated to this fund, over GBP 41 million has been allocated to projects with a major focus on hydrogen production, with the remaining funding going to supporting CCUS infrastructure in UK industrial clusters.	Total: GBP 171 million Hydrogen-related GBP 41 million 2019 – end date not specified Provider: UKRI	No.
Industrial Energy Transformation Fund	This fund is designed to support the uptake of technologies that	GBP 315 million	No. [61,62]

[61] Hydrogen skills and standards for heat https://www.gov.uk/government/publications/hydrogen-skills-and-standards-for-heat

[62] BEIS (2021) Industrial Energy Transformation Fund – Phase 2 Guidance https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1019066/ietf-phase-2-autumn-guidance.pdf

Funding arrangement	Description	Budget / duration / provider	International eligibility to participate
	improve energy efficiency and reduce carbon emissions associated with industrial processes. This is done through providing support for feasibility and engineering studies, and capital support for decarbonisation technologies such as hydrogen fuel switching. In phase two of the fund, GBP 220 million is intended to be offered to enable hydrogen fuel-switching amongst a range of other decarbonisation technologies.	2018 – 2025 Provider: BEIS	
Scottish Zero Emission Mobility Innovation Fund	The fund's aim is to support the development and manufacture of new zero emission vehicles and related components and systems to meet Scotland's Mission Zero for transport by supporting Scotland's vehicle supply chain and innovation ecosystem. The fund supports the scaling of manufacturing of components, systems and vehicles in the zero emission niche and heavy duty vehicles sector, as well as trialling of integrated technologies.	GBP 28m Four years From FY22/23 Scottish Government	Yes, as subcontractor.
Red Diesel Replacement Competition	Fund for researching alternatives for diesel to power construction and mining machinery. The aim is to promote alternative fuels, including hydrogen fuel cells. [63]	GBP 40 million 2021 – 2025 Provider: BEIS	Yes. International partners can collaborate, however the project must be led by a UK-based entity and at least 50% of project must be conducted in the UK. [64]
Clean Maritime Demonstration Competition	Research and development funding for technology trials and feasibility studies across clean maritime technologies to	Round 1: GBP 23,259,000 Round 2: GBP 12 million	Closed.

[63] BEIS (2021) Red Diesel Replacement Competition: Phase 1 Guidance. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1020615/RDR_Phase_1_Competition_-_Guidance.pdf

[64] BEIS (2021) Red Diesel Replacement Competition: Phase 1 Guidance. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1020615/RDR_Phase_1_Competition_-_Guidance.pdf

Funding arrangement	Description	Budget / duration / provider	International eligibility to participate
	accelerate maritime decarbonisation in the UK. Technologies that are supported by this fund include renewable hydrogen. [65]	2021 – 2022 Provider: DfT with Innovate UK	
'Green Fuels, Green Skies' Competition	Fund to support the development of the emerging UK sector on its pathway to produce sustainable aviation fuel (SAF) at scale.	GBP 15 million 2021 – 2022 Provider: DfT	
Local Net Zero Programme	The UK Government will fund and deliver commercial decarbonisation initiatives on a local- and regional-scale through the Local Net Zero Programme (which was formerly known as the Local Energy Programme). GBP 22 million has so far been invested to establish five Local Net Zero Hubs (which are joint-ventures between private development entities and local authorities). As part of the Programme, the Hubs support and help identify suitable commercially-viable decarbonisation projects within local areas. with the hubs are currently supporting the development of projects with a potential total capital value of over GBP 2 billion. [66]	GBP 22 million	No.

UKRI Opportunities

A real-time database of domestic funding opportunities from the UKRI can be found here

- https://www.ukri.org/opportunity/

[65] HM Government (2021) Clean maritime demonstration competition (CMDC) https://www.gov.uk/government/publications/clean-maritime-demonstration-competition-cmdc

[66] BEIS (2021) Net Zero Strategy: Build Back Greener https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

International funding for hydrogen RD&D

Outlined below is a funding mechanism which has been established to facilitate international collaboration across science and technology R&D. While not hydrogen-specific, international entities may be able to leverage general international funding arrangements for hydrogen RD&D.

Funding arrangement	Description	International eligibility to participate
Fund for International Collaboration (FIC)	GBP 160 million has been allocated to the Fund for International Collaboration to enhance the UK's ability to build new, and strengthen existing, partnerships with global research and innovation leaders.[67]	Yes.

1.3.4 Other key hydrogen policies

The UK is currently progressing work to ensure the legal and regulatory environment appropriately supports the development of a domestic hydrogen economy. The UK Hydrogen Strategy identified that standardised legislation and regulation will be required to de-risk and facilitate the scaling up of hydrogen production and infrastructure in the UK and internationally. As such, work is underway to create hydrogen-specific technical standards, codes, regulations, and legislation which are necessary to establish and scale-up a domestic hydrogen economy.

Legislation

Several existing legislative instruments tangentially regulate hydrogen. For example, hydrogen is defined as a 'gas' and therefore regulated under the *Gas Act 1986*. Whilst a comprehensive analysis of this legislation is beyond the scope of this report, hydrogen's regulation under the *Gas Act 1986* means that research and projects must comply with various codes and supply agreements, including the Uniform Network Code, the Independent Gas Transporter Uniform Network Code, and the Supply Point Administration Agreement.

Utility-scale hydrogen and renewable energy projects will require approval under various legislative instruments, including the *Planning Act 2008* and the *Electricity Act 1989*. Planning processes differ across the devolved nations and are dependent on the nature of a project.

Additionally, hydrogen is heavily regulated under health and safety laws and regulations. As such, hydrogen-related research, demonstrations, trials and projects must comply with the following legislation and regulations:

- *the Gas Safety (Management) Regulations 1996,* which establishes standards and auditing requirements for pipelines carrying gas;
- *the Pipeline Safety Regulations 1996,* which establishes technical standards and requirements for pipeline design, construction and maintenance; and
- *the Planning (Hazardous Substances) Regulations 2015,* which sets out the approval mechanism to store hydrogen.

[67] UKRI (2021) Fund for International Collaboration https://www.ukri.org/our-work/collaborating-internationally/fund-for-international-collaboration/

Hydrogen standards[68]

Following the publication of the UK's Hydrogen Strategy, government consulted with the public, academia, industry and trade associations to define a what constitutes 'low carbon' hydrogen. Published in 2022, the UK's Low Carbon Hydrogen Standard (LCHS) has been designed to strike a balance between encouraging growth by supporting market development, while ensuring that new government supported production makes a direct contribution to the UK's carbon reductions targets. As such, hydrogen producers applying for funding from the Net Zero Hydrogen Fund and Low Carbon Hydrogen Business Model are required to meet the standard. The LCHS sets a maximum threshold for greenhouse gas emissions allowed in the production process and a methodology to calculate those emissions. It also includes a list of eligible production pathways, requirements around minimising fugitive emissions and a sustainability criteria. In the British Energy Security Strategy (April 2022), the UK government has committed to developing the standard into a certification scheme to underpin the deployment of low carbon hydrogen and support future international trade.

Other policies

Since the publication of the UK Hydrogen Strategy, the UK Government published other documents, including the UK Low Carbon Hydrogen Standard guidance document,[69] Net Zero Hydrogen Fund government response,[70] Low Carbon Hydrogen Business Model government response,[71] Indicative Heads of Terms for the hydrogen business model, Electrolytic Allocation Market Engagement document and the Hydrogen Investor Roadmap.[72] The Roadmap showcases the UK's hydrogen offer and the scale of our ambition for the role of the hydrogen economy in meeting Net Zero. Details on these are available on UK Government webpage. The government has taken a number of actions to support industry's use of low carbon hydrogen, to aid industrial decarbonisation and support the growth of the hydrogen economy, including:

- Launching a call for evidence on 'hydrogen-ready' industrial equipment, which focuses on industrial boilers given the significant potential demand for hydrogen from this equipment category.
- Publishing and responding to a call for evidence on stakeholders' use of Combined Heat and Power (CHP) technology, and potential routes and perceived barriers to decarbonisation.
- Engaging closely with some industrial sites in large clusters to better understand the barriers they face to fuel switching, to identify any additional demand-side support needed.
- Considering the impact of major current and planned policies on existing hydrogen producers, including the Industrial Carbon Capture Business Model (ICC BM) and the UK Emissions Trading Scheme (ETS).
- The UK Government is also working with industry, regulators and others to deliver a range of research, development and testing projects to assess the feasibility, costs and benefits of using 100% hydrogen for heating, ahead of a strategic decision in 2026 on the role of hydrogen in decarbonising heat, which includes:

[68] HM Government (2021) UK Hydrogen Strategy
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

[69] https://www.gov.uk/government/publications/uk-low-carbon-hydrogen-standard-emissions-reporting-and-sustainability-criteria

[70] https://www.gov.uk/government/consultations/designing-the-net-zero-hydrogen-fund

[71] https://www.gov.uk/government/consultations/design-of-a-business-model-for-low-carbon-hydrogen

[72] https://www.gov.uk/government/publications/hydrogen-investor-roadmap-leading-the-way-to-net-zero

- Supporting industry to deliver a neighbourhood trial of hydrogen for heating (SGN's H100 Fife project in Levenmouth, Scotland), with the trial involving around 300 homes due to commence in 2023. This project has also received GBP 6.9 million of funding from the Scottish Government.
- Announcement of plans to take forward proposals for potential hydrogen Village Trial locations, covering areas within Whitby (Ellesmere Port) and Redcar (Teesside). Stage 2 (the detailed design stage of the Village Trial) is expected to run until Spring 2023, after which a decision on the final location selection is expected.
- Publishing the government response to a public consultation on facilitating a 'grid conversion' hydrogen heating trial in April 2022. Based on the consultation response the UK Government confirms to proceed with legislation to: i) allow GDNs to effectively and safely carry out the activities needed to deliver the village trial, and ii) enable enhanced consumer protections to ensure that those living in the trial area continue to receive fair treatment.
- The Government has also confirmed to include the legislative changes proposed in the hydrogen heating trial consultation in its landmark Energy Security Bill, which was introduced on 6 July 2022.

Other policies which support the commercial uptake of hydrogen technologies include the:

- **Zero Emission Bus Regional Areas (ZEBRA) scheme:** BEIS will provide up to GBP 120 million this year through the ZEBRA scheme towards 4,000 new zero emission buses, either hydrogen or battery electric, and the infrastructure needed to support them; and **Renewable Transport Fuel Obligation (RTFO):** The RTFO aims to increase the use of renewable transport fuels. Because hydrogen fuel is classified as a 'development' fuel under the RTFO, its production is incentivised with higher buy-out value certificates compared to more established renewable fuels. Both BEIS and DfT continue to work together on development of this strategy and associated research workstreams to understand implications for UK hydrogen production and specific technologies.
- **Jet Zero Strategy:** In July 2022 the UK Government published a Jet Zero Strategy, setting out its vision and approach for the aviation sector to reach net zero by 2050 - or "Jet Zero" - focusing on the rapid development of technologies in a way that maintains the benefits of air travel, whilst maximising the opportunities decarbonisation brings for the UK. The Strategy recognises the role that hydrogen could play in decarbonising aviation.

1.4 The United Kingdom's domestic hydrogen RD&D projects

1.4.1 Major domestic hydrogen RD&D projects

Projects funded by government bodies and led by industry

The table below illustrates the type of hydrogen R&I projects funded by the UK government. While the funds are led by government bodies, the projects themselves are led by the private sector. The list is non-exhaustive and there are many other projects funded by the UK Government that are complete, ongoing, or have yet to be announced.

Table 6: Some of the RD&D projects led by government bodies

Program	RD&D projects
EIP Hydrogen Supply Competition 1	The Hydrogen Supply Competition has two phases. The first phase is funding for feasibility studies and the second phase is implementation and demonstration of selected projects from phase one. Implementation and demonstration projects funded under the competition are:[73] • **Dolphyn**: The production of renewable hydrogen from offshore floating wind in deep water locations. This project will enable the detailed design of a 2MW prototype system and is led by Environmental Resources Management Limited (ERM). • **HyNet**: Development of an end-to-end industrial decarbonisation cluster that will produce, transport store and utilise low-carbon hydrogen across North West England. Hydrogen will be produced from natural gas SMR with CCUS. Led by a consortium of Progressive Energy, Essar, Johnson Matthey and SNC-Lavalin. • **Gigastack**: Demonstration project to deliver bulk, low-cost and zero-carbon hydrogen through ITM Power's gigawatt scale PEM electrolysers. The aim is to reduce the cost of electrolytic hydrogen. Led by ITM Power. • **Acorn Hydrogen Project**: Hydrogen production from SMR with CCS, which will repurpose existing natural gas pipelines to transport CO_2 to an offshore storage site in the North Sea. The project is led by Pale Blue Dot Energy and supported by BEIS and industry partners, including Storegga, Shell and Harbour Energy.[74] • **HyPER:** Development of low carbon bulk hydrogen supply through demonstration of the sorption enhanced steam reforming process. Led by Cranfield University. A second phase, Hydrogen Supply Competition 2, is underway for 2021-2025
NZIP Low carbon Hydrogen Supply 2 Competition	This competition has a stream 1 supporting feasibility studies to be followed by demonstrations for a subset of projects, and a stream 2 for projects delivering physical demonstrations.[75] Under Stream 2, GBP 38 million of funding is awarded to 5 projects led by ITM power, Vattenfall, ERM/ Environmental Resources Management, H2GO power and Gemserv.

[73] HM Government (2020) Hydrogen Supply Competition Phase 2 successful projects <https://www.gov.uk/government/publications/hydrogen-supply-competition/hydrogen-supply-programme-successful-projects-phase-2>

[74] Offshore Energy (2021) Storegga, Shell, Harbour become equal partners on Acorn CCS < https://www.offshore-energy.biz/storegga-shell-harbour-become-equal-partners-on-acorn-ccs/>

[75] https://www.gov.uk/government/publications/low-carbon-hydrogen-supply-2-competition-successful-projects

Program	RD&D projects
Green Distilleries Fund	The Green Distilleries Fund has two phases: the first being for feasibility studies and the second for demonstration projects. Examples of feasibility studies which relate to hydrogen include:[76] • Decarbonising the distillation process via direct fuel switching from fossil fuels to hydrogen. Led by Locogen Ltd. • **WhiskHy:** An electrolysis system that will produce hydrogen from renewable resources, supported by waste heat from a distillery which will then be looped back into the distillery's heat or power system. Led by Supercritical Solutions. • **Hy/BioDDP:** Development of dual fuel hydrogen/natural gas burners that can be co-fired with biofuel. Led by Colorado Construction and Engineering. • **HyLaddie:** Feasibility study of the Dynamic Combustion Chamber (DCCTM) system, which is a condensing oxy-combustion boiler that combusts hydrogen to generate industrial grade steam. Led by Protium Green Solutions Ltd.
Industrial Decarbonisation Challenge Fund	Successful stage one RD&D projects funded under this fund include: • **Green Hydrogen for Humber:** Feasibility study on the production of renewable hydrogen at the GW scale distributed to a mix of industrial energy users in Humberside.[77] Led by ITM Power. • **HyNet**: HyNet has received funding from the Industrial Decarbonisation Challenge Fund (for a description of HyNet *see Hydrogen Supply Competition* 1 above).
Scottish Energy Transition Fund	The Scottish Government, through the Energy Transition Fund, provided GBP 15 million to Aberdeen City Council for the Aberdeen Hydrogen Hub - a strategic programme that aims to accelerate the hydrogen economy in Aberdeen, establishing the city as a hydrogen model region that can be replicated elsewhere. The Aberdeen Hydrogen Hub will play a leading role in supporting the Scottish Government's Net Zero Emissions target and presents the opportunity to deliver Scotland's first commercially investable, 'green hydrogen' production facility focussed initially on the decarbonisation of transport. Through the Energy Transition Fund, the Scottish Government also provides funding to The Hydrogen Backbone Link Project which aims to position Scotland in a leading role for the development of pan-European hydrogen infrastructure including export capability. It will address the opportunity for Scotland and the rest of the UK to supply hydrogen to Europe as part of an extensive hydrogen transport and distribution system. The Project will undertake concept studies and subsequent technology development for the re-purposing and optimisation of existing pipeline infrastructure both on and offshore. Scottish Government support for this project will ensure that opportunities are maximised for growing the supply chain in Scotland and stimulating manufacturing opportunities in hydrogen generation and transmission.

[76] HM Government (2021) Green Distilleries Competition: Phase 1 feasibility reports https://www.gov.uk/government/publications/green-distilleries-competition/green-distilleries-competition-projects-selected-for-phase-1

[77] ITM Power (2020) Green Hydrogen for Humberside Project Deployment Study. https://www.itm-power.com/news/green-hydrogen-for-humberside-project-deployment-study

Projects led by industry and consortia

A wide range of demonstration and research projects are also being led by the private sector and supported by public research institutes and government departments. Some illustrative examples include:

- **Hy4Heat**: BEIS appointed Arup+ in 2018 to lead a project assessing whether it is technically feasible, safe and emission efficient to replace natural gas (methane) with hydrogen in residential and commercial buildings. The project is split into separate work packages, ranging from defining hydrogen quality standards and developing a hydrogen-fuelled boiler to demonstrating hydrogen appliances in a purpose-built temporary facility.[78] This builds off the 2018 'Logistics of Domestic Hydrogen Conversion' report commissioned by BEIS to explore the logistical challenges of transitioning UK properties from natural gas to hydrogen.[79]
- **Bacton Energy Hub scoping study:** The UK North Sea Transition Authority jointly funded and commissioned the Bacton Energy Hub scoping study, in partnership with Progressive Energy, which assessed the technological and economic feasibility of upgrading and/or retrofitting existing gas terminal and wind power infrastructure to support low carbon hydrogen production in the Bacton Catchment Area. The study concluded that the Bacton Catchment Area is 'ideally positioned to become a significant hydrogen production site'.[80]
- **HYDeploy:** HyDeploy is an energy trial to evaluate the safety, feasibility and effectiveness of blending 20% hydrogen (by volume) into the natural gas supply. Larger demonstrations on the public gas network in the North East and the North West of the UK are underway, both of which are due to conclude in 2023. HyDeploy is being delivered by a consortium, comprising Northern Gas Networks, Keele University, Health & Safety Laboratory, ITM Power, Cadent Gas Limited and Progressive Energy.[81]
- **Holyhead Hydrogen Hub:** The UK Government recently announced GBP 4.8 million funding – subject to an approved business case – to develop the Holyhead Hydrogen Hub. The Holyhead Hub is a proposed hydrogen production plant and fuelling hub demonstration project for heavy-duty FCEVs. It is to be strategically positioned near local port infrastructure to support hydrogen-powered freight and port operations.[82]
- **GenComm Project:** Led by the Belfast Metropolitan College, the GenComm Project has received funding from both the European Union and UK Government to trial electrolytic hydrogen production to fuel hydrogen FCEV buses.
- **H2FC SUPERGEN Hub**: Hydrogen production research at H2FC SUPERGEN is currently investigating chemical looping for the production of hydrogen via the reforming of fuels such as natural gas and biogas.[83] Led by Newcastle University, support by the University of Liverpool and the University of South Wales. The UKRI EPSRC provides funding support for the H2FC SUPERGEN Hub via the Research Council's UK Energy Programme.

[78] Hy4Heat (2021) About Us https://www.hy4heat.info/about-us

[79] Frazer-Nash Consultancy (2018) Logistics of domestic hydrogen conversion. Prepared for the Department for Business, Energy & Industrial Strategy. Viewed at https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/760508/hydrogen-logistics.pdf

[80] UK Oil & Gas Authority (2021) Bacton Energy Hub https://www.ogauthority.co.uk/media/7612/bacton-study-2021_short_version_final.pdf

[81] HyDeploy (2022) About https://hydeploy.co.uk/about/

[82] BEIS (2021) UK Hydrogen Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

[83] H2FCSUPERGEN (2021) Hydrogen Production http://www.h2fcsupergen.com/research-type/hydrogen-production/

1.4.2 Major domestic commercial hydrogen projects

The scope of this report is on research, development and demonstration (RD&D) projects. For information on commercial hydrogen projects, see *HyResource*, an online knowledge sharing platform across the hydrogen community led by CSIRO, Future Fuels CRC, NERA and the Australian Hydrogen Council.

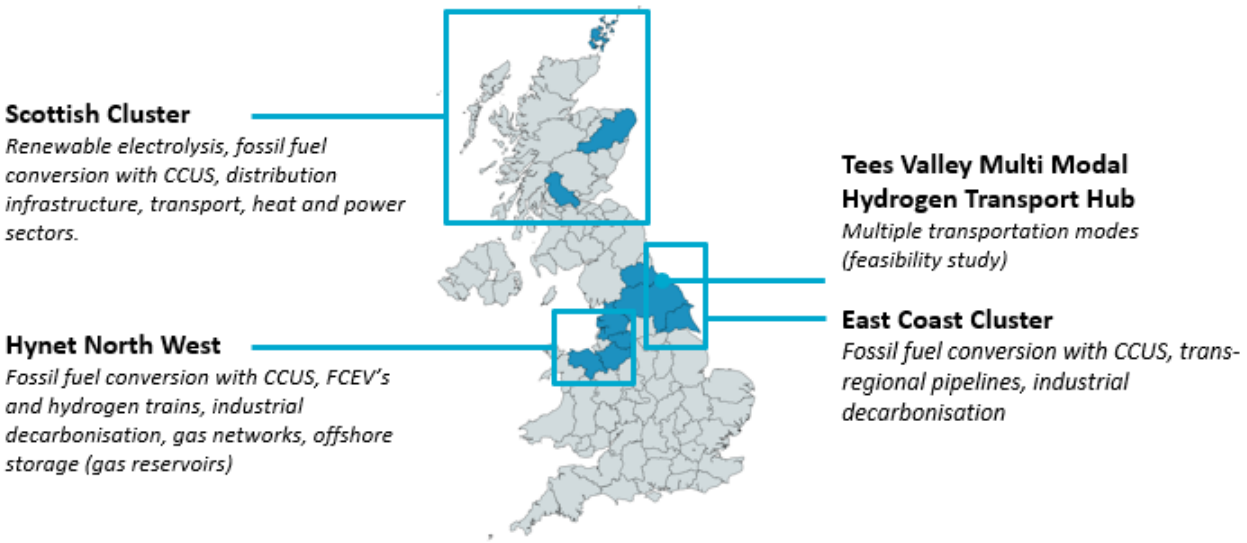
HyResource provides a directory of publicly available databases and information sources on international projects:

- https://research.csiro.au/hyresource/projects/international/

1.4.3 The United Kingdom's hydrogen RD&D clusters

Industry, academia and government are collaborating to fund and deploy several hydrogen industrial clusters (also known as hydrogen valleys or ecosystems). These are demonstration and pilot projects across the value chain that cut across sector applications. They stem from the UK Government's *Ten Point Plan for a Green Industrial Revolution*, which commits to establishing two industrial clusters (known as SuperPlaces) in areas such as the North East, the Humber, North West, Scotland and Wales by the mid-2020s, and 4 by 2030. It is intended that they capture up to 10 Mt of carbon dioxide per year and integrate renewables, CCUS and hydrogen. The five major clusters of integrated hydrogen value chain activity in the UK are:

Figure 5: The UK's hydrogen clusters



Two clusters are on track to be established by the mid-2020s, with a further Scottish cluster expected to be developed by 2030. Feasibility studies for other potential industrial clusters, including the South Wales Industrial Cluster, are currently ongoing. Current demonstrations within the clusters are dependent on the geographical advantages of each region, however, common focus areas include hydrogen production from fossil fuel conversion with CCUS, pipeline networks for the transportation and storage of carbon dioxide (CO_2), and utilisation of hydrogen across transportation and heat and power sectors, among other uses.

In addition, the Scottish, Northern Irish and Welsh Governments will have responsibility for country-level implementation. The Scottish Government provides support for research, innovation and demonstration of technologies along the entire hydrogen value chain, including through targeted funding provided to support critical hydrogen research. This includes GBP 100 million (2022-26) of renewable hydrogen funding

and GBP 80 million to help the Scottish Cluster Carbon Capture Project accelerate its efforts to help Scotland's just transition to net zero through the Emerging Energy Technologies Fund. The Welsh Government announced its Hydrogen Pathway report in December 2020, setting out recommendations to drive the national deployment of hydrogen. Wales' HyBRID (Hydrogen Business Research and Innovation for Decarbonisation) SBRI initiative has allocated a budget of GBP 2 million (2021-22) to support a spectrum of feasibility and front-end engineering design (FEED) stage demonstrating projects across Wales. Northern Ireland's Department for the Economy (DfE) published a new energy strategy in 2021, The Path to Net Zero Energy, followed by the energy strategy action plan in 2022, which together provide a comprehensive strategic framework to reduce carbon emissions and deliver an affordable, secure, resilient and sustainable energy system. A GBP 4.5 million pilot Green Innovation Challenge Fund, delivered by the Centre for Advanced Sustainable Energy (CASE), has also been announced by the DfE to support development of the disruptive technologies and innovative projects, including hydrogen-related projects.

Further, the UK Government's Industrial Strategy includes the Industrial Clusters Mission which aims to establish a net-zero carbon industrial cluster by 2040 and at least one low-carbon cluster by 2030. The government seeks to achieve this ambition by driving demand for low-carbon products and technologies and positioning the UK's industrial clusters as attractive investment options from the private sector. Public investment for industrial clusters has been provided by the Industrial Strategy Challenge Fund. [84]

In October 2021, the UK Government completed the first phase of evaluation of the 5 cluster submissions received by the BEIS as part of the CCS Infrastructure Fund grant process. HyNet and East Coast Clusters have been announced as 'Track-1' clusters, which puts them on course for deployment by the mid-2020s. The Scottish Cluster was announced as a 'Track 2' 'reserve cluster'. 'Track-2' clusters are expected to be developed by 2030. Feasibility studies for other potential industrial clusters, including the South Wales Industrial Cluster, are ongoing.

Table 7: The UK's hydrogen clusters

Cluster	Description
HyNet North West	HyNet North West is an end-to-end industrial decarbonisation cluster that will produce, store, transport and utilise low-carbon hydrogen to facilitate the decarbonisation of North West England (Liverpool, Manchester and Cheshire) and North Wales. The first phase of the project is the development of a low-carbon hydrogen production plant with CCUS (fossil fuel conversion), which will have the capacity to produce 3.8GW of hydrogen. CCS infrastructure will be established to capture and store CO_2 emissions from the hydrogen production process and local emitters. Existing natural gas pipelines will be repurposed to transport hydrogen to offshore storage and local industry, including manufacturing sites and transport refuelling stations (small and medium FCEVs and trains). Captured CO_2 will be stored in depleted gas reservoirs offshore in Liverpool Bay. [85] From 2030, hydrogen production capacity will be scaled up and hydrogen will be stored in 19 underground salt caverns in the Cheshire salt basin to manage peaks in demand and facilitate grid reliability.

[84] UKRI (2021) Industrial decarbonisation challenge < https://www.ukri.org/our-work/our-main-funds/industrial-strategy-challenge-fund/clean-growth/industrial-decarbonisation-challenge/>

[85] HyNet North West (2021) Fact sheet: Carbon Capture and Storage https://hynet.co.uk/wp-content/uploads/2021/06/HyNet-Factsheet-CCS.pdf

Cluster	Description
	From 2030, the project expects to scale up and produce over 30TwH of hydrogen, which will be used to decarbonise heavy transport once associated infrastructure has been established.[86] The project is led by Progressive Energy in partnership with Eni, Cadent, Hanson, CF Fertilisers, IVOVYN, Essar and the University of Chester.[87]
East Coast Cluster[88] *Track-1 Cluster*	The East Coast Cluster (ECC) is an end-to-end industrial cluster decarbonisation project, located near Hull in the North East of England. The ECC is comprised of (and is a collaboration between) several decarbonisation projects, including Zero Carbon Humber, Net Zero Teesside. Once operational, the ECC aims to capture, transport and store 50% of the UK's industrial CO_2 emissions a year by 2030. The two projects are enabled by Northern Endurance Partnership which includes BP, Eni, Equinor, British Steel, Mitsubishi Power, National Grid and the University of Sheffield Advanced Manufacturing Centre (AMRC). Zerocarbon Humber is a low-carbon hydrogen production with CCUS decarbonisation project. The project is anchored by Equinor's H2H Saltend project. The H2H Saltend project will establish low-carbon hydrogen production through autothermal reformation of natural gas with CCUS to be used as a fuel to decarbonise regional industry clusters, including at the Saltend Chemicals Park. By 2027, a CO_2 pipeline and storage infrastructure will be established to transport captured CO_2 emissions via pipelines to offshore storage in the Southern North Sea. By 2028, the project will be expanded to support hydrogen blending. The Net Zero Teesside (NZT), as part of the ECC, is the development of a low-carbon gas-fired power station (860MW) with CCS, located near Teesside. An advanced CO_2 pipeline network will capture and transport emissions from the power station and regional industry emitters to offshore storage in the North Sea. The ECC is a 'Track-1' cluster expected to be operational in the mid-2020s.
Scottish Cluster	The Scottish Cluster is an end-to-end industrial decarbonisation project that will establish hydrogen production and CCUS- and CCS-enabled technologies to support industry decarbonisation in Scotland. The Scottish Cluster intends to use CCUS and hydrogen technology to decarbonise the transport, heat and power sector, and will repurpose existing infrastructure to transport and store CO_2. [89] If developed, the Scottish Cluster intends to store CO_2 offshore in the North Sea. The Scottish Cluster has recently been announced a 'Track-2' 'reserve cluster' by the UK Government, meaning funding will not be provided for its immediate

[86] HyNet North West (2021) Vision Document: Unlocking Net Zero for the UK < https://hynet.co.uk/wp-content/uploads/2020/10/HyNet_NW-Vision-Document-2020_FINAL.pdf>

[87] Stones J (2021) What is HyNet? https://hynet.co.uk/about/; ICIS (2021) UK cluster sequencing could support 10G of hydrogen capacity. HyNet North West https://www.icis.com/explore/resources/news/2021/08/04/10670520/uk-cluster-sequencing-could-support-8gw-of-hydrogen-capacity

[88] East Coast Cluster (2021) East Coast Cluster selected as one of the UK's first two carbon capture and storage projects. https://eastcoastcluster.co.uk/press-release/east-coast-cluster-selected-as-one-of-the-uks-first-two-carbon-capture-and-storage-projects/; Net Zero Teesside (2021) The Northern Endurance Partnership enabling Net Zero Teesside and the East coast Cluster https://www.netzeroteesside.co.uk/northern-endurance-partnership/

[89] The Scottish Cluster (2021) The Scottish Cluster https://www.thescottishcluster.co.uk/#:~:text=The%20Scottish%20Cluster%20brings%20together,net%20zero%20Scotland%20a%20reality

Cluster	Description
	development.[90] Project partners include Arup, Aberdeenshire Council, Dentons, ExxonMobil, Shell, and Wood.[91] The Scottish archipelago Orkney is a core part of the UK's renewable energy plans. The GBP 28.5 million 2019 ReFLEX (Responsive Flexibility) Orkney Project seeks to maximise the island's energy production by linking renewable electricity generation, transport and heat networks through a novel Virtual Energy System (VES). The project is funded by UKRI through the Industrial Strategy Challenge Fund.[92]
Tees Valley Multi Modal Hydrogen Transport Hub	While not an industrial cluster, the Tees Valley Multi-Modal Hydrogen Transport Hub is a feasibility study to assess the benefits and complexities of creating a multi-modal transport hub. The project will focus on research, testing and trials across various transportation modes to strengthen early collaborations and facilitate decarbonisation in the transport sector.[93] The hub is expected to be fully operational by 2025.[94] The project has received GBP 3 million in government funding.

1.5 International collaboration

The UK has signalled a strong intention to foster international collaboration on hydrogen RD&D, with a particular focus on supporting domestic industry, accelerating the development and commercialisation of hydrogen technologies, de-risking and driving investment, and establishing cross-cutting mechanisms to facilitate the development of a global hydrogen economy.

The UK drives global hydrogen innovation through multilateral partnerships and engagement with international forums and multilateral organisations and committees. Examples include the Clean Energy Ministerial, the International Partnership for Hydrogen and Fuel Cells in the Economy, and the Mission innovation Clean Hydrogen Mission, which is co-led by the UK, US, Chile, European Commission, and Australia. In particular, the UK has committed to using its global leadership roles – such as its 2021 G7 Presidency and co-Presidency of COP26 – to strengthen these efforts and facilitate greater coordination and progress with respect to hydrogen innovation across various areas, including technical innovation and policy development. The UK's co-Presidency launched the Breakthrough Agenda, including the Hydrogen Breakthrough which committed countries to work together with the goal to make affordable, low carbon hydrogen globally available by 2030. 33 countries, including all G7 members, endorsed the Hydrogen Breakthrough. Through the UK's 2021 G7 presidency, a clear statement of support for the role of hydrogen was achieved for the very first time.

The UK also recognises bilateral partnership as an effective and equally important means to drive hydrogen innovation, particularly between its North Sea and European counterparts. The UK *Hydrogen Strategy*

[90] The Scottish Cluster (2021) Our partners https://www.thescottishcluster.co.uk/our-partners

[91] The Scottish Cluster (2021) Our partners https://www.thescottishcluster.co.uk/our-partners

[92] James Ellsmoor (2019) The Virtual Energy System Of The Future Is Coming To Life In The Orkney Isles, Forbes. Viewed at https://www.forbes.com/sites/jamesellsmoor/2019/04/15/virtual-energy-system-of-the-future-coming-to-life-in-the-orkney-isles/?sh=e71d4b6fa608

[93] HM Government (2021) Net Zero Strategy: Build Back Greener https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf

[94] HM Government (2021) Tees Valley Multi-Modal Hydrogen Transport Hub Masterplan https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/969468/tees-valley-multi-modal-hydrogen-transport-hub-masterplan.pdf

emphasises that the UK is open to further bilateral partnerships and that the UK will be open to 'more specific and in-depth collaboration' where strategic hydrogen priorities, interests and/or challenges align.

A number of domestic RD&D funding mechanisms allow leading UK participants to collaborate with international partners. Examples include the hydrogen competitions supported by BEIS Net Zero Innovation Portfolio, and the Engineering and Physical Sciences Research Council funding. The UK has also established funds for international RD&D collaboration, such as the Fund for International Collaboration (FIC).

1.5.1 Overview of the United Kingdom's approach to international collaboration

The *UK Hydrogen Strategy* recognises the importance of international RD&D collaboration to accelerate the development and commercialisation of hydrogen technologies to achieve the UK's domestic hydrogen targets.[95] It outlines the UK 's ambition to strengthen international collaboration to 'drive development and deployment of low-carbon technology as efficiently as possible.'[96]

The UK's approach to international hydrogen R&D highlights that:

- sharing the results of cutting-edge research with international partners will accelerate technological developments and cost reductions;
- development of common codes and technical standards across jurisdictions will support economies of scale and facilitate a global hydrogen market; and
- international collaboration on policy and regulatory issues will expedite the creation of low-carbon hydrogen markets and further incentivise innovation and investment.

A UK Net Zero Research and Innovation Framework further confirms the UK's view on the role of international collaboration in de-risking investment and establishing cross-cutting mechanisms (including low-carbon hydrogen standards, rules and regulatory mechanisms). As such, collaboration is seen as necessary to facilitate the development of a hydrogen economy, both in the UK and globally.

Multilateral and international partnerships

The UK drives hydrogen innovation through multilateral partnerships and engagement with international forums and multilateral organisations and committees. For example, the UK plays an active role in the Clean Energy Ministerial, the International Partnership for Hydrogen and Fuel Cells in the Economy, and the Mission innovation Clean Hydrogen Mission, which the UK co-leads with Australia.[97]

In particular, the UK has committed to using its global leadership roles – such as its 2021 G7 Presidency and co-Presidency of COP26 – to strengthen these efforts and facilitate greater coordination and progress with respect to hydrogen innovation across various areas, including technical innovation and policy development.[98] The UK launched the Breakthrough Agenda, including the Hydrogen Breakthrough which committed countries to work together with the goal to make affordable, low carbon hydrogen available globally by 2030. 33 countries endorsed the Hydrogen Breakthrough, including all G7 members. Since the

[95] HM Government (2021) UK Net Zero Research and Innovation Framework https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1030656/uk-net-zero-research-innovation-framework.pdf; BEIS (2021) UK Hydrogen Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

[96] BEIS (2021) UK Hydrogen Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

[97] BEIS (2021) UK Hydrogen Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

[98] BEIS (2021) UK Hydrogen Strategy https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1011283/UK-Hydrogen-Strategy_web.pdf

Breakthrough's launch the UK has worked collaboratively with leading initiatives and countries to develop a shared understanding of how international hydrogen cooperation can be advanced.

1.5.2 United Kingdom's bilateral relationships

The UK *Hydrogen Strategy* identifies several bilateral partnership opportunities at the regional and global scale to help establish a global hydrogen market, including:

- collaboration with North Sea partners with respect to hydrogen production, storage and transportation;
- further activity under the Horizon Europe program;
- joint research and innovation, particularly when strategic priorities and interests align;
- developing common regulatory and market frameworks; and
- facilitating long-distance hydrogen trade.

Since the publication of the Hydrogen Strategy, the UK has formalised relationships, including with countries in Europe, the Middle East, the Americas, and Asia - who share common interests on the development and deployment of low carbon hydrogen. Developing these partnerships has enabled the UK to draw on experience and best practice as well as establish the groundwork for future trade and investment opportunities. The UK also supports other countries to achieve their climate goals and harness the opportunities of low carbon hydrogen, for example, through its UK Partnering for Accelerated Climate Transitions programme.[99]

1.5.3 The United Kingdom's joint international RD&D projects

UK research institutions and private sector bodies have various international partnerships with respect to hydrogen and fuel cell technologies RD&D. A selection of partnerships is outlined in Table 8 below.

Table 8: A selection of UK's joint international RD&D projects

Country	Projects
Qatar	In October 2021, Qatar Energy and Shell signed an agreement to collaborate on hydrogen projects in the UK, producing hydrogen via renewables and fossil fuel with CCS. These projects will focus on decarbonisation, particularly related to industrial cluster development and for the transport sector, with a focus on the London metropolitan area.[100]
Brazil	The Sustainable Gas Institute (SGI) at Imperial College London and Brazilian research institutions have engaged in several R&D projects. The SGI is a research body focused on researching the role of natural gas, hydrogen and biogas/biomethane in future low-carbon energy systems. Brazilian institutions and organisations that have partnered with the SGI include: the National Agency for Petroleum, Natural Gas and Biofuels, the National Council for Scientific and Technological Development, and the Research Centre for Gas Innovation.

[99] UK Pact (2021) The UK supports Mexico's path to a low-carbon economy https://www.ukpact.co.uk/news/the-uk-supports-mexicos-path-to-a-low-carbon-economy

[100] Argus Media (2021) Qatar's QE and Shell to work on UK hydrogen projects. News Article. https://www.argusmedia.com/en/news/2264986-qatars-qe-and-shell-to-work-on-uk-hydrogen-projects

Country	Projects
Japan, India, US, Brazil	The UK EPSCR has partnered with the Indian Institute of Technology, Rice University (USA), the University of Louisville (USA), the University of São Paulo and Kyushu University (Japan) on the Centre for Doctoral Training in Sustainable Hydrogen program. The program trains researchers in the field of sustainable hydrogen. Project partners are involved in the design, development and implementation of the training program.[101]
Germany	Ulm University (Germany) has partnered with the University of Nottingham on the Metal Atoms on Surfaces and Interfaces for Sustainable Future (MASI) research project. The project aims to investigate the viability of green ammonia as an alternative zero-emission fuel and a new vector for hydrogen storage.[102] The Scottish Government funded RSE Scotland-Germany Hydrogen Research Scheme, awarded over GBP 97,000 to four collaborative projects between Higher Education Institutes in Scotland and Germany. The successful projects include: • Green Hydrogen from Brewing Biomass: Research into the use of brewing biomass as a feedstock for green hydrogen production (Robert Gordon University and Bonn-Rhein-Sieg University of Applied Sciences). • New Structures for Delivery of Sustainable Hydrogen: Research into new thin supported ceramic membranes for use in solid oxide electrolysis (University of St Andrews and Technical University of Munich). • Digital Toolbox for Hydrogen Production: Bridging Material Innovations, Electrolyser Architecture and Grid-scale Impact (DiTo-H2): Development of a modelling framework that will quantify how advances at the material level translate to performance gains at electrolyser and energy grid levels, and facilitate rapid decision-making on the value of integrating new technology as it becomes available (University of Strathclyde and Technical University of Braunschweig). • Fabrication of Hydrogen Sensor for the Hydrogen Gas Leak Detector: Research to explore the development of a highly sensitive hydrogen detection sensor to ensure safety from hydrogen leaks (National Subsea Centre/Robert Gordon University and University of Applied Sciences Berlin).
Australia	While no dedicated hydrogen or low-emissions technology RD&D program exists between Australia and the UK, researchers in both countries have been collaborating on an ongoing basis through the UK Science and Innovation Network and through existing institution-to-institution relationships. As at 2020, there were 565 agreements between Australian and UK institutions, and 10% of the UK's papers are co-authored with Australia. Since the establishment of the Fund for International Collaboration (FIC), Australia has also been engaging with Innovate UK on industry led collaborations in various technology areas.[103] It is expected that the recent announcement of the partnership between the UK and Australia on low emissions technologies will catalyse growth in hydrogen RD&D collaborations.

[101] EPSRC (2021) EPSRC Centre for Doctoral Training in Sustainable Hydrogen - SusHy
https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/S023909/1

[102] EPSRC (2021) Metal Atoms on Surfaces and Interfaces (MASI) for Sustainable Future
https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/V000055/1

[103] UK Science and Innovation Network (2020) UK Science & Innovation Network Country Snapshot: Australia
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/970195/Australia_Country_Snapshot_2020.pdf

Country	Projects
Netherlands	Eindhoven University of Technology has partnered with the University of Surrey on the REDAEM: Anion-Exchange Membranes for Reverse Electrodialysis research project. The project will involve synthesising anion exchange membranes and exploring the use of sonochemistry during the grafting stage.[104]

1.6 Data insights: The United Kingdom's hydrogen RD&D activity

The following section provides data-driven insights on UK's RD&D activity across hydrogen technologies. Research publication data, patent data, and commercial project data has been used to understand hydrogen related activity. While limitations exist with such an approach, these data sources do provide an opportunity to consider activity across the innovation spectrum from basic research to demonstration. It also aims to help identify technology areas that have received significant focus in each country and key organisations to support international collaboration efforts.

Several universities, public research institutions and private companies are highly active in early-stage hydrogen research and late-stage technology commercialisation. This is reflected in hydrogen research publication output and patent output data summarised in the two sections below.

The data for this section was sourced from the CSIRO's publications team, CSIRO's IP team, IP Australia, and the IEA's hydrogen projects database.

Figure 6: Hydrogen innovation activity data

1.6.1 Research publication data

Research publications in hydrogen are an indicator of basic and applied research activity. CSIRO's publications team has conducted a research publication scan to identify UK organisations conducting research across the hydrogen value chain. The publications search approach was developed in 2019 to support the report *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia*. This search approach was applied in 2021 to provide an updated dataset for this report. The details of the search approach can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[105]

[104] EPSRC (2021) REDAEM: Anion-Exchange Membranes for Reverse Electrodialysis https://gow.epsrc.ukri.org/NGBOViewGrant.aspx?GrantRef=EP/R044163/1

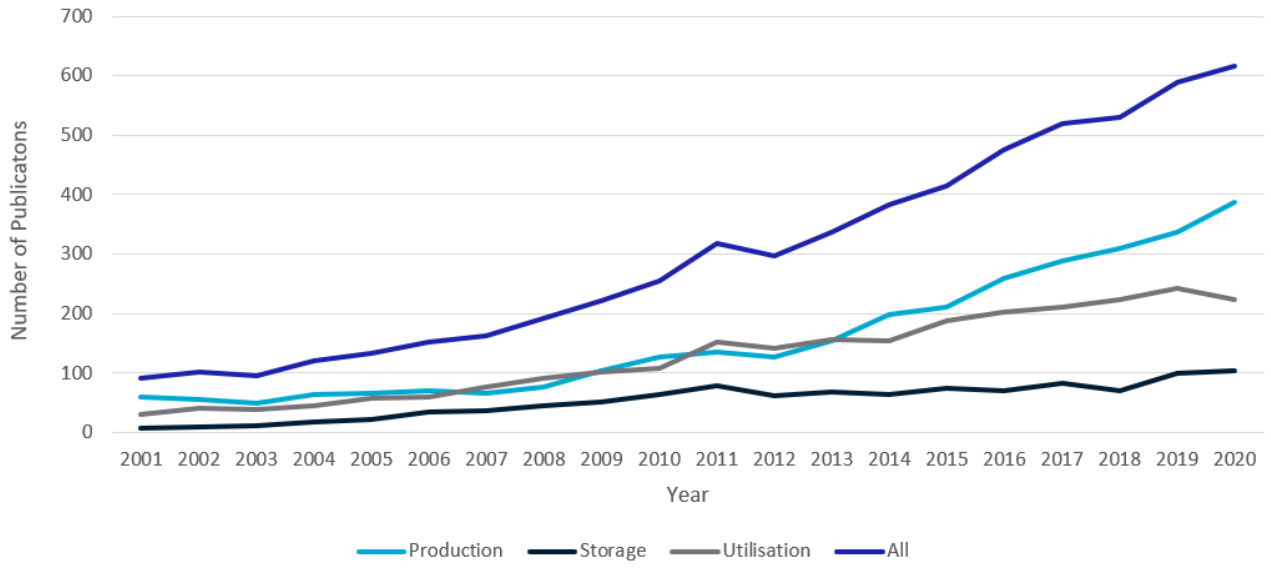
[105] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

Figure 7 shows UK institutions ranked in terms of publication output across hydrogen production, storage and distribution, and utilisation from 2016-2020. Figure 8 shows the UK's country-wide research publication output trends across the hydrogen value chain.

Figure 7: Top institutions by publication output (2016-2020)

Domestic Ranking	Production	Storage and Distribution	Utilisation	Overall
	7th Global Rank	*8th Global Rank*	*7th Global Rank*	*7th Global Rank*
1st	Imperial College London	University of Cambridge	Imperial College London	Imperial College London
2nd	University of Cambridge	University of Manchester	University College London	University College London
3rd	University College London	University of Oxford	University of Oxford	University of Cambridge
4th	University of Leeds	UK Research & Innovation (UKRI)	University of Cambridge	University of Oxford
5th	University of Oxford	University of Nottingham	University of Birmingham	University of Manchester

Figure 8: The UK's hydrogen-related research publication output (2001-2020)



1.6.2 Patent data

Patent activity in hydrogen is an indicator of applied R&D and innovation occurring across the value chain. This section draws on two different patent analytics approaches. CSIRO developed a search approach in 2019 to support the *Hydrogen Research, Development and Demonstration: Priorities and opportunities for Australia* report. CSIRO applied this approach to provide a patent landscape across the hydrogen value chain for each country. The details of the search approach and any limitations can be found in the *National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository*.[106]

[106] CSIRO (2019) National Hydrogen Research, Development and Demonstration (RD&D): Technical Repository. Available at https://www.csiro.au/en/work-with-us/services/consultancy-strategic-advice-services/csiro-futures/futures-reports/hydrogen-research

The second approach, performed by IP Australia, builds on the hydrogen technology taxonomy developed in CSIRO's 2019 report to provide information on specific hydrogen technologies that sit within production, storage, and utilisation. The full data visualisations, details of the search approach and any limitations can be found at *Patent analytics of hydrogen technologies: an interactive visualisation.*[107]

It should be noted that analysis of patent data is not necessarily representative of patent impact. As such, this data should be viewed holistically with the other data presented in this section, particularly project deployment.

Patent landscape of hydrogen value chain

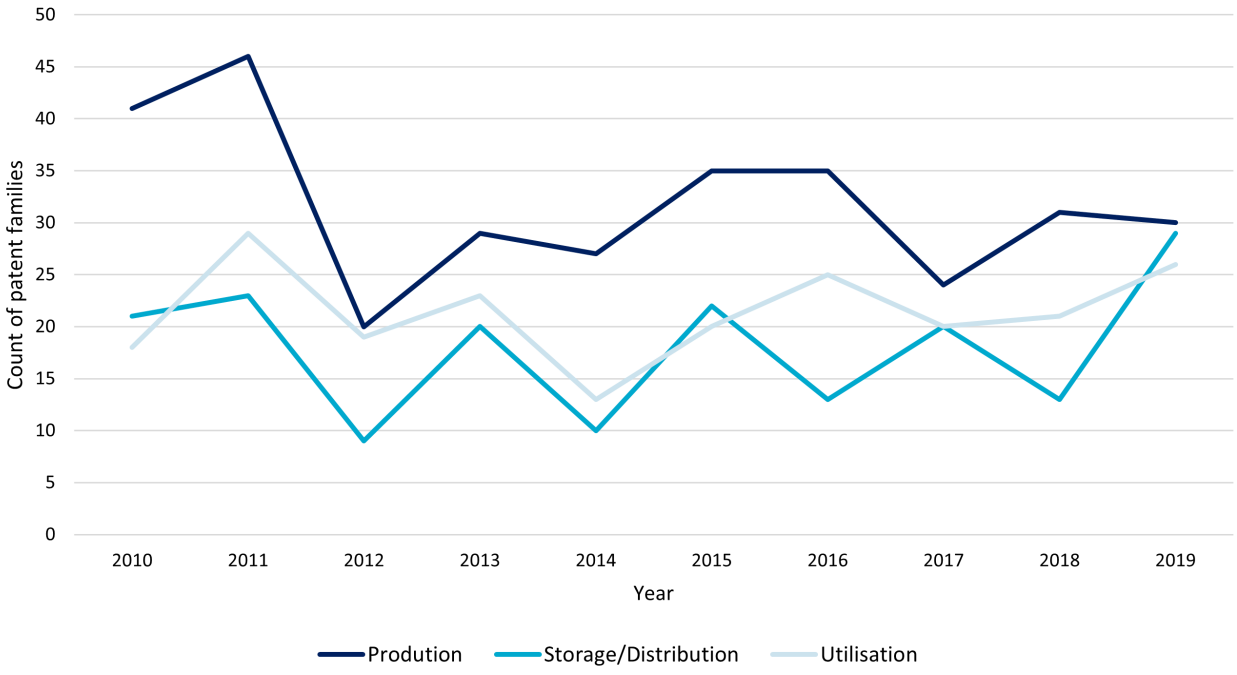
Performed by the CSIRO, this patent landscape analyses patent family[108] filings across the hydrogen value chain.

Figure 9 outlines patent filings over time across the areas of hydrogen production, storage/distribution and utilisation.

Figure 10 shows the jurisdictions in which UK patent applicants are filing patents, outside of the United Kingdom. This provides an indication of which global markets, or manufacturing/commercialisation destinations are of interest to UK patent applicants or inventors.

Note that patent databases have a delay of roughly 18 months, therefore 2020 and 2021 have been omitted from the graphs below. Some patent filings may also be counted twice as the categories of production, storage and utilisation may not be mutually exclusive in all instances and some could relate to multiple areas of the hydrogen value chain.

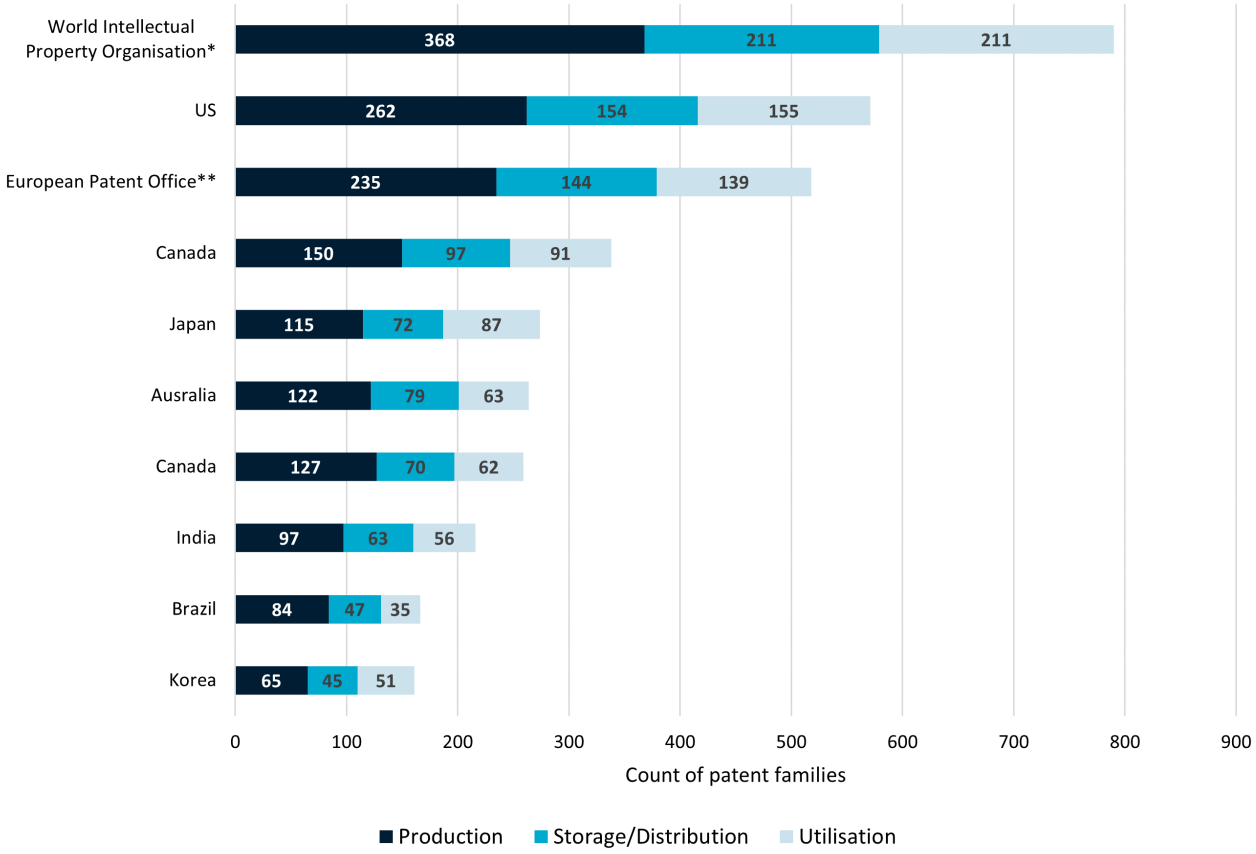
Figure 9: Patent filings over time across production, storage/distribution and utilisation



[107] IP Australia (2021) Patent Analytics on Hydrogen Technology, Australian Government. Available at https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

[108] Applications with the same priority, but filed in different jurisdictions, are known as patent families. Patent families enable us to analyse inventive activity regardless of the number of countries in which protection is sought. Patent families are used in analytics to represent a single invention.

Figure 10: Location of patent filings by UK patent applicants



*** The World Intellectual Property Organisation (WIPO) is an international organisation that promotes the protection of intellectual property and supervises administrative cooperation amongst the intellectual unions regarding protection of intellectual property. Patents filed in the WIPO enable applicants to obtain protection for their inventions in up to 153 of the parties to the Patent Cooperation Treaty.**

**** The European Patent Office enables investors, researchers and companies to obtain protection for their inventions in up to 44 countries, including all 27 EU member states.**

Patent analytics of specific hydrogen technologies

Data extracted from IP Australia's interactive visualisation provides an in-depth analysis of specific hydrogen technology developments. Figure 11 (below) shows the number of patent families filed since 2010 for specific technology areas by UK applicants.

Table 9 (below) shows the number of patent families filed by UK applicants since 2010 by sub-technology area, expressed as a percentage of total global patent family filings.

Table 9 also shows the top organisations in the UK filing patents in each technology area. It should be noted that the majority of fuel cell technologies are categorised under the 'electricity generation' category.

Figure 11: UK's patent family output by sub-technology area (2010-2020)

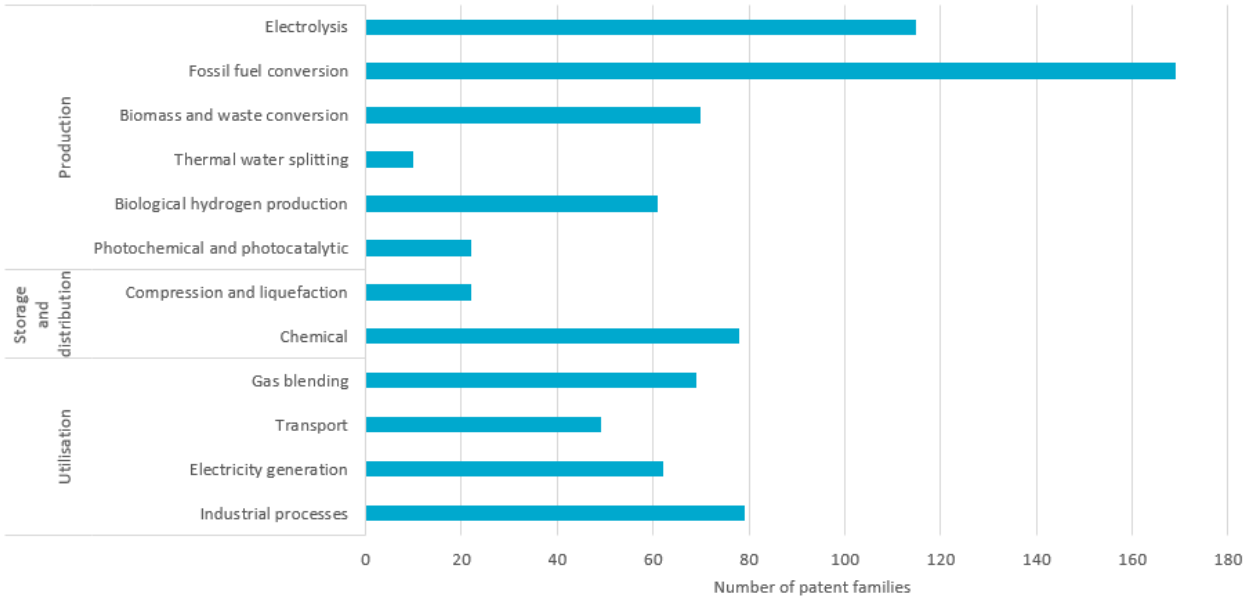


Table 9: The UK's IP output (number of patent families filed by UK applicants) by sub-technology area from 2010-2020

Technology area		IP output (% of global)	Leading companies	Leading non-profit and universities
Production	Electrolysis	1.4%	Xergy, CGON, Torvex Energy, Ion Science, Johnson Matthey	University of Glasgow, University of Surrey, Cardiff University, Oxford University Innovation
	Fossil fuel conversion	2.7%	Johnson Matthey, CompactGTL, British Petroleum Company, Gas2, Velocys Technologies	University of Newcastle Upon Tyne, Loxley, Neil, Rennie, Simon, Lind, Robert, Olive Stamp
	Biomass and waste conversion	2.4%	Johnson Matthey, Advanced Plasma Power, Velocys Technologies, CAE(IP), INEOS Bio	University of Oxford, Oxford University Innovation, University of Cambridge, University of Newcastle Upon Tyne, Coventry University
	Biological	2.5%	Johnson Matthey, Cambridge Display Technology, Promimagen, Systagenix Wound Management	MRC, United Kingdom Research and Innovation, University of the West of England (Bristol), Cardiff University
	Photochemical and photocatalytic	1.2%	Cambridge Innovation Technologies Consulting, OMMICA, Microsharp	Imperial Innovations, University of St Andrews, University of Oxford, Oxford University Innovation, University of Glasgow
	Thermal water splitting	1.4%	N/A	Oxford University Innovation

Technology area		IP output (% of global)	Leading companies	Leading non-profit and universities
Storage and distribution	Compression and liquefaction	3.1%	Intelligent Energy, LGT Advanced Technology, Xergy, Storelectric, GE Aviation Systems	N/A
	Chemical storage	3.1%	Intelligent Energy, IH IP Holdings, GE Aviation Systems, USW Commercial Services, Cella Acquisition	University of South Wales Commercial Services, University of Manchester, Lancaster University, University of Liverpool, University College Dublin, National University Ireland
Utilisation	Gas blending	4.8%	Johnson Matthey, Fujifilm Imaging Colorants, Intelligent Energy, BP Alternative Energy Holdings	Imperial Innovations, University of Edinburgh, Loughborough University
	Transport	1.9%	Johnson Matthey, Ulemco, Inova-Power, Reaction Engines	N/A
	Electricity generation	1.5%	Cere Intellectual Property Company, Intelligent Energy, CMR Fuel Cells (UK), Ge Aviation Systems, Ceres Intellectual	Imperial Innovations, University of Nottingham, University of Strathclyde, University of South Wales Commercial Services
	Industrial processes	1.8%	Edwards, Johnson Matthey, Fujifilm Imaging Colorants, Air Fuel Synthesis, Ricardo	Court Of Edinburgh Napier University, University of Oxford, Coventry University

IP Australia patent analytics on hydrogen technology

IP Australia has developed an interactive visualisation tool to provide hydrogen insights to researchers, academics, business and policy sectors. For more hydrogen IP statistics including key destination markets, origin profiles, applicant profiles, collaborations and specific patent searches, refer to IP Australia's Hydrogen Patent Landscape tool:

- https://www.ipaustralia.gov.au/tools-resources/publications-reports/patent-analytics-hydrogen-technology

1.6.3 Project data

IEA Hydrogen Projects Database

Data from the IEA Hydrogen Projects Database (as at October 2021)[109] provides insight on clean hydrogen technology value chains deployed at pilot and commercial scale across the UK. Note that the following limitations should be taken into account:

- The database does not indicate whether the technologies used are indigenous or purchased from an overseas provider. While many countries often deploy their own technologies at scale, many countries purchase technologies from overseas to deploy locally. As such the database indicates deployment activity, but not necessarily the ability to translate indigenous R&D into commercial scale-up.
- This dataset counts only low-carbon hydrogen projects and their associated value chains. As such, hydrogen production projects from gas, coal and oil without CCS are not included. Similarly, utilisation projects not related to a clean hydrogen project source are not included.
- The dataset reflects only projects occurring domestically, and therefore does not count projects undertaken by UK companies outside of the UK. As such, the table may understate the UK's activity, particularly its contribution to international supply chain development. This data should therefore be considered holistically with the rest of this report.
- Any limitations stated in the data collection methodology, definitions and assumptions should be taken into account (see IEA Hydrogen Projects Database for details).

For the purposes of this report, the dataset has been filtered to include only projects from 2010 through to projects expected to be operational by 2030, as this timespan best reflects current activities. Projects without a specified date have been excluded from the table below. Further, only projects that are at feasibility study, final investment decision, demonstration, and operational stages are included. Projects at the 'concept' stage are not included. It should be noted that the majority of projects listed span production, storage and multiple end-uses, and as such can be counted in more than one technology category.

Table 10: UK's domestic clean hydrogen project data

Technology	Sub-technology		Domestic project count	% of global
Production	Electrolysis	PEM	11	6.0
		Alkaline	7	6.0
		SOE	-	-
		Other or unspecified	7	2.8
	Fossil fuel conversion	Coal gasification with CCS	-	-
		Natural gas with CCS	10	27.8
		Oil with CCS	-	-
		Methane pyrolysis	-	-

[109] IEA (2021) Hydrogen Projects Database. Available at <https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database>

Technology	Sub-technology		Domestic project count	% of global
	Biomass and waste Conversion		-	-
	Photochemical and photocatalytic		-	-
	Biological production		-	-
	Thermal water splitting		-	-
Storage and distribution	Compression and liquefaction		34	6.7
	Chemical carriers	Ammonia	-	-
		Methane	-	-
		Methanol	-	-
		Synfuels	1	10
Utilisation	Gas blending		9	6.7
	Transport		18	7.6
	Electricity generation		12	9.0
	Industrial processes	Refining	-	-
		Ammonia	-	-
		Methane	-	-
		Iron and steel	-	-
		Biofuels	-	-
		Synfuel	1	4.3
		Other industry	9	6.6

IEA Hydrogen Projects Database

The latest version of the IEA Hydrogen Projects Database can be found at:

- https://www.iea.org/data-and-statistics/data-product/hydrogen-projects-database

UK Hydrogen production and infrastructure projects

Beyond the IEA database, the UK's Hydrogen Investor Roadmap included a mapped sample of UK hydrogen production and infrastructure projects, suggesting up to 20GW of potential hydrogen projects identified in the UK pipeline (through to 2037).[110]

[110] A good summary of deployment projects can be found in the Hydrogen Investor Roadmap
https://www.gov.uk/government/publications/hydrogen-investor-roadmap-leading-the-way-to-net-zero

As Australia's national science agency and innovation catalyst, CSIRO is solving the greatest challenges through innovative science and technology.

CSIRO. Unlocking a better future for everyone.

Contact us

1300 363 400
+61 3 9545 2176
csiro.au/contact
csiro.au

For further information

CSIRO Hydrogen Industry Mission
Dr Patrick Hartley, Research Director
+61 3 9545 2595
patrick.hartley@csiro.au

CSIRO Energy
Dan O'Sullivan, Program Manager
+61 7 3833 5569
dan.osullivan@csiro.au

CSIRO Futures
Vivek Srinivasan, Associate Director
+61 3 9545 8057
vivek.srinivasan@csiro.au