Hydrogen Innovation Initiative

The UK Hydrogen Innovation Opportunity

UK Capabilities

April 2024

The Hydrogen Innovation Initiative (HII)

HII is a trusted group of organisations bringing together key stakeholders to create an investible, globally competitive hydrogen technology and services sector, here in the UK. Our vision is for UK technology to power the global hydrogen economy – transforming UK industry into a net zero powerhouse.

HII partners:

Advanced Propulsion Centre UK
Aerospace Technology Institute
Catapult Compound Semiconductor Applications
Catapult Connected Places
Catapult Digital
Catapult Energy Systems
Catapult High Value Manufacturing
Catapult Offshore Renewable Energy
Catapult Satellite Applications
Glass Futures
NPL National Physical Laboratory
Net Zero Technology Centre – Technology Driving Transition

Supported by Innovate UK

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Acknowledgments

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HII Industrial Advisory Board

The HII Industrial Advisory Board (IAB) is made up of experts bringing insight of the opportunities and challenges of the hydrogen economy from across the value chain, from production, distribution and consumption.

It brings expertise from the following organisations*:

Airbus, bp, Cummins, GKN Aerospace, H2GO Power, Hydrogen Energy Association, Hydrogen UK, Johnson Matthey, Macquarie, National Gas, ZeroAvia

*HII and the HII IAB do not represent the direct interests of the organisations.

This report provides an overview of UK capability in hydrogen technologies. It has been produced as a supporting report to *The UK Hydrogen Innovation Opportunity*.

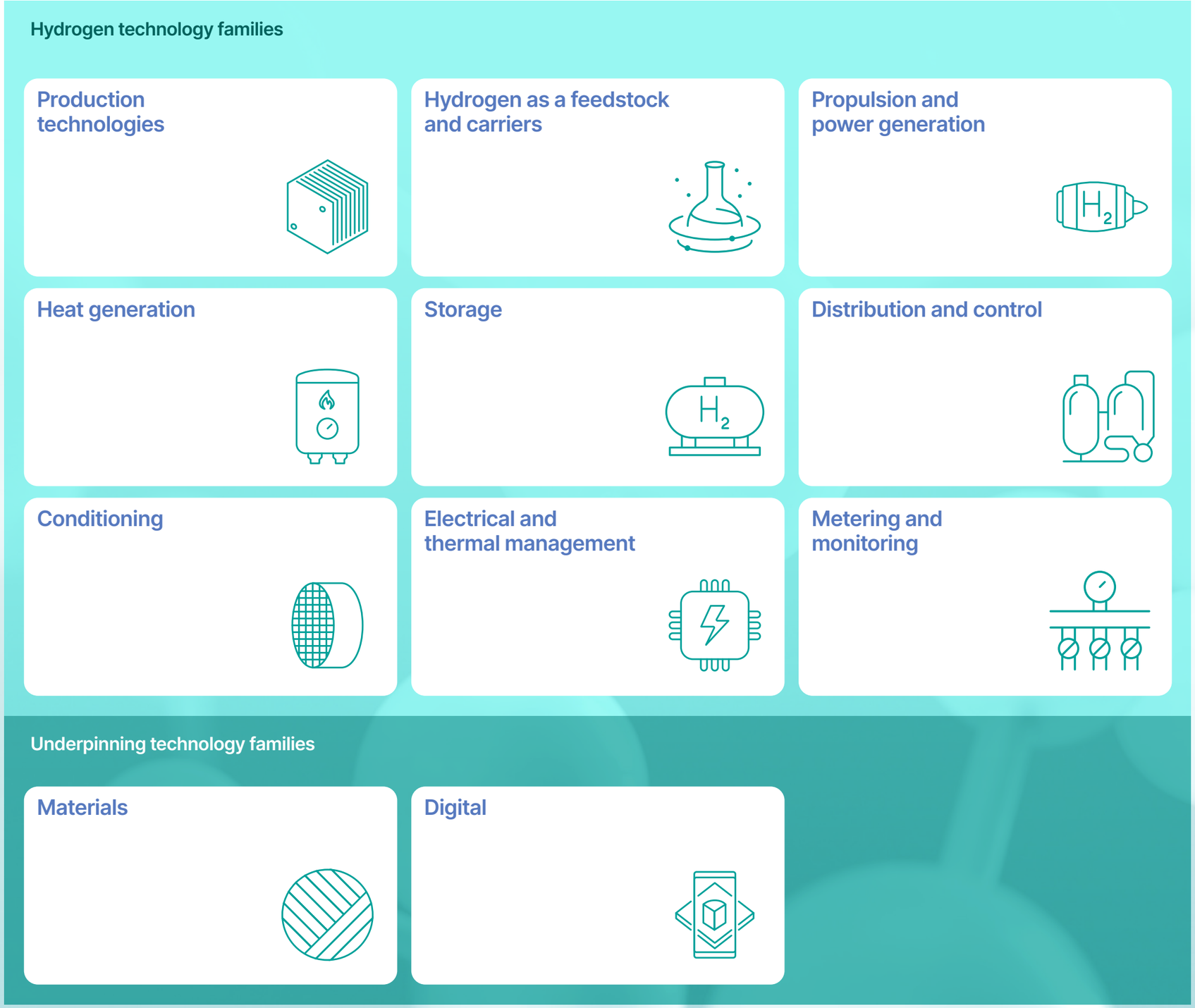
UK capabilities in hydrogen technologies

The ***UK Hydrogen Innovation Opportunity*** lays out the vision for the UK to become a leading exporter of hydrogen technology, with a ten-year window of opportunity to convert investment in innovation into globally competitive supply chains. It sets out the size of the prize for the UK and highlights what is needed to make it happen.

The analysis in the ***UK Hydrogen Innovation Opportunity*** is underpinned by evidence and analysis contained in four supporting reports:

1. **Hydrogen technology roadmaps**
   A summary of the technology innovation opportunities for the UK in the hydrogen economy, based on stakeholder engagement and extensive literature review.
2. **UK capabilities (this report)**
   An overview of the UK's current capability in hydrogen technologies and the critical enablers required for the UK to maximise its potential in the hydrogen technology market.
3. **Sectors and scenarios**
   A summary of sector needs for hydrogen and hydrogen technologies, globally and in the UK, up to 2050 and modelled UK scenarios.
4. **Techno-economic methodology**
   A method statement explaining the analysis behind the hydrogen economy and technology market figures quoted in the reports ***UK Hydrogen Innovation Opportunity*** and ***Hydrogen technology roadmaps***.

This report provides an overview of UK capability in hydrogen technologies. It has been developed through a combination of extensive industrial engagement, mapping of the UK landscape and analysis of UK funding.



The UK's jumping-off point

The UK is not 'starting from zero'. We have an accelerating base of hydrogen technology supply chain companies, a world-class scientific base and an array of demonstration projects. The need is to prioritise and coordinate investment to build and scale hydrogen supply chains serving multiple markets domestically and internationally.

The UK has a strong pipeline of hydrogen project developers in production, distribution, and storage as well as numerous potential off-takers across multiple sectors. This is supported by a strong engineering construction sector which can initiate, build and operate projects. We also have strong foundations in science and early-stage innovation with many academic and industry-led innovation projects occurring in the UK.

However, the UK often fails to capitalise on manufacturing opportunities that arise from its strong foundations in Research, Development & Innovation (RD&I). For example, the UK lacks a critical mass of large Tier 1 and sub-system suppliers that can provide packaged solutions for project developers and end users. When compared to competitor nations, the capabilities are patchwork and centred in a handful of companies. While the UK also possesses several emerging technology companies with unique offerings and intellectual property (IP), these companies require significant investment to graduate from a technology company to an established sub-system supplier. Figure 1 provides a snapshot of the UK's current supply chain capability.

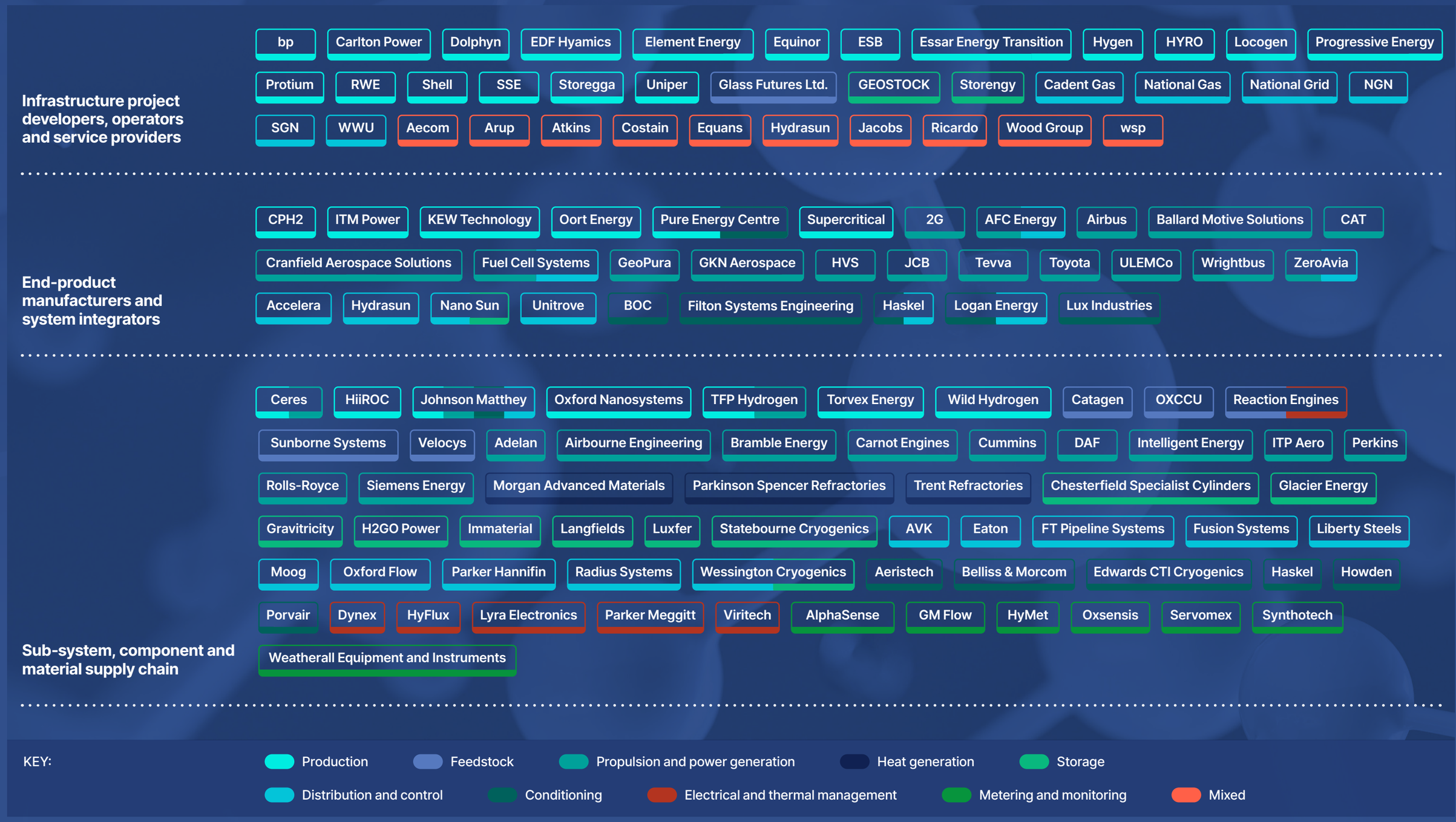
The reasons often cited by industry for the lack of scaled up sub-system manufacturing capability in the UK are lack of later-stage capital support, larger demand from competitor nations and ease of trading with supply chains from mainland Europe versus the UK. However, despite these challenges, there is still a window of opportunity for the UK to commercialise innovative technology across the hydrogen value chain. Through the desk-based research and extensive stakeholder engagement, two opportunity areas were identified. These were:

1. **Technologies in emerging markets where the UK has strong academic and industrial innovation capabilities.** Examples from the key technologies highlighted in the ***Hydrogen technology roadmaps*** include: thermochemical hydrogen production; solid state hydrogen storage technologies; cryogenic hydrogen storage and technologies that support hydrogen carriers, particularly ammonia crackers.
2. **Areas where the UK has manufacturing capabilities or IP in a growing market that could support initial market deployment.** Examples from the key technologies highlighted in ***Hydrogen technology roadmaps*** include: electrolysers and fuel cell technologies and components; carbon fibre-based hydrogen storage; Carbon Capture, Usage and Storage (CCUS) technologies and compressors.

The remaining sections explore each tier from Figure 1 and offer a high-level narrative on the UK's current capabilities, highlighting UK strengths and weaknesses. The report first steps through the different parts of the UK landscape, then talks about our capability around critical enablers followed by current UK funding mechanisms.

Figure 1. Examples of UK industrial players developing hydrogen-related capability, illustrated by organisation type and technology family. This list is non-exhaustive.

An accelerating UK hydrogen technology supply chain



Infrastructure project developers, operators and service providers

The UK is ramping up hydrogen production projects and supporting demonstrations of infrastructure for hydrogen transport. Early demonstrations of hydrogen infrastructure for production, storage & distribution or consumption in the UK can provide a key route to market for UK hydrogen technology developers.

One of the key policy levers to build a nascent supply chain is to launch government-funded infrastructure projects i.e. for hydrogen production and hydrogen distribution. If largescale UK projects launch earlier than competitor regions, they can act as a key route to market for UK hydrogen technology supply chain companies, providing an opportunity to demonstrate their products in an operational environment. Technology supply chain companies will also seek to co-locate factories next to their market such as, for example, electrolyser manufacturers may locate near to a critical mass of hydrogen electrolysis plants.

The UK is supporting projects for electrolytic hydrogen production through the Hydrogen Allocation Rounds and incentivising large scale CCUS-enabled hydrogen through their Cluster Sequencing process. The Hydrogen Allocation Round 1 kickstarted 11 projects to provide 125 MW (cumulatively) [1] of low carbon hydrogen production across a diverse set of locations, with the first projects targeting operation in 2025.

In Europe, IPCEI Hy2Use fund is aiming to support the deployment of 3.5 GW of renewable hydrogen, targeting operation in 2025 [2]. Complementary support is also offered for the rollout of hydrogen distribution infrastructure across a portfolio of 37 projects. Shell's HH1, in Rotterdam is targeting a 200 MW electrolyser plant [3].

In addition to ramping up production projects, the UK government has launched the Hydrogen Business Model (HBM) and business models for Hydrogen Transport and Hydrogen Storage are under development. This type of revenue support informs the investment decisions of infrastructure developers, helping to unlock supply chain development.

The availability of refuelling infrastructure is critical to stimulate the use of hydrogen for transport (aviation, maritime, road and off highway). Government intends to publish a Zero Emission HGV Infrastructure Strategy in 2024. In 2023, EU states agreed to build hydrogen fuelling stations in all major cities and at least every 200km along the core Trans-European Transport Network.

The UK has provided significant funding demonstration programmes for transport infrastructure including the Zero Emission Road Freight Demonstration (ZERFD) and the Zero Emission Vessel and Infrastructure (ZEVI).

One strong element in the UK is the skills and expertise of engineering, procurement, and construction (EPC) companies. This is mainly down to the UK's expertise in the oil and gas sector alongside other large infrastructure areas such as water and telecommunications. This expertise is important, especially as a good route to market for many hardware producers is forming strong partnerships with EPC providers who can integrate their solutions into relevant hydrogen end applications.

End-product manufacturers and system integrators

The UK has the potential to become a competitive original product manufacturer, but it must act swiftly to attract and convert a critical mass of capability.

The UK benefits from established industrial bases and systems integration expertise, demonstrated by transport original equipment manufacturers (OEMs) such as Wrightbus, JCB, Stellantis and Toyota. However, despite the positive progress in RD&I and late-stage demonstrators, the UK does not yet manufacture hydrogen vehicles or equipment. While the market is still emerging, investment decisions will be made imminently so landing investments from established manufacturers is crucial for the UK to remain competitive.

In addition to the UK's existing industrial base, new entrants are also entering the market across different value chains areas. In refuelling station platforms for example, Unitrove and ZeroAvia are servicing maritime and aerospace respectively. In stationary power, GeoPura, NanoSun and Fuel Cell Systems also offer fully packaged hydrogen power units for construction sites and events. Similarly in electrolyser system manufacture, ITM Power are building a 1 GW manufacturing facility in Sheffield [4]. However, ITM Power are simultaneously expanding in Germany, securing a 100 MW contract and recently opening a facility [5]. Companies are attracted to Europe by favourable IPCEI funding.

The examples highlighted above show that pockets of capability for end products and system integration exist. The issue is that this capability is often only one or two companies deep, with some uncertainty around whether scale-up facilities will land in the UK. Therefore, any future innovation support for hydrogen needs to unlock and accelerate the growth of end-product manufacturers and system integrators.

Sub-system, component and material supply chain

The UK has both disruptive technology developers and established manufacturers in the component and material supply chain. The former need support maturing and anchoring their hydrogen technologies in the UK while some established manufacturers need support to tailor and grow their sector adjacent capabilities for the hydrogen industry.

Much of the UK's promising supply chain activity occurs at the sub-system, component, and material supply chain level. The UK's capability can broadly be split into two categories: technology developers with technology that requires scaling and established manufacturers who need help to transition or expand.

In terms of more technology developers, the UK has many fuel cell developers including solid oxide fuel cell technology from Ceres Power, automotive and aerospace focused PEM fuel cells from Intelligent Energy, lightweight high power density fuel cells for aerospace from ZeroAvia, and fuel cells utilising printed circuit board technology from Bramble Energy. In hydrogen combustion, Carnot Engines is developing a high-efficiency ammonia / hydrogen fuelled engine concept tailored for heavy-duty maritime applications. Innovative hydrogen production companies such as HiiROC and Levidian are also maturing, advancing the trials of their novel low carbon hydrogen production processes. In terms of earlier stage technology, there are a range of promising UK electrolyser stack technologies, such as membrane-free technology from CPH2, high-temperature high-pressure electrolysis from Supercritical, direct seawater electrolysis systems from Torvex Energy, and waste-water electrolysis from HydroStar. The UK is also home to H2GO Power, a novel metal hydride hydrogen storage start-up for stationary and seasonal storage applications.

The breadth and scope of companies with innovative technologies in the UK is a testament to our strong RD&I and science base. The perennial challenge for the UK has always been transitioning these companies from promising start-ups with RD&I bases to established Tier 1/Tier N suppliers with manufacturing facilities. With more advanced technology companies such as those listed, the route to maturity has often been via acquisition from an overseas company. While providing financial stability, this leaves the risk of IP and manufacturing leakage. This has occurred in previous funding mechanisms without CAPEX support where companies matured under the UK innovation ecosystem but manufacturing was ultimately taken abroad. Any future hydrogen investment mechanism will need to invest in both emerging RD&I companies with large growth potential as well as engage more effectively and earlier with private finance. This includes both venture capital and private equity firms alongside public sector finance initiatives such as British Business bank and UK Infrastructure Bank (UKIB) to help anchor UK technology and help business owners keep promising technology in the UK.

In addition to new entrants, the hydrogen supply chain is dominated by established manufacturers and companies who are transitioning or expanding their capabilities into hydrogen. A notable example is Johnson Matthey who 'develop and manufacture leading edge membranes and catalyst coatings' [6] which are critical for fuel cells and other hydrogen technologies, including steam methane reforming (SMR), ammonia cracking, hydrogen purification, and emissions reduction in industrial combustion applications.

The UK also possesses established capability in the fabrication of stationary hydrogen storage vessels and the production of steel pipelines for hydrogen networks.

> **There are multiple routes to building supply chain capacity. Companies in one sector can transfer application of their technology to another, adjacent sector through horizontal innovation.**

Langfields, WEFCO and Chesterfield Cylinders are fabricating steel hydrogen storage tanks for stationary applications for UK and export markets. For hydrogen networks, Tata Steel and Liberty Pipes Hartlepool can manufacture steel pipelines that are suitable for trunk or branch hydrogen networks.

The UK also has extensive manufacturing and design capability in internal combustion and gas turbines. In aerospace, there's considerable transferable expertise in kerosene burning aerospace gas turbines, with a complimentary academic and industrial RD&I base underpinning all aspects, including materials development. Rolls-Royce have achieved a major milestone in the 'world first run of a modern aero engine on hydrogen' [7]. In stationary power applications, Siemens Energy have capability to service small hydrogen-derived gas turbines for industrial and power applications from their facility in Lincoln, utilising the experience of natural gas turbines. Similar support from adjacent industries can be found in the UK's design and manufacturing capability for heat exchangers for aerospace, with Parker Meggitt and Reaction Engines developing products for use with hydrogen as the working fluid.

Similarly, the UK is home to world-class fossil fuel internal combustion engine (ICE) manufacture, with transferable technology for hydrogen ICE. As such, JCB have successfully introduced hydrogen ICE into two product platforms [8]. For internal combustion engines, Perkins, Cummins, Ecomar and Carnot Engines are exploring hydrogen combustion technology for multiple transport and off-highway applications.

There are multiple routes to building supply chain capacity. Companies in one sector can transfer application of their technology to another, adjacent sector through horizontal innovation. However, in this route, to reach commercialisation, capability must be tailored for hydrogen technologies through research, testing and demonstration, and supported by sector-specific standards and certification harmonisation. Transitioning the capability of established manufacturers could be an easier route for the UK. This can be achieved through partnerships between these established manufacturers, technology entrants and our excellent science and research base. Further support for nascent supply chains may be provided through demonstrations of new technologies on public estates.

Industries such as hydrogen, sustainable aviation fuels, CCUS and chemicals often compete for the same fabrication capability, compressor technology and high voltage transformers capacity. Therefore, expanding capacity of the tiered supply chain will also have cross-sectoral benefits beyond hydrogen.

Research, development and innovation (RD&I) landscape

At the core of the UK's capability in the hydrogen economy is its world-class science base.

This research and development base across the hydrogen technology supply chain opens up major opportunities to address gaps in the global market place [9].

One of the UK's key strengths is our collaborative RD&I ecosystem, as illustrated in Figure 2. The UK benefits from collaboration across world-class centres of excellence at universities, networks of academic hubs and facilities, Public Sector Research Establishments, supported by the backbone of a National Quality Infrastructure. Research organisations such as the Catapult Network aid translational research, and collaboration is further supported through regional initiatives, such as those employed in the industrial clusters. All of these organisations support industrial research activity alongside a strong community of sector specific technology centres.

Particular strengths include world-leading expertise in electrochemical processes at universities such as Imperial College London, University of Birmingham and Loughborough University supporting fuel cell and electrolysis product development, previously part of a wider network of institutions in the H2FC Supergen Hub.

UK research and development in hydrogen gas turbines and internal combustion engines for propulsion is also world leading. Expertise from universities such as University of Cambridge and Cranfield University are supported through specialist facilities such as the Whittle Laboratory, National Centre for Combustion and Aerothermal Technology (NCCAT).

Strengths in the UK research community can also be found in the development of biomass reforming and handling, thermochemical on-board cryogenic tanks, carbon capture and storage, e-fuel and e-chemical production, solid-state storage, alternative fuel powertrain engineering and compound semi-conductors. However, in these specialisms, the UK's manufacturing expertise in the design, build and test of componentry and systems is only partially realised.

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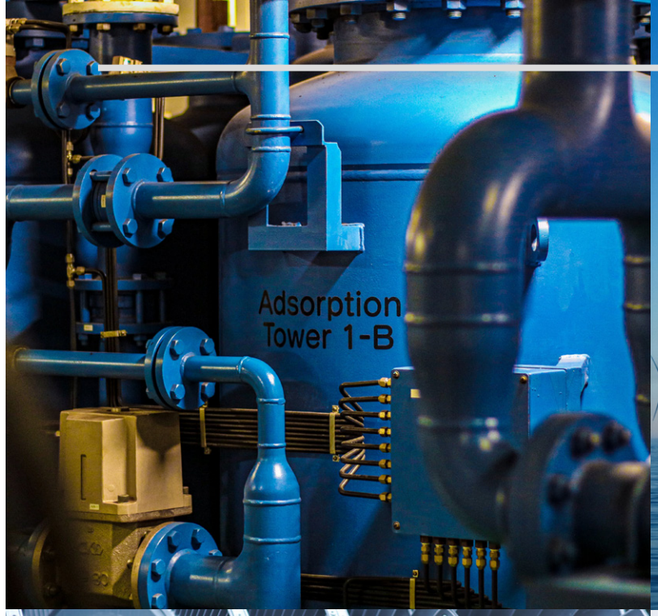


Figure 2. UK Research, Development & Innovation (RD&I) landscape showing research groups and facilities supporting hydrogen technology discovery, development and deployment.

R&D Landscape

Discover
Develop
Deploy

Universities

- University of Bath
- University of Birmingham
- Brunel University
- University College London
- University of Cambridge
- Cranfield University
- Durham University
- Imperial College London
- Loughborough University
- University of Newcastle
- University of Oxford
- St. Andrews University
- University of Southampton
- University of Surrey
- University of South Wales
- University of Strathclyde
- Ulster University
- Queens University Belfast

National Quality Infrastructure

- National Physical Laboratory
- British Standards Institution
- Office for Product Safety and Standards
- UK Accreditation Service

Research organisations

- Carbon Trust
- Connected Places Catapult
- Compound Semiconductor Applications Catapult
- Digital Catapult
- Energy Systems Catapult
- European Marine Energy Centre
- Glass Futures
- High Value Manufacturing Catapult
- Hydrogen Innovation Initiative
- Offshore Renewable Energy Catapult
- Satellite Applications Catapult
- TWI

Sector technology centres

- Advanced Propulsion Centre
- Aerospace Technology Institute
- Net Zero Technology Centre

Academic research hubs

- HyRES EPSRC Hydrogen Hub
- Hi-ACT EPSRC Hydrogen Hub
- HyDEX
- Henry Royce Institute
- Energy Research Accelerator
- Materials Innovation Factory
- Net-Zero Research Network
- UK-ARC
- UK Catalysis Hub
- UK CCS Research Centrecommercial services and consultancy

Academic-led facilities for industry

- Translational Energy Research Centre
- IAAPS
- National Centre for Combustion and Aerothermal Technology
- Renewable Hydrogen Research and Demonstration Centre
- Industrial Decarbonisation Research and Innovation Centre
- Aerospace Integration Research Centre
- Whittle Laboratory

Public sector research establishments

- Health and Safety Executive (PSRE)
- National Nuclear Laboratory
- National Physical Laboratory

Private sector open access R&D facilities

- AMRICC
- AVL
- CEIMIG
- DNV
- Element
- HORIBA MIRA
- Kiwa
- MPI
- TÜV SÜD (NEL)
- UTAC

Access to critical enablers

Access to critical enablers including simulation and test infrastructure, knowledge, skills and partnerships is a key anchor for supply chain companies.

Simulation and test infrastructure is required to support product development, all the way from material testing to full-scale product testing. Test capability exists at the Health and Safety Executive (HSE) Laboratories, across a range of UK research organisations and universities (e.g., IAAPS, HORIBA MIRA, TWI) and in support of specific projects e.g., National Gas' Future Grid programme. Industry has indicated significant lead times for access to hydrogen test houses and in sourcing hydrogen (especially liquid hydrogen) both in the UK [10] and in other nations. This presents an opportunity – if the UK can strengthen its test infrastructure it can attract supply chain companies.

The Henry Royce Institute, the UK's national institute for advanced materials research and innovation, highlights the need to develop the UK capability to test, set standards and accredit new materials for the hydrogen sector, especially for testing at extreme temperature conditions [11]. The UK has the expertise to establish these capabilities, however currently most materials testing is conducted overseas, undermining the UK's leadership in this field.

The Aerospace Technology Institute (ATI) is seeking to address the gaps in test infrastructure for the specific requirements of liquid hydrogen aircraft technologies by defining an operating model for a group of open-access facilities through its Hydrogen Capability Network (HCN) [12], and working to support the smaller-scale supply of liquid hydrogen for the test network. Access to hydrogen supply for research purposes in both its gaseous and liquid forms could fast become a bottleneck, limiting development and testing activities for key technologies.

The UK also has significant capability in simulation at different scales. The Energy Systems Catapult has a whole system modelling environment – ESME (Energy Systems Modelling Environment) and a dynamic energy system simulation tool: Energy Path Operations (EPO), a part of the Whole Energy System Accelerator (WESA).

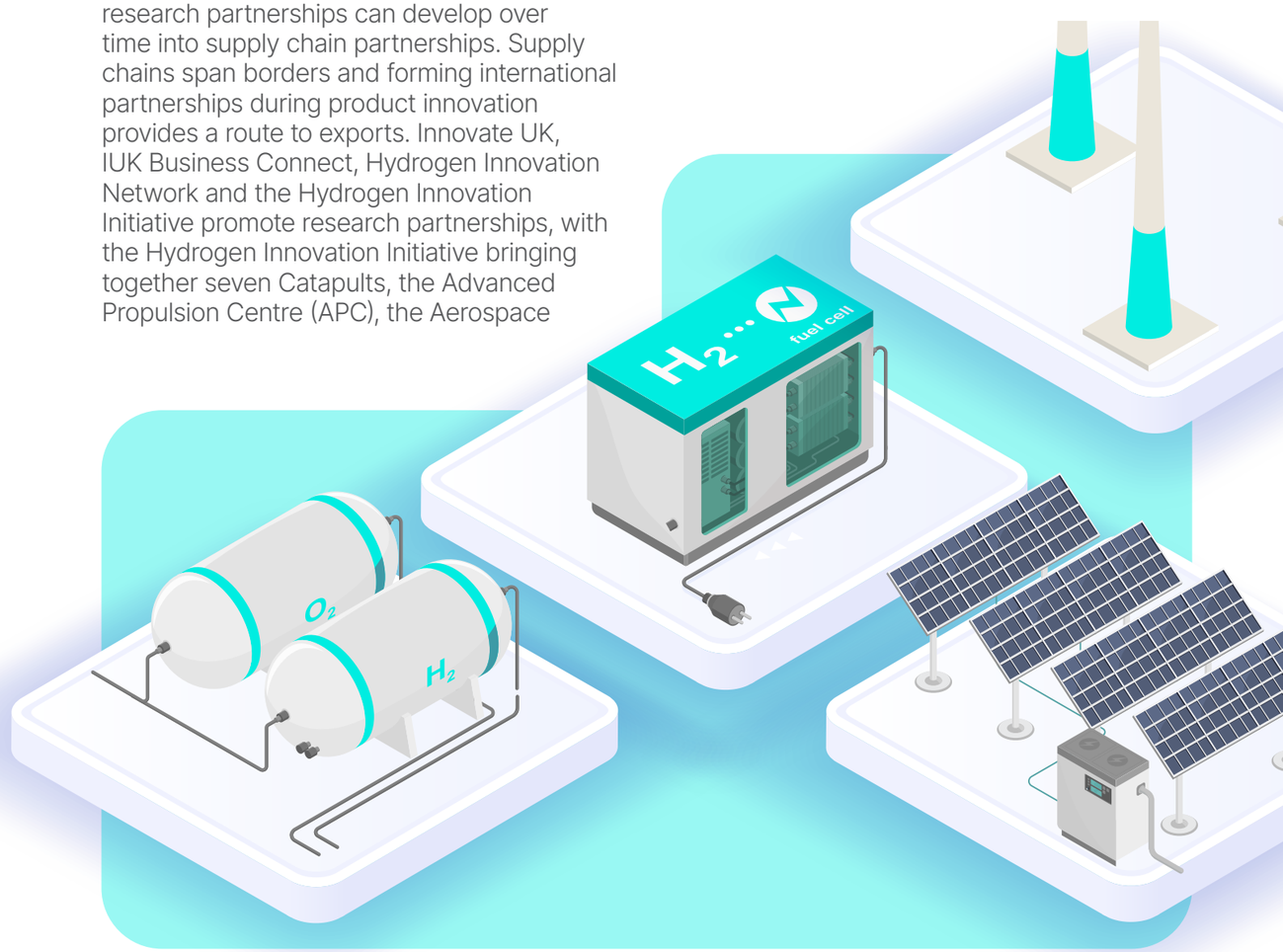
Knowledge is enabling for hydrogen technology discovery, development and deployment. There are significant knowledge gaps acting as barriers to the deployment of hydrogen technology. A lack of knowledge in market intelligence, business models, engineering design, planning and permitting approaches, measurement and test methods, materials, safety and the global warming potential of hydrogen all play an inhibitive role.

The Hydrogen Innovation Initiative has been supplied by Innovate UK to connect innovation across hydrogen production, distribution, storage and consumption. As well as working to launch new accelerator and supply chain development programmes, HII is developing resources for industry that address market and technological barriers on subjects from hydrogen's use in agriculture through to digital certification of hydrogen and alternative fuels.

The National Physical Laboratory addresses measurement protocols for hydrogen, and the wider National Quality Infrastructure works to develop guidance, good practice and standards. The Department for Energy Security and Net Zero is funding pre-normative work under the Hydrogen Regulators Forum. The Carbon Trust has launched their Clean Hydrogen Innovation Programme, focussed on hydrogen storage and distribution. However, there is still significant effort needed to address knowledge gaps that support both UK supply chain companies in both the technology development and deployment.

Alongside the identified technological and engineering capabilities, the UK also possesses considerable expertise in social scientific and economic disciplines. Timely and meaningful engagement of this expertise is essential given the roles that social acceptance and economic viability of technologies can have upon design, policy and investment decisions, as well as upon the speed and ease with which they can be introduced to society. With this in mind, it is noteworthy that the EPSRC Hydrogen Hubs UK-HyRES and HI-ACT integrate these disciplines.

Partnerships are critical to the delivery of technology development. Collaborative research partnerships can develop over time into supply chain partnerships. Supply chains span borders and forming international partnerships during product innovation provides a route to exports. Innovate UK, IUK Business Connect, Hydrogen Innovation Network and the Hydrogen Innovation Initiative promote research partnerships, with the Hydrogen Innovation Initiative bringing together seven Catapults, the Advanced Propulsion Centre (APC), the Aerospace Technology Institute (ATI), Glass Futures, the National Physical Laboratory and the Net Zero Technology Centre. Sector bodies and regional cluster bodies provide a critical role. There is an opportunity to provide better integration across these organisations whilst simultaneously increasing international partnerships, for the benefit of UK industry. HII is working to address this, with a hydrogen sector specific remit, similar to the activity of the APC and ATI for the automotive and aerospace sectors, respectively.



Access to private and public funding

Companies undertaking high-risk technology development and on growth trajectories need access to finance in different forms commensurate with the phase of the innovation and with their stage of growth. Any future hydrogen investment mechanism needs to invest in emerging RD&I companies with large growth potential as well as providing access to the capital funds required to industrialise. An appropriate mix of loans and grants that support the journey from technology development through supply chain scale-up is critical.

HII and Innovate UK (IUK) Business Connect have estimated the annual draw-down from government grants for hydrogen innovation projects per annum in the UK (see Figure 3). UK public funding for hydrogen innovation has increased significantly since 2019.

Hydrogen innovation has been funded through numerous funding calls. Many calls have been aligned to sector needs including, for example, the Aerospace Technology Institute, the Advanced Propulsion Centre, the Red Diesel, Industrial Fuel Switching, the Clean Maritime Demonstration Competition etc. Numerous calls have been launched within funding or aligned to UK net zero calls such as the calls under the Net Zero Innovation Portfolio (NZIP).

The analysis looked at government grants for projects between Technology Readiness Levels (TRLs) 4 to 7, and so does not include funding via UK research councils for fundamental research or funding to support deployment. Some of calls for demonstrators require TRL 7 thereby precluding some UK companies from a demonstration opportunity, which can support their route to market.

Figure 3 shows that hydrogen innovation is already happening across many sectors. However, these activities are happening in sector silos linked to existing UK industrial communities. This runs the risk of a supply chain that is fragmented and serving only a few sectors instead of an integrated, diverse supply chain meeting the needs of many.

In hydrogen, the opportunities to leverage the investment community are strong. This can include both venture capital and private equity firms, like those accessed by the Henry Royce Institute for their Royce Hydrogen Accelerator, alongside public sector finance initiatives such as British Business bank and UKIB to help anchor UK technology and help business owners keep promising technology in the UK.

Figure 3. Estimated UK public funding (spend per annum) for hydrogen research, development and innovation (TRL* 3+) per annum, split by sector.

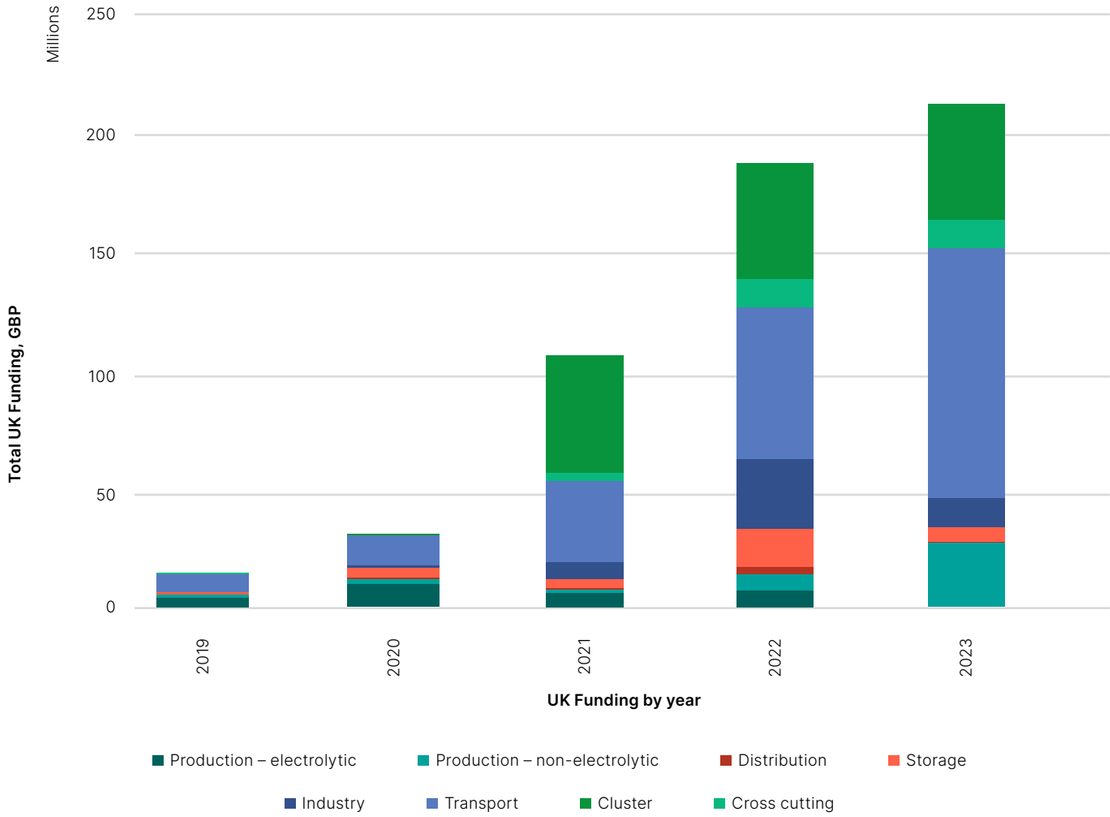


Figure 3 notes:

- *TRL = Technology Readiness Level.
- This initial analysis has been conducted by IUK Business Connect in collaboration with the HII programme from available information on grant funding that has been awarded since 2017. This does not include Ofgem Strategic Innovation Fund or the Network Innovation Allowance, which would increase the amount against distribution. The analysis does not include funding for fundamental research via UK Research Councils.
- The term cross-cutting here is used to refer to funding granted towards projects that do not clearly fit into a sector.
- The term cluster here is used to refer to funding awarded to projects bringing together different sectors to demonstrate decarbonisation through adoption of hydrogen.

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