The UK Hydrogen Strategy: Industrial Decarbonization and Industrial Policy

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Abstract The UK hydrogen strategy aims at making the UK a leader in green industries and improving national energy security. Its "twin track" approach simultaneously promotes hydrogen from natural gas with carbon capture and hydrogen from low-carbon electricity. Despite the UK's initial focus on applying hydrogen to industry, it has since emphasized creating demand by using hydrogen for heating and transportation. Exporting hydrogen itself was not considered until relatively late, and potential connections to Europe have been pushed by industry rather than government. Given the rise in industrial policy measures including for hydrogen in other countries, the UK's goal of becoming a major hydrogen player seems unlikely without a significant change in policy clarity and ambition.

1 Introduction

The UK's position on hydrogen is firmly couched in industrial policy: hydrogen development was point 2 in the UK's 10-point plan for a green industrial revolution, launched in November 2020 in response to the economic downturn. This document, and the 2021 UK Hydrogen strategy, see hydrogen as an opportunity to develop an internationally competitive hydrogen industry within the UK. The strategy aims to use not only "green" hydrogen produced with renewable electricity, but also "blue" hydrogen with carbon capture and storage. It emphasizes the economic opportunities of hydrogen, especially for jobs in peripheral areas and for growing British industries in an emerging market. For this, the UK has emphasized exporting technologies and products, like propulsion technologies, electrolyzers, and fuel cells rather than hydrogen itself (UK Government, 2021, 2023a). This focus on industrial policy is

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an important shift for the UK, where previous approaches to decarbonization were largely driven by legally binding emissions targets and prices.

Since the war in Ukraine, the UK doubled its hydrogen ambition to 10 GW of low-carbon hydrogen production capacity by 2030 citing the need for energy security—higher than most European countries. The goal is to use this hydrogen at home to build its competences in hydrogen services and applications. Although the strategy envisions industry as the main end-use sector, in practice significant support has gone to uses such as domestic heating, despite doubts regarding their relative inefficiency and emissions intensity (Howarth & Jacobson, 2021; Rosenow, 2022). While there are many green and blue hydrogen projects announced, final investment decisions are few and favor small-scale green hydrogen production projects. Further revenue support will be provided by levies on energy consumption, the future of which is still uncertain. Civil society and research have questioned why the government does not prioritize industrial uses and whether blue hydrogen deserves public sector investment. Critics argue that the government's hesitation to support industry will lead to the UK falling behind in the global green race for technological leadership, comparing it unfavorably to other players like Germany and Japan (UK E3G, 2023a; Steel, 2022a, 2022b).

The UK's focus on developing its internal hydrogen capacities rather than import is also reflected in its relatively limited engagement in the international arena. Its efforts are largely focused around increasing international hydrogen demand to promote a market for its technologies and encouraging foreign firms to invest in the UK. Unlike other European countries, it does not participate formally in dialogues on ports (Clean Energy Ministerial, 2020), and plans for hydrogen interconnections with Europe for hydrogen trade have been led by firms in the gas sector rather than the government (Project Union, 2022). Yet, since 2023, there is evidence for increased interest in hydrogen trade with Europe, and the UK government has increased its efforts to connect with selected European partners such as Germany and Norway. At the same time, the UK has increased its presence in dialogues around harmonizing regulatory standards to enable future trade.

The remainder of this chapter provides a detailed review of the UK hydrogen policy, including domestic and the emerging international elements. It first outlines the current state of the UK's climate and energy policy and reviews the status of hydrogen development. It then looks closely at the UK hydrogen strategy and policy, including key funding initiatives and the debate over hydrogen use prioritization. It elaborates on the external dimensions of the UK's hydrogen strategy, which is comparatively inward-facing, but nevertheless hints at a future interest in trade with the European continent. It then outlines key conclusions for international hydrogen politics.

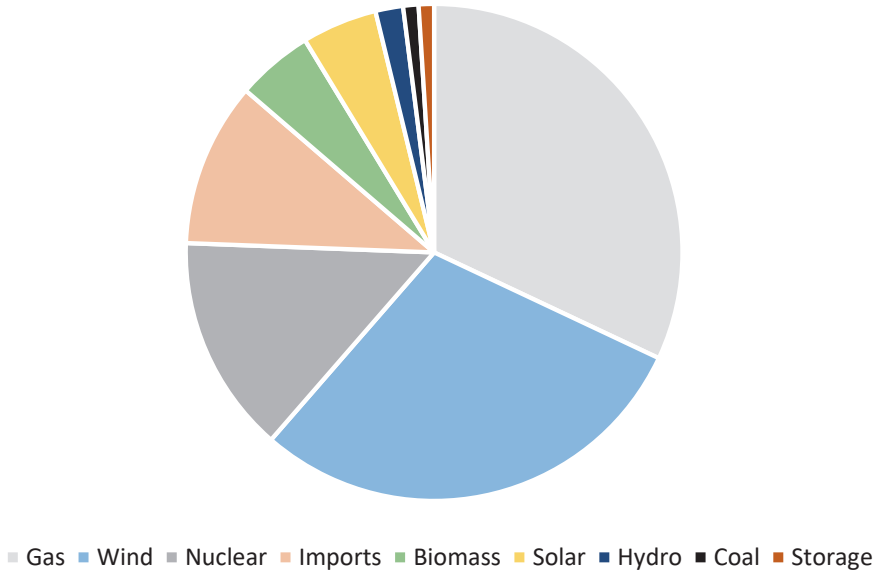

Fig. 1 Total UK electricity generation by source, 2023. *Source* Author, based on data from the UK National Energy System Operator

2 The State of Climate and Energy Policy in the UK

The UK has historically been a fossil-fuel producer and used its indigenous resources (coal, gas, and oil) to fuel its industries and ensure energy security. Following the discovery of oil and gas reserves in the North Sea in the 1970s, companies such as Shell and BP have gone on to become important players in the UK and the global political economy (Christophers, 2020). However, today most of the gas used in the UK is no longer produced domestically, but is imported from Norway and Qatar (EIA, 2022).[1] As domestic resources have fallen, the UK has increasingly focused on "low-carbon" options including nuclear and renewable energy. Its 2008 Climate Change Act established legally binding obligations to reduce emissions and respond to climate change; the UK is a leading member of the Powering Past Coal Alliance and aims to fully decarbonize its electricity system by 2035. In 2023, its electricity mix was dominated by renewables and nuclear (55%), with the remainder largely made up of gas (32%) and imports (11%) (see Fig. 1).

Before Brexit, the UK was closely aligned with the EU on the development of its electricity market, engaging in real-time electricity trade across the Channel and

[1] In 2021, the UK produced 934,000 barrels per day in total liquid fuels and 1.1 trillion cubic feet of natural gas. This travels to in pipelines to its 1.2 million b/d of refining capacity and is exported in the form of crude oil mainly to Europe, as well as refined motor gasoline and fuel oil (see also: UK EITI, 2022).

with Ireland. While energy trade continues, the UK's sometimes contentious relationship with the EU has impacted climate and energy cooperation. The UK's goal to re-negotiate rules on electricity trading and interconnections with the EU has been stymied due to the UK suggesting it would go back on its previous agreements regarding the Irish border (Kuzemko et al., 2022). A further blow to energy cooperation was the UK's announcement of a crisis contingency plan that would allow it to reduce energy exports if needed following the Russian invasion of Ukraine. Emergency measures would mean that National Grid could shut off interconnectors to Europe and stop gas flows (Lawson, 2022). In spite of this, there are promising signs for future energy cooperation. 2021 saw new electricity interconnections with Norway and France, and the UK imported large amounts of electricity from Europe (around 24.6 TWh), while exporting 4.2 TWh to Europe (Martin, 2022). Further cooperation can be seen in the UK's MOU with the North Seas Energy Cooperation—therefore effectively re-joining the group, although it can no longer be a formal member (Blondeel et al., 2022).

Beyond Brexit, the UK's climate and energy strategy faces increasing challenges, exacerbated by the 2022 energy crisis. Chief among them is decarbonizing heating: 85% of homes use gas for heating, accounting for 15% of the UK's carbon footprint (HoC, 2022). More gas in the UK is used by domestic consumers than any other user, including power generation (Mettrick & Ying, 2022). A further challenge for UK climate policy is industrial decarbonization of important industries including chemicals and pharmaceuticals, metals, and glass. The UK has a strong interest in maintaining these industries and has made efforts to balance decarbonization with industrial policy aims. Industry is supported with incentives to decarbonize, such as the Renewable Heat Incentive, which spent £684 million per year on commercial, industrial, and public premises in 2019–2020 alone. Industries are also given free allocations under the UK Emissions Trading System (ETS), including cement, steel, and chemicals.[2] The UK has increased its focus on industrial policy since Brexit, creating the Department for Business, Energy, and Industrial Strategy (BEIS) in 2016. Its mandate included "helping to ensure that the economy grows strongly in all parts of the country, based on a robust industrial strategy… it will make the most of the economic opportunities of new technologies, and support the UK's global competitiveness." (May, 2016) This is a shift in tone for the UK, which had not consistently prioritized competitiveness in low-carbon industries (Lockwood, 2022).

In 2023, the UK saw another shift in its ministerial landscape when BEIS was transformed into the Department for Energy Security and Net Zero (DESNZ), highlighting the renewed importance of energy security.[3] The UK is seeking to increase fossil fuel as well as hydrogen production. The government and UK Oil and Gas authority (now renamed the North Sea Transition Authority) portrayed the continued

[2] For full list 2021–2025 see https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1137620/uk-ets-allocation-table-november-2022.csv/preview.

[3] Although DESNZ has now replaced BEIS, most of the UK's hydrogen policy documents were published by BEIS. Therefore I occasionally refer to BEIS rather than DESNZ documents.

exploitation of fossil fuels as necessary for energy security. It also frames it as integral to the energy transition, since British fossil fuels have a lower carbon footprint (NSTA, 2022). In 2022, the government scrapped the moratorium on new fossil-fuel extraction that had been in place since 2019 and began licensing for new extraction including coal, fracked gas, and offshore oil and gas (Cavcic, 2023). The current Labor government does not plan on revoking these licenses, although they may be subject to legal action under the legally binding Climate Change Act. Hydrogen is therefore appealing for the UK as a way to address its energy security, decarbonization, and industrial development goals.

3 The Current Status of UK Hydrogen Development

The UK has taken a "twin track" approach where it promotes both blue and green hydrogen, with the hope that this can help address the difficulties of decarbonizing industry and heating. It defines "low-carbon hydrogen" as green hydrogen made with renewable electricity, blue hydrogen from natural gas with carbon capture and storage (CCS), and biomass and waste conversion with or without CCS.[4] It also remains open to other ways of generating hydrogen, i.e., from nuclear power.

Hydrogen is used at around 30 industrial sites in the UK with approximately 2.5 GW capacity (BEIS, 2022f). Of this, around two-thirds were by-products of industrial processes like oil refining and steelworks which were then used onsite (BEIS, 2022a, 2022b, 2022c, 2022d, 2022e, 2022f, 2022g, 2022h, 2022i, p. 24). The remaining third is produced via steam methane reforming without carbon capture and used as feedstock for ammonia production at a few large sites. BEIS therefore suggests that the hydrogen-producing sites could decarbonize by retrofitting their facilities with carbon capture technology subsidized by the Industrial Carbon Capture Business Model (ICC BM), a longstanding support scheme for industry which includes capital grants as well as revenue support (BEIS, 2022b). Those sites that currently generate hydrogen for ammonia production could instead purchase low-carbon hydrogen. According to a government report in 2021, less than 1% of hydrogen production capacity in the UK was from electrolysis (BEIS, 2021c, p. 117).

Before it launched its official hydrogen strategy, the UK government funded several programs targeting hydrogen production and use. The ultra-low emission vehicles in the UK package of £500 million, which ran from 2015–2020, included funding for hydrogen use in transport (DfT, 2014). Further projects, like the hydrogen-powered double decker buses for London, received additional co-funding from the EU. In addition, the BEIS Energy Innovation Program, which ran from 2015 to 2021, funded several low-carbon hydrogen projects. These included the 2018 low-carbon hydrogen supply competition, which received £33 million in funding

[4] According to the April 2023 "Low Carbon Hydrogen Standard"; to be considered low-carbon, hydrogen must have a GHG emissions intensity of 20 g CO_2e/MJLHV of produced hydrogen or less.

to develop hydrogen supply projects that could improve carbon capture rates or lower prices for other forms of "low-carbon" (electrolytic or other) hydrogen (BEIS, 2022i). Another keystone project was the £25 million Hy4Heat project, launched in 2017. The project aimed to establish whether residential and commercial gas could be replaced with hydrogen in homes and businesses and included community trials (DESNZ, 2023a).

Here, it is important to note that the "devolved administrations" of Scotland, Wales, and Northern Ireland have their own hydrogen strategies, interest groups and developments. Several flagship hydrogen projects took place in Scotland, and the Scottish Government published its own hydrogen policy statement in December 2020 before the UK, as well as developing a Hydrogen Action Plan and £100 million investment program. Similarly, the Welsh government has published different hydrogen documents and is home to large wind farms and industrial collaborations. Northern Ireland has also received EU and UK funding for hydrogen transportation projects and has favorable hydrogen production and storage conditions. While acknowledging that the UK hydrogen strategy may be informed by the activities of devolved administrations as well as other local actors, the focus in this chapter is the UK's government hydrogen strategy.

With the election of a new government in July 2024, the UK's hydrogen strategy may yet shift significantly. For example, Keir Starmer pledged during his campaign to double the UK's green hydrogen target to 10 GW (Parkes, 2023), and a key point of Labor's manifesto is "making Britain a clean energy superpower" (The Labor Party, 2024) seeking to increase renewable energy installation and supporting green hydrogen. Similarly, the government aims to set up "Great British Energy," a publicly-owned energy production company to drive the transition (UK Government, 2024a). However, the precise ways in which the UK's hydrogen strategy may evolve was not yet decided at the time of writing (September 2024). This chapter therefore primarily focuses on what has been done by the previous Conservative government; further work can explore the ways in which Labor's approach differs—or not—once more concrete measures have been put into place.

4 UK Hydrogen Policy: An Inward-Facing Strategy

4.1 Hydrogen Policy Overview

DESNZ is the most important actor in UK hydrogen policy and is responsible for roadmaps related to hydrogen use, such as industrial decarbonization, heating, and transport. The strategy for the UK's hydrogen policy was established by the Ten Point Plan in November 2020. It defined a target of 5 GW of low-carbon hydrogen production capacity by 2030 and launched the Net Zero Innovation Portfolio of £1 billion, to be shared across priority areas, which include hydrogen. The government's stance established in the Ten Point Plan is that green hydrogen will be more expensive

than blue hydrogen in the short term—which it has not changed despite rising gas prices since the Russian invasion of Ukraine (BEIS, 2021a).

The 2021 Hydrogen Strategy specifies the next steps for hydrogen and its use in hard-to-decarbonize sectors. It projects that hydrogen could make up between 20 and 35% of total final energy consumption by 2050. The goals of the hydrogen strategy are clearly stated as green industrialization, good jobs, and technological leadership. For example, by 2030, the UK aims to develop four industrial clusters ("SuperPlaces"). Under the scheme, sites in northern England, Scotland, and Wales with automotive manufacturing, steel and chemical production will receive funding for the deployment of carbon capture and storage technologies. The goal is to maintain these industries in the UK, while creating a new carbon capture and storage industry with an estimated 50,000 jobs by 2030. The aim is to support "good jobs" and address deindustrialization in the UK heartland. The strategy does not express an interest in exporting hydrogen in the shorter term, but rather stimulating domestic supply chains which could then create export opportunities for UK businesses serving international demand for goods and services (BEIS, 2021c, p. 8).

As tensions with Russia increased, so did the UK's focus on energy security and the importance and ambition of its hydrogen targets. In the British Energy Security Strategy, launched in 2022, the government announced that it was doubling its low-carbon hydrogen ambition to 10 GW by 2030, at least half of which should be electrolytic, and introduced an interim target of 1 GW of electrolytic hydrogen to be under construction or in operation by 2025 (BEIS, 2022a). Yet at least in the short term, the natural gas used for blue hydrogen would largely be imported. The energy security strategy estimates that there are 7 years of gas reserves remaining in the UK, including "yet to find" resources (IEEFA, 2022). Therefore, only green hydrogen production could be conceived of as contributing to UK energy security.

The July 2022 Hydrogen Update to the Market lays out a strategy to reach these 10 GW and has an increased focus on energy security, while maintaining its industrial policy framing. Moreover, it states that industrial hydrogen producers will be sufficiently incentivized by the Industrial Carbon Capture Business Model (ICC BM) and the ETS to decarbonize. It therefore concludes that there is no need for a previously envisioned phaseout plan for carbon-intensive hydrogen nor a research and innovation facility for hydrogen use in industry (BEIS, 2022f, p. 8). This document only briefly mentions the potential to export excess low-carbon hydrogen, retaining its focus on developing domestic hydrogen production and use. Outside of the UK, hydrogen trade—both imports and exports—is not foreseen until after 2030, but continental Europe is named as a potential partner. A further update to the market, issued in December 2022 (BEIS, 2022e), mainly highlights the importance of building local markets, while mentioning that the UK could eventually export hydrogen to Europe. This document adds that this interconnection could also be used to import hydrogen to build supply chain resilience.

The government's approach to hydrogen exports appears to further shift toward exports in August 2023, stating that "We want to play a key role in exporting hydrogen to others, including to continental Europe where we see increased hydrogen demand, alongside established energy trading and interconnection with the UK" (DESNZ,

2023b, p. 18). To enable this trade, the government is aiming to develop legal frameworks for connecting hydrogen produced offshore to Europe via pipeline (DESNZ, 2023c). However, in terms of official plans for infrastructure, the government is still letting business lead the way (see Sect. 5.4).

Also in 2023, the government took a more concrete position on hydrogen transmission and storage infrastructure, arguing that the future system operator should "take on a central strategic planning role" (DESNZ, 2023d, p.7). However, problems with infrastructure planning remain due to uncertainties about hydrogen use cases which will influence what infrastructures are needed. A 2022 study (BEIS, 2022d) commissioned by the Government illustrates this issue. Its estimates of infrastructure requirements vary significantly depending on what uses are foreseen for hydrogen. For example, it estimates that between 0.6 and 13.2 TWh of salt cavern storage and anywhere between 700 km and 26,000 km of pipeline would be needed by 2035, depending on the chosen end-use scenario. 24,750 km of potential transport infrastructure is estimated for hydrogen use in buildings alone. This differs again from the plans proposed by the UK's National Grid plc and National Gas Transmission (NGT). Their "Project Union," which focuses on connecting key industrial clusters, would be 2000 km, equivalent to approximately 25% of the UK's current gas pipelines. They claim that repurposing existing pipelines to connect clusters in England, Wales, and Scotland would be up to five times more cost-effective compared to new build (Project Union, 2022, p. 8).

The UK hydrogen strategy sees hydrogen as "essential for achieving net zero," though sustainability elements seem to play a less important role in the policy's framing than industry development and energy security. Nevertheless, the April 2023 UK low-carbon hydrogen standard sets a maximum threshold for emissions intensity of hydrogen production that is lower than that agreed by the EU. It sets a maximum a GHG emissions intensity of 2.4 kg CO_2e per kg of hydrogen to be considered "low carbon," and therefore able to participate in funding initiatives (DESNZ, 2023e).[5] In addition, the UK Environment Agency publishes guidance on green and blue hydrogen production techniques (UK Government, 2023b, 2024b). Companies applying for an environmental permit to produce hydrogen may follow these best practices, or propose an alternative approach to the regulator, which has the same or greater level of protection to the environment.

In general, the hydrogen standard and strategy consider blue hydrogen as an important option, and the narrative in policy documents and discourse is that the government will not pick winners but enable both pathways. A further narrative is that blue hydrogen will enable the scale-up of innovations in carbon capture and storage, which will be an important local industry. Civil society and think tanks have publicly criticized this stance on blue hydrogen and urged the government to focus on green hydrogen. While the UK Committee on Climate Change (CCC) sees a role

[5] The original standard has been updated, with the main substantive difference that there are now more eligible hydrogen production pathways, including 'gas splitting producing solid carbon'. See https://questions-statements.parliament.uk/written-statements/detail/2024-01-29/hlws211.

for blue hydrogen in reducing emissions, they note that the use of blue hydrogen would need to be reduced beginning in the late 2030s (Ambrose, 2021).

Data on the current project pipeline are difficult to find. The UK Government's Hydrogen Investment Roadmap, published in February 2024, estimates a potential cumulative production capacity of over 25 GW by 2030, based on the known pipeline of over 250 hydrogen projects (UK Government, 2024c). While it does not share specific information on these projects, the pipeline appears to be dominated by green, rather than blue hydrogen: by 2030, the estimated production capacity for electrolytic hydrogen is around 17 GW, versus just under 10 GW of CCUS-enabled hydrogen. This would represent a major shift from a report published a year prior, where the UK's hydrogen pipeline consisted of 84% blue hydrogen projects, none of which had achieved FID at that time, however (Westwood Global Energy Group, 2023).

4.2 Key Funding Initiatives

In order to develop hydrogen markets, the government has support mechanisms along the value chain. The first is funding innovation and demonstration projects. The second are capital subsidies for hydrogen production projects on the small to medium scale. Finally, the government will also provide revenue support to hydrogen production projects via the Hydrogen Production Business Model. This contract-for-difference-style program guarantees revenues, thereby aiming to provide certainty for investors, with the first round promising £2 billion in support. Of this, £90 million will come from the Net Zero Hydrogen Fund (NZHF), while the rest will be funded by the so-called hydrogen levy, though the exact design of this remains uncertain. At a later stage, the government may also provide subsidies for hydrogen transport and storage. A large share of funding for hydrogen innovation and demonstration projects come from the £1 billion Net Zero Innovation (NZIP) portfolio. This funding was announced by Boris Johnson in 2020 as part of his plan for a "green industrial revolution" and promotes a broad swath of technologies such as wind and CCS, as well as hydrogen (including the £240 million NZHF). Additional schemes for industrial decarbonization and CCUS also include hydrogen-related technology development (see Table 1).

In the innovation sphere, the main goal of funding schemes is to increase technology-readiness levels (TRLs) for developing technologies. Key partners here include UK Research and Innovation (UKRI) which mainly focuses on engineering and physical sciences funding for lower TRLs, through lab-based research. The Innovate UK program, which supports scaling-up solutions with higher TRLs that are not yet commercially viable. The UK government is also supporting local technology manufacturing with the £960 million for a Green Industries Growth Accelerator, which includes funding for several low-carbon technologies such as nuclear, CCS, and offshore wind as well as hydrogen. According to news reports in March 2024, this funding may be increased to £1.1 billion in the UK's Spring Budget (Norris, 2024).

Table 1 Key UK funding initiatives including hydrogen

Funding Program	Amount	Funding source	Description
Hydrogen-specific funding initiatives			
Net zero Hydrogen fund (NZHF)	£240 million	NZIP	Innovation, DEVEX, and CAPEX support
Hydrogen production business model	First round provides £2 billion	Government-funded until hydrogen levy comes into effect. Round 1 (£2 billion draws £90 million from NZHF)	Revenue support based on contract for difference-style long-term agreements, funded by Government likely until 2025 (DESNZ, 2023f). First round promises £2 billion in support, 7 rounds total planned until 2029
Hydrogen transport business model	Unknown	Unknown	Feedback closed February 2024, to launch in 2025. Will apply to onshore large-scale piped infrastructure; may include subsidy (Hydrogen Transport Revenue Support Contract)
Hydrogen storage business model	Unknown	Unknown	Feedback closed February 2024, to launch in 2025. May include minimum revenue floor (and/or cap on revenue "Hydrogen Storage Contract". Funding source unknown, potentially levy-based
Low-carbon hydrogen supply 2 competition	£62 million allocated	NZIP	Innovation projects for hydrogen supply
Hydrogen BECCS innovation program	£31 million allocated	NZIP	Innovation in hydrogen BECCS (bioenergy with carbon capture and storage) technologies
Industrial hydrogen accelerator program	£26 million, £13 million allocated	NZIP	Innovation projects for industrial fuel switching
Hydrogen research hubs	£20 million	UKRI Engineering and Physical Sciences Research Council (EPSRC)	Investment in hydrogen research hubs: UK-HyRES Hub and HI-ACT Hub (£10 million each)
Hydrogen storage and distribution supply chain collaborative R&D competition	£4.35 million	Innovate UK	Funding collaborative research and development projects aimed at developing hydrogen supply chains (December 2023 Hydrogen update to market)
Hydrogen innovation initiative (Hii) seed program	£6 million	Innovate UK	R&D collaboration with UK research partners

(continued)

Table 1 (continued)

Funding Program	Amount	Funding source	Description
Hydrogen storage and distribution supply chain collaborative R&D	£4.2 million	Innovate UK	R&D projects related to hydrogen storage and distribution supply chain
Hydrogen skills and standards for heat	Over £2 million	NZIP	Defining safety criteria to repurpose natural gas equipment for hydrogen and train a workforce of hydrogen installers (HVP, 2021)
Other funding initiatives that may include hydrogen			
Direct air capture and greenhouse gas removal program	£10 million allocated to hydrogen	NZIP	Funding for developing technologies that enable the removal of greenhouse gases from the atmosphere
longer duration energy storage	Up to £68 million for all technologies	NZIP	Innovation competition for longer-duration energy storage including power-to-X
Industrial Energy Transformation Fund (IETF)	£289 and £185 million for all technologies	IETF	Support for energy-intensive industries to invest in energy efficiency and low-carbon technologies. Hydrogen fuel switching is only covered under the IETF if industry will switch to hydrogen in the next 5 years (DESNZ, 2023g). IETF extension announced in the Powering Up Britain plan, increasing total grant funding by £185 million
Red diesel replacement competition	£40 million for all technologies, £26 million allocated to hydrogen	NZIP	Innovation competition for low-carbon fuel and system alternatives to red diesel construction, and mining and quarrying sectors
Industrial fuel switching	£57.5 million total, of which 23 million for hydrogen	NZIP	Industrial fuel switching 2 competition has devoted 23 million to hydrogen spending
Green distilleries competition	£12.33 million for all technologies, £6 million allocated to hydrogen	NZIP	Innovation competition for using low-carbon fuel in distilleries

(continued)

Table 1 (continued)

Funding Program	Amount	Funding source	Description
Local industrial decarbonization plans competition	£5 million available for all technologies	Industrial Decarbonization Challenge	Funding for local clusters to develop strategic industrial decarbonization plans and explore technological solutions (some awarded plans include hydrogen)
Clean maritime demonstration competition rounds 1–4	£95 million + £34 million for all technologies	UK Shipping Office for Reducing Emissions (UK SHORE) program	3rd round: 19 projects to conduct technology and system demonstrations in clean maritime solutions, with six projects exploring the use of hydrogen and/or hydrogen-derived fuels. 4th round's scope includes hydrogen as well. (December 2023 Hydrogen update to market)
Clean maritime research hub competition	£7.4 million for all technologies	UK SHORE and Physical Sciences Research Council	Early research in clean maritime applications, including hydrogen-based, to run until 2027
Zero-emission vessel and infrastructure (ZEVI) competition	£77 million for all technologies	UK SHORE and Innovate UK	Funding to accelerate the roll out of zero-emission solutions for vessels and port-side infrastructure that are nearing commercialisation. Hydrogen and hydrogen-related fuels are in scope
Zero-emission heavy goods vehicles and infrastructure demonstrators	£140 million for all technologies of which £85 million for hydrogen	Innovate UK	Funding for research and development fund aimed to increase zero-emission road freight in the UK
Advanced fuels fund	£165 million available, £135 million allocated for all technologies	Advanced Fuels Fund	Support for UK SAF projects through to construction
Advanced propulsion center's (APC) collaborative R&D competition, Round 22: Zero-emission vehicles project	£77.1 million for all technologies	£38.4 million from APC, £38.7 million from auto industry	Funding to develop clean transport technologies. Five projects funded will use hydrogen technologies

(continued)

Table 1 (continued)

Funding Program	Amount	Funding source	Description
Tees valley hydrogen transport hub fund	up to £15 million available	Tees valley hydrogen transport hub fund	Green hydrogen infrastructure for heavy goods vehicles like delivery trucks; and creating hydrogen-powered airport ground-based support vehicles
Green industries growth accelerator (GIGA)	£960 million for all technologies	Strategic manufacturing sectors fund (£4.5 billion total)	Manufacturing support for UK clean energy supply chains: includes carbon capture, utilization and storage, electricity networks, hydrogen, nuclear and offshore wind. May be increased to 1.1 billion
CCUS Infrastructure Fund (CIF)	£1 billion	CIF	Funding for carbon capture projects for industry and power; and for transport and storage networks
Industrial decarbonization challenge (IDC)	£210 million	Industrial strategy challenge fund, CIF	Funding for industrial decarbonization including hydrogen deployment, cluster plans, and innovation. Of this, £40 million provided by CIF
Transition export development guarantees	Unknown (but at least ~ 450 million in loans reported)	UK Export finance	Loan guarantees for working capital, capital expenditure or R&D for clean energy, hydrogen and decarbonization (BEIS, 2021b). Total sums unknown. Examples in December 2023 Hydrogen Strategy Update include underwriting a £400 million loan to global multinational Johnson Matthey for R&D, and a £50 million to boost exports of electric and hydrogen-powered buses

Source Author's own compilation based on government documents

When technologies are commercially viable, funding is also provided to encourage production with CAPEX support via the NZHF, although larger-scale transport and storage are not included in these funding mechanisms. In 2023, the NZHF announced its selection of projects to receive over £58.9 million in total for hydrogen production (DESNZ, 2023h). Of the 22 successful applicants, only two projects were for blue hydrogen, while the rest were for green hydrogen from renewable energy.[6] Of

[6] Note: The only exception is the project "Tees Green Methanol" which will produce hydrogen from EDF's existing nuclear capacity and new-build wind and solar, and captured biogenic carbon.

the projects with formal offtake arrangements, most were for transportation (buses, trucks, port machinery, and local transport fleets). Only two went to industry: one for TATA Chemical Europe (Green Hydrogen Winnington and Middlewich) and another for Pilkington UK's glass production (Green Hydrogen St Helens). Further projects aim to provide industry with hydrogen but did not have formalized offtake agreements at the time of research. Support for blue hydrogen production may also be provided by the CCS Infrastructure Fund, but precise amounts are not yet determined. As of August 2024, negotiations between the UK government and developers were ongoing for the two blue hydrogen projects being considered: BP's Teesside project and Hynet HPP1 (BP, 2024; DESNZ, 2023i).

The UK government is further scaling up its support for hydrogen via its Hydrogen Production Business Model (HPBM).[7] This bears strong similarities to the Contracts for Difference (CfD) model utilized in support of renewable electricity generation in that it is used to cover the difference between the cost of production and the sale price of hydrogen. Projects may only receive subsidies if they meet the requirements of the low-carbon hydrogen standard and if hydrogen is sold for certain qualifying purposes, i.e., power generation, transportation, or industrial use. Export or blending into the gas grid are not eligible (BEIS, 2022i). In early 2024, the winners of the first round of the HPBM were announced ("Hydrogen Allocation Round 1"). This includes 125 MW of capacity for 11 projects, with a total allocation of £2 billion in revenue support; of this, £90 million come from the NZHF (DESNZ, 2023j). The strike price agreed upon by the government is £241/MWh, which is weighted by the total volumes expected to be produced over the contract's lifetime and will vary relative to changes in natural gas prices. Set for 2025, the second allocation round aims to award 875 MW. This is "subject to affordability and value for money," if the same strike price is agreed upon, this would be around £14 billion in revenue support. In total, seven rounds are planned until 2029. The government has committed to covering HPBM costs until 2025, after which alternate funding will be used. A first suggestion was a levy on energy consumption which did not rule out households. Following a backlash from civil society to this plan (Dyson & Britchfield, 2023), the Energy Act scrapped these plans and specified that the relevant market participants are gas shippers, although it leaves further details to secondary legislation.

In addition to support for hydrogen production, the government also has plans to subsidize hydrogen storage and transport. As of mid-2024, the Hydrogen Transport and Hydrogen Storage Business Models were still in planning, with the first allocation rounds foreseen in 2025. For both of these support schemes, the funding sources are unknown but could also be levy-based. Different potential designs have been debated. For hydrogen transport, which would apply to onshore large-scale piped infrastructure, subsidies would be negotiated in a "Hydrogen Transport Revenue Support Contract." For hydrogen storage, a similar contract would be negotiated, potentially including a minimum floor or a cap on revenues with the goal of supporting

[7] Note: the HBPM was formerly called the Hydrogen Business Model (HBM), which was split into separate business models for production, transport and storage.

2 geological storage projects by 2030. This will make up part of a "core hydrogen network" which should help to build competitive markets (UK Government, 2024c).

A new development following the election of the Labor government in 2024 is the proposal of a National Wealth Fund of £7.3 billion, which is aimed at boosting infrastructural investment. Of this, 2.5 billion is intended to finance "clean steel" and 500 million for green hydrogen (Makortoff, 2024). The 7.3 billion for this fund should come from the Treasury, based on a new tax on oil and gas companies. Further details on the bank's structure and funding will be announced in October 2024 at the UK's International Investment Summit (UK Government, 2024d).

4.3 Hydrogen Use Prioritization: Heated Debates

The UK Hydrogen strategy does not set out clear priorities for which sectors should use hydrogen by when, with the reasoning that it does not want to rule out important opportunities. However, its strategy has been accused of being influenced by lobbying interests, as well as criticized for its potentially harmful impacts by civil society.

The 2021 strategy suggests that hydrogen can be used in sectors where electrification is too costly or not feasible, and other decarbonization options are limited, listing examples such as industrial furnaces and heavy transport (BEIS, 2021c, p. 9). Industry is expected to lead the way in early hydrogen use, including fuel switching in the mid-2020s and playing a key role in industrial decarbonization by the mid-2030s. The greatest demand for low-carbon hydrogen is expected by the UK hydrogen strategy to come from the chemicals and steel industry before 2030 (BEIS, 2021c, p. 54). Currently, the chemical and pharmaceutical industry targets emissions reductions of 90% by 2050 based on access to hydrogen, clean electricity, and CCS (CEFIC, n.d.). In 2022, the industry lobby group UK Steel said that switching to hydrogen before 2050 would not be feasible unless there is government support across the value chain to promote R&D and reduce the cost of electricity, hydrogen, and infrastructure (UK Steel, 2022a, 2022b). In the meantime, Tata Steel announced in 2024 that it would close both its blast furnaces and replace them with an electric arc furnace, which is expected to start production in 2027 (Varriale, 2024).

The UK's hydrogen strategy also argues that hydrogen is useful in areas where gas is now used, such as flexible power generation and storage, and envisions hydrogen use for flexible power generation by the late 2020s, as well as for heavy transport and domestic heating, potentially also via blending into the gas grid (BEIS, 2021c, pp. 9–10). The government has decided to allow gas and hydrogen blending of up to 20%, pending the outcomes of industry trials around safety, and will decide on whether hydrogen will be used for heating—in 2026. The decision on hydrogen for heating is contentious. In 2023, the UK's National Infrastructure Commission has recommended to exclude support for hydrogen in residential heating (UK National Infrastructure Commission, 2023). Despite growing public backlash and a number of trial cancellations, the Conservative government continued to push hydrogen for home heating (Harvey, 2023a, 2023b), while the new Labor government has not

developed a clear position on this. In addition, in 2022 the government launched a £20 million competition at the Tees Valley Transport Hub which trials hydrogen use for transport and refueling facilities. While such projects fit into the approach of creating "hydrogen markets" within the UK to stimulate demand, they do not fit with the strategy of prioritizing low-regret and strategically important options like industrial decarbonization.

This stance on creating markets for hydrogen by using it for heating and transport has been supported by coalitions of politicians and industry actors. The UK Hydrogen and Fuel Cell Association embraces hydrogen production from all sources and sees hydrogen as playing a valuable role in heating UK buildings. From the public sector, the All-Party Parliamentary Group (APPG) on hydrogen describes itself as "a cross-party group of MPs and Peers that focuses on raising awareness of and building support for large-scale hydrogen projects—such as conversion to a hydrogen domestic gas grid." The administration's secretariat is funded by a list of companies with stakes in influencing hydrogen policy, including gas distribution networks, fossil-fuel companies, and chemicals and engineering corporations such as Bosch and Johnson Matthey.[8] The Chief Executive of Johnson Matthey's Catalyst Technologies business, Jane Toogood, was appointed the government's Hydrogen Champion and co-chairs the Hydrogen Delivery Council alongside the Minister for Energy Efficiency and Green Finance (see Box 1). In her role as Hydrogen Champion, Toogood acts as an independent expert advisor through engagement with industry and investors to enable blue and green hydrogen projects. Toogood has promoted even further government support for CCS and the blending of gas into the national grid and use of hydrogen for heating to create markets for hydrogen and therefore increase demand (DESNZ, 2023k).

The UK Hydrogen Delivery Council

The UK Hydrogen Delivery Council (formerly Advisory Council) is a forum for ministerial engagement with key hydrogen sector actors. Its representatives skew toward actors with an interest in maintaining fossil-fuel systems, including:

- Fossil-fuel extraction representatives (Shell, BP, Equinor)
- 2 industrial gases representatives (BOC Linde, Inovyn)
- 1 CCS firm (Storegga)
- 1 project developer for blue hydrogen and hydrogen heating (Progressive Energy)
- 2 gas network representatives (National Gas, Director of Gas of Energy Networks Association)

[8] In further detail: Equinor, Shell (fossil-fuel companies); Cadent, Northern Gas Networks, SGN (gas distribution networks); EDF and national grid (energy suppliers); Baxi, Energy and Utilities Alliance (gas and boiler firms). See: https://connectpa.co.uk/wp-content/uploads/2022/03/scan.pdf.

In comparison, actors with an interest in developing green hydrogen are relatively minor:

- 1 wind representative (Orsted)
- 1 electrolyzer manufacturer (ITM power)
- 1 green hydrogen supply and distribution company (Ryze)
- 1 green renewable energy supplier (Octopus Energy)

There are also some actors, who have interests in both green and blue hydrogen, with stakes in CCS within the UK. These include:

- 3 energy and energy technology firms (SSE, Siemens Energy, RWE)
- 2 representatives from chemicals and engineering firm Johnson Matthey
- 2 investors (Mitsubishi UFJ Financial Group, Macquarie Capital)

Finally, there are some non-industry actors:

- 3 UK State actors: Minister for Energy Efficiency and Green Finance, UK gas and electricity regulator Ofgem, UK Infrastructure Bank
- 1 Research director (Imperial College).

Source Own research on hydrogen positions using company materials and news sources.

The government's stance on hydrogen end uses has been criticized by civil society, especially researchers, and the UK Climate Change Committee, the independent statutory body established under the Climate Change Act 2008 to advise governments and report to Parliament on progress. In their March 2023 report on decarbonizing power systems, the CCC recommended that the government commit to a cross-sectoral infrastructure strategy and focus on low-regrets hydrogen use, while identifying areas where hydrogen is unsuitable and electricity can be used instead (Climate Change Committee, 2023). The House of Commons cross-party Science and Technology Committee, which was appointed to examine science policy and administration, has also expressed doubts on the current approach to heating and questioned its economic viability (HoC, 2022). In the same report, a representative of the UK Mineral Products Association said that it was important to use low-carbon hydrogen for industry because heating and transport can be electrified, whereas cement and lime production cannot be (p.32). Likewise, the UK's National Infrastructure Commission strongly recommended that the government rule out the use of hydrogen for heating.

Civil society organizations focused on sustainability, like E3G, also highlight the importance of no-regret industrial uses, versus uses which could be replaced by electrification. Further coalitions including affected communities, renewable energy companies and associations, and sustainability organizations have publicly opposed hydrogen for heating and gas blending (see for example E3G, 2023b; Harvey, 2023a, 2023b). Some have also argued that the UK's hydrogen policy has been influenced by fossil fuel and industry lobbying. The former head of the UK Hydrogen and Fuel Cell Association, Chris Jackson, resigned in July 2021 after accusing fossil-fuel

companies within the association of making false cost estimates for blue hydrogen production to access billions in taxpayer subsidies (Ambrose, 2021). In 2022, the Guardian reported that there were over 120 paid hydrogen lobbyists operating in Parliament, from multinational oil companies like Shell and BP to smaller hydrogen companies like Ryze (Harvey, 2022).

4.4 Positioning the UK's Hydrogen Industry: Strengths and Weaknesses

To emerge as a hydrogen leader, the UK's strategy highlights a few key points, which would make the UK competitive: its physical advantages for hydrogen production such as energy resources and storage infrastructure; its local demand for hydrogen in industry, and its skilled labor and innovative capacity. Compared to other northern European countries, its project announcements of almost 2.2 Mt by 2030 could make it a leader in production capacity if these reach final investment decisions.[9] Yet, its current policy approach has been criticized by different actors as lagging behind other countries. Inaction on setting strategic priorities, they suggest, can lead to the UK losing its competitive advantage.

The Ten Point Plan and Hydrogen Strategy see the UK's renewable energy potential, especially its offshore wind capacity, as an important advantage in its role as a future green hydrogen producer. The UK has the further geological advantage of good storage potential. Salt caverns, which are geologically relatively rare in other locations in Europe, have been positively assessed in the UK (Williams et al., 2022). This would give the UK a comparative advantage vis-à-vis countries where hydrogen cannot be stored for longer periods. When it comes to blue hydrogen, offshore gas resources, and gas transportation infrastructure are seen as a potential advantage. Disused oil fields in the North Sea are suggested as an opportunity to store carbon from CCS and ease the North Sea transition by re-using existing infrastructure and resources (DBT, n.d.).

Another advantage laid out in government documents is the UK's existing expertise in hydrogen use and the ability to draw on a skilled workforce and well-developed innovation system. Unlike other countries without extensive industry such as chemicals manufacturing and refining, UK firms are experienced in working with hydrogen and can be first movers in adopting this technology. They can also draw on skilled workers in industries that will use hydrogen (chemicals, steel) and industries that will eventually produce hydrogen (oil and gas, renewables) as well as the broader high-skilled labor pool for training and recruiting new workers (see for example CEFIC, n.d.). One of the world's leading electrolyzer manufacturing firms (ITM Power) is also based in the UK, and recently announced its plans to expand capacity (ITM

[9] NW hydrogen report – but important to note that none of these have reached FID, unlike in other countries, and that they are overwhelmingly for blue hydrogen projects (IEA, 2022a).

Power, 2023). More broadly, the UK possesses innovative advantages, due to its long-standing, publicly supported research and innovation infrastructure. Taken together, its industrial experience, skilled labor, and strong innovation system are envisioned as making the UK a leader in adopting low-carbon hydrogen and eventually exporting goods and services.

In parallel to this, the UK hydrogen policy also acknowledges trade-offs between a policy focused on keeping short-term hydrogen costs low and establishing durable competitive advantages to create local industry:

> We recognize that there may be trade-offs within and between some of these principles. For example, the levelized cost of hydrogen using electrolytic production technology is higher today than for CCUS-enabled hydrogen, and it will take time for production to reach industrial scale. That said, with the right support today, this technology presents a genuine opportunity for export of UK expertise and technology, and there is also significant potential for longer-term cost reduction with continued innovation, scale-up of manufacture and access to increased amounts of low-cost renewable electricity. (BEIS, 2021c, p. 18)

By maintaining a broad policy approach—devoting time and funding to both blue and green hydrogen and supporting a wide array of use cases from household heating to transport—the government risks its engagement in hydrogen remaining too shallow and scattered to truly establish advantages. Given that green hydrogen manufacturing competition from Europe is seen as a potential threat to the UK's supply chain position, Wood Mackenzie's analysis for BEIS also suggests supporting electrolysis manufacture and other key technologies (BEIS, 2022h, pp. 81–82). Manufacturing has not been a central focus of the UK's strategy despite its leading electrolyzer manufacturer struggling with supply chain issues and financial difficulties (IEA, 2023)—although new funding for manufacturing from GIGA could eventually begin to address this gap.

Other potential disadvantages of the UK hydrogen landscape are its starting position in terms of innovation and comparatively low levels of funding. The IEA's patent analysis reveals that Japan, the US, Germany, Korea, France, and China all have higher shares of hydrogen-related patents than the UK (IEA, 2023). The only realm where the UK comes close to other economies is for patents in the realms of methanol production and aviation fuels. Out of the top ten global hydrogen innovation clusters, none are in the UK (IEA, 2023, p. 30). A separate Mission Innovation analysis of hydrogen publication outputs shows that although the UK ranks among the top ten in publications on certain value chain areas, it does not make the top ten for publications overall. The same report shows that the UK has committed comparatively little public funding for hydrogen development, and even less for R&D funding.[10] In addition, some existing domestic funding has also not been able to reach recipients: BEIS returned £1.6 billion in unspent R&D funding to the UK treasury in February 2023 (The Engineer, 2023).

[10] These segments are hydrogen production, and storage and distribution (it does not rank overall or for utilization) (Delaval et al., 2022a, p. 8).

Different actors have therefore argued that the UK's lack of clear policy choices and leadership will result in other countries pulling ahead in the "green race." Interestingly, this narrative emerges from different camps (blue vs green, either/or). For example, the UK Steel Net Zero strategy argues that the UK is being left behind in the race toward Net Zero, as they perceive the UK as less supportive than France, Germany, and Canada (British Steel, 2022; UK Steel, 2022, p. 49). Sustainability NGO E3G describes recent policy packages as unlikely to convince investors that the UK will be a leader in the green industrial revolution (E3G, 2023a). The House of Commons Science and Technology Committee, which gathered evidence from different stakeholders, also highlights that the Government's aversion to making decisions on technologies creates a risk of pursing the wrong technologies. It requests that the Government set out clear criteria to identify the potential role of hydrogen in each sector (HoC, 2022, p. 63). The report also summarizes feedback on how the UK compares to other hydrogen leaders, which is not favorable: the policy support in the US, Europe, and Asia enables other countries to build future export industries, while the UK risks falling behind (see for example pp. 56–57, 63–64). Some comments also draw lessons from the UK's failure to retain key parts of the renewable energy industry and want to ensure that the same does not happen for hydrogen.

5 External Dimensions of the UK Hydrogen Strategy

The UK government's hydrogen policy is based on building up a local hydrogen supply and market, placing less emphasis on trade in hydrogen with other countries. The 2021 hydrogen strategy has no substantial international dimension, and exports are only briefly mentioned in policy documents as a potential long-term option once a robust local hydrogen economy is developed. The government's support for hydrogen production does not extend to projects that will export hydrogen, and it has also been less active than other European counterparts in pursuing international partnerships on hydrogen trade. Instead, the most important engagements with the international sphere are setting standards for what constitutes low-carbon hydrogen and increasing investment into the UK hydrogen economy from international actors. Despite this lack of government action on developing international hydrogen trade, private UK gas firms are pushing for greater connections with the European continent via the European Hydrogen Backbone.

5.1 Diplomacy and Political Dialogue

At the international level, the UK has promoted hydrogen at the G7, G20, and the United Nations Framework Convention on Climate Change (UNFCCC). Its G7 presidency in 2021 was the first to achieve a statement of support for the role of low-carbon hydrogen, which became the basis for the so-called Hydrogen Action

Pact (according to BEIS, 2022e). At COP26, the UK led the launch of the Breakthrough Agenda, which included a hydrogen component ("Hydrogen Breakthrough") (Climate Champions, n.d.). The hydrogen component of this agenda was endorsed by 36 other countries including major players like the US, China, the EU, Japan, Korea, and Australia. The key work packages for hydrogen for 2022–23 included coordination on standards and certification, demand creation and management, R&D, finance, and landscape mapping. The coordination of the Breakthrough Agenda has been taken over jointly by Mission Innovation and the Clean Energy Ministerial. The UK is also involved in international political dialogues on hydrogen through its membership in the G20, which recently released a declaration on harmonizing hydrogen standards (Collins, 2023). It has also signed an agreement with Brazil—which holds the 2024 G20 presidency and will host COP30—to create a "hydrogen hub" (see Sect. 5.2).

The UK is further involved in international initiatives through Mission Innovation, where it co-leads the Clean Hydrogen Mission alongside Australia, Chile, the EU, and the US.[11] The national hydrogen strategy frames this role as championing research acceleration and as a "unique opportunity to showcase UK R&I expertise and to leverage its outputs to spur further technological progress" (BEIS, 2021c, p. 94). The Hydrogen Updates to Market also highlight the role that the UK plays as co-lead of the Mission's research activities and its position in shaping the Mission's Action Plan to stimulate investment (BEIS, 2022e, p. 14). It is also involved in the IEA's Hydrogen Collaboration Program, where it participates in different workstreams on energy storage and conversion, underground storage, safety of large hydrogen applications, and technology analysis and modeling (IEA, 2022b).

At the Clean Energy Ministerial, the UK government engages in some projects like the "twin cities" initiative (Kobe, Japan - Aberdeen, Scotland) and as a member of the expert panel for the CEM-led Northwest European Hydrogen Initiative. Although it was not involved in CEM's Global Ports Coalition or the working group on large-scale hydrogen supply chains (see 2021–2022 work plan: Clean Energy Ministerial, 2020), it has since joined the CEM's Hydrogen Trade Forum. The Northwest European Hydrogen initiative is of increasing interest to UK policymakers as the geographic connection to other countries would enable energy trade in the future.[12]

As the NW Hydrogen Monitor report lays out, the UK will need to harmonize its regulatory standards with trading partners in Europe—from hydrogen certification schemes providing evidence of emissions intensity per unit, to blending thresholds, to the definition of what is low-carbon (IEA, 2022a, p. 7). One area in which the UK is less advanced than other NW Hydrogen countries is that it does not yet have a Guarantees of Origin scheme, nor a designated body to issue such certification (p. 79). However, NationalGas documents from early 2022 show that private actors

[11] Launched in 2021, with the goal of reducing end-to-end hydrogen costs to $2/kg by 2030. For further members see website at http://mission-innovation.net/missions/hydrogen/.

[12] This includes Austria, Belgium, Denmark, France, Germany, Luxemburg, the Netherlands, Norway, and Switzerland. The UK provided funding for the project along with Germany, Luxembourg, the Netherlands, Norway, and Switzerland. See (IEA, 2022a, 2022b).

are highly supportive of establishing such guarantees of origin to facilitate hydrogen trade (NationalGas, 2022). The UK government has now proposed origin guarantees as a part of its low-carbon hydrogen certification scheme, which is expected to be launched in 2025.

Through its participation in the International Partnership on Hydrogen and Fuel Cells in the Economy (IPHE), the UK is also working to develop standards with key frontrunner countries. As set out in its July 2022 update to market, developing common standards in international fora is a key focus for its international work (BEIS, 2022f, p. 24). The December 2022 update reiterates the importance of this partnership and the UK's own plans for standard-setting. IPHE documents show the UK's centrality in this network and its interest in developing common standards and methodologies, in terms of how much hydrogen blending is permitted across countries or the role of electricity imports in the production of renewable fuels (IPHE, 2022). The December 2023 Hydrogen Update links this deepening involvement in standards and certification to an increasing interest in trade. For example, at COP28, the UK signed a declaration of intent on mutual recognition of hydrogen certification schemes with 38 other countries.

5.2 Bilateral Initiatives and Partnerships

In terms of bilateral partnerships and initiatives, the goal of these relationships is to exchange policy and innovation expertise to grow the UK's hydrogen economy and global markets (BEIS, 2022e, p. 14). The UK prioritizes bilateral relationships with countries that are seen as similarly ambitious and with whom the UK has longstanding relationships via government-to-government forums like IPHE and the CEM Hydrogen Mission. Out of the countries participating in these fora, those with whom the UK has announced high-level cooperation are foremost the US and European hydrogen frontrunners. The US-UK cooperation encompasses the strategic energy dialogue, which includes hydrogen, and the official Energy Partnership with the US, which aims to accelerate global hydrogen development.

The UK has also increased its cooperation with European countries with whom it is geographically well-positioned for hydrogen trade. In February 2023, Belgium and the UK signed an MOU to work together on energy, announcing a new cooperation agreement to build a further electricity interconnector, and increasing collaboration on hydrogen, CCS, and offshore wind. In March 2023, these parties held their first annual UK-Belgium hydrogen working group in Brussels (UK Government, 2023c). In March 2023, France and the UK also signed a statement of cooperation on energy, which likewise focused on increasing electricity interconnections as well as cooperation on hydrogen, CCUS and nuclear power. The text of the agreement reveals that work together on hydrogen would encompass cooperation on "low-carbon hydrogen" deployment, market adoption, certification and definitions (UK

Government, 2023d).[13] Since this MOU, there has been little public cooperation on hydrogen however. Ireland and the UK also signed an MOU on the energy transition including hydrogen in September 2023.

The UK has re-engaged more closely with the North Sea countries on hydrogen in the past years. It jointly hosted the North Sea Neighbors Conference in November 2022, which featured CCUS and hydrogen, and rejoined the North Sea Energy Cooperation (UK Government, 2023c). In 2023, it also signed the Ostend Declaration of energy ministers on the North Seas with the intention to develop cross-border projects and hydrogen markets. Particularly close cooperation can be seen with Norway: the UK signed an MOU with the country to further strengthen cooperation on hydrogen, especially CCS and North Sea carbon storage, and expanded its MOU on CCS to include closer collaboration on hydrogen. Denmark and the UK have also signed an MOU for energy cooperation that includes hydrogen, establishing a joint working group to discuss hydrogen grids. According to the IPHE, Norway considers the UK a major cooperation partner for hydrogen blended with gas exports, alongside Germany and the Netherlands (IPHE, 2022). Building on this partnership, the UK and Germany have signed a partnership agreement to accelerate the development of an international hydrogen industry, with five collaboration pillars. These include accelerating project deployment, setting safety standards, research and innovation, promoting hydrogen trade and trade in related goods and services, and joint market analysis for planning and investment (DESNZ and Lord Callanan, 2023). In April 2024, the two governments also agreed to conduct a feasibility study for green hydrogen export from the UK to Germany (Cucuk, 2024).

The turn toward the EU is supported by a report commissioned by UK DESNZ to explore the possibility of hydrogen exports to continental Europe. Published in May 2024, it argues that the UK has a strong possibility to export hydrogen via pipeline to continental Europe, particularly Germany, the Netherlands, and Belgium (Arup, 2024). This is underpinned by Scottish efforts to develop bilateral connections and cooperation with countries and regions in Europe. Before the UK's government signed collaboration agreements, Scotland signed multiple agreements for low-carbon technologies and hydrogen with Denmark (Scottish Government & Government of Denmark, 2021) and German regions including Hamburg, Bavaria, and North Rhein-Westphalia (Scottish Government & Government of Baden-Württemberg, 2022). In other words, sub-national actors within the UK that stand to gain from hydrogen may also drive further collaboration with Europe.

The UK government has also signaled interest in cooperation with more geographically distant hydrogen partners. At COP28, the UK and Brazil signed a joint statement of intent to increase their collaboration through a joint hydrogen hub for knowledge-sharing and technical cooperation (DESNZ, 2023l). In 2023, the UK signed a hydrogen MOU with Kazakhstan as well as a joint statement with Japan on energy cooperation that includes hydrogen. Australia and Korea are also partnering with Innovate UK for collaboration on hydrogen competitions (BEIS, 2022e, p. 15).

[13] Here, low-carbon refers to renewable and other low-carbon sources, definition unclear.

There has been relatively little engagement by the UK with low and middle-income countries. The exceptions are the UK's joint statement with the Republic of South Africa to expand scientific cooperation to include hydrogen. Chile and the UK also discussed hydrogen at the 2022 UK-Chile trade dialogue (DIT, 2022), and the Energy Transition Action Plan announced with Colombia includes hydrogen (UK Government, 2024e).The Mexico-UK PACT has awarded grants to fourteen projects, one of which was on developing a hydrogen roadmap for Mexico (UK Pact, 2021).

In terms of concrete R&D cooperation, most UK R&D funding is for projects based in the UK with the exception of a general science and technology fund (the Fund for International Collaboration, £160 million) (Delaval et al., 2022b, p. 25). Priority partners in this context are China, Canada, South Korea, and the US (UK RI, 2023) and energy features as one area of focus for cooperation with Canada (UK RI, 2021). However, for now, no hydrogen research collaborations have been developed via this mechanism.

5.3 Competing for Hydrogen Innovation Leadership and Investment

Support for developing hydrogen supply chains remains mainly focused on support for UK research and manufacturing (see Sect. 4.2) and on attracting foreign investors to the UK. Initial engagement has come from the Department for International Trade (DIT), which has published an investor roadmap for the hydrogen sector. The DIT has been using the investor roadmap mentioned above to "socialise the UK hydrogen ambition globally…engaging overseas investors and industry stakeholders interested in developing projects in the UK, and also to showcase UK progress toward developing long-term export opportunities" (BEIS, 2022f, p. 14). According to this roadmap, the Office for Investment at DIT and DESNZ are working with potential foreign investors to help them enter UK markets. The DIT now has a dedicated team that promotes hydrogen trade and investment and investigates export opportunities for UK businesses, leading virtual trade missions and press engagement. The department also encourages FDI teams to attract foreign buyers and add to UK supply chains. BEIS has also attempted to attract international investors with its Hydrogen Investor Roundtable.

To support the export of hydrogen products, UK Export Finance has enhanced its Export Development Guarantees to support clean technologies including hydrogen. This includes loan guarantees for working capital, capital expenditure or R&D for clean energy, hydrogen and decarbonization (BEIS, 2021b). While the total support available here is unknown, the December 2023 Hydrogen Strategy Update reveals that it underwrote a £400 million loan to global multinational Johnson Matthey for R&D. The government also guaranteed £50 million for Northern Ireland-based bus manufacturer Wrightbus to support its low-carbon transport exports, which includes hydrogen-powered buses (UK Export Finance, 2023). Both these companies play

important roles in the UK hydrogen sphere: Johnson Matthey funds the secretariat of the All-Party Parliamentary Group (APPG) on hydrogen, and its Chief Executive of Catalyst Technologies serves as the government's hydrogen champion and co-chair of the Hydrogen Delivery Council; Wrightbus has been awarded government funding for its vehicles (Wrightbus, 2023), and for hydrogen production through NZHF funding round 1 at the Ballymena Hydrogen Facility (DESNZ, 2024).

In addition to this direct support, the UK is planning a Carbon Border Adjustment Mechanism (CBAM) which would include hydrogen as well as cement, steel, iron, electricity. The planned UK CBAM is undergoing consultation and would apply from January 2027. This measure could shield low-carbon hydrogen produced in the UK from competition from imported "gray" hydrogen. The EU's CBAM also covers hydrogen; therefore, it will be necessary to carefully align UK and EU standards on emissions reporting and pricing.

5.4 Private Sector-Led Engagement on Hydrogen Trade Infrastructure

As pointed out above, the national hydrogen strategy does not set out a strategy for international transport infrastructure or hydrogen exports and the UK has only begun seriously considering this at the end of 2023. Also at the international level, the UK has been less publicly engaged in fora around establishing international infrastructure for hydrogen trade. However, there is some indication that private actors are interested in the development of international hydrogen infrastructure for export. Among them are HydrogenUK, which in May 2024 published a report on the UK's hydrogen trade potential; and the European Hydrogen Backbone, an initiative of 33 energy infrastructure operators across Europe, includes the UK's National Grid plc and National Gas Transmission (NGT). The current European Hydrogen Backbone envisions the UK repurposing natural gas pipelines within the country for hydrogen, and that a gas pipeline running from Bacton could be converted to connect the UK to future hydrogen flows with Belgium and the Netherlands. Between 2035 and 2040, further pipelines could be repurposed establishing flows between the UK and Ireland (EHB, n.d.). Belgium and Ireland also mention hydrogen trade with the UK by 2040 in their Hydrogen Backbone plans. Although it is not mentioned in the UK's plan, the overall Hydrogen Backbone study also represents further export routes by 2040 from Norway to the UK by repurposing the Langeled South natural gas pipeline (EHB, 2022, p. 31). The undersea network between the UK, Belgium, and the Netherlands would also connect to Denmark and Germany. However, this publication also highlights the long lead times for such projects of up to 10 years, suggesting the need to begin feasibility studies as soon as possible.

Although this has not been taken up by the UK government, NGT has proposed a connection to European hydrogen networks as part of their UK hydrogen infrastructure plan called "Project Union." Their proposal includes but does not emphasize

a connection to the European Hydrogen Backbone project to be operational by the early 2030s (Project Union, 2022, p. 5). NGT proposed a 12-month feasibility study to Ofgem, which has approved £5.626 million in funding (Ofgem, 2023a, 2023b). In the Ofgem project evaluation, the publicly available information makes no mention of interconnection or exports to continental Europe.

6 Discussion and Conclusions

The UK is currently aiming to position itself as a technology leader in the global hydrogen economy, with a focus on developing its local hydrogen use and markets. Yet, there are a number of barriers to its success in becoming a technology leader; within the UK, some have expressed concern that more ambitious actors like the EU and US will pull ahead. The UK's ambitions for leadership in the global geoeconomics of hydrogen will be unlikely to materialize without taking strategic decisions on which technologies and pathways to prioritize.

Within the UK, the government's ambitious vision is supported by a portfolio of £240 million in public funding for R&D, hydrogen production, hydrogen use, and infrastructure development. Further funding mechanisms for industrial decarbonization, innovation, and manufacturing can also be used for hydrogen, but also focus on other technologies like wind and solar. The UK's hydrogen strategy aims to build local demand for hydrogen and hydrogen technologies; these technologies should then be exported around the world. To this end, the UK is also promoting the hydrogen industry in international fora and contributing to standard-setting. However until recently, the government has not yet been active in developing strategies for international infrastructure or supply chains and has largely left strategies for EU interconnections to the private sector. This lagging coordination with Europe could be seen as an extension of the UK's decision to pull away from Europe following Brexit, with consequences for its abilities to plan for emerging hydrogen markets. Alternatively, it could be perceived as the government playing a two-level game: downplaying hydrogen coordination in its national policy in keeping with its UK-first image, while participating in international initiatives and partnerships to develop European connections without much fanfare.

The UK hydrogen policy also exhibits a number of contradictions, as it seeks to balance its stated industrial policy goals with technology openness and cost concerns. It aims to quickly ramp up what it perceives as low-cost options, using blue hydrogen as a bridge until green is cheaper, and continues to consider hydrogen as an option to decarbonize residential heating. Simultaneously, it aims to build up a UK hydrogen industry and become a world leader in technology and applications. However, critics point out that this will require making choices about where to dedicate resources. The openness to any "low-carbon hydrogen" (including blue hydrogen) means that resources may be spread more thinly between areas like carbon capture and storage, on the one hand, and the development and scaling up of the UK's electrolyzer industry. Moreover, the focus on creating "domestic hydrogen markets"

by promoting hydrogen for areas of heating and transport where electrification is widely viewed as the more cost-effective option may waste valuable resources. The failure to commit to strategic decisions on certain technologies and key use cases may therefore be an obstacle to industry-building.

The current approach may therefore fail to achieve the UK's goal to become a hydrogen technology leader and promote green local jobs in the UK heartland, especially in industrial decarbonization. In addition, the UK may face increasing competition from the US and the EU, which are now increasing their hydrogen ambition and related industrial policy measures. Realistically, the UK is in no position to compete with the US or the EU in terms of the volumes of subsidies it can devote to hydrogen development. At the same time, its lack of a concerted strategy to cooperate with Europe on hydrogen development or infrastructure may leave it lagging behind other countries in terms of investment, as the EU turns to Northern Africa for its hydrogen imports. It remains to be seen whether the change in government will be able to make the change in the UK's strategy needed for industrial decarbonization and technological leadership.

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