RIFS DISCUSSION PAPER

Research Institute for Sustainability (RIFS)
Potsdam, July 2023

The UK Hydrogen Strategy: Falling Behind in the Green Race?

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Part of a series edited by Yana Zabanova and Rainer Quitzow

Summary

The UK aims to become a leader in green industries by developing a competitive hydrogen industry, bringing new jobs, and revitalizing peripheral areas of the country. Hydrogen is also seen as an opportunity for the country to improve its energy security, as extracting fossil fuels is increasingly costly and unfeasible given the UK's decarbonization goals. Its hydrogen strategy takes a "twin track" approach, that is, simultaneously promoting hydrogen from gas with carbon capture and hydrogen from low-carbon electricity. The UK strategy focuses on the importance of applying hydrogen to industry including chemicals, steel, and glass. However, its funding and research initiatives rather place an emphasis on developing local hydrogen markets by using hydrogen for heating and transportation. In the short term, the UK aims to develop "blue" hydrogen, which is perceived as cheaper, to replace household gas use. Funding for hydrogen innovation comes from the government, but revenue support is likely to be funded by levies on energy consumption.

This approach seems unlikely to result in the green industrial leadership the government hopes to achieve. The unwillingness of the government to take strategic decisions on hydrogen types and uses means that its funding is stretched across different cases. And, while the UK participates in international standard-setting initiatives to better participate in global markets, it is not officially coordinating with or investing in hydrogen infrastructure that could connect it with Europe and thereby enable regional hydrogen trade. Given the rise in industrial policy measures including for hydrogen in the US and EU, the UK's goal of becoming a major hydrogen player seems unlikely without a significant change in policy clarity and ambition.

This Discussion Paper is part of a series of case studies on hydrogen strategies in European and global front-runner countries. The Discussion Paper series is being edited by Yana Zabanova and Rainer Quitzow as part of the project "Geopolitics of the Energy Transformation: Implications of an International Hydrogen Economy" (GET Hydrogen). In the context of the project, the paper has benefited from the financial support of the German Federal Foreign Office.

Federal Foreign Office

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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 has a clear focus on the economic opportunities of hydrogen, especially for jobs in peripheral areas and for growing British industries in an emerging market. Exports of key technologies and goods are of interest, but there is little mention in the current framework of exports of hydrogen itself. This focus on industrial policy is an interesting 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 still for the UK to use this hydrogen at home to build its competences in hydrogen services and uses. Although the strategy envisions industry leading the way, in practice significant support has gone to uses such as domestic heating, despite having been called into question for their relative inefficiency and emissions-intensity (Howarth & Jacobson, 2021; Rosenow, 2022). While there are many green and blue hydrogen projects announced, only a few small-scale green hydrogen production projects have so far seen final investment decisions. Further revenue support will be provided by levies on energy consumption, which may be passed on to consumers. 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.

The UK's focus on developing its internal hydrogen capacities rather than trade is 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 or global supply chains, and plans for hydrogen interconnections with Europe for hydrogen trade are led by gas firms rather than the government. Yet, a signal that the government is interested in hydrogen trade with Europe has emerged through its engagement dialogues around harmonizing regulatory standards, including hydrogen certification an blending.

This paper therefore outlines the UK's climate and energy policy and current challenges, and the status of hydrogen development. It then looks closely at the UK hydrogen 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.

2. Status of climate and energy 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 global political economy (Christophers, 2020). However, production has fallen off in recent years; 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 2021, around 54 per cent of its electricity generation was from renewables and nuclear, with the remainder made up of gas and coal.

Pre-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 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). Failures to reach agreements with the EU have also impacted the UK's participation in Horizon Europe and Euratom research programs. 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 if needed (Lawson, 2022). Despite these issues, there are a number of promising signs for future energy cooperation. 2021 saw new electricity interconnections with Norway and France, and the UK imported record amounts of electricity from Europe (around 24.6 TWh or 7.4 per cent of electricity supply), while exporting 4.2 TWh to Europe (Martin, 2022). Further informal cooperation can be seen in the UK's MOU with the North Seas Energy Cooperation – therefore effectively re-joining the group, although it cannot be a formal member (Blondeel et al., 2022).

Beyond Brexit, the UK's climate and energy strategy faces increasing challenges which were exacerbated by the 2022 energy crisis. Chief among them is decarbonizing heating: most homes (85 per cent) use gas to heat, accounting for 15 per cent 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 an interest in maintaining these industries, as for example the chemical and pharmaceuticals industry is its second-largest manufacturing sector and accounted for over £53 billion of exports (CIA, n.d.). 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

[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).

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 & 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." This is a shift in tone for the UK, which had not consistently prioritized promoting technological competitiveness in low-carbon industries such as solar PV (Lockwood, 2022). In 2023 the UK saw another shift in its ministerial landscape with the creation of the Department for Energy Security and Net Zero (DESNZ), while retaining a strong focus on industrial policy within its climate and energy policy.[3]

The UK strategy to address these issues relies on increasing fossil fuel production as well as hydrogen production. The government and UK Oil and Gas authority (now renamed the North Sea Transition Authority) portrayed the continued exploitation of fossil fuels as not only necessary for energy security, but also integral to the energy transition because 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). However, this is currently being challenged in the UK courts. Hydrogen is therefore appealing for the UK as a way to address its energy security, decarbonization, and industrial development goals.

[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 the rest of this report refers to BEIS strategies and documents.

3. The current status of UK hydrogen development

The government 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/waste conversion to hydrogen with or without CCS.[4] It also remains open to using other low-carbon energy sources such as 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 are by-products of industrial processes like oil refining and steelworks which are then used onsite (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, with support from the Industrial Carbon Capture Business Model (ICC BM). The ICC BM is an existing 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. Less than 1 per cent 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. 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). Projects including hydrogen-powered double decker buses were co-funding by the EU. The BEIS Energy Innovation Program, which ran from 2015-2021, funded several low-carbon hydrogen projects including the 2018 Low Carbon Hydrogen Supply competition, which received £33 million in funding to develop hydrogen supply projects that could improve carbon capture rates or lower prices for other forms of “low-carbon” hydrogen (BEIS, 2022i). In addition, the £25 million Hy4Heat project, launched in 2017, aimed to establish whether residential and commercial gas could be replaced with hydrogen in homes and businesses (DESNZ, 2023a). Low-carbon hydrogen was also included in the Industrial Strategy Challenge Fund of £170 million which aimed to decarbonize key industrial clusters.[5]

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 infrastructure. While acknowledging that the UK hydrogen strategy may be informed by the activities of devolved administrations as well as other local actors, this report focuses primarily on the UK’s government hydrogen strategy.

[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.

[5] However, this Industrial Strategy and the “Grand Challenges” were withdrawn in March 2023. See https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/missions.

4. UK Hydrogen Policy: an inward-facing strategy

4.1 Hydrogen policy overview

DESNZ is the most important actor in the hydrogen policy space and is responsible for related roadmaps where its use is relevant 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; despite the high prices for gas since the Russian invasion of Ukraine, this is still the official position (BEIS, 2021a).

The 2021 Hydrogen Strategy concretizes the next steps for hydrogen and its use in hard-to-decarbonize sectors. It projects that hydrogen could make up between 20-35 per cent 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 auto manufacturing, steel and chemical production will receive funding for the deployment of carbon capture technologies. The goal is to maintain these industries in the UK, while creating a new carbon capture industry of 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. A key difference to the original Hydrogen Strategy is that the update 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 phaseout plan for carbon-intensive hydrogen (BEIS, 2022f, p. 8) nor a research and innovation facility for hydrogen use in industry. 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 also 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. However, there is no official work on what kinds of infrastructure would be needed for trade with continental Europe or further abroad.

In terms of the infrastructure needed to transport hydrogen, the government has taken a less active role than in promoting production and use. There are a number of questions which are not yet answered including the extent to which gas blending will be permitted, and whether hydrogen will be used for heating, that make the question of infrastructure difficult. A 2022 study (BEIS, 2022d) commissioned by the Government illustrates this issue, as its estimates of what infrastructure would be needed vary significantly depending on what uses are foreseen for hydrogen. For example, it estimates that by 2035, between 0.6 and 13.2 TWh of salt cavern storage would be needed. By 2035, anywhere between 700 km and 26,000 km of pipeline would be needed (24,750 of which would be for hydrogen use in buildings alone). This differs again from the plans proposed by the UK's NationalGrid plc / National Gas Transmission (NGT), whose "Project Union" focused on connecting key industrial clusters would be 2,000 km (25 per cent 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 effective compared to new build (Project Union, 2022, p. 8).

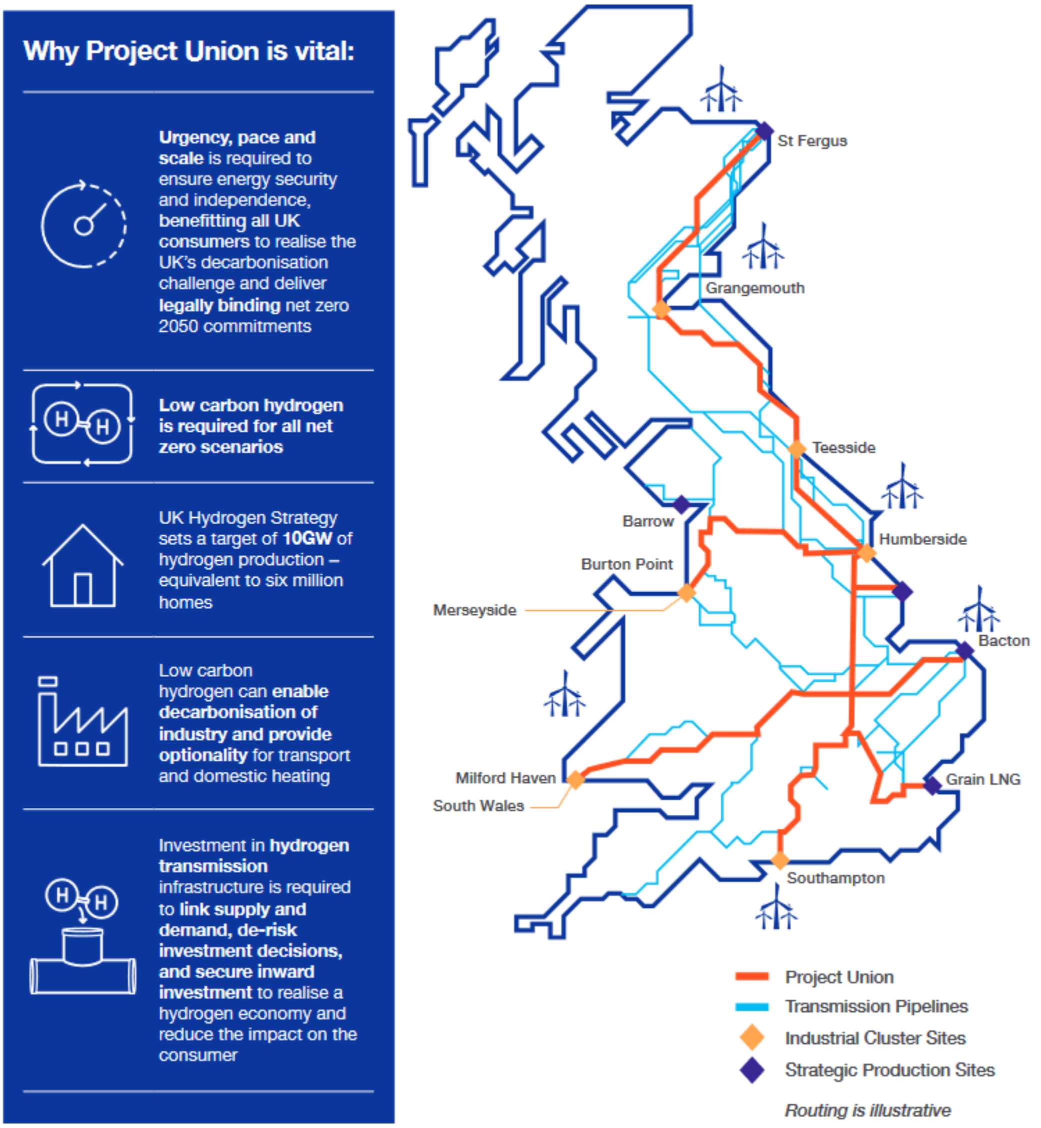

Figure 1: Proposed UK Hydrogen Backbone (Source: Project Union, 2022, p. 4, reproduced with permission).

The UK hydrogen strategy sees hydrogen as "essential for achieving net zero", but sustainability elements play a less important role in the policy's framing than industry development and energy security. The April 2023 Low Carbon Hydrogen Standard sets a maximum threshold for emissions intensity of hydrogen production: emissions must be under GHG emissions intensity of 20 gCO_2e/MJLHV of produced hydrogen or less for the hydrogen to be considered "low carbon", and therefore able to participate in funding initiatives (DESNZ, 2023d). The standard considers 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 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). The current project pipeline is 84 per cent blue hydrogen. Given that no blue hydrogen projects have achieved final investment decisions (FID) which would need to be taken by 2024, it seems unlikely that much of this pipeline will turn into actual hydrogen production projects. As of March 2023, only a few small-scale green hydrogen pilot projects had achieved FID (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 is funding hydrogen production projects on the small to medium scale. Finally, the government will also provide revenue support via the Hydrogen Production Business Model. This contract-for-difference style program guarantees revenues, thereby aiming to provide certainty for investors.

Funding for hydrogen innovation and project development come from the NZIP portfolio, including the Net Zero Hydrogen Fund (NZHF) of £240 million, and by further schemes for industrial decarbonization and CCUS (see Table 1). Funding for revenue support will be provided by levies on energy consumption.

Table 1: Key UK funding initiatives including hydrogen

Funding Program name	Amount	Funding source	Description
Hydrogen-specific funding initiatives			
Net Zero Hydrogen Fund	£240 million	NZIP	Innovation, DEVEX and CAPEX support
Hydrogen Production Business model	unknown	Funded by government until hydrogen levy comes into effect (DESNZ, 2023c)	Revenue support, contract for difference-style long-term contracts.
Low Carbon Hydrogen Supply 2 Competition	Up to £60 million	NZIP	Innovation projects for hydrogen supply
Industrial Hydrogen Accelerator Programme	£26 million	NZIP	Innovation projects for industrial fuel-switching
Hydrogen BECCS Innovation Programme	£30 million	NZIP	Innovation in hydrogen BECCS (bioenergy with carbon capture and storage) technologies.

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. (2 million figure via HVP, 2021)
Other funding initiatives that may include hydrogen			
Longer Duration Energy Storage Demonstration	up to £68 million	NZIP	Innovation competition for longer-duration energy storage including power-to-X.
Red Diesel Replacement Competition	£40 million	NZIP	Innovation competition for low-carbon fuel and system alternatives to red diesel construction, and mining and quarrying sectors
Green distilleries Competition	£12.33 million	NZIP	Innovation competition for using low-carbon fuel in distilleries
Industrial energy transformation fund (IETF)	£315 million	IETF	Support for energy-intensive industries to invest in energy efficiency and low-carbon technologies. Within the IETF, the Industrial Steel Challenge fund provides up to £66 million for innovation funding to develop technologies that reduce energy and resource use (DESNZ, 2023e). Hydrogen fuel-switching is only covered under the IETF if industry will switch to hydrogen in the next 5 years.
CCUS Infrastructure fund (CIF)	£1 billion	CIF	Funding for carbon capture projects for industry and power; and for transport and storage networks. The CIF will also provide revenue guarantees and support for construction and investment in blue hydrogen projects via the NZHF. Power CCS will be funded by consumer subsidies.
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	UK Export finance	Loan guarantees for working capital, capital expenditure or R&D for clean energy, hydrogen and decarbonization (BEIS, 2021b).

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 i.e., through lab-based research but also includes the Innovate UK program, which supports scaling up solutions with higher TRLs that are not yet commercially viable.

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 March 2023, the winners of funding round 1 were announced and allocated £37.9 million for hydrogen production (DESNZ, 2023f). Of the 15 successful applicants, only two projects were for blue hydrogen, while the rest were for green hydrogen from electrolysis. Yet, few of these projects had guaranteed offtakers. Of 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 to study whether its boilers can be safely run on hydrogen (Green Hydrogen Winnington & Middlewich) and another for Pilkington UK's glass production (Green Hydrogen St Helens). Further support for blue hydrogen production may be provided by the CCS Infrastructure Fund, but precise amounts are not yet determined.

In addition to this support for hydrogen production, revenue support will also be provided by the Hydrogen Production Business Model (HPBM)[6]. This bears strong similarities to the Contracts for Difference (CfD) model in that it is used to cover the difference between the cost of production and the sale price of hydrogen. The HPBM may also provide limited CAPEX/OPEX for hydrogen storage, and limited CAPEX for hydrogen transport (BEIS, 2022c). Policy documents published in late 2022 outline the suggested guidelines for which projects could receive this support, including the Low-carbon Hydrogen Production Business Model Terms (BEIS, 2022i). This suggests that subsidies would only apply if the hydrogen met the requirements of the Low Carbon Hydrogen Standard, and that hydrogen is sold for certain qualifying purposes, i.e., power generation, transportation, or industrial use, but not for export or blending into the gas grid. These 15-year contracts would be possible for all projects and sizes but could be terminated early under certain conditions.

Independent research by civil society based on the government's analysis of strike prices suggests that the HBM could cost £3.5 billion in support per year from 2030 (Richardson, 2023). Funding for this revenue support will be provided by a levy on energy consumption from "relevant market participants" after 2025. Before then, the government has committed to covering HBM costs. The hydrogen levy has been criticized by civil society organizations as unfair: the government has declined to provide an estimate of what the cost would be for consumers, and money could flow from households (also low-income ones) to hydrogen producers, including gas companies that have made record profits from the energy crisis (Dyson & Britchfield, 2023). As of June 2023, the hydrogen levy was still included in the Energy Security Bill, which was still in the legislative process (HoL, 2023).

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 for the environment and people.

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 per cent by 2050 based on access

[6] The HBPM was formerly called the Hydrogen Business Model (HBM), which was then split into two separate business models for hydrogen transport and hydrogen storage.

to hydrogen, clean electricity, and CCS. It also warns that if this is not economically feasible the industry could shrink or relocate (CEFIC, n.d.). The steel industry's lobby group UK Steel also does not see switching to hydrogen as feasible before 2050 unless there is government support across the value chain to promote R&D and reduce the cost of electricity, hydrogen and infrastructure (UK Steel, 2022). As of April 2023, there have been some examples of large-scale investments in hydrogen by these industries within the UK. The steel industry has pledged to reduce emissions via electrification and low-carbon hydrogen use, for which a trial program has been announced by British Steel (British Steel, 2022). However, London-based INEOS, one of the largest chemicals manufacturers in the world, announced 2 billion euros of investments in hydrogen production and use in Germany, Norway, and Belgium but not yet in the UK (INEOS Group, 2021).

In addition to use for industry, the UK's hydrogen strategy argues that hydrogen is useful in areas where gas is now used such as flexible power generation and storage (BEIS, 2021c, p. 9-10). It envisions hydrogen being used 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. The government's strategy has been to keep its options open, with a decision on gas blending originally aimed for 2023 and decisions on hydrogen heating planned for 2026 (Delaval et al., 2022b). Until then, further resources have been devoted to gas blending and heating trial projects in UK villages such as Whitby. In addition, the government launched an additional £20 million competition at the Tees Valley Transport Hub which trials hydrogen use for transport and refueling facilities. This fits into the general approach of creating "hydrogen markets" within the UK to stimulate demand but does not fit with the strategy of prioritizing low-regret and strategically important options like industrial decarbonization.

This stance on creating markets for hydrogen by blending into gas grids and/or using hydrogen for heating 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.[7] The Chief Executive of Johnson Matthey's Catalyst Technologies business, Jane Toogood, was appointed the government's Hydrogen Champion and co-chairs the Hydrogen Advisory Council alongside the Minister of Energy (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, 2023b).

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

[7] 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.

because heating and transport can be electrified, whereas cement and lime production cannot be (p.32). Civil society organizations focused on sustainability, like E3G, also highlight the importance of no-regrets 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, 2023a; Harvey, 2023). 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).

Box 1: The UK Hydrogen Advisory Council

The UK Hydrogen Advisory Council is a forum for ministerial engagement with 20 key hydrogen sector actors. Its representatives skew towards actors with an interest in maintaining fossil fuel systems, including:

- 4 fossil fuel extraction representatives (Shell, BP, Equinor)
- 2 industrial gases representatives (BOC Linde, Inovyn)
- 1 CCS firm (Storegga Energy)
- 1 project developer for blue hydrogen and hydrogen heating (progressive energy)
- 1 gas network representative (Energy Networks Association Gas Goes Green Champion)

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

- 2 wind representatives (Orsted, non-industry "Offshore wind sector champion")
- 1 electrolyzer manufacturer (ITM power)
- 1 green hydrogen supply and distribution company (Ryze)

There are also some actors who have interests in both green and blue hydrogen, although they tend to promote blue hydrogen and gas blending within the UK. These include:

- 2 energy and energy technology firms (SSE, Siemens Energy)
- 1 chemicals and engineering firm (Johnson Matthey)
- 1 maritime services firm (Lloyd's Register Marine and Offshore business)
- 1 international bank (Mitsubishi UFJ Financial Group)

Finally, there are some non-industry actors with mixed interests:

- 2 Research directors for chemical engineering (University of South Wales and Imperial College)
- 1 independent, publicly funded research, and policy center (Energy Systems Catapult)
- 1 UK gas and electricity regulator (Ofgem)

Sources: https://www.gov.uk/government/groups/hydrogen-advisory-council and own research on hydrogen positions using company materials and news sources.

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. And, compared to other northern European countries, its project announcements of almost 2.2Mt by 2030 could make it a leader in production capacity if these reach final investment decisions.[8]Yet its current policy approach has been criticized by different actors as lagging behind other countries. Inaction on certain key decisions about 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 leg up on 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); and 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 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

[8] 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).

supply chain position, Wood Mackenzie's analysis for BEIS also suggests supporting electrolysis manufacture and other key technologies (BEIS, 2022h, p. 81-82). However, this is not a central focus of the UK's strategy despite its leading electrolyzer manufacturer struggling with supply chain issues and financial difficulties (IEA, 2023).

Adding to the UK's hydrogen disadvantage when it comes to establishing innovative advantages are its starting position and problems with 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 specific sub-sectors of hydrogen use in methanol production and aviation. Out of the top ten 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 10 in publications on certain value chain areas, it does not make the top 10 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.[9] Further challenges in innovation funding have arisen since UK institutions are no longer eligible for European research funding, raising concerns in the House of Lords Science Committee that this will result in brain drain (Zakir-Hussain, 2022). 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).

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 towards Net Zero, as they perceive the UK as less supportive than France, Germany, and Canada (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, 2023b). 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 and therefore setting the UK back. 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 p. 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.

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

5. External dimensions of the national hydrogen strategy

The UK government's hydrogen policy is based on building up a local hydrogen supply and market, placing significantly 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 also does not appear to be actively 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 Hydrogen Backbone.

5.1 Diplomacy and political dialogue

At the international level, the UK has promoted hydrogen at the G7 and UNFCCC. Its G7 presidency was the first to achieve a statement of support for the role of low carbon hydrogen, on which the Hydrogen Action Pact was based (according to BEIS, 2022e). At COP26, it 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 work programs to coordinate 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. According to the December 2022 Hydrogen Update to Market, the UK and USA will also co-lead the Hydrogen Breakthrough Dialogues in 2023. Progress and next steps will be reported at COP28 by the Ministerial.

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.[10] 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 Programme, where it participates in different workstreams on energy storage and conversion, underground storage, safety of large hydrogen applications, and technology analysis and modelling (IEA, 2022b).

At the Clean Energy Ministerial, the UK government engages in some projects like the "twin cities" initiative (Japan-Aberdeen) and as a member of the expert panel for the CEM-led Northwest European Hydrogen Initiative. Here it is also interesting to note which projects the UK is less involved in. For example, the CEM Global Ports Coalition headed by the European Commission includes ports from all other major hydrogen regions except the UK (North America, Continental Europe, South America,

[10] 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/.

Arabian Peninsula, Japan, South Korea, Australia) (Clean Energy Ministerial, n.d.). Similarly, the UK does not seem to be highly involved in other global market projects such as the working group on large-scale hydrogen supply chains, co-chaired by Portugal and Netherlands (see 2021-2022 work plan: Clean Energy Ministerial, 2020). However, the Northwest European Hydrogen initiative is of particular interest to UK policymakers as the geographic connection to other countries would enable energy trade in the future.[11] 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 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 currently under consultation (BEIS, 2023).

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 how electricity imports fit into making renewable fuels (IPHE, 2022). This deepening involvement in standards and certification suggests an interest in trade in the longer-term.

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 the international partnership on fuel cells and 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 recently increased its cooperation with some 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 and CCS as well as offshore wind. 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 hydrogen, CCUS and nuclear power. Interestingly, this announcement states that the UK-France partnership would support the UK's hydrogen ambition while France aims to use hydrogen in its own power system. 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 & French Government, 2023).[12] The UK also jointly hosted the North Sea Neighbors Conference in November 2022, which

[11]) 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, 2022)

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

featured CCUS and hydrogen; and recently signed an MOU with Norway to further strengthen cooperation on hydrogen, especially CCS and North Sea carbon storage (Hydrogen Central, 2023). 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). Interestingly, the devolved governments of the UK have also begun to pursue bilateral connections and cooperation with other countries and regions in Europe. Scotland has signed multiple collaboration agreements for low-carbon technologies and hydrogen with Denmark (Scottish Government & Government of Denmark, 2021) and multiple German regions including Hamburg, Bavaria, and North Rhein-Westphalia (Scottish Government & Government of Baden-Württemberg, 2022). This could be another way that sub-national actors within the UK can drive further collaboration with Europe, even without the UK government's engagement.

The UK government has also signaled interest in cooperation with more geographically distant hydrogen frontrunners, such as Australia, Korea, and Chile. The UK and Australia may cooperate on hydrogen as a part of broader energy cooperation, including within the 2021 letter of intent to establish a partnership on low-emissions technologies (Australian Government, 2021), and a statement of intent in 2023 on critical materials (King, 2023). Chile and the UK also discussed hydrogen at the 2022 UK-Chile trade dialogue (DIT, 2022). Australia and Korea are also partnering with Innovate UK for collaboration on hydrogen competitions (BEIS, 2022e, p. 15). However, there has been relatively little engagement by the UK with lower-income countries. The two exceptions are the UK's joint statement with the Republic of South Africa that its MoU on scientific cooperation would be expanded to include hydrogen; and the Mexico-UK PACT which awarded grants to 14 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 via this mechanism.

5.3 Competing for hydrogen innovation leadership and investment

Support for developing hydrogen supply chains remains at a relatively early stage in the UK and mainly focuses 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 towards developing long-term export opportunities" (BEIS, 2022f, p. 14). According to this roadmap, the Office for Investment, DIT, and DESNZ are also 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 investigate 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, while UK Export Finance has enhanced its Export Development Guarantees to support clean technologies including hydrogen.

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. Also at the international level, the UK does not engage publicly in fora around establishing international infrastructure for hydrogen trade, such as the Clean Energy Ministerial's work on ports or supply networks. However, there is some indication that private actors are interested in the development of international hydrogen infrastructure. The European

Hydrogen Backbone, an initiative of 32 energy infrastructure operators across Europe, includes the UK's Nationalgrid plc / National Gas Transmission (NGT).

The current 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, and 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. For example, the potential "for export opportunities by connecting to the European Hydrogen Backbone" is in a small box showing a map of the UK labelled "promote energy independence" (Project Union, 2022, p. 5). NGT has now proposed a 12-month feasibility study for £7.9m which is now under consultation with Ofgem (Ofgem, 2023). In the Ofgem project evaluation, the publicly available information makes no mention of Europe, exports, or the interconnection.

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 are worth pursuing.

Within the UK, the government's ambitious vision is supported by a portfolio of 240 million in public funding for green hydrogen R&D, production, and use. It further plans to use levies on energy bills to generate more funding for hydrogen use. Funding for blue hydrogen may draw from further resources, but so far few projects have reached final investment decisions. The goal is to build a local economy and demand for low-carbon hydrogen products which can 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, the government has not yet been active in developing strategies for international infrastructure or supply chains and has left strategies for EU interconnections to gas companies. This lack of official 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. Or 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 key challenge for the UK government is balancing its stated policy goals of industrial policy with technology openness and cost concerns. On the one hand, it aims to quickly ramp up what it perceives as low-cost options, using blue hydrogen as a bridge until green is cheaper and switching gas heating infrastructure to hydrogen. But on the other hand, the aim is to build up a UK hydrogen industry and become a world leader in technology and applications, which 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, and the UK's existing competitive advantages in electrolysis and electrolyzer innovation. In addition, the focus on creating "domestic hydrogen markets" to stimulate household demand, while there are already effective alternative solutions, entails a waste of valuable resources. The failure to commit to strategic decisions on certain technologies and key use cases is therefore an obstacle to industry-building.

This lack of clarity may be linked to the role that fossil-intensive industry has played in the strategy's development. Civil society argues that the strategy is being led by industry rather than scientific evidence, and the Government's promises of more intensive engagement with civil society were box-ticking exercises at best. Others suggested that the government had not realized the extent to which green hydrogen costs had fallen and expressed the hope that this was understood, and stances were shifting behind the scenes. In any case, the industry-dominated nature of the UK's hydrogen strategy and the ensuing focus on blue hydrogen risk locking the country into carbon-intensive pathways. However, this may be challenged in the UK courts by the Climate Change Act of 2008. Already, the Net Zero Strategy was found to be insufficient as it lacked quantifications of how the government would achieve emissions targets. Further concerns about justice are raised by the proposed hydrogen levy: estimations show that hydrogen revenue support which would flow back to energy companies could cost up to £3.5 billion in support per year from 2030. These costs would fall harder on the UK's poorest households.

The current approach is contrary to 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 US and the EU, which are now increasing their hydrogen ambition and related industrial policy measures. Realistically speaking, 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 current lack of a concerted strategy to cooperate with Europe on hydrogen development or infrastructure may leave it lagging behind other countries in terms of foreign investment as the EU turns to Northern Africa for its hydrogen imports. Without a concerted change in the UK's strategy, its lack of strategic decisions and inward-looking policy may result in other countries pulling ahead in the "green race".

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8. About the author

Silvia Weko works as a research associate with RIFS on the project Geopolitics of the Energy Transformation: Implications of an International Hydrogen Economy (GET Hydrogen), which she joined in 2023. From 2019-2022 she worked on the project Investigating the Systemic Impacts of the Global Energy Transition (ISIGET). Her research focuses on the politics of sustainability transitions, including themes such as renewable energy technology transfer and innovation, trade flows, and attitudes towards transitions. She is a doctoral candidate at the University of Erfurt with the Graduate Center for Effective and Innovative Policymaking in Contested Contexts (EIPCC).

The **Research Institute for Sustainability (RIFS)** conducts research with the aim of investigating, identifying, and advancing development pathways for transformation processes towards sustainability in Germany and abroad. The institute was founded in 2009 as the Institute for Advanced Sustainability Studies (IASS) and has been affiliated with the Helmholtz Centre Potsdam - GFZ German Research Centre for Geosciences under its new name since 1 January 2023 and is thus part of the Helmholtz Association. Its research approach is transdisciplinary, transformative, and co-creative. The Institute cooperates with partners in science, political and administrative institutions, the business community, and civil society to develop solutions for sustainability challenges that enjoy broad public support. Its central research topics include the energy transition, climate change and socio-technical transformations, as well as sustainable governance and participation. A strong network of national and international partners and a Fellow Programme supports the work of the Institute.

RIFS Discussion Paper

July 2023

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DOI: 10.48481/rifs.2023.023