7 Hydrogen Policy

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7.1 Policy context

Hydrogen is considered a strategic energy carrier in future energy scenarios as it supports the climate change agenda. It can also contribute to energy security and reliability through having multiple production feedstocks, and through storage it can enable the deployment of renewables. The hydrogen economy is expected to spur economic growth, create new supply chains, business models, job opportunities and innovations. At a local level, authorities are also interested in the opportunities of hydrogen and fuel cells as a solution to improve air quality and noise pollution in urban areas. Limited reserves and potential policy interventions that internalise the cost of negative externalities are likely to increase the cost of using fossil fuel in the long term, strengthening the role of H2FC technologies to deliver energy affordability.

7.1.1 Environmental drivers

Environmental policy is concerned with climate change, air, water, noise pollution and the depletion of resources, and it constitutes one of the main drivers for the promotion of H2FC. The Lisbon Treaty states that environmental requirements must be embedded into all EU policies 'with a view to promoting sustainable development' [1]. The potential of H2FC technologies to contribute to all dimensions of sustainable development (environmental, social and economic) justifies their inclusion in energy policy instruments. Hydrogen pathways present strong environmental credentials; however, they have not featured in as many policies as renewables because of the UK's 'pragmatic' approach to the development of EU environmental policy [1].

Hydrogen can play a significant role in improving air quality in urban areas, as it produces zero emissions at the point of use, and can also reduce noise pollution from the transport sector. Hydrogen produced from renewables yields lower carbon emissions than conventional fossil fuels, and production from fossil fuels can have low GHG emissions with CCS. Regardless of the production route, clear and stable long-term policies provide certainty to investors, facilitating investment in innovation. The range of international agreements ratified by the UK positions H2FC technologies as one of the few pragmatic pathways to deliver low carbon and environmentally friendly energy alternatives beyond 2030.

7.1.1.1 Air quality drivers

Policies for improving air quality have direct impacts on human health and the environment, for example respiratory problems, premature deaths, acidification, etc. Air pollution from particulate matter was responsible for 29,000 UK deaths in 2008 [2]. 430,000 premature deaths in the EU are related to air pollution, and targets have been established to reduce this to 224,000 by 2030 [3]. The economic costs of air pollution due to sick leave, healthcare, crop yield loss and damage to buildings are around €8 bn, €2.4 bn, €1.7 bn and €0.3 bn respectively [3]; and the benefits of clean air policies continue to significantly exceed the cost of action [4]. The EU imposes severe penalties to member states that consistently exceed the thresholds and occurrences of the legislated air quality pollutants, according to the EU Air Quality Directive 2008/50/EC. These fines are transferred to the local authorities responsible for breaching those limits. As a result, many are considering now banning diesel vehicles and expelling polluting industries from urban areas while exploring alternative solutions such as promoting electric, hybrid and fuel cell electric vehicles (FCEV). Nowadays, smog is so severe in some megacities worldwide that industrial activity and traffic are restricted during critical days. Madrid for example has a protocol for high NO_2 pollution episodes when vehicles with odd or even number plates are forbidden from driving on alternate days; motorbikes and electric, hybrids and gas vehicles are exempt [5]. FCEVs could decrease the need for imposing such tough restrictions, and allow residents to avoid such restrictions.

7.1.1.2 Climate change and Energy savings drivers

Climate change has been a key driver in UK environmental policy. As established in the Climate Change Act 2008, the UK aims to reduce GHG emissions by 80% by 2050 compared to 1990 levels [7]. Carbon Budgets provide interim targets, and by 2028-2032, the savings of 431 $MtCO_2e$ are expected mainly from transport (38%) and the residential sector (30%); areas where H2FC can support decarbonisation goals. The fifth carbon budget recommends limiting the carbon intensity of the power sector to below 100 gCO_2e/kWh by 2030 House of Commons [8]. Several hydrogen pathways are compatible with this goal and one of the proposals for defining a green hydrogen standard suggests a threshold at 36.4 gCO_2e/kWh [9].

The UK adhered to the Conference of Parties (COP21 and COP22), and so is committed to 'improving national carbon reduction strategies, advancing innovation to drive forward clean energy, increasing transparency of actions and scaling up ambitious climate finance from a range of public and private sources' [10]. In response, the Government may promote investment in H2FC technologies so long as they can reach cost parity with incumbent technologies and fit with the Government's new industrial strategy.

7.1.2 Energy security, resilience and affordability drivers

Energy supply disruptions would have significant impacts as the EU imports half of the energy that it consumes; 90% for crude oil and 66% for natural gas [11]. The UK energy security strategy is based on six policy areas: resilience, energy efficiency, reliable networks, maximising UK production, working internationally and decarbonisation [12]. Reliance on single suppliers (e.g. Russian gas or Middle East oil), poor reliability (e.g. intermittency of renewables) and unavailability of energy infrastructure (e.g. natural disasters, failure or cyber-attacks) are significant risks that H2FC technologies can help to mitigate.

Hydrogen can improve national energy independency, as it has numerous production pathways including fossil fuels, biomass and other renewables, easing geopolitical reliance on oil and gas suppliers. Energy system reliability can be improved by building hydrogen storage capacity to balance renewable electricity generation. Furthermore, these technologies can exploit synergies between the power and heating systems with power-to-gas, gas-to-gas and gas-to-power technologies.

Providing cheap energy, while meeting expected demand increases and decarbonisation targets simultaneously is challenging; however, energy affordability is a key economic and social priority for most governments. Key policy areas to achieve this focus on controlling policy costs on bills by reducing subsidies, increasing competition and developing energy efficiency programs [13]. While some technologies can improve system efficiency (e.g. FC micro-CHP), subsidising them would only increase energy bills in the short-term. The role of H2FC to deliver affordability is currenty limited due to immaturity and low production levels. Similarly, the lack of large-scale demonstration projects in the areas of hydrogen storage and CCS limits the achievement of cost reductions. However, in the long-term these technologies could make a significant contribution with a commitment to research, development and deployment.

Examples of policy interventions that could lead to this outcome include:

- The internalisation of negative externalities of energy produced from fossil fuels, such as the Carbon Price Floor;
- Mandatory targets excluding fossil fuels from the energy mix of some systems (e.g. Renewables Obligations or converting the gas network to hydrogen)
- Establishing compulsory storage capacity (including hydrogen) when permitting intermittent renewable energy projects;
- Promoting CCS until hydrogen can be produced from renewables at the scale needed to meet the demand from the energy systems (heating, power, transport).
- Deeming hydrogen as a renewable fuel

7.1.3 Latest Policy Developments in Scotland

The Scottish Energy Strategy is part of the Scottish Government's vision for the future energy system [14]. It explores the role of hydrogen in the Scottish energy system and recognises that by 2050 it could become one of the main components in the energy mix. This strategy applies a whole systems view which recognises the interactions between heating, power and transport systems, and aims at a 50% of energy coming from renewables by 2030 [15].

A hydrogen economy is an interesting option for Scotland, It eases the transition for the oil and gas industry as there are many similarities and synergies between supply chains and labour skills. The strategy identifies the role of hydrogen to decarbonise heat and considers that it could do so more cheaply than other alternatives. In line with the UK's Renewable Transport Fuels Obligation (RTFO) consultation process, it supports the inclusion of hydrogen as a renewable fuel of non-biological origin.

Several relevant projects are being taken forwards in Scotland: Orkney's 'Surf and Turf' and 'BIG HIT', and the Levenmouth Community Energy Project produce green hydrogen from wind power [15]. In 2017, the Scottish Government published its commitment to invest more than £500m over the next four years in the Scotland's Energy Efficiency Program, with the goal of delivering near zero carbon buildings by 2035 [16]. The Scottish Government is committed to fund innovative H2FC projects; however, a specific budget has not been allocated yet for promoting these technologies as the current energy strategy is under consultation.

7.2 Policy Instruments

Numerous policy instruments are applied to the heating, power and transport systems. Due to the synergies between heating and power, this section separates energy demand, energy generation and transport policies.

7.2.1 Energy demand policies

The key energy demand policy instruments that influence H2FC technologies outside industry are related to heating and electricity consumption in buildings, as summarised in *Table 7.1*. These policies focus on developing energy efficiency standards and increasing the share of renewables mostly in heating, with the ultimate goal of reducing GHG emissions. Since the UK's shift towards a service economy, there is renewed interest in defining a new industrial strategy to rebalance the UK economy.

Industrial processes are responsible for 9% of EU GHG emissions [6], 18% of SO_X emissions, 12.5% of NO_X and 7% of particulate matter ($PM_{2.5}$) [19]. EU Policy instruments associated with industry and large corporations are displayed in *Table 7.2*, while *Table 7.3* represents those that are particular to the UK. Typically, their main goal is reducing GHG emissions; however, reducing pollution is also stressed under European legislation, a concern that is expanded as well under the UK Regulations to energy efficiency and energy security.

Table 7.1: Energy demand policies relevant to H2FC in buildings. H: Heating; P: Power.

<table>
<tr><td>Building Regulations</td><td>System: H, P</td><td>Objective: Energy efficiency / GHG emissions</td></tr>
<tr><td colspan="3">Sets standards for the construction and design of most new buildings and some renovations. Specify energy conservation requirements and must consider systems such as decentralised energy supply and district heating or cooling from renewables, heat pumps and cogeneration. Understanding hydrogen as a ‘mains gas’ could facilitate H2FC technologies to be installed in new buildings (e.g. hydrogen boilers, FC micro CHP).</td></tr>
<tr><td>Domestic Renewable Heating Incentive (RHI)</td><td>System: H</td><td>Objective: Increase the share of renewables / Reduction of GHG emissions</td></tr>
<tr><td colspan="3">A UK financial incentive to promote the generation and use of domestic renewable heat as a means to reduce GHG emissions. Eligible technologies include heat pumps, biomass boilers and solar thermal panels. A review should be put forward to assess the inclusion of FC micro CHP as this technology could deliver the same policy objectives as the accepted ones.</td></tr>
<tr><td>Energy Performance Buildings Directive</td><td>System: H</td><td>Objective: Increase the share of renewables / Energy efficiency</td></tr>
<tr><td colspan="3">Mandates that all new public buildings built in the EU by 2019 must consume 0 $kWh/m^2/year$ and other buildings by 2021.The Directive requires that energy used to operate buildings comes from</td></tr>
</table>

renewables (mainly), therefore hydrogen must be renewable to be eligible. FC micro CHP running on biofuels could also meet the policy objective.		
Private Rented Sector Regulations	**System:** H	**Objective:** Energy efficiency
Dwellings and non-domestic buildings must reach an 'Energy Performance Certificate' rating 'Band E' by 2020 and 2023, respectively. Property owners must give consent for the installation of energy efficiency technologies. In the case of non-domestic buildings, they cannot refuse if the payback of the investment is 7 years or less. The funding can be private (e.g. tenant) or via a public scheme. Among the list of appropriate improvements are CHP and gas-fired condensing boilers; both compatible with hydrogen and FC micro CHP.		
Salix Loans	**System:** H	**Objective:** Energy efficiency and reduction of GHG emissions, energy affordability, innovation
A finance scheme funded by the UK Government that provides interest-free loans for energy efficiency projects undertaken by public sector organisations that yield a payback period under 5 years in England and 8 years for the rest of the UK. Lifetime carbon savings costs must be less than £100/t CO_2 in England (£200/t CO_2 in the rest of the UK). These cost savings can be recycled into new capital projects. Despite not including explicitly H2FC, such projects can meet the eligible criteria. Previous projects include boilers and NG CHP, which could also run on hydrogen.		

Table 7.2: Large and industrial organisations EU energy demand policies relevant to H2FC. T: Transport (aviation); H: Heating; P: Power.

EU Emissions Trading System (ETS)	**System:** H, T	**Objective:** Reduction of GHG emissions
The world's largest carbon trading scheme, covering 45% of the EU's GHG emissions. Energy intensive industries are given a carbon emissions allowance cap and the possibility to trade their surplus/deficit. Currently, auction prices of ETS are too low as allowances are still too many. The		

incentive to reduce emissions for these organisations is low, which is detrimental for the private investment on efficient H2FC. In contrast, the revenues from the allowances' trade can be invested in hydrogen related projects by national governments as under the EU ETS Directive, 50% of the revenues obtained must be invested in climate and energy efficiency related purposes by member states.		
Industrial Emissions Directive (IED)	**System:** H, P	**Objective:** Reduction of pollution / Reduction of GHG emissions
The main EU instrument for regulating pollution from energy and industrial installations. It issues permits and controls installations' air, water, land, noise and waste pollution, in addition to energy efficiency, safety, use of raw materials and decommissioning. It encourages the following of 'Best Available Techniques' (BAT) by participants of different industries. Some of these apply to members of the H2FC supply chain (e.g. technical ceramics, chemical, polymers, oil and gas, waste and precious metals). The IED also regulates GHGs (CO_2, CH_4, N_2O, fluorinated gases) and their precursors (NO_X, SO_X and black carbon) in facilities not covered under the EU ETS or 'when it is necessary to prevent local pollution'. As H2FC technologies can produce low pollution and GHG emissions under certain pathways, they should be included in new iterations of BAT as recommended technologies.		

Table 7.3. Large and industrial organisations UK energy demand policies relevant to H2FC. T: Transport; H: Heating; P: Power.

Climate Change Agreements	**System:** H	**Objective:** Reduction of GHG emissions
Voluntary agreements between UK industry and the UK Environmental Agency. Enrolled companies can get a rebate of 90% from electricity and 65% from other fuels from their Climate Change Levy (CCL), as long as, they meet energy efficiency and carbon reduction targets established by the Government for their sector. H2FC technologies projects could be funded by the Government from the income obtained from the CCL and the 'buy-out' fee.		

CRC Energy Efficiency Scheme	**System:** H	**Objective:** Reduction of GHG emissions
A compulsory scheme that applies to eligible large energy users in the public and private sectors (supermarkets, water companies, banks, central government and devolved administrations). These organisations must report emissions generated from their electricity and gas consumption. It works similarly to the ETS. Allowances can be bought at a fix price and traded in the secondary market. This will be replaced by a Climate Change Levy from July 2019. Organisations using FC micro CHP must report electricity generation only as heat is excluded. Under this scheme, emissions from H2FC vehicles without road license must also be reported (e.g. forklift trucks, excavators, etc), as well as, energy used to provide heating, power and lighting to railways buildings (e.g. FC auxiliary power units).		
Effort Sharing Decision, Effort Sharing Regulation	**System:** H, T	**Objective:** Reduction of GHG emissions / Energy efficiency / Increase the share of renewables
This sets up legally binding carbon targets for sectors not included on the EU ETS. The policy focuses on improving building standards, more efficient and less carbon intensive heating systems and renewable heating. Allowances are too large to drive any H2FC demand in the short term. The revenues of the scheme could be used to fund H2FC innovation in hard to decarbonise sectors such as transport, agriculture and waste (e.g. agricultural tractors and refuse trucks powered by fuel cells).		
Energy Savings Opportunity Scheme	**System:** H, P, T	**Objective:** Energy efficiency and reduction of GHG emissions
Regulation transcribed in the UK to implement the EU Energy Efficiency Directive (2012/27/EU). A mandatory energy assessment and saving scheme to audit the energy consumption of buildings, industrial processes and transport from large undertakings. Non-compliance carries penalties. Its aim is to identify (and recommend) cost-effective energy saving measures by assets that represent at least 90% of the total energy consumption. H2FC technologies can be eligible only if they cover this share and are cost-efficient.		

Enhanced capital allowances (ECA)	**System:** H, T	**Objective:** Energy and water efficiency, reduction of GHG emissions
Allows businesses to deduct the full cost of eligible energy and water efficiency equipment from the profits of each company before tax. As energy efficient technologies such as steam boilers, CHP, and auxiliary power units are eligible, H2FC technologies for energy generation are implicitly acceptable.		
Non-domestic Renewable Heating Incentive (RHI)	**System:** H	**Objective:** Increase the share of renewables / Reduction of GHG emissions
A UK financial incentive to promote the generation and use of renewable heat in buildings and facilities (excluding dwellings) as a means to reduce GHG emissions. The list of eligible technologies includes biomass CHP, biogas and biomethane. FC micro CHP and biomethane (a renewable gas) can deliver the intended policy objectives, and so should be included within future iterations.		

7.2.2 Energy generation policies

Energy supply is responsible for a third of UK GHG emissions, and three quarters of this corresponds to power stations [20]. Decarbonising electricity supply is fundamental to achieving meaningful GHG reduction targets, and also to reducing air pollution. Energy production and distribution is a major source of SO_X and NO_X pollutants, emitting 58% and 20% respectively in Europe [19], or 52% and 30% in the UK [21].

Energy generation policies can be classified in two broad groups. One includes policy instruments that relate to hydrogen production (*Table 7.4*), whose main objectives are GHG emissions reductions and air pollution. In the short-term fossil fuel pathways are inevitable for producing hydrogen; however, emissions could be drastically reduced when sufficient hydrogen can be generated from renewables. In the meantime, CCS policies may be necessary to broach the transitionary technological and production gap.

The second group comprises instruments that denote the role of H2FC technologies in supporting conventional power and heating systems (*Table 7.5*). Among this group, the main policy targets are increasing the share of renewables in the electricity and heating networks, and guaranteeing the energy security of the power system. H2FC technologies have an important role in grid support as they could improve system reliability by providing storage and capacity to balance the intermittency of renewables (as shown in Chapter 5). Many synergies between different energy systems are possible as hydrogen is a flexible energy carrier that can be converted between electricity and synthetic gases.

Table 7.4. Energy generation policies relevant to the production of hydrogen. H: Heating; P: Power.

Carbon Capture and Storage Directive (CCS)	**System:** H, P	**Objective:** Reduction of GHG emissions
Directive (2009/31/EC) regulates the environmental, health and safety concerns related to the capture, transport and storage of CO_2 and it establishes the context for private investment in CCS infrastructure. The main objective is to reduce GHG emissions mainly from energy generation powered by fossil fuels. Nowadays, fossil fuel feedstock pathways are the only realistic way to generate hydrogen at the scale required to meet the demand from heating, power and transport. CCS is fundamental to allow such pathways to meet the carbon intensity thresholds for renewables specified in different Directives and Regulations targets (as well as, a potential future green hydrogen standard).		
Carbon Price Floor (CPF)	**System:** P	**Objective:** Reduction of GHG emissions
Aims to decarbonise the electricity grid by penalising the UK's high-carbon power generation industry with carbon price support rates. With the development of hydrogen storage and its use to generate electricity, the government might decide in the future to apply the CPF to hydrogen (produced from fossil fuels). It should be determined how the deployment of CCS may alter the carbon price support rates.		

EU Emissions Trading System (ETS)	**System:** P	**Objective:** Reduction of GHG emissions
Introduced earlier in Table 7.2.		
Industrial Emissions Directive (IED)	**System:** H, P	**Objective:** Reduction of pollution / Reduction of GHG emissions
Introduced earlier in Table 7.2. Just one BAT for hydrogen production exists, relating to the clhor-alkali process, which emits mercury. Hydrogen production plants have to follow the IED (e.g. SMR, methanol cracking, coal and biomass gasification, etc.).		

Table 7.5. Energy generation policies relevant to the role of H2FC for supporting other energy systems P: Power.

Capacity Mechanisms (CM)	**System:** P	**Objective:** Energy Security
Provides a payment to electricity generators to ensure that enough capacity is available in moments of stress on the power system. This is necessary given the rising proportions of renewables on the grid and intermittency of their output. Hydrogen storage can respond quickly and for long periods of time and it is adequate for transmission and distribution deferral, arbitrage, inter-seasonal and seasonal storage applications. CM should consider hydrogen as a special case and exempt it from the obligation to provide unlimited capacity, as reservoirs have a finite volume.		
Contracts for Difference (CfD)	**System:** P	**Objective:** Affordability / Energy security / Reduction of GHG emissions
A contract by which a generator is paid the difference between the ‘strike price’ (the production costs) and the ‘reference price’ (average market price). By doing so, investment risks are minimised and low carbon electricity projects can be deployed at lower cost. The use of electrolysers and reformers could contribute to deliver energy security and lower emissions as electricity could be produced from low carbon feedstocks (wind, biogas or biofuels); however, these projects are unlikely to succeed in the CfD auctions due to the fact that these technologies are not competitive.		

Feed-in-Tariffs (FiT)	**System:** P	**Objective:** Increase the share of renewables
A support mechanism to promote the generation of small-scale renewable and low carbon electricity. Eligible installations get paid a regulated tariff rate by electricity suppliers (FiT licensees) for a number of years for the electricity that they generate and the one that they export back to the grid [22] in addition to the energy savings in their bills from their auto-generated electricity. Electricity generated from renewables (PV, wind, hydro, AD) and Micro CHP (≤ 2Kw and powered by fossil fuels) are eligible technologies. So far, just solid oxide fuel cells micro CHP running on natural gas would meet this criteria. An amendment to accept renewable hydrogen makes sense. The scheme has to control that FiT are not claimed twice when converting from electricity to hydrogen and vice versa.		
Renewable Obligations	**System:** P	**Objective:** Increase the share of renewables
Obligated UK electricity suppliers to source a specific proportion of electricity from eligible renewable sources. Generators obtained Renewable Obligation Certificates to trade with suppliers that need to meet their Obligations, providing an additional revenue stream. The scheme closed for new generators on the 31st March 2017 and it was replaced by the Contracts for Difference scheme. Under the current RO, there is no scope for introducing renewable hydrogen.		

7.2.3 Energy policies in transport

In the EU and the UK, Transport is responsible for around 23% of all GHG emissions [6, 20], 46% of NO_X, 15% of $PM_{2.5}$ and 12% of NMVOC [19][21]. As the final energy consumption by transport in 2015 was almost 40% of the total of the country [23], tackling energy efficiency in transport is critical to improve national energy security and air quality.

Hydrogen is recognised as one of the principal alternative fuels with a considerable potential for long-term oil substitution [24]. Many policies are in place to improve transport efficiency and reduce its carbon and air quality footprint (*Table 7.6*).

There are four main reasons to support the intake of H2FC in transport:

1. there are several hydrogen pathways that can yield low well-to-wheel GHG emissionsEdwards et al. [25];
2. FC powertrains are more efficient than internal combustion engines;
3. Tailpipe emissions are negligible,[1] which supports the Government's vision for almost every car and van to be an ultra-low emission vehicle by 2050 (and thus all new vehicles sold from 2040) [26];
4. the strong position of the UK's research capabilities and automotive sector, and their potential to deliver economic growth and job creation.

A summary of the main transport energy policy instruments that can fund the procurement of FCEV appears in *Table 7.7*.

Table 7.6. Transport energy policies relevant to H2FC. T: Transport; H: Heating; P: Power.

Energy Savings Opportunity Scheme	**System:** H, P, T	**Objective:** Energy efficiency and reduction of GHG emissions
Introduced earlier in *Table 7.3*. Fuel cells and FCEV can be eligible if they are cost-efficient and they represent 90% of the total energy consumption of the large undertaking (e.g. of a logistics or commercial fleet).		
EU Emissions Trading System (ETS)	**System:** H, T	**Objective:** Reduction of GHG emissions

[1] Although particle matter from the tyre-road interaction remain and issue.

Introduced earlier in *Table 7.2*. Aviation companies are given a carbon emissions allowance cap and the possibility to trade their surplus/deficit. Currently, these have no impact as there are no commercial H2FC powered planes yet.		
Rail electrification	**System:** T	**Objective:** Reduction of GHG emissions
Network rail aims to electrify over half of the rail network by 2021 (75% of all traffic miles). This presents an opportunity to discontinue diesel locomotives and electrify segments of the rail network with fuel cell trains.		
Renewable Transport Fuel Obligations (RTFO)	**System:** T	**Objective:** Reduction of GHG emissions
Encourages the supply of renewable fuels. Producers must render renewable transport fuel certificates (RTFCs) to prove that they have met their Obligations (currently around 6% annual by volume). Producers of renewables can get income from their RTFCs. A new RTFO consultation process proposes to include hydrogen as a ‘synthetic fuel from renewable electricity’. If successful, other renewable pathways will also be eligible (e.g. biomass gasification).		
Road emissions and vehicle emissions standards for heavy duty and light duty vehicles. Congestion charges and low emission zones.	**System:** T	**Objective:** Reduction of air pollution / GHG emissions
Policies set the maximum carbon emissions for new vehicles and promote low carbon technologies. Carbon intensities per kilometre are used as proxies for energy efficiency. EU limits exist for cars but not yet for heavy duty vehicles as opportunities for engine improvement and substitution are more limited. As emissions are measured on a tank-to-wheel basis, FCEV benefit from this type of policies, as they produce zero emissions at the tail pipe. PEMFC FCEV will meet even the strictest future Emission Standards. Solid oxide fuel cell vehicles are also likely to meet vehicle efficiency targets when using biofuels (e.g. bioethanol). These vehicles are likely to emit under 75 gCO_2e/km and therefore they will be excluded from the congestion charge. Ultra-low emission zones are not a driver		

for the uptake of FC powered lorries, as this only affects old vehicles not compliant with Euro 5 and upwards.

Table 7.7. Transport financing policies for hydrogen, FCEVs and infrastructure. T: Transport; H: Heating

Alternative Fuels Infrastructure Directive (AFID)	**System:** T	**Objective:** Energy security
Directive 2014/94/EU aims at developing a market for alternative vehicle powertrains, fuel technologies and infrastructure. Measures include direct and tax incentives for the procurement of FC vehicles and the building of infrastructure, facilitating authorisation processes and preferential access to parkings and lanes for H2FC vehicles.		
Enhanced capital allowances (ECA)	**System:** T	**Objective:** Energy and water efficiency, reduction of GHG emissions
Introduced earlier in Table 7.3. The ECA scheme allows businesses to deduct the full cost of FCEV (zero emissions company cars and goods vehicles) and refuelling stations and equipment, from the profits of the company before tax.		
FCEV Fleet Support scheme	**System:** T	**Objective:** Create a market / Information provision
Funded by Office for Low Emission Vehicles to promote deployment of hydrogen refuelling infrastructure and uptake of FCEV and hydrogen hybrid and dual fuel powertrain vehicles (cars and heavy goods vehicles with dual fuel and range extenders) by providing grants for the purchase and maintenance of such fleets.		
Local Sustainable Transport Fund	**System:** T	**Objective:** Economic growth / Reduction of GHG emissions

Provides funds to local authorities to deliver sustainable projects that support local development and cleaner environments. Could contribute to the development of local hydrogen supply chains by funding hydrogen refuelling infrastructure and the procurement of FC buses.

7.2.3.1 Refuelling infrastructure

Directive 2014/94/EU aims to develop a market for alternative vehicle powertrains, fuel technologies and infrastructure. Moving from oil towards alternative fuels will improve energy security and reduce the environmental impact of transportation [24]. Developing sufficient hydrogen infrastructure is considered as essential to increase the market share of hydrogen-powered vehicles, warranting market push. This Directive also encourages member states to deploy refuelling stations considering cross-border links to enable the circulation of the vehicles across the EU.

A range of policy measures is suggested:

- Direct incentives for purchasing hydrogen vehicles and building refuelling infrastructure,
- Tax incentives to promote these means of transport,
- Use of public procurement,
- Demand-side non-financial incentives, for example preferential access to restricted areas, parking policy and dedicated lanes,
- Technical and administrative procedures and legislation with regard to the authorisation of hydrogen supply, in order to facilitate the authorisation process.

7.3 A Green Hydrogen Standard

The UK's Fifth Carbon Budget recommends limiting the carbon intensity of the power grid to under 100 g/kWh by 2030 [8]. Any power generated from hydrogen and relevant technologies should meet this limit. There is currently no standard guaranteeing the environmental characteristics of a hydrogen source. However, numerous green hydrogen standardisation initiatives have been undertaken in recent years in several EU countries. This trend has not been observed in other countries, due to greater concern with the take-off of the technology than with the real benefits, as some see fossil fuels as unavoidable in the short-term.

Some of these initiatives define green hydrogen as being derived from renewable energy sources, while the definition intended by the UK Government is more focussed on the embedded carbon intensity. The latter allows hydrogen produced from nuclear power or fossil fuel with carbon capture to be considered as green. *Table 7.8* compares technical characteristics of green hydrogen standardisation initiatives. The definitions of these initiatives exclude other broader environmental objectives (e.g. air quality targets and water footprints) and other enhanced sustainability criteria (e.g. impact on biodiversity), mainly because these are not included in other bioenergy standards and it would create standard for hydrogen that are more stringent than for other energy sources.

Table 7.8. European Green Hydrogen standardisation initiatives.

Initiative / Country Origin	Policy Objective	Baseline GHG threshold	Qualification level	Qualifying processes	Boundary of the system
AFHYPAC (France)[2]	Renewable energy source	None	Must be 100% renewable	Renewable electrolysis; reforming of biomethane.	Point of production
BEIS (UK)	Reduction of CO_2 emissions	To be determined and revisable according to	To be determined. A single threshold differentiated according to end use (e.g. transport)	Any (technology neutral)	Point of production

[2] L'Association Française pour l'Hydrogène et les Piles à Combustible

		carbon budgets.			
CERTIFHY (EU wide)	Renewable energy source / CO_2 emissions	Hydrogen produced via SMR of natural gas	At least 60% lower than SMR[3] (this is ≤ 36.4 $gCO_2e/MJ\ H_2$ for the past 12 months)	Any renewable pathway as long as meet the qualification level. Purification quality 99.5%.	Point of production
Clean Energy Partnership (Germany)	Renewable energy source / CO_2 emissions	None for electrolytic hydrogen; H_2 produced via SMR of natural gas for hydrogen produced from biomass	For biomass-based hydrogen, lower emissions than the baseline, level not specified	Renewable electrolysis; hydrogen from biomass produced in certified green thermochemical or biological conversion processes.	Point of production
TÜV SÜD (Germany)	Greenhouse gas reduction potential	Hydrogen produced via SMR of natural gas or fossil fuels, depending on process	35-75% emissions reduction below baseline (which is 83.8-89.7 gCO_2e/MJ), depending on	Renewable electrolysis; steam-reforming of biomethane; pyro-reforming of glycerine.	Point of use

[3] The baseline carbon intensity considered by CertifHy for SMR is 91 $gCO_2e/MJ\ H_2$

			production process, and time phase		

As with renewable certification for electricity, standards for hydrogen must trace the origins of a homogenous product (hydrogen molecules), so that ‘brown hydrogen’ produced from fossil fuels can be distinguished from a premium lower-carbon ‘green hydrogen’. This is a challenging task as illustrated in the range of initiatives put forward. Before member states include the standard in their policy frameworks, they will have to agree the carbon intensity thresholds, the eligible feedstocks, the boundaries of the system (point of production or at the point of use), and a range of other administrative characteristics related to the Guarantees of Origin (e.g. expiration and value of a guarantee). So far, one of the key strengths of hydrogen has been excluded from all the proposals. The reason is that unless air quality targets are included in the Renewable Energy Directive and apply to biofuels, the green hydrogen standard would be unnecessarily restrictive and discriminatory for hydrogen.

7.4 Discussion

7.4.1 Buildings

The energy demand policy instruments that may influence H2FC in buildings (*Table* 7.1) do not mention these technologies explicitly. There is some room within current building regulations to interpret hydrogen as a mains gas and accept FC micro-CHP as an eligible technology within the Energy Performance Buildings Directive, Private Rented Sector, Salix loans and RHI schemes. A key objective of these instruments is improving energy efficiency of buildings; an area in which FCs excel, as reported in Chapter 4. Another objective is increasing the share of renewables, making it important to create a green hydrogen standard. Without a clear certification, despite being more efficient, FC do not necessarily contribute to meet this objective. This distinction is also fundamental for including hydrogen in the domestic RHI.

UK policy making lags behind in this area compared to countries such as Japan, where the ENE-Farm program has subsidised the purchase of 181,000 residential micro-CHP FC systems, and targets 1.4 million by 2020 and 5.3 by 2030 [27]. In the UK, the H21 Leeds City Gate feasibility study has explored converting the existing gas network to hydrogen [28]. In an interview, the gas distribution company acknowledged that a political mandate to switch from natural gas to hydrogen would be needed for the project to succeed, involving the conversion of domestic appliances. Such a mandate was used when the UK converted the town gas infrastructure to natural gas. There are, however, potential policy conflicts between the trend in heat electrification and the conversion of the gas network to hydrogen. Financing mechanisms would also be needed for roll-out of new appliances and the preparation of new safety standards and codes, and training for the engineers. Regarding energy security, generation could be more decentralised, it could incorporate greener hydrogen into the network over time, and it could take advantages of synergies between the power and heating systems thanks to power-to-gas technologies. Furthermore, if the final hydrogen quality is sufficient, the system could provide hydrogen for FC transportation modes as well.

7.4.2 Industry

Current policy instruments regarding energy demand in industry do not seem particularly effective at promoting demand for H2FC; however, via levies they could become a relevant financing source for projects of national interest. EU Policies regarding large and industrial corporations (*Table* 7.2) target carbon and air quality emissions. The Industrial Emissions Directive defines 'Best Available Techniques' (BAT) that may lead to more efficient industrial processes and lower emissions. BAT do not reflect the progress made with H2FC, as these are seldom included this technologies. Currently, the EU ETS allowances are too cheap and plentiful, and are not a relevant factor in promoting more efficient but also more expensive fuel cells. However, they can generate revenue for funding relevant projects such as CCS and hydrogen storage, but only with an order-of-magnitude higher carbon price. UK policy instruments that can play a similar financing role include the Climate Change Levy from the Climate Change Agreements and the Carbon Reduction Commitment. Perhaps the UK policy instrument that could have the major impact is the Enhanced Capital Allowance. This deducts project costs from taxable profits, which is an effective funding mechanism, despite H2FC technologies not being implicitly included, as some approved technologies can run with hydrogen (e.g. CHP, boilers).

The efficacy of other UK instruments related to industrial energy demand (*Table 7.3*) is less evident. For example, breaching the Climate Change Agreements carries a fee of £12/tCO_2e for those who wish to remain in the scheme. This means that hydrogen and its technologies are competitive only when their costs are inferior to the Climate Change Levy discount[4] and the cost of avoiding carbon emissions (£12/tCO_2). Above these floor prices, the incentives are either to not participate in the scheme (foregoing the rebate) or simply pay the penalty to remain. The Energy Savings Opportunity Scheme can have little impact because it is difficult to deliver cost-effective solutions for H2FC technologies with current levels of demand. The RHI does not take in consideration the role that FC micro CHP could play to provide renewable heat in industry and while it accepts biomethane, no reference is made to hydrogen. Having a green hydrogen standard could help to accept this quality of hydrogen in the same conditions as biomethane.

7.4.3 Electricity

Most energy policy instruments in relation to hydrogen production aim at reducing GHG emissions (*Table 7.4*). The IED has defined one hydrogen production BAT in regards to the chlor-alkali process (electrolytic production) and other BAT deal with FC components (e.g. catalyst materials, ceramics, etc.). The growth of hydrogen consumption for energy generation purposes may result in the development of new BAT for other production methods (e.g. SMR, Gasification).

Policies dealing with CCS are relevant to the success of hydrogen in the medium term, particularly for countries phasing out nuclear power. Hydrogen produced with fossil fuels cannot exceed the carbon intensity limits established by the CCC (e.g. 100 g/kWh by 2030) if it is to assist with decarbonisation.

[4] £1.88/MWh for natural gas, £5.41 for electricity, £12.10 for liquefied petroleum gas and £14.76/MWh for others

This is unlikely to occur without CCS or significant expansion of renewables. Unfortunately, the UK Government cancelled its three-year long CCS commercialisation competition weeks before the deadline in 2015 [30]. This abrupt change in policy broke investor confidence, and without policy support (particularly around the areas of insurance and long-term contracting), the private sector is unlikely to fund such schemes. CCS is restrictively expensive for carbon mitigation (various estimates around €60–150/tCO_2) [31, 32] which compares to relatively low carbon prices of £18/tCO_2 [33] with the UK's CPF and around £5/tCO_2 in Europe [34].

Hydrogen can play an important role in supporting the power grid via policy instruments that increase the use of renewables (Renewable Obligations, FiT) or provide energy security (CfD and capacity markets) (*Table 7.5*). Within the CfD, power generators could include hydrogen storage as part of their production costs. Long-term price stability would reduce investment risks and thus financing costs, supporting the deployment of this technology. This could be an interesting option for renewable generators as storing their surplus output as hydrogen could help them to decrease their production costs (e.g. wind, solar). Complex issues around double-counting of production must be resolved though. Small CHP is one area where FC technologies could be applicable for FiTs. Electricity generated from hydrogen that is produced from renewables is unlikely to claim a FiT because it cannot be claimed twice.

The capacity mechanism requires generators to provide power at times of system stress. Hydrogen can provide capacity from hours to a whole season, for applications such as transmission and delivery deferral, arbitrage and seasonal storage. Hydrogen could have an important role in providing energy security and reliability to the grid, but a policy change is needed to accommodate these technologies.

7.4.4 Transport

Transport energy policy instruments target a broad range of objectives (*Table 7.6* and *Table 7.7*). The Renewable Transport Fuel Obligations (RTFO) is a key policy, aiming to increase the share of renewable fuels from biological origin. So far, bioethanol, biomethane and biodiesel are eligible for these certificates. With uptake of FCEVs, renewable hydrogen can support the increase of renewable fuels, and also contribute to improve local air quality. The Department for Transport are considering whether to increase the range of eligible fuels to renewable fuels of non-biological origin DfT [35] . Hydrogen is one such fuel and this proposal opens the door to a broad range of pathways including electrolysis and methanol cracking. Any biological pathways should also be eligible provided they meet the sustainability criteria specified in the Renewable Energy Directive for biofuels. A successful proposal could have a significant positive effect on H2FC transportation by creating an incentive for hydrogen production. It is not clear how this could be managed without a Guarantees of Origin system, as suggested by green hydrogen standardisation initiatives.

Another important instrument for FCEVs is more stringent standards for energy efficiency and emissions. Competition in this regard will be between battery electric vehicles (BEVs) and FCEVs, rather than with fossil fuels. While BEVs are well suited for urban driving and city logistics of small lorries, FCEV strengths are longer range and power. This may result on FCEVs working in long-haul trucks, coaches and high-utilisation vehicles.

The UK aims at electrifying over half of the rail network by 2021 to replace diesel engines; however, there is not a clear roadmap explaining how this will be undertaken. Air quality is again an important driver, of special importance in urban areas, and so new class 66 diesel locomotives are no longer being delivered in the UK for failing to meet emission requirements [36].

The funding instruments for procuring FCEVs (*Table* 7.7) offer effective routes to increasing market share. The Local Sustainable Transport Fund could be used to deploy fleets of buses. Grants given by the Fleet Support scheme are enabling private companies to test commercial FCEVs and generate operational data to fill the remaining information gap for these novel technologies. This could prove influential in reassuring customers that the FCEVs are safe, mature and reliable. The Alternative Fuels Infrastructure Directive is a positive step; however, participation is voluntary and there are not specific targets for infrastructure. In contrast, Japan has very clear objectives for the number of FCEV cars

(800,000 units by 2030), buses (over 100 by 2020) and refuelling stations (320 high pressure by 2025 and 100 low pressure) [27].

7.4.5 Innovation needs

Although H2FC technologies are being commercialised in many areas, challenges must still be overcome. Cost and efficiency can be improved across production, distribution and end-use technologies. Hydrogen distribution is energy intensive, so novel transportation vectors (e.g. as hydrates, encapsulated within other materials), and modes (e.g. shipping tankers) are areas of continuous research. Innovation in the area of hydrogen storage is needed (e.g. nano-materials), and further advances will be made once enough large storage facilities are demonstrated (e.g. salt domes, enhanced oil recovery). Applications in transport are continuously being rolled-out (e.g. hydrogen trains, hybrid automotive powertrains, mobile refuelling stations, auxiliary power units). The synergies of hydrogen with energy systems (power, heat, transport) are an evolving research topic. New safety, codes and standards are still under development (e.g. a green hydrogen standard). H2FC supply chains require a new skills-base to research, develop and maintain these new technologies. To overcome the lack of technical skills, the KnowHy EU program is offering free training for technicians in the areas of FC for transport, handling equipment, micro CHP and auxiliary power units [37].

Research funding combines private and public sources (e.g. EU Horizon 2020, Innovate UK, Research Councils). In the UK, most of the budget from innovation policy goes to Higher Education; however, policy also stresses the relevance of local strategies for economic development. Many Local Enterprise Partnerships in England recognise innovation as a driver for their economic growth plans and have designed strategies to access EU funding [38]. The impact of Britain leaving the European Union on innovation is still unknown, as it is not clear whether the UK will be able to negotiate its participation in the Horizon 2020 program or if it will match the funds with a new national plan.

Hydrogen powertrains are an area of interest in the national industrial strategy as they could increase the exporting potential of the UK automotive sector. The UK is home to manufacturers of FCEVs (Microcab Industries, Riverside, Wright En-Drive), hybrid powertrains (ULEMCO) and electrolysers (ITM Power), plus global technology developers (Johnson Matthey) and numerous world-class universities active in H2FC research. With the right support, the UK is in a strong position to take a global leading position in the H2FC industry.

7.5 Hydrogen Policy in the Global Context

H2FC energy policies around the world are very contextual to the specific characteristics of each country, such as industrial capabilities and access to feedstocks, economic situation and the relative strength of different policy objectives (public health, air quality, climate change, energy security and affordability). The most proactive countries, members of the IPHE (International Partnership for Hydrogen and Fuel Cells in the Economy), have developed strategic roadmaps where hydrogen plays a significant future in the energy mix by 2050. This section presents the policies of some of those countries.

7.5.1 China

Currently there are few hydrogen refuelling stations (HRS) in China [39]; however, important policy initiatives were introduced in 2016. The National Development Reform Commission and China's National Energy Administration released "Energy Technology Revolution & Innovation Initiative (2016-2030)" and the "Energy Technology Innovation Oriented Roadmap"[39]. The objective of these programs is encouraging the uptake of H2FC technologies by 2025 and popularising them by 2050 [40]. China is very interested in developing FCEV manufacturing capabilities within its 'China Manufacturing 2025' program and to this end is setting up the 'New Energy Vehicle Technology Innovation and Demonstration Fund'. Furthermore, in the period 2016-2020 the Ministry of Finance is subsidising FC cars with £23,230[5], light duty buses and vans with £58,075 and £34,845 for fuel cell

[5] RMB in this paragraph converted to GBP using the 2017 exchange rate: £0.12 = ¥1

heavy duty buses and trucks [40]. Subsidies of £464,486 are also available for new HRS with a capacity of 200 kg H_2 or more [40].

In the period 2016-2020, the Chinese Government is funding H2FC and FCEV R&D and demonstration projects for a value of £90 million [39]. Also China is funding R&D with £20.3[6] million for ‘New energy vehicles’ pilot projects, where two of these are FCEV [40]. At local level, due to air quality issues, several cities have set plans for procuring FC buses (e.g. 100 in Beijing, 300 in Yunfu). China has adapted policy instruments to promote FCEV and refuelling infrastructure. Unlike petrol cars, FCEV are exempt from the lottery to obtain license plates; the consumers just have to queue until they can get one according to the quotas available for such vehicles. Other benefits include the access to high speed lanes [39].

Despite the poor penetration of H2FC technologies in China, there is a clear industrial strategy combining public and private investments to transform the country in a global leader of FCEVs. FC and vehicle manufacturers are establishing joint-ventures and partnerships with local companies to ramp up the manufacturing capabilities of the country; however, the lack of targets for deployment of the technologies in the local market suggest the country is interested in using these technologies in the short to medium term for economic growth and exports.

7.5.2 Germany

Germany follows the same EU directives than the UK and it also participates actively in research and development programs such as the Horizon 2020. Besides, the ‘Ministry of Transport and Digital Infrastructure’ (BMVI) contributed with €500 million from 2007-2016 to the ‘Innovation Programme for Hydrogen and Fuel Cell Technology’ (of a total of €1.4 bn). This project has been extended up to 2026 (known as NIP2); BMVI funds this with €50 million in 2016-2017 and more than €80 million from 2018 onwards [41] and the ‘Ministry for Economical Affairs and Energy’ with another €25 million per

[6] RMB in this paragraph converted to GBP using the 2017 exchange rate: £0.12 = ¥1

year [42]. The objective is to activate the market, develop demonstration programs and investing in R&D of F2FC technologies applied at the transportation sector [41] . BMVI has also allocated €7.9 million for deploying FC trains in non-electrified routes. According to Alstom, in Germany under half of the rail network is electrified and it would take 95 years at the current investment rate to complete the work; as an interim solution 200 fuel cell propulsion systems are being deployed over the next 10 years [43].

Germany has also very strong subsidisation programs and penetration targets to push efficient and renewable heating systems. The BAFA ('Federal Office for Economic Affairs and Export Control') provides a basic subsidy of €1,900 per each micro CHP FC of up to $20kW_{el}$ applied in the refurbishment of residential and commercial installations, a quantity that increases to £3,515 once additional heat and power bonuses are also taken in consideration [44]. Germany introduced in 2016 the kfW (Creditbank for Reconstruction) program 433 that provides an upfront subsidy for the procurement of fuel cells (0.25kWel-5kWel). This program has a budget of €500 million (for the period 2016-2024) and aims at installing between 60-70,000 domestic units per year. The targets are improving the reliability of the technologies and activating the market [45]. The program grants a basic subsidy of €5,700/unit plus €450 for each 0.1 kW_{el} [44]. This means that a $1Kw_{el}$ fuel cell is subsidised with €10,200, once the installation is finished. The KWK law is a subsidy similar to the UK FiT that gives financial support via annual payments for generated (€0.04/kWh) and exported power (€0.08/kWh) to the grid from heating systems (CHP) up to $50Kw_{el}$. According to Rosner and Appel [44] calculations this makes FC devices in a typical single German family house (4 people) almost 30% cheaper than incumbent condensing boiler gas devices (without the subsidies, the savings are around 18%). This scheme benefits the local industry greatly, as tree of the four major fuel cell micro CHP manufacturers are German (Bosch, Vailant and Viessmann). The country makes the most of EU funding for this type of devices. The FCH JU project 'PACE' will have deployed over 2,500 units by 2018, via a grant of almost €34 million. The intended objective is to generate economies of scale and reducing costs [46].

Rosner and Appel [44] identify subsidies, lobbying and technology reliability as the main success factors for the market penetration of H2FC technologies into the German market. German policies are also closely related to EU policy and decarbonisation is one of the main objectives. To meet with the new EU Alternative Refuelling Directive and with the support of EU funding, Germany emphasises the need to deploy enough HRS infrastructure. There are currently 23 HRS in Germany [39]. Germany considers that over 400 HRS, these start to become profitable. As a result, via the H2Mobility Germany joint venture, Germany is going to invest €350 million to deploy up to 400 HRS nationwide by 2023, regardless of the demand for hydrogen [47].

7.5.3 Japan

Japan policy targets for 2030 focus on achieving energy security (25% of self-sufficiency), economic efficiency (reducing electricity costs using nuclear and coal-fired thermal power generation) and reducing GHG emissions to similar levels to the EU and US [48]

Japan seems committed to achieve a hydrogen society by 2050. To this end, the country has a clear roadmap of how this can be achieved and to achieve this it expects to spend £7bn[7] by 2030 and £56.8bn by 2050 [40]. The immediate policy target in regards to H2FC for Japan is increasing the penetration of these technologies and investing in research and development. Japan understands that for the commercial success of H2FC, cost reductions are critical and this is more likely to be attained by achieving higher economies of scale and faster learning rates [49].

The strategic roadmap of H2FC in Japan follows three stages [50]. In the first one, the aim is to increase the use of stationary H2FC technologies for residential (micro CHP FC ~$700W_{el}/600_{th}$), commercial and industrial applications (cogeneration); the rolling stock of FCEVs and refuelling infrastructure. During this phase, it is likely that GHG emissions may increase, as hydrogen is produced via SMR.

[7] JPY in this paragraph converted to GBP using the 2017 exchange rate: £0.0071= ¥1

The Ministry of Economy, Trade and Industry (METI) new strategic roadmap includes a new target for 40,000 FCEVs by 2020, 200,000 by 2025 and 800,000 by 2030, a considerable increase from the 909 vehicles currently deployed. This will be funded via subsidies. In addition, Japan will deploy 100 buses in the Olympic games 2020, funded via subsidies for R&D and demonstration programs. For HRS the aims is to deploy 160 HRS (70 MPa) by 2020 and 320 by 2025 and 100 more at low pressure (35 MPa) by subsidizing capital and operational expenditure from central and local governments [27].

In 2016, under the ENE-FARM scheme, micro CHP PEMFC units cheaper than £10,069[8] were eligible for subsidies between £496-£1,063/unit and SOFC units under £11,984 were subsidised by £638-£1,347/unit [51]. Additional subsidies included the retro fit of devices (£212/unit). A secondary policy target of these devices is contributing to ensure energy security by providing power backup when earthquakes occur. METI expects that the number of small stationary FC will increase from the current 180,511 to 1.4 million by 2020 and 5.3 million by 2030 via procurement subsidies [27].

In the second stage (late 2020s), the hydrogen supply chain will be fully developed and hydrogen will become a fuel for power production. Some initiatives suggest that hydrogen from brown coal gasification could be imported from Australia to that end. In the last phase (late 2040s), a green hydrogen standard or similar will be implemented where the focus will shift towards the use of renewable hydrogen or low carbon hydrogen. By then, hydrogen pipelines will be installed in selected locations and the market is expected to be self-sustained as economies of scale will not require further public incentivisation [49].

The clear signs that the Japanese Government sends to the markets has allowed the birth of a very robust H2FC exporting industry, where almost 200,000 stationary CHP FC devices have been sold, and where two of the only three series FCEV manufacturers are Japanese (e.g. Toyota Mirai and Honda FCX). The Government clearly supports the industry and it will procure FCEV for the public sector. This approach is similar to the one applied by the USA.

[8] JPY in this paragraph converted to GBP using the 2017 exchange rate: £0.0071= ¥1

7.5.4 USA

The USA is a very active country in regards to H2FC policy making. The USA congress allocated for 2017 a budget of $105.5 million for investments in H2FC research and development, system analysis, technology validation, safety, codes and standards, market transformation and technology acceleration [52]. In contrast, the UK Parliament does not have an explicit budget, beyond the one given to Research Councils that indirectly can fund H2FC research.

The main USA incentives to promote hydrogen and fuel cell technologies include grants for eligible projects costs; tax incentives such as tax credits; direct loans, loan guarantees and leases; rebates for the purchase of hydrogen vehicles and sale of hydrogen; exemptions from restrictions and requirements such as access to high-occupancy vehicle lanes; and other requirements to disseminate rules and promote research groups and committees. At Federal level, there are eight main incentives (alternative fuel excise tax credit, fuel cell motor vehicle tax credit, improved energy technology loans, alternative fuel tax exemption, airport zero emission vehicle and infrastructure incentives, alternative fuel infrastructure tax credit, alternative fuel and advanced vehicle technology research and demonstration, and low and zero emission public transportation research, demonstration and deployment funding). At state level, there are another 262 incentives.

The USA currently funds eight programs that promote the uptake of H2FC technologies (Air Pollution Control Program, Congestion Mitigation and Air Quality (CMAQ) Improvement Program, Clean Cities, State Energy Program (SEP) Funding, Clean Construction USA, Clean Ports USA, Voluntary Airport Low Emission (VALE) Program, Clean Agriculture USA). While all of these programs focus on improving air quality standards, some have secondary objectives. The ‘Clean Cities’ program also targets ‘energy, economic, and environmental security’ and the State Energy program (SEP) aims at implementing renewable energy and energy efficiency programs and is the only one not targeting transportation. Except the SEP, all the programs focus on actions to reduce emissions from road (cars, heavy duty vehicles, port operations vehicles) and off-road fleets (e.g. agricultural vehicles, ground airport and seaport vehicles) [53].

USA Regulations focus mainly on vehicles acquisition or fuel use; driving or idling, registration or licensing; fuel taxes; fuel production or quality; renewable fuel standards or mandates; air quality or emissions; climate change or energy initiatives [54]. Public procurement initiatives are one of the key strategies to promote the uptake of FCEVs. The USA has five federal laws that promote the acquisition of such vehicles by state government and federal agencies by setting specific percentages in public fleets or allocating the costs among the whole fleet. For example, under the Energy Policy Act (1992) amended in January 2008, 75% of new light duty federal vehicles must be run win alternative fuels (e.g. fuel cell vehicles, hybrids, advanced lean burn vehicles and dual fuel vehicles running on biofuels). Executive Order 13693, issued in March 2015, also requires federal agencies with 20 vehicles or more to improve fleet and vehicle efficiency through the elimination of non-essential vehicles and achieve a 30% reduction of fleet-wide GHGs savings relative to a fiscal year (FY) 2014 emissions baseline by FY 2025. Furthermore, by 31-12-2020, and 31-12-2025, 20% and 50% (respectively) of light-duty vehicle acquisitions must be zero emission vehicles (ZEVs) or plug-in hybrid electric vehicles (PHEVs); and plan to install charging and other infrastructure to support them. The 'Procurement Preference for Electric and Hybrid Electric Vehicles' legislation determines that the US Department of Defence must create regulations that favours the procurement of vehicles with electric of hybrid electric propulsion systems (excluding tactical combat vehicles). Several USA states have set up a joint target of 3.3 million ZEVs by 2025, which includes FCEV [39].

In the USA, there are some success stories, such as the penetration of FCEV in California where there are 23 HRS with a further 100 expected by 2023 thanks to the $100 million pledged by the state Government. At Federal level, this infrastructure benefits from a tax credit of 30% of the cost up to $30,000 [39]. However, despite many years implementing H2FC demonstration and research programs, the uptake of such technologies by private customers nationwide is rather low. This could be explained by the fact that following the vast and diverse range of relevant regulations requires an extraordinary effort and there is a lack of policy consistency between each state. This lack of consistency could be detrimental for the promotion of these technologies at national level as it reduces the size of the internal market.

7.6 Conclusions

NREL [55] identified 30 years ago that hydrogen would be “a critical and indispensable element of a decarbonised, sustainable energy system”. They also recognised that hydrogen would “be derived from renewable energy sources, although fossil fuels [could] serve as a transitional resource”, and stressed the importance of hydrogen to provide energy security, cost-effective and non-polluting energy. Similarly, by 2003 the EU recognised the important contribution of H2FC technologies to meet energy security and climate change concerns [56]. These premises are just as valid today and growing in importance, yet these technologies are overlooked in most policy instruments.

H2FC energy policy making is very active in the EU, USA, Japan, China and Germany. Countries recognise the long-term potential of promoting these technologies to deliver objectives related to air quality, GHG emissions, energy security and affordability and/or economic growth. In the USA, policy is driven mainly by the need to improve air quality and most programs are related to transport. China has also serious air quality issues; however, the main objective is developing automotive manufacturing capabilities to deliver economic growth. In Japan, the policy objective is using hydrogen to deliver energy security, probably due to the demise in public acceptance of nuclear power. Germany’s main driver is reducing carbon emissions and it subsidises heavily domestic stationary installations. The country also focuses on the automotive and rail sectors, due to the global leadership of German manufacturers in those areas. Japan and Germany have a clear roadmap for the uptake of stationary and mobile H2FC devices with important subsidies, as achieving a critical mass is seen as fundamental to materialise economies of scale and reducing costs. In contrast, the UK does not have a defined roadmap with clear targets (beyond of the one defined by private groups such as one published by E4Tech and Element Energy [36]), and there are no explicit subsidies for stationary or mobile H2FC devices and FCEVs beyond the scheme promoted by OLEV in 2016 to deploy very few FCEV. The main policy lessons from other countries suggest that the consistency of policies and strong support for H2FC technologies result in high sales and economies of scale that improve learning rates and materialise considerable cost savings. The idea is that by reducing costs, H2FC becomes more competitive and this increases sales to a point where no more subsidies are necessary.

The main UK energy policy drivers for H2FC technologies are related to mitigating environmental emissions, improving energy efficiency, energy security and delivering economic growth. A secondary objective in some policies to increasing renewable energy content, which neglects pathways that are equally able to meet the above aims (e.g. GHG reduction and air quality), but are not renewable. The UK Government defends a technology neutral approach in policy making; however, many of the policy instruments reviewed implicitly exclude H2FC technologies. A broader interpretation of these policies could accept hydrogen as a 'mains gas', or fuel cell micro-CHP as a form of CHP. Developing a green hydrogen standard will help to facilitate its recognition in reducing carbon emissions or increasing renewable energy shares.

High capital costs are one of the main weaknesses of H2FC technologies due to low economies of scale. Operating costs can also be higher compared with incumbent technologies, and the lack of refuelling infrastructure is a key constraint for uptake of fuel cell vehicles. Countries such as Germany, understand this and are investing at a large scale to provide the incipient infrastructure to help drive FCEV sales up and make the deployment of further infrastructure profitable. As has been seen with other technologies, notably solar photovoltaics, national governments can play a crucial role in stimulating uptake can lead to manufacturing scale-up and competition between private firms, which leads to dramatic cost reductions. The cost of fuel cell vehicle powertrains is expected to converge with that of battery electric vehicles within 10–20 years, and the cost of stationary fuel cells is falling at a comparable rate to wind and solar power. The potential for cost parity with incumbent technologies exists, if market growth can be fostered. Demonstration projects that will enable learning-by-doing to decrease prices in the long run are necessary at the early stages for hydrogen, as with other technologies.

Hydrogen is a very flexible carrier that can be integrated in the power grid but also in heating networks, thanks to gas-to-power, gas-to-gas and power-to-gas technologies. Due to its contributions to energy security and stabilising highly-renewable electricity systems, policy makers should consider the particularities of hydrogen when defining policy instruments aiming at improving the capacity and reliability of the energy systems.

Evidence suggests that despite limited policy intervention, H2FC technologies are reaching a commercial stage and are competitive in several niche applications However, stronger policy signals can yield substantial benefits, as shown in the number of home heating systems and vehicles deployed in Japan, and the strength of Japanese manufacturers; Germany follows the lead. With the right policy support, the UK is in a strong position to claim a leading role in the H2FC industry through a commitment to innovation and manufacturing capabilities.

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