UK H2Mobility communication addressing hydrogen myths and misconceptions

Executive summary

UK H2Mobility is an industry grouping of industrial partners that works with Government and 3rd parties to accelerate the development of hydrogen mobility as a viable decarbonization solution for the UK.

Figure 1: UK H2Mobility 2022 Members

Hydrogen mobility is a solution for decarbonising transport across a number of transport segments. Hydrogen and fuel cell technologies are now reaching a state of maturity that will allow the technology to be deployed globally as a reliable and cost-effective direct replacement for fossil fuel vehicles. Hydrogen fuel, the fuel cell and other vehicle components, can be made from abundant resources. Fuel cell electric vehicles (FCEVs) offer a similar refuelling experience and range to the fossil fuelled vehicle in use today. Supporting hydrogen mobility also helps to upskill and create new jobs across the UK energy sector, as the global hydrogen economy and associated supply chains continue to develop.

Despite this, hydrogen transport has been subject to criticism from lobbying bodies[1, 2] and a number of myths around hydrogen transport have filtered into public consciousness. These have often provided a rationale for the limited support which hydrogen transport receives in the majority of transport sectors. These arguments are perceived by the hydrogen industry and UK H2Mobility members as damaging to the UK's goal of accelerating decarbonization, and some are founded on outdated information.

This document aims to address these arguments. Figure 2 sets out the four key arguments to be addressed in this document and a summary response from UK H2Mobility. Subsequent pages provide a more detailed analysis of each myth.

[1] Hydrogen Science Coalition | Bringing an evidence based viewpoint into the political discussion on hydrogen (h2sciencecoalition.com)
[2] Hydrogen as a fuel - The Centre For Sustainable Road Freight (csrf.ac.uk)

Hydrogen myths	UK H2Mobility response
Myth 1 **Efficiency** "The efficiency of fuel cell vehicles is too low and would result in additional strain on the electricity production sector"	**FCEV efficiency has increased 300%** • Efficiency improvements across all FCEV types • System grid benefits of hydrogen balancing supply and demand help accelerate grid decarbonisation. • Analysis on a fleet level improves efficiency picture.
Myth 2 **Price** "The price of hydrogen and fuel cell electric vehicles (FCEVs) are prohibitively expensive for widespread adoption outside of a few niche use cases"	**60% cost reductions in 12 years**[3] Fuel cell vehicle costs have fallen dramatically and price parity with BEV is expected by mid 2020s and with ICE by 2028[4].
Myth 3 **Technology Readiness** "The technology readiness and reliability of hydrogen vehicles is too low to support widespread adoption of the technology"	**Significant reliability increases** Fuel cell passenger cars (for example, Toyota's Mirai) and buses (ie Wrightbus), have reached series production. FCEV sales increased 82% in 2021[5].
Myth 4 **CO_2 impact** "The CO_2 impact of hydrogen is too high for effective decarbonisation of road transport"	**New production is ultra low CO2** All new hydrogen production capacity will necessarily be ultra low carbon. By-product hydrogen allows for infrastructure to develop in concert with green-hydrogen production.
Additional benefits of investing in the hydrogen economy **UK Jobs & Skills** **Low socialised infrastructure costs** **Long term abundance of construction materials** **Less adjustment for commercial operations** **Lower reliance on a single technology**	

Figure 2: Synopsys of UK H2Mobility position

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[3] Fuel Cell Cost Decreased by 60% since 2006 | Department of Energy
[4] Deloitte-Ballard Joint White Paper Assesses Hydrogen & Fuel Cell Solutions for Transportation
[5] 'Hydrogen car sales almost doubled last year

Vehicle Efficiency

Summary of the argument against hydrogen

"Hydrogen vehicles are less efficient than battery electric vehicles and their deployment wastes the finite amount of renewable electricity production that we currently have."

UK H2Mobility Evidence

Whole System efficiency favours hydrogen

The arguments against hydrogen on an efficiency basis focus on the thermodynamic losses from energy transitions. These will decrease over time, as more efficient systems are designed and R&D into new technologies makes them cost-effective (see *Improving Fuel Efficiency* section), however, hydrogen is projected to remain less efficient than battery solutions when compared using the same electricity as an input to the process.

Hydrogen vehicles and battery electric vehicles, however, do not use the same electricity as the energy input to their processes. The electricity used for hydrogen vehicles can be produced weeks or months prior to vehicle fuelling and stored as hydrogen for this interim period. This contrasts with battery electric vehicles that rely on stable electricity available at the point of demand when the charging system plugs into the grid. This temporal shifting of electricity consumption, through the use of hydrogen, brings with it numerous system efficiency benefits, and hence this needs to be considered when discussing vehicle efficiency. The argument for hydrogen on an efficiency basis is summarized below in Figure 3.

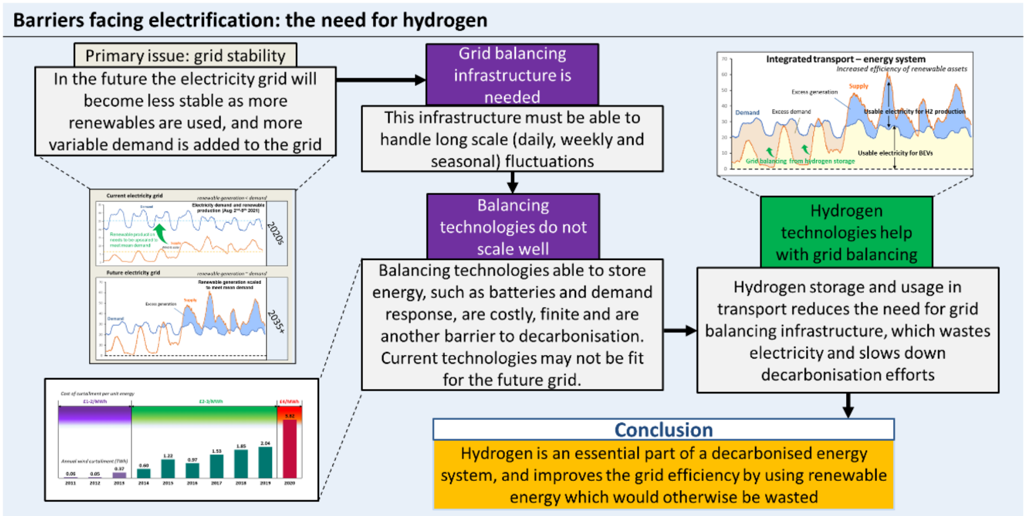


Figure 3: Overview of the system efficiency argument for hydrogen

The current electricity grid relies heavily on fossil fuel production sources to manage intermittent demand (and supply). During 2021, wind and solar generation contributed 25% to the total electricity grid demand[6], with the majority of the long-term grid balancing achieved by varying the generation of electricity from natural gas.

[6] Energy Trends: UK electricity - GOV.UK (www.gov.uk), ET_5.1_MAR_22.xlsx (live.com)

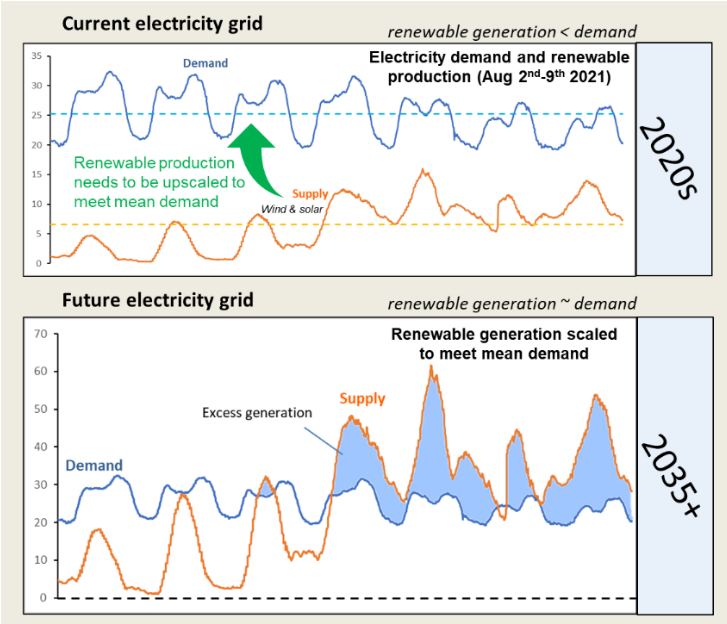


Figure 4: Current and future electricity grid comparison (GW)

As the grid decarbonises, the renewable generation capacity will need to be upscaled, leading to large weekly and seasonal fluctuations in raw electricity production as illustrated in the 2035+ scenario illustrated in Figure 4. There will therefore be an increasing need to efficiently match demand to supply.

Hydrogen is the most scalable, non-fossil, way to balance the electricity grid during periods of high electricity production by using this excess renewable energy to produce hydrogen. Hydrogen storage can be low-cost and efficient and does not require large volumes of raw materials. There is no technology available today which can provide storage for electricity over a period of months at the scale required to maintain a stable electricity grid, aside from conversion to chemicals such as hydrogen. Evidence of this can be seen in BEIS' study on modelling the 2050 electricity system[7], which concluded that: a scenario that includes hydrogen as an energy vector results in lower system costs than a grid without hydrogen, and that carbon intensities between 5-15gCO_2/kWh by 2050 are achievable in an economically viable fashion with hydrogen (compared to 10-25gCO_2/kWh without hydrogen). Thus, without hydrogen, decarbonizing the grid will not only be slower but also more costly to end users by 2050.

In addition to the longer term trajectory, grid balancing is an issue today. An increasing portion of renewable energy in the UK is curtailed, as shown in Figure 5, to the cost of close to £300M in 2020 for electricity users. Increasing intermittent, renewable power production has increased the cost of curtailing power on a per kWh basis four-fold since the early 2010s. This results in high network costs, which currently make up c.20% of household electricity costs (2021) and are projected to rise considerably. The net outcome of this congestion is that renewable developers struggle to get grid connections in certain areas, and when it is possible a portion of their generation capacity is wasted, resulting in under-exploitation of natural offshore resources around the UK and higher electricity prices.

[7] Modelling 2050: electricity system analysis (publishing.service.gov.uk)

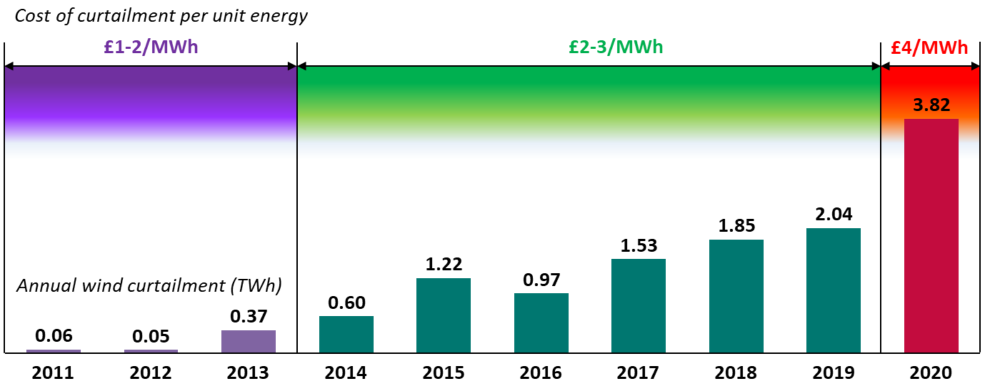


Figure 5: UK Annual Wind Power Curtailment, data taken from Electric Insights[8]

Hydrogen mobility uptake helps to decongest the grid and enable additional renewable energy generation. As outlined above hydrogen production will help to stabilise the grid by increasing demand at peak times of renewable production and reducing demand during high electricity demand periods. Electrolysers can also be connected direct to renewable assets, bypassing the grid entirely.

However, the hydrogen produced needs a viable end market to support the capital investment in electrolysers. Hydrogen mobility is one of the most likely first mover markets for hydrogen, with OEM products already available for car, bus and van products, and more products expected for trucks and heavy-duty sectors over the coming years. Currently, hydrogen production from electrolysis is at a small scale, and does not use a significant portion of the excess generation capacity from today's grid. Without significant scale up of the hydrogen mobility industry, this will continue to be the case and grid balancing issues will continue to result in wasted electricity and a slowing down of new renewable penetration.

Investment in hydrogen mobility will not only help to reduce prices to electricity end users, but will also improve the overall grid efficiency and decarbonisation speed when considered as a system rather than an isolated chain. Hydrogen can increase renewable deployment by providing a viable offtaker in locations where grid connections are not possible, whilst in locations where grid connections are possible, nearby hydrogen mobility offtake reduces local and national grid balancing issues, which in turn helps more renewable power to be added onto a more stable grid.

[8] Record wind output and curtailment | Q4 2020 Quarterly Report | Electric Insights

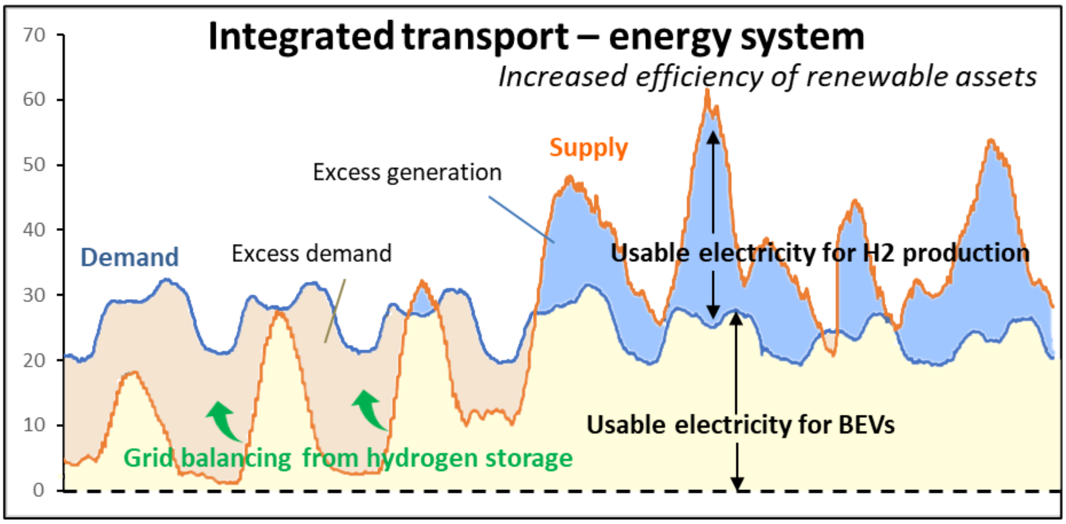


Figure 6: Integrated system approach to decarbonising transport (Units: GW)

By fully encouraging both hydrogen and battery vehicle uptake, without caveats of ruling out an option based on siloed energy efficiency analysis, both sectors will develop and produce zero carbon solutions that satisfy the requirements of customers and fit well within a zero carbon energy system. Economics can be a driving force in this system, to ensure that energy is used most efficiently for the whole energy system: a hydrogen and electric fuel solution will allow hydrogen producers to capitalise on low electricity prices during high production periods, whilst keeping grid balancing costs low for BEV users during periods of excess demand. In addition, it is critically important that the final decarbonisation solution is viable for the end user from a price and operational capability perspective, particularly in the current environment of increasing fuel and electricity price increases and the energy security issue. The issue of price is explored further in the second section to this report, *Vehicle and hydrogen price*.

The remainder of this section outlines other arguments which are worth considering in addition to the energy system benefits argument discussed above. The topic of hydrogen vehicle efficiency compared to batteries is a complex issue, with many facets to consider, hence the need for an addendum to the commentary above.

Additional factors

End use comparison

The efficiency comparison between FCEVs and BEVs is typically done on a kWh/km basis, i.e. based on calculations under the assumption that one mile driven in a fuel cell vehicle is directly comparable to that of a BEV. This is not the case for the majority of vehicle operators, since hydrogen vehicles offer improved mileages and refuelling times, and are lighter vehicles than their BEV equivalents (crucial for weight limited commercial vehicle operations); the 2022 Toyota Mirai has a vehicle range of 402 miles and an estimated fuelling time of 5 minutes[9]. This results in fleet productivity gains for FCEVs, and analysis on this fleet level is more appropriate than direct comparison between vehicles. When considering entire vehicle fleets for commercial transport, the increased productivity of hydrogen results in less vehicles needing to be bought, less dead mileage, less strain on supply chains, a lower carbon footprint, lower space requirements on depots and lower costs to the customer in terms of vehicle capital and maintenance investments. The cumulative

[9] 2022 Toyota Mirai Specs & Options

effect of this is that the system is more efficient and wastes less energy e.g. in vehicle construction, depot conversion infrastructure, or fuel used during dead mileage. This paper recommends that a holistic approach is taken when evaluating the energy efficiency of different technology solutions.

Improving fuel efficiency

Hydrogen mobility and battery electric technologies are not at the same technology readiness level, and have not had the same historic investment from the UK Government. Electricity production and transmission have benefited from centuries of state subsidy, research and development and scale up. Similarly, battery technology has improved dramatically due to the mobile electronics boom from the 80-00s and even electric motors have now been in mass production in hybrid vehicles since 1997[10]. The technology to produce, supply and use hydrogen for mobility is still nascent and has rapidly improved in efficiency in the last 10 years (see Figure 7). These rapid improvements mean that efficiency comparisons are therefore often made using outdated numbers.

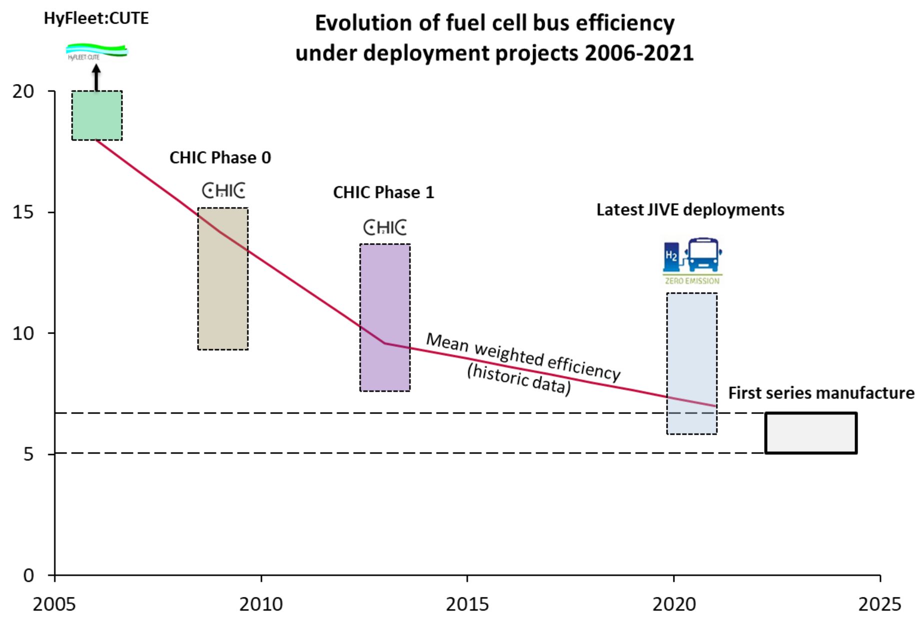


Figure 7: Historic improvements in fuel cell bus efficiency

The bus sector was amongst the first to develop for hydrogen fuel cell technology, with buses deployed under the HyFleet:CUTE project over a decade ago. These vehicles had an average fuel consumption of over 18 kg/100km, which has subsequently fallen significantly through drivetrain optimization to close to 6 kg/100km for the latest deployments under JIVE 2, a remarkable 300% improvement in efficiency. These kind of efficiency improvements are common across all fuel cell transport modes.

Hydrogen production is also becoming more efficient as the technology matures. Incumbent alkaline and polymer electrolyte membrane electrolysis technologies have seen efficiency improvement from scale-up of between 17-30% to around 70% system efficiency[11]. New technologies are being developed to improve electrolyser efficiency, resulting in more

[10] https://global.toyota/en/prius20th/evolution/#:~:text=The%20first%2Dgeneration%20Prius%20was,mass%2Dproduced%20hybrid%20passenger%20vehicle.
[11] https://www.sciencedirect.com/science/article/pii/S0360319917339435#tbl1

hydrogen being produced per unit of electricity input. As solid oxide electrolyser technology continues to decrease in price, a switch to SOECs combined with combined waste heat utilisation would increase production efficiency to c.80%[12], whilst novel research into high-performance electrolysis cells have demonstrated that efficiencies above 95% are possible[13, 14]. Therefore, it is highly likely that the hydrogen supply chain efficiency will continue to improve as demand increases.

Efficiency of hydrogen production from other sources

The above arguments have focused on hydrogen production with electricity as the starting point, however, if other hydrocarbon based energy sources e.g. biological sources are considered as a starting point then the energy efficiency of the BEV and fuel cell vehicle energy chain is approximately equal, due to the higher conversion efficiency of gasification technology (around 90% on a HHV basis[15]) compared to burning biomass to produce electricity. In addition, whilst reformation of natural gas is not a zero-carbon solution, it can be made ultra-low carbon or even negative carbon via use of biological feedstocks and carbon capture and storage (see below section, *CO2 impact of hydrogen*).

Vehicle and hydrogen price

Summary of the argument against hydrogen

"Hydrogen vehicles are more expensive than battery electric vehicles to buy and hydrogen fuel is currently approximately four times more expensive than electricity, assuming 16p/kWh and £10/kgH$_2$ dispensed hydrogen price, a value representative of present day prices from hydrogen refuelling stations (HRS)."

UK H2Mobility Evidence

The purchase price of hydrogen vehicles has dropped demonstrably and the most developed sectors are targeting diesel hybrid parity by c. 2025. The 2022 Toyota Mirai FCEV is priced at £49,995[16], representing a substantial drop from the sale price of £66,000 of the previous generation which applied for five years previous. In more developed hydrogen markets such as the US the Mirai is selling at the equivalent of £37,000[17] (comparable to a Tesla Model 3 Long Range). This trend is mimicked in other sectors, as demonstrated by the reduction in fuel cell bus price over the previous decade (see Figure 8), with several OEMs considering commercial rollout at capital costs below €400,000 per bus.

12 Solid Oxide Based Electrolysis and Stack Technology with Ultra-High Electrolysis Current Density and Efficiency (energy.gov)
13 A high-performance capillary-fed electrolysis cell promises more cost-competitive renewable hydrogen | Nature Communications
14 Our technology | H2Pro
15 Life Cycle Assessment of Hydrogen Production via Natural Gas Steam Reforming (nrel.gov)
16 Mirai Design 4 Door Saloon | Toyota UK
17 2022 Toyota Mirai Fuel Cell Vehicle | Innovation is Power

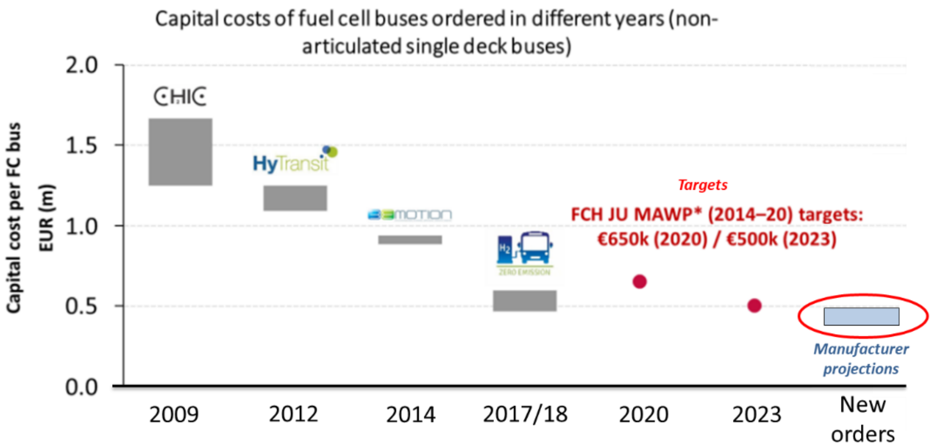


Figure 8: Reduction in fuel cell bus prices from CHIC to JIVE[18]

The hydrogen industry has, over the past decade, effectively demonstrated that hydrogen vehicles have a cost competitive future, despite receiving a very small fraction of the total Government support for zero-emission vehicles.

Hydrogen fuel costs have the potential for dramatic cost reductions as the supply chain matures and the demands scale up. Current high prices from the current generation of hydrogen stations are high due to the small stations being poorly utilized. The station capital depreciation therefore adds significant cost to the hydrogen on a £/kg basis as shown in Figure 9.

Similar to vehicle prices, station capital costs have also fallen and will continue to fall as the supply chain matures. However, the most powerful driver for fuel cost reductions will be the increasing demand at stations from new vehicle deployments across a range of vehicle modes. Real-world deployment projects for next-generation large hydrogen stations done by the UK Aggregated Hydrogen Fright Consortium[19] have returned quotes for UK hydrogen prices in the range of £6-8/kg (prior to the energy security crisis), a 20-40% reduction from current stations. European Commission president Ursula Von der Leyen has announced an ambition for green hydrogen production costs below €2/kg by 2030, which, after transport and dispensing, positions hydrogen to be substantially cheaper than taxed diesel today.

[18] JIVE 2 | Fuel Cell Electric Buses (fuelcellbuses.eu)
[19] Aggregated Hydrogen Freight Consortium (uk-ahfc.co.uk)

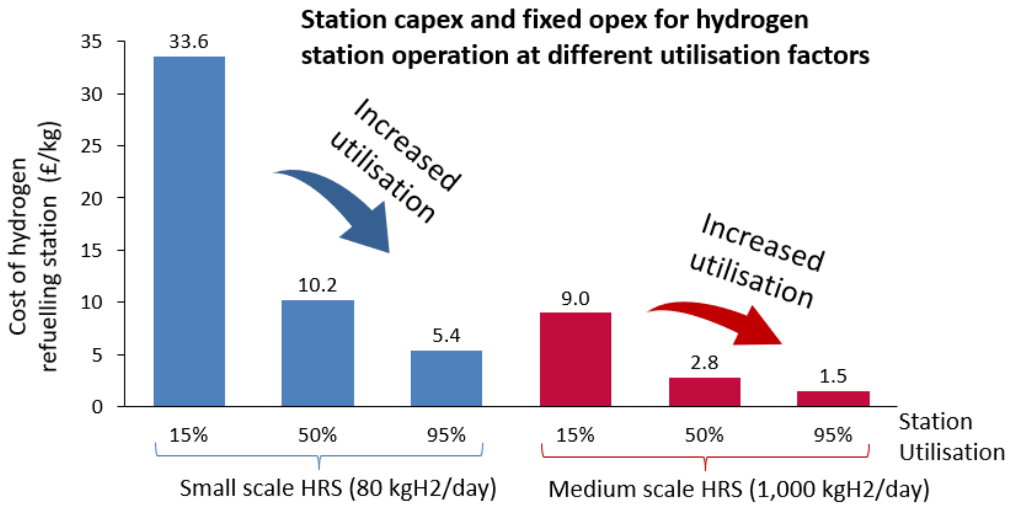


Figure 9: Station contributions to hydrogen price (not including hydrogen production and transportation costs) - Element Energy modelling

The price of hydrogen production is also expected to fall, due to decreasing levelized cost of electricity (LCOE) for offshore renewable production (see Figure 11), decreasing electrolyser capital costs and increasing electrolyser efficiency. Government targets for 10GW of hydrogen production by 2030[20] and the BEIS Hydrogen Investor Road Map shown in Figure 10 show that the UK will scale its clean hydrogen production capacity by c.1000 times over the next 8 years from <10MW in 2022. Scale will be a major driver for hydrogen production price reductions.

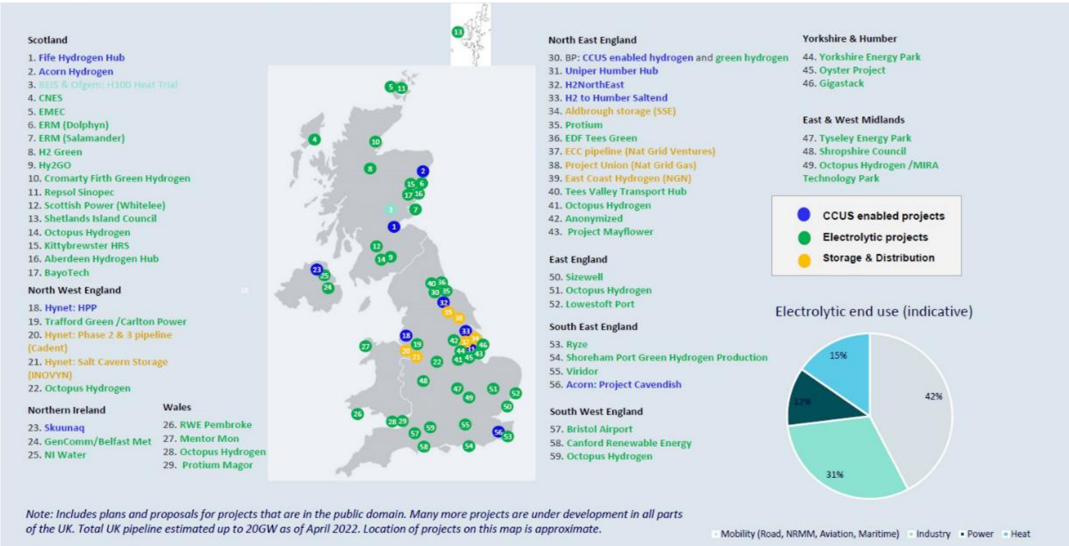


Figure 10: Publicly announced plans for hydrogen production projects in the UK[21]

In addition to the reduction in hydrogen production cost, the differences in the supply chains for hydrogen and electricity will improve the dispensed price of hydrogen relative to electricity. End user electricity prices have increased over the past decade, which is at odds with the decreasing unit cost of producing renewable energy, as shown in Figure 11. This

[20] https://www.gov.uk/government/publications/british-energy-security-strategy/british-energy-security-strategy
[21] Hydrogen Investor Roadmap (publishing.service.gov.uk)

disconnect illustrates the economic driver for electrolytic hydrogen because hydrogen can be produced at the point of electricity production via direct connection, hydrogen producers can access the low-cost renewable power price without paying for a costly grid supported by natural gas. Consumers of grid electricity require renewable energy to be balanced and transmitted to their point of demand, which is a major barrier for decarbonisation as outlined in the *Vehicle Efficiency* section above, and adds additional cost on to the price of electricity leading to some of the price increases seen.

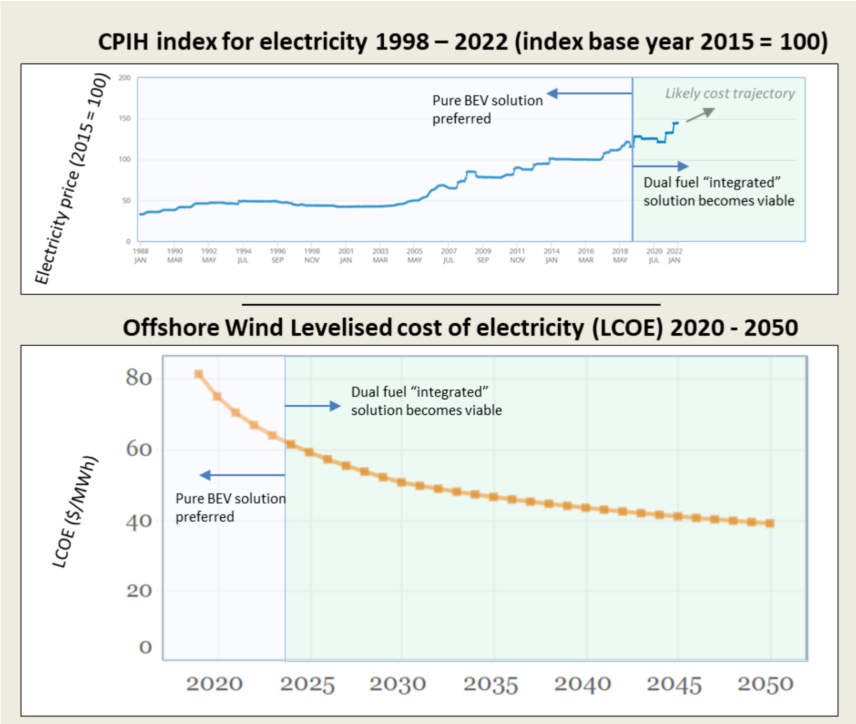


Figure 11: Comparison of consumer electricity price[22] and offshore wind production costs[23]

Furthermore, hydrogen supply chain costs will also reduce with scale as new technologies like liquid hydrogen and the conversion of the gas grid to accept hydrogen[24] unlock opportunities for lower cost, bulk hydrogen supply from very low cost hydrogen production geographies.

Combining these factors into a model for the operating cost of hydrogen trucks compared to battery solutions (see Figure 12) and it is evident that, once demand for large scale stations can be achieved, hydrogen becomes competitive with BEV options at current electricity prices by mid-late 2020. There is significant uncertainty in the current electricity market, however, if the energy security crisis were to continue to inflate prices, then hydrogen could outcompete BEV fuel cost within this decade.

[22] CPIH INDEX 04.5.1 : ELECTRICITY 2015=100 - Office for National Statistics (ons.gov.uk)
[23] Offshore Wind | Electricity | 2021 | ATB | NREL
[24] Energy Networks Association – Britain's Gas Grid to Be ready to deliver Hydrogen across the country from 2023

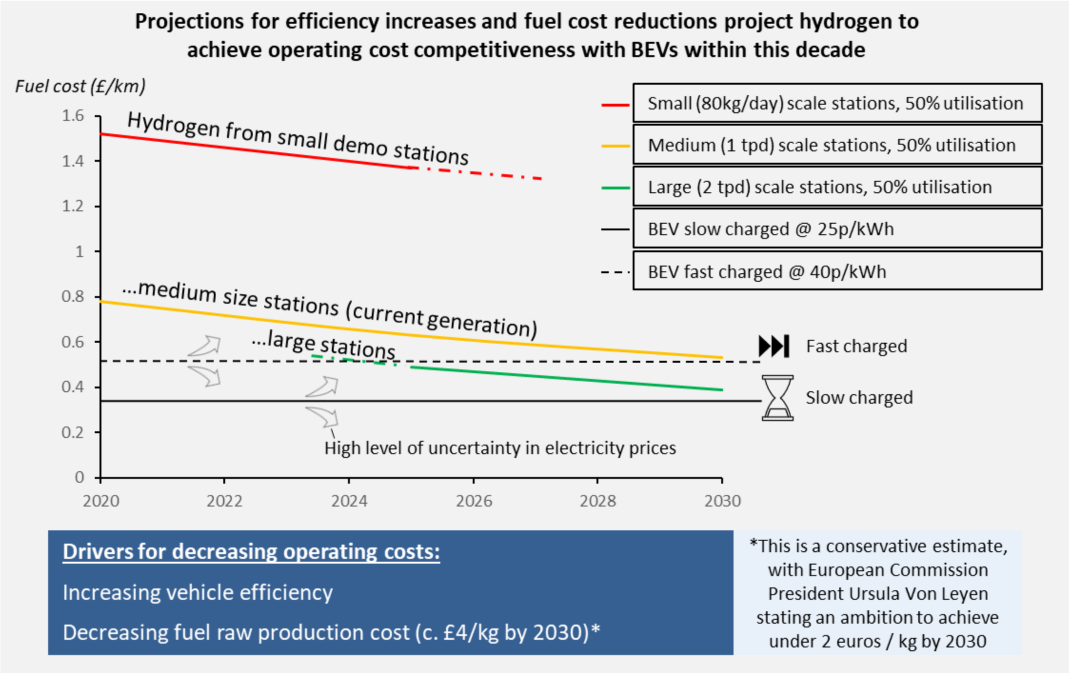


Figure 12: Hydrogen truck fuel costs compared to BEV (UK articulated trucks)[25]

Station and vehicle performance

Summary of the argument against hydrogen

"Hydrogen vehicles and stations perform unreliably and are not ready to be used in commercial operations beyond demonstration purposes."

UK H2Mobility Evidence

Vehicles

Fuel cell vehicles have matured to a point where numerous global vehicle manufacturers now have credible hydrogen products on the market which have been proven to perform reliably, and the number of companies looking to deploy hydrogen vehicles in the UK is increasing. Toyota Mirais and Hyundai Nexos have been operating reliably on UK roads for over 5 years. Jaguar Land Rover are developing a fuel cell passenger car, Renault and Vauxhall are developing van models as well as a wealth of UK SMEs. In the heavy duty sector, Wrightbus are selling commercial numbers of fuel cell buses, CaetanoBus in partnership with Toyota have deployed fuel cell buses, and Alexander Dennis and Optare have development programs. Hyundai are manufacturing hundreds of fuel cell trucks (with advanced plans for series production of trucks starting 2025-27 from Daimler, Volvo and Iveco) and Alstom's fuel cell Breeze train is poised for UK deployment.

[25] Main assumptions: BEV truck consumption: 1.3 kWh/km, H2 truck consumption: 10kg/100km (2020), 7.5 kg/100km (2030), H2 production costs: £8/kg (2020), £4/kg (2030), Distribution costs: £2/kg (2020), £1.5/kg (2030), RTFO subsidy: £5/kg (2020), £3/kg (2030), Station cost: £1.40 - £10.20 (dependent on HRS size)

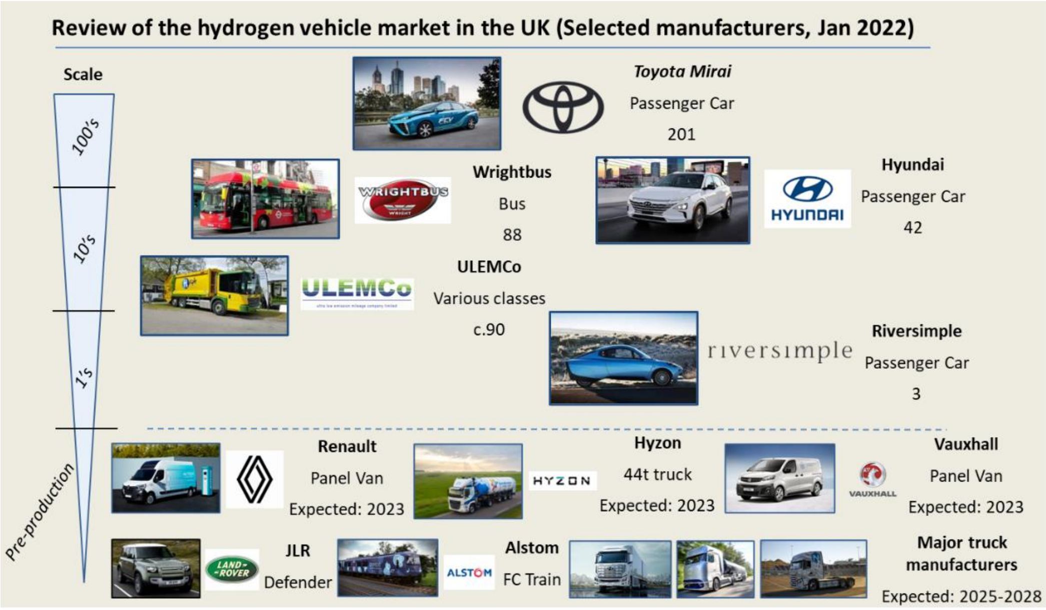


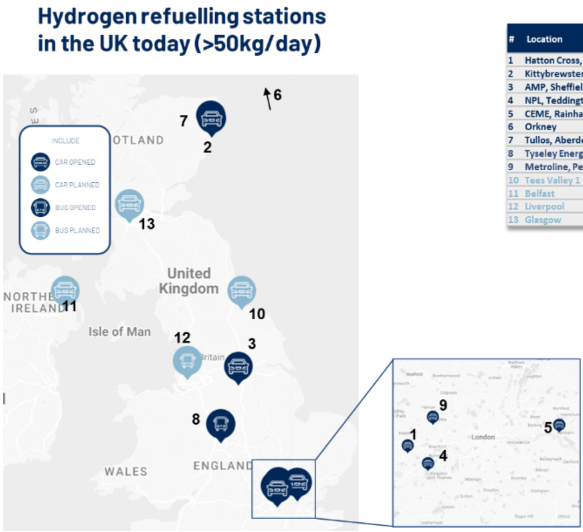
Figure 13: Hydrogen vehicle products coming to the UK market

Early vehicle prototypes experienced teething issues but the later generations of products from major manufacturers have delivered an impressive level of reliability, with latest feedback from the European JIVE bus project indicating that bus performance issues are now more akin to diesel bus issues and are far better than experienced in the previous FC generation. Numerous taxis, buses and vans have seen high levels of utilisation (over 50,000 km/year) without major fault (over 99% overall availability in the H2ME project)[26], and the technology is now at a readiness state to deploy at scale. Globally, the commercial operation of fuel cell vehicle fleets is proving to be viable: HysetCo (operated by Hype), a French hydrogen taxi firm, operates over 200 vehicles in Paris; Toyota and DRIVR have deployed 100 Mirai hydrogen taxis in Copenhagen and Clevershuttle, a ride-pooling startup, operates Mirais in Germany. The Hyundai Hydrogen Mobility project has successfully deployed 50 trucks to date in Switzerland with plans for further hundreds of vehicles by 2025.

Stations

The hydrogen refuelling station (HRS) reliability has been a key question to address which has limited the growth of the hydrogen industry. As of September 2022, the UK has a small hydrogen station network of 9 operational stations in the UK, the majority of which are resulting from early research and development projects or from the hydrogen transport program (HTP)[27], which funded a number of stations across the UK. 6 of these 9 stations are small with dispensing capabilities of less than 100 kg/day, only able to refuel c.20 cars per day and not suited to commercial vehicle operation.

[26] H2ME Vehicle and Infrastructure Performance Report
[27] Hydrogen for Transport Programme (HTP) (ricardo.com)



#	Location	Operator	Capacity (kg/day)	Pressure (bar)	H_2 source	Launch
1	Hatton Cross, London	Air Products	80 (250)	350 & 700	Delivered SMR	2012 (2021)
2	Kittybrewster, Aberdeen	BOC	360	350 & 700	On-site WE	2015, 2018
3	AMP, Sheffield	ITM Power	80 (540)	350 & 700	On-site WE	2016 (2022)
4	NPL, Teddington	ITM Power	100	350 & 700	On-site WE	2020
5	CEME, Rainham	ITM Power	100 (270)	350 & 700	On-site WE	2016 (2021)
6	Orkney	ITM Power	80	350	On-site WE	2016
7	Tullos, Aberdeen	Aberdeen City Council	80	350 & 700	On-site WE	2017
8	Tyseley Energy Park, Bham	ITM Power	1,200	350 & 700	On-site WE	2021
9	Metroline, Perivale	Nel/Ryse	1,500	350	Delivered WE	2021
10	Tees Valley 1	TBC	TBC	TBC	TBC	[2023]
11	Belfast	Energia	TBC	350 & 700	On-Site WE	[2022]
12	Liverpool	N/A	TBC	TBC	TBC	TBC
13	Glasgow	N/A	TBC	350 & 750	Delivered	[2023]

Figure 14: Status of the hydrogen refuelling network in the UK

Small station scale reduces reliability as the station economics make it unfeasible to invest in the required equipment redundancy and ongoing maintenance to achieve high reliability. In addition, smaller stations typically have less inbuilt redundancy with typically only one dispenser deployed, meaning the system acts in a linear manner and requires downtime if any component in the system has a fault. At higher station capacities, with greater utilisation, it is more economic to ensure that multiple dispensing systems are installed in parallel to allow filling of multiple vehicles, hence increasing the reliability that a dispenser will be operational on site even in the event of an issue with a given component. Therefore, hydrogen stations follow a typical bathtub curve (Figure 15) where dispensing greater volumes of hydrogen increases reliability.

The link between station size and reliability is evidenced in the UK by the 9 smallest UK stations achieving an average availability of c.91% compared to the BOC Kittybrewster station in Aberdeen, the largest of the first generation stations, which has historically operated with over 99% availability. There is an encouraging trend to transition to larger scale stations, with the ITM station in Birmingham the latest to open fully with a maximum capacity of 1,200kg/day in December 2021. Therefore, with the scale of demand increasing at fuelling stations, not only the price of hydrogen but also the reliability performance for the UK hydrogen station fleet is expected to increase to levels which are appropriate for commercial and relied-upon operations. An “ecosystem” where hydrogen supply and demand are aligned will allow hydrogen infrastructure to grow in line with vehicle sales. More volume will generate economies of scale and reduce costs for both infrastructure and fuel cell technology.

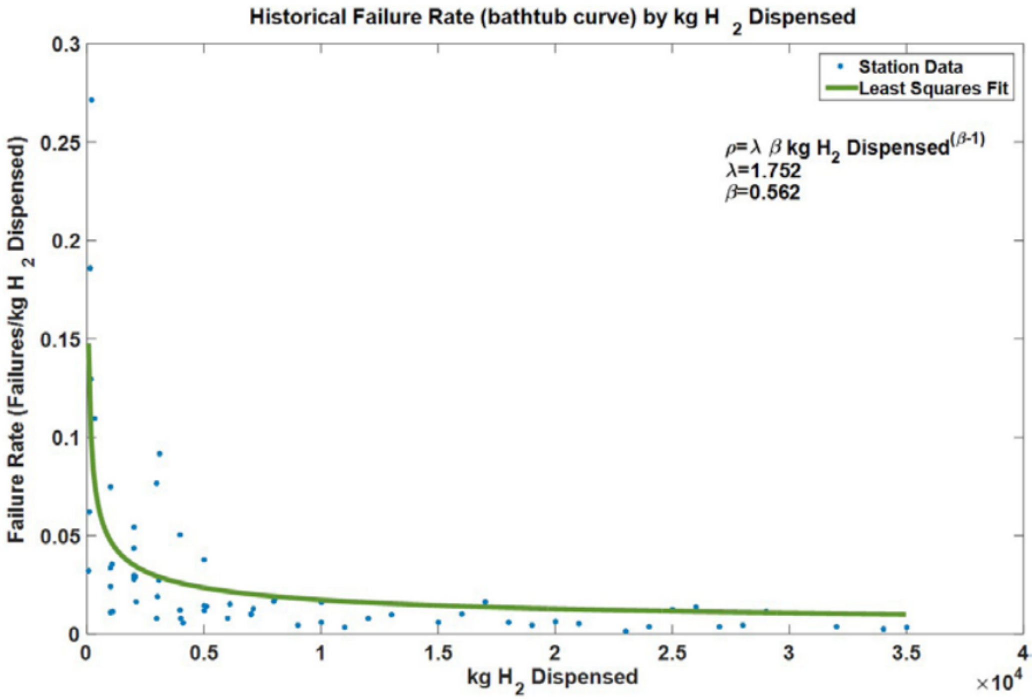


Figure 15: Historical failure rate data from the US DOE Fuel Cell Technologies Office Learning Demonstration[28]

CO_2 impact of hydrogen

Summary of the argument against hydrogen

"Hydrogen is produced from fossil fuels which results in a high carbon intensity. Using hydrogen for mobility will increase our dependence on these highly polluting sources and be counterproductive to the decarbonization effort."

UK H2Mobility Evidence

Hydrogen is an energy vector and, like electricity, can be produced from a number of sources with varying carbon intensity.

All members of UK H2Mobility agree that any significant transport demand (anything over low 10s of commercial vehicles) will require a new hydrogen production facility, given that there is very limited legacy hydrogen production available in the UK. Any new build hydrogen production facility, for hydrogen mobility or other applications, will be ultra-low carbon due to both customer demand and Government policy which effectively requires an ultra-low carbon strategy for producing hydrogen. People want to use hydrogen vehicles for their carbon reduction potential and fleet operators are under pressure to decarbonize: the primary driver for the transition is environmental, not economic. Policy can also ensure the decision to build low carbon hydrogen production, with the CO2 limits set under the Renewable Transport Fuels Obligation (RTFO) and the strict target recently set under the BEIS Low Carbon Hydrogen Standard, prime examples. These legislations ensure that new

[28] Hydrogen Station Data Collection and Analysis; DOE Hydrogen and Fuel Cells Program FY 2016 Annual Progress Report (energy.gov)

production facilities for transport should have a carbon reduction performance significantly above current BEV designs charging from the UK grid at 212 gCO2/kWh[29], see Figure 16.

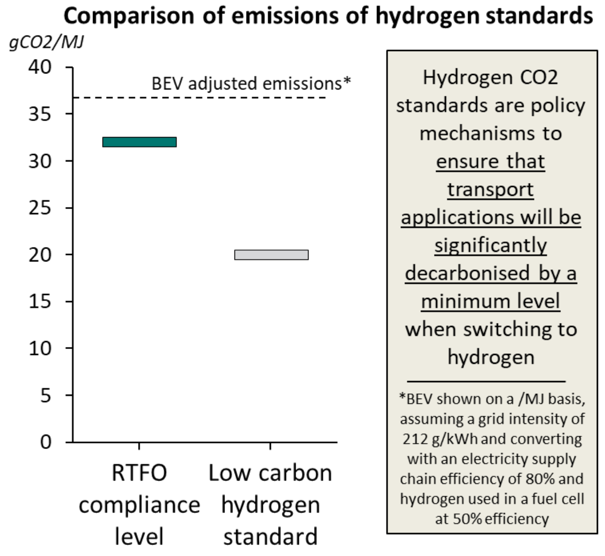


Figure 16: Comparison of the CO2 performance of BEVs using the grid and hydrogen standards

The process of replacing the legacy UK grey hydrogen production with green alternatives is already underway[30, 31, 32], with numerous companies investing in developing new, ultra-low carbon hydrogen production facilities in the UK. 25 such projects across the UK targeted at hydrogen mobility were highlighted in the recent publication of the Hydrogen Investor Roadmap[33] (see Figure 10). Hence, any risk of hydrogen mobility helping develop new grey hydrogen production capacity can be alleviated.

The second controversy revolving around hydrogen's carbon content is the debate on the relative carbon footprint of green and blue hydrogen. A recent academic publication[34], picked up by major media outlets in the UK[35], has generated appropriate concern over the potential emissions from blue hydrogen production. This publication was based on the US energy system model, which is significantly different from the UK in a number of ways:

- The predominant technology considered by UK blue hydrogen projects is auto thermal reforming (ATR), which has a much higher greenhouse gas capture rate, compared to the older SMR technology predominantly explored in the US.
- The upstream emissions from the UK natural gas mix to be used for blue hydrogen production are considerably lower than the US, particularly if UK continental shelf gas is used.

[29] Greenhouse gas reporting: conversion factors 2021 - GOV.UK (www.gov.uk)
[30] Hydrogen projects in Teesside | What we do | Home (bp.com)
[31] Industrial scale renewable hydrogen project advances to next phase (itm-power.com)
[32] HyNet North West
[33] Hydrogen Investor Roadmap (publishing.service.gov.uk)
[34] How green is blue hydrogen? - Howarth - 2021 - Energy Science & Engineering - Wiley Online Library
[35] Biden-backed 'blue' hydrogen may pollute more than coal, study finds | Hydrogen power | The Guardian

Further detail on the specifics and sensitivities to an analysis for the UK market is available in the ZEMO report on low carbon production methods[36], however, as illustrated in Figure 17, both green and blue hydrogen production methods have the capability to be close to zero or even negative in terms of carbon intensity. The gasification of municipal waste when combined with CCS technology, for instance, can have a very large carbon negative footprint. The use of hydrogen for transport will require any new source to be very close to zero carbon, both due to customer demand and government steer, and hence future hydrogen mobility deployments are set to play an active role in the decarbonization of the UK, regardless of the blue – green colour classification.

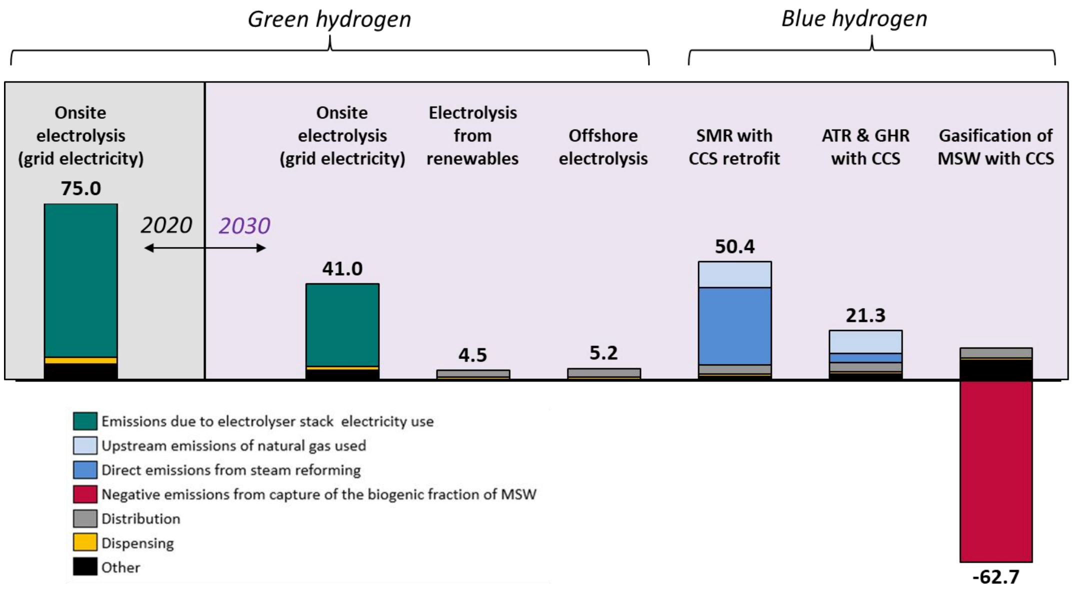


Figure 17: Overview of hydrogen CO_2 impact across a number of potential hydrogen supply chain scenarios (gCO2e/MJ H_2 LHV), data from ZEMO report[37]

Additional benefits of investing in the hydrogen economy

UK Jobs and Skills

Hydrogen transport is a key sector to invest in, in order to upskill the UK workforce to remain at the forefront of the energy transition. There is cross-party, widespread political will[38,39,40] to develop hydrogen given its potential for job creation and UK energy security, and the recent UK Energy Security Strategy increased the ambition for hydrogen industry jobs by 2030 from 9,000 to 12,000[41] following the increase in the UK production target from 5 GW to 10 GW. Other planned projects could go beyond this, with the ENA's Innovation Impacts report stating that investment into a hydrogen gas grid to help decarbonise Britain's six

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[36] Low Carbon Hydrogen Well-to-Tank Pathways Study – Full Report. A report for Zemo Partnership prepared by Element Energy, August 2021.
[37] Low Carbon Hydrogen Well-to-Tank Pathways Study – Full Report. A report for Zemo Partnership prepared by Element Energy, August 2021.
[38] Hydrogen industry investment could bring thousands of jobs to Yorkshire, says Keir Starmer | Yorkshire Post
[39] SNP minister claims Scotland 'on cusp of greens job revolution' | Herald Scotland
[40] Hydrogen strategy set out to create thousands of jobs - STV News
[41] Major acceleration of homegrown power in Britain's plan for greater energy independence - GOV.UK (www.gov.uk)

Industrial clusters would create 25,000 jobs in Britain's industrial heartlands[42]. An early mover case study on the impact of hydrogen sector investment is ITM Power, which has now grown from SME status to employ over 400 staff, expected to increase to 800 upon opening of their second factory.

Whilst the hydrogen mobility sector is in its nascent years, the UK has the potential to develop jobs linked to homegrown production, distribution and end use technologies in a way that the UK has missed the opportunity for in the off-shore wind and battery markets. With consistent support and clear policy signalling, the UK has the opportunity to support and create hundreds of thousands of jobs across the hydrogen market beyond the energy transition.

Long term abundance of manufacturing raw materials

Hydrogen fuel cell vehicles are constructed using readily available materials which do not add significant additional strain onto existing supply chains. The primary components of PEM fuel cells are made from polymers, carbon supports and metals, the rarest of which is platinum. Platinum is used in both fuel cells and diesel catalytic converters in small quantities. However, the amount of platinum required for fuel cells does not substantially strain the supply chain of the element which is available from a number of stable countries. The amount of platinum used in fuel cells has been decreasing over years, reducing the cost and increasing the technology sustainability. Latest technology advancements have led to rapid reductions in the required platinum loading for fuel cells to achieve the same or even improved power outputs (see Figure 18), and hence the amount of platinum required per vehicle has now fallen to comparable levels to the platinum requirement for diesel catalysts. Moreover, the platinum used in fuel cells can be from recycled sources and is 100% recoverable and recyclable as it has very little degradation or consumption in use. It is inherently more sustainable when compared to resources used in other storage technologies which cannot be easily or effectively recovered and are often needed in much higher quantities. Therefore, the widespread adoption of hydrogen vehicles would relatively improve the global vehicle supply chain and would result in less exploitation of earth's natural resources.

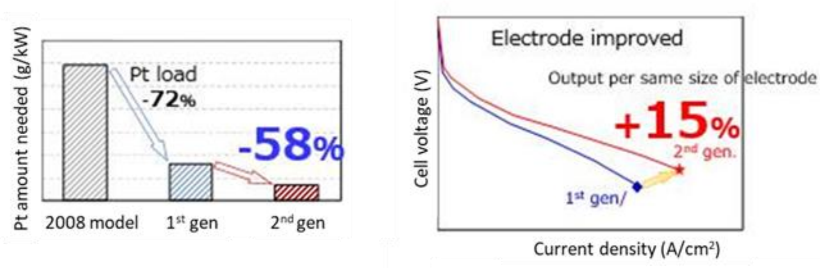

Figure 18: Toyota Mirai Fuel Cell stack data

Familiarity for end users and less adjustment for commercial operations

Hydrogen fuel cell vehicles offer comparable end user experiences to fossil fuel vehicles in terms of payload, driving range and refuel time. This has benefits not only in terms of making a zero emission solution accessible for all transport modes and weight classes, but also has the additional benefit of reducing operational adjustments for commercial operations. This results in the continued operation of today's supply chains at maximum capacity, and hence

[42] Hydrogen investment set to create 25,000 green jobs in Britain's industrial heartlands - Climate Action

helps to support cost effective decarbonisation across all other sectors in addition to transport.

Low socialised costs for the public

All infrastructure costs for hydrogen, the electrolyser, transport mechanism and dispensing unit, are accounted for in the projected hydrogen price at dispenser. This is not the case for electric systems, where grid upgrade costs and balancing mechanisms will have a socialised cost across all sectors using electricity. Whilst this cost socialisation is not necessarily a negative aspect inherent to BEVs, it is crucial to highlight these costs when assessing the most cost effective route to decarbonisation. There is abundant private money ready to invest in building out a hydrogen refuelling ecosystem, which is waiting for a clearer signal from Government that transport demand will materialise and be properly incentivised.

Lower reliance on a single technology

The development of the hydrogen sector through investment mitigates risk in case of the failure of a single technology to reach market penetration in all sectors of transport. It is highly unlikely that one technology will ultimately be most appropriate for the wide range of vehicle weight classes, duty cycles and transport modes we use today, and hence investing in developing multiple options across the transport sector reduces the risk of failing to achieve decarbonisation goals in the most cost-effective manner. Gill Pratt, Chief Scientist at Toyota, explained that the most efficient path to carbon neutrality has diverse power train solutions to account for variation in energy sources and transportation needs as well as the need to optimise the use of scarce battery materials.