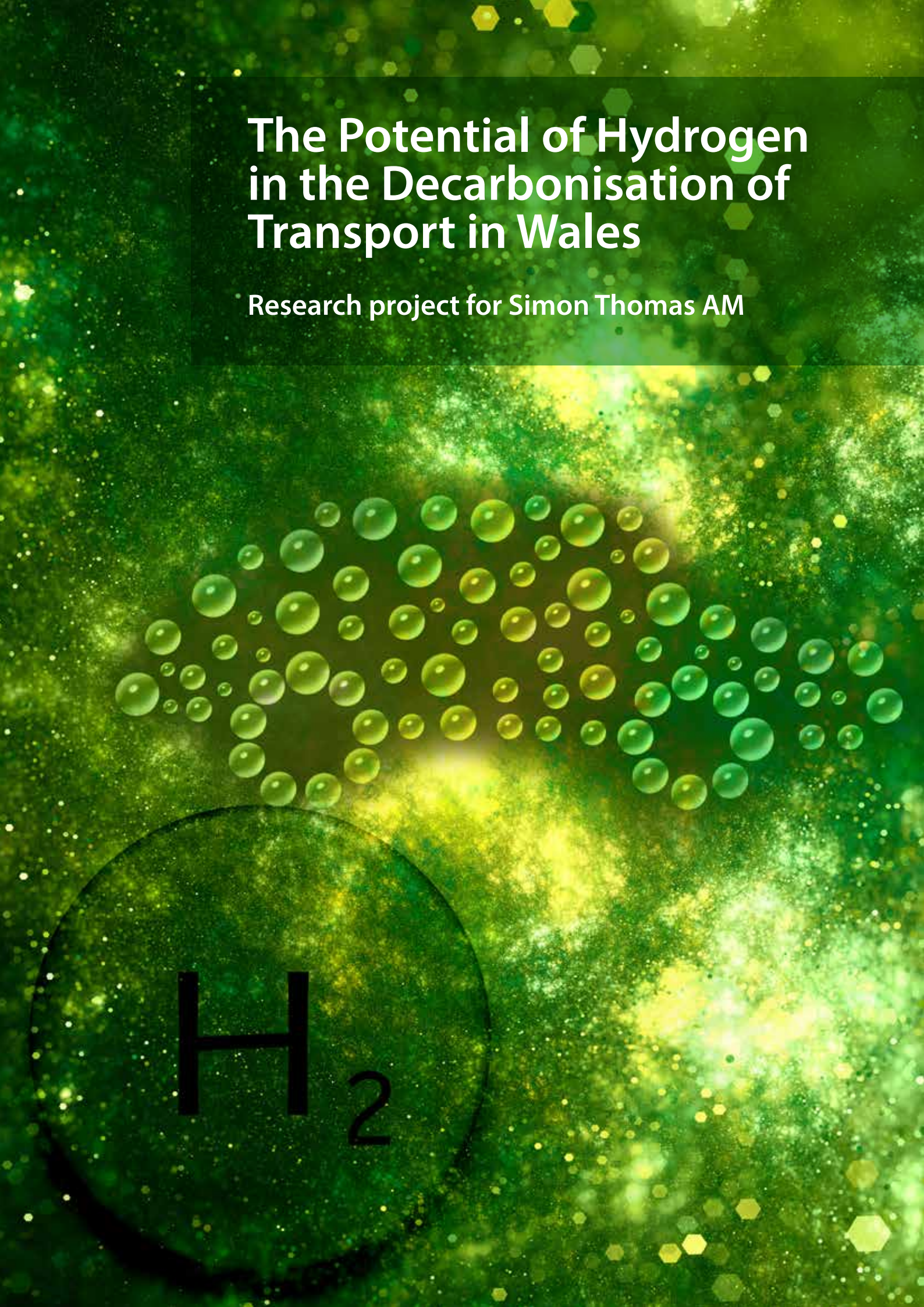
The Potential of Hydrogen in the Decarbonisation of Transport in Wales

Research project for Simon Thomas AM



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Foreword – Simon Thomas AM

I commissioned this paper to explore the potential of hydrogen to help solve some of the biggest problems facing Wales now and in the future - air pollution, climate change and the need for clean, renewable energy.

Very little research has been conducted on the use of hydrogen for these purposes in Wales to date and I hope this paper will help initiate a discussion that will lead to action being taken to develop a hydrogen economy in Wales. I would like to thank Guto Owen and Ynni Glan for this research.

Hydrogen presents an opportunity to make a valuable contribution to decarbonisation and the fight against air pollution. It also has great economic potential.

Currently, in Wales, the hydrogen sector is in its infancy with no overall strategy in place and few concrete examples. However, there is great potential in terms of: resources such as water; industry such as companies with expertise and interest in the technology; interest from various stakeholders ranging from environment, to public health, to science sectors; regulatory frameworks such as the Clean Air Act and the Well-being of Future Generations Act already being in place; and funding opportunities.

One of the barriers to building a hydrogen economy in Wales is its significant cost due to the market being at a relatively early stage and the ensuing risk aversion.

The potential uses of hydrogen for decarbonisation are vast and, for this reason, this paper focuses on its potential use in the transport sector.

Electric vehicles are currently taking off and Plaid Cymru have already demonstrated our support for this sector in the fight against air pollution and in the decarbonisation of transport through securing funding for electric vehicle charging points throughout Wales. We have also announced our commitment to phase out the sales of diesel and petrol-only vehicles in Wales by 2030. It is important to keep our options open to different technologies in order to fulfill this target.

In my opinion, the more immediate potential for the use of hydrogen is to power our trains and buses and heavy-duty freight. In the absence of a commitment by the Conservatives in London to electrify our railway, we should take a step further in Wales, following Germany, Austria, Ontario and China and develop hydrogen-powered trains. The new Wales & Borders Rail Franchise and proposed Metros for Cardiff and the Valleys, Swansea Bay and North East Wales present timely opportunities to make the business case for the introduction of hydrogen trains and buses in Wales.

On a smaller scale, there is potential for pilot projects that would have a visual impact in towns and cities with illegal levels of air pollution, such as hydrogen school buses.

One role of government in the development of a hydrogen economy is to signal its support for the use of the technology by industry through developing a hydrogen strategy and enabling and facilitating its use.

We need to use all the tools available in the fight against air pollution and climate change and, if we start now, there is potential for Wales to take a leading role in the emerging hydrogen economy.

1 Introduction

Hydrogen, by weight, is by far the most energy dense of fuels at 142 MJ/kg. By comparison, petrol holds 46.4 MJ/kg and Lithium Ion batteries 0.58 MJ/kg. (By volume petrol is the winner.) But although hydrogen is the most abundant element in the universe, it does not exist in its natural molecular state on Earth, except in harsh environments such as hydrothermal vents. Hydrogen prefers to form compounds with other elements - such as oxygen (H20, water), carbon (CH4, methane) and nitrogen (NH3, ammonia).

Hydrogen is already used on a vast scale in industry and, while its current dominant production method steam methane reforming (SMR) is unsustainable without carbon capture, its handling characteristics are well-understood. This will support the introduction of sustainable and scalable methods of production, chiefly in the form of electrolysis - which splits water using electricity.

Due to its versatility, abundance and practical benefits, hydrogen offers one of the main pathways to decarbonisation - at scale and across all sectors, including transport. As a clean fuel, it is also being promoted as one of a select few zero emission technologies for reducing air pollution

Air pollution has been classified as the largest environmental risk to public health in the UK and has been described by the World Health Organisation as "a public health emergency". Air pollution is estimated to cause 1,300 early deaths each year in Wales and 40,000 in the UK. Overall air pollution is estimated to cost the UK economy £20 billion a year[1].

Hydrogen technologies make the cleanest and most efficient use of fossil fuels; and release the full potential of renewables. Many large-scale and community renewable projects (wind, solar and marine) are currently held back in Wales due to the constraints of the electricity grid. To release this potential, renewable electricity can be utilised to produce hydrogen instead via electricity (power-to-gas). And the hydrogen can be stored; injected into the gas grid; used to balance the electricity grid; used to synthesise other chemicals sustainably (methane, ammonia fertiliser, methanol); and be a mainstay fuel for transport which is the main area of focus for this report. The reach of the hydrogen economy therefore extends far beyond transport.

The report provides a survey of current hydrogen transport activities in Wales; details examples from the rapidly growing number of global hydrogen transport activities; highlights funding and regulatory mechanisms which are being used at EU level and elsewhere to accelerate their adoption and provides an associated cost-benefit analysis; assesses the Welsh Government's level of commitment to promoting the hydrogen economy and the feasibility of using hydrogen to decarbonise different aspects of the transport sector in Wales; and provides a set of recommendations and priorities for the Welsh Government on hydrogen - including both regulatory and funding mechanisms.

Throughout the report, an attempt is made to set out and communicate the emerging, strategic and global case for hydrogen in helping to meet not only the urgent and difficult challenge of decarbonisation but in also reducing air pollution and in providing energy storage at scale and seasonally, (see Figure 1).

1 https://publications.parliament.uk/pa/cm201719/cmselect/cmenvfru/433/433.pdf

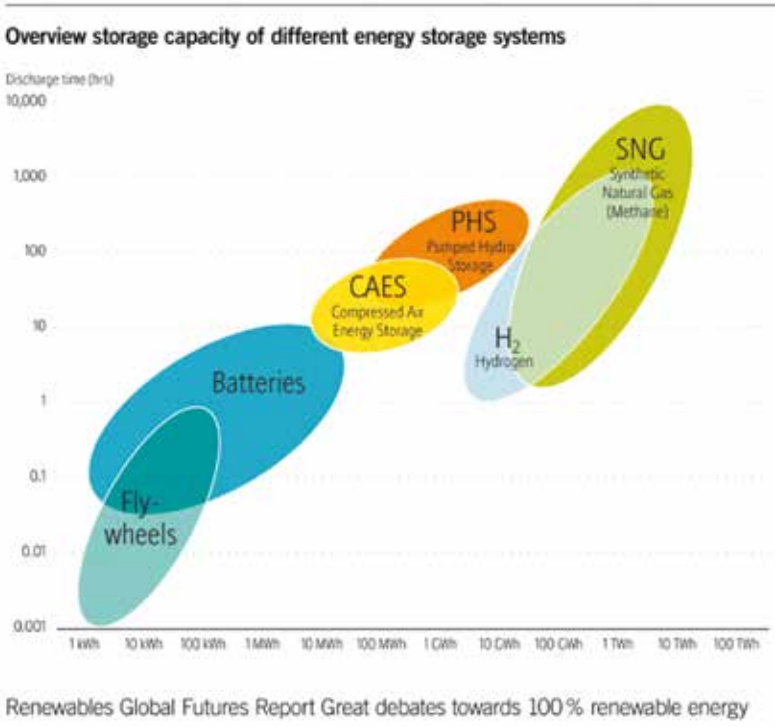


Figure 1 - Energy Storage

Hydrogen and SNG (produced from H2 + CO2) provide by far the greatest energy storage potential by both capacity and duration (season to season). Not shown are other derivatives of hydrogen namely ammonia (NH3) and methanol (CH3OH) which also offer huge storage potential. Note that the graph is on a logarithmic scale which greatly reduces the apparent scale of the hydrogen & SNG bubbles.

2 A survey mapping out the current use of hydrogen in the transport sector in Wales

There are currently few uses of hydrogen in the transport sector in Wales. Despite several initiatives, including the Welsh Government's 2010 Hydrogen Highway announcement[2], the scale of deployment has been limited and piecemeal.

A survey of current activities has been undertaken and these are listed below, to include the very few working examples of hydrogen in current use, aspirational projects and wider transport initiatives which could embrace hydrogen.

2.1 Working Examples

2.1.1 Riversimple set to trial their Hydrogen Car in Wales

Llandrindod Wells-based Riversimple[3] is about to run a 12-month trial of 10 of their hand-built hydrogen cell cars in Monmouthshire[4]. The trial will inform the full commercialisation of the revolutionary car, expected from 2019 onwards. A self-service mobile refuelling point will be installed in one of the council car parks, in Abergavenny or Monmouth.

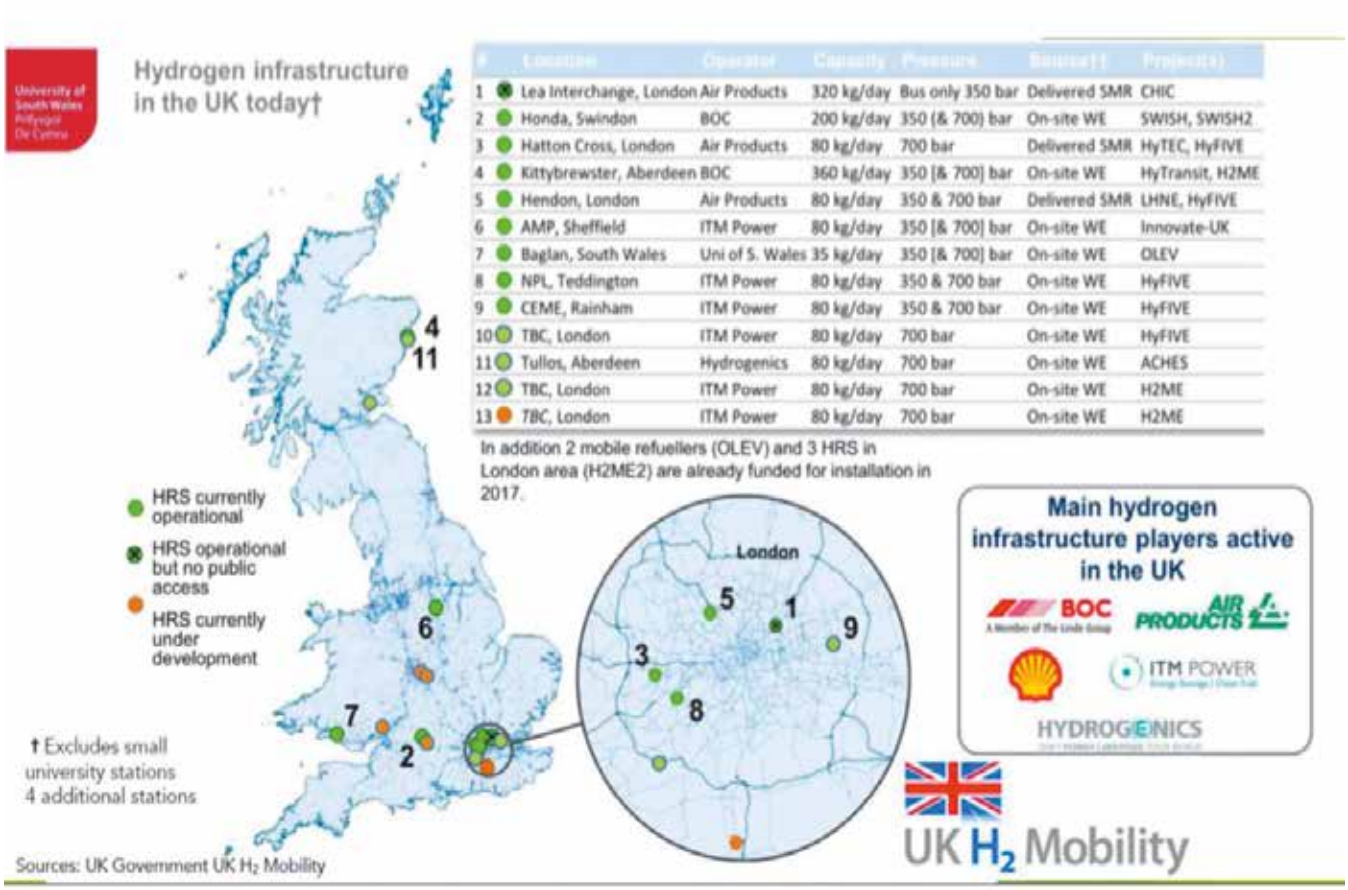
Riversimple were awarded £2m of funding from the Welsh Government in 2015 and in January 2018 joined a trade delegation to China with the UK Prime Minister, which included a visit to Wuhan a city of 11 million people and which set to become a Hydrogen City (see 3.4.3).

2 http://news.bbc.co.uk/1/hi/wales/8511319.stm
3 http://www.riversimple.com
4 http://www.bbc.co.uk/news/uk-wales-mid-wales-42876575

2.1.2 Wales' First 700 bar Green Hydrogen Filling Station

Wales' first public hydrogen filling station is at the University of South Wales' (USW) Hydrogen Centre in Baglan, Port Talbot[5]. The station will be developed by Pure Energy Centre as part of the UK H2 Mobility scheme[6], backed by the UK Government, to boost and fund the installation of hydrogen stations and the uptake of fuel cell vehicles in the UK.

The USW's hydrogen filling station in relation to the emerging UK network is shown in Figure 2 below.



		Location	Operator	Capacity	Pressure	Source††	Project(s)
1	●	Lea Interchange, London	Air Products	320 kg/day	Bus only 350 bar	Delivered SMR	CHIC
2	●	Honda, Swindon	BOC	200 kg/day	350 (& 700) bar	On-site WE	SWISH, SWISH2
3	●	Hatton Cross, London	Air Products	80 kg/day	700 bar	Delivered SMR	HyTEC, HyFIVE
4	●	Kittybrewster, Aberdeen	BOC	360 kg/day	350 [& 700] bar	On-site WE	HyTransit, H2ME
5	●	Hendon, London	Air Products	80 kg/day	350 & 700 bar	Delivered SMR	LHNE, HyFIVE
6	●	AMP, Sheffield	ITM Power	80 kg/day	350 [& 700] bar	On-site WE	Innovate-UK
7	●	Baglan, South Wales	Uni of S. Wales	35 kg/day	350 [& 700] bar	On-site WE	OLEV
8	●	NPL, Teddington	ITM Power	80 kg/day	350 & 700 bar	On-site WE	HyFIVE
9	●	CEME, Rainham	ITM Power	80 kg/day	350 & 700 bar	On-site WE	HyFIVE
10	●	TBC, London	ITM Power	80 kg/day	700 bar	On-site WE	HyFIVE
11	●	Tullos, Aberdeen	Hydrogenics	80 kg/day	700 bar	On-site WE	ACHES
12	●	TBC, London	ITM Power	80 kg/day	700 bar	On-site WE	H2ME
13	●	TBC, London	ITM Power	80 kg/day	700 bar	On-site WE	H2ME

Figure 2 UK Hydrogen Infrastructure

2.1.3 Hydrogen Fuel Cell Cars at Mid & West Wales Fire Service and Swansea University

Mid & West Wales Fire Service (MWWFS) and Swansea University have added, respectively, two and one hydrogen cars to their fleets[7,8]. All are Hyundai models and will be making use of the hydrogen filling station at the University of South Wales' Hydrogen Centre.

Providing range and the convenience of short filling time, the adoption of these hydrogen cars should go some way to promoting the technology to others in the public sector and beyond in Wales and, in the case of MWWFS, help dispel some of the safety concerns on hydrogen.

5 http://pureenergycentre.com/pure-energy-centre-wins-waless-first-700-bar-green-hydrogen-filling-station/
6 http://www.ukh2mobility.co.uk
7 https://www.walesonline.co.uk/news/wales-news/fire-vehicles-powered-hydrogen-soon-12890226
8 http://www.swansea.ac.uk/media-centre/news-archive/2018/swanseauniversityaddsnewhydrogenfuelcellvehiclefcvtoitszero-emissionfleet.php

2.2 Aspirational Projects

The following aspirational list of projects on hydrogen transport in Wales include proposals which either did not receive funding and those which are currently at various stages of consideration. Notably, most projects are located within areas of severe air pollution in Wales.

Knowledge of hydrogen transport is increasing in Wales, especially amongst fleet managers who are faced with limited options in decarbonising their fleet; in reducing air pollution; and in adhering to the Wellbeing of Future Generations Act. But while interest is growing, as evidenced by a *Zero Emission Range Extender* workshop in Baglan in May 2015 and at the *European Hydrogen Road Tour*[9] event in Cardiff in October 2012, the number of concrete initiatives has been very limited to date.

2.2.1 Cardiff Council

In 2015, Cardiff Council were engaged in discussions involving a 3-city bid with Birmingham and London for European and UK Government funding for hydrogen buses and infrastructure. Cardiff withdrew its participation due, it is understood, to match-funding issues. However, the bid proved successful and Birmingham's 22 new hydrogen buses will be brought into service from March 2019, see 3.2.2. London is also expanding its hydrogen bus fleet, see 3.2.3.

In May 2017, Cardiff Council organised a workshop on Sustainable Fuels to inform its corporate transport plans involving compliance with urgent air pollution legislation in the city and the phase out of its polluting diesel bus fleet. Strong references were made at the workshop to the proposed Clean Air Zone in Cardiff and the on-going UK High Court cases on air pollution brought against the UK Government and the Welsh Government by Client Earth[10].

In January 2018, the Welsh Government admitted to the Court that its current stance on air pollution was unlawful and promised to deliver measures to address the issue later in 2018[11].

Amongst the notable presentations at the Cardiff Council Sustainable Fuels Workshop was that from Dundee Council, who have introduced widespread EV charging to the city and are also intent on developing hydrogen infrastructure to connect with other Scottish cities, notably Aberdeen (see 3.2.1).

To address the issue, Cardiff Council committed to produce and publish a Clean Air Strategy in 2018[12] and has published a Transport and Clean Air Green Paper[13] which is out to consultation until 1 July 2018.

In agreement with the Welsh Government, the Clean Air Strategy will outline the baseline situation in Cardiff with regards to key pollutants, set out proposed measures to improve air quality, and present an appraisal of these measures in terms of their air quality impacts, cost and timescale for implementation in an Action Plan. One significant measure that the Clean Air Strategy will discuss in detail is whether the Council considers the introduction of a Clean Air Zone.

9 http://www.scandinavianhydrogen.org/h2moves-scandinavia/road-tour/
10 www.clientearth.org
11 https://www.businessgreen.com/bg/news/3025296/welsh-government-admits-lacking-plan-to-clean-up-air-pollution
12 https://cardiff.moderngov.co.uk/documents/s18272/Air%20Quality%20APR.pdf
13 https://www.cardiff.gov.uk/ENG/resident/Parking-roads-and-travel/transport-and-clean-air-green-paper/Pages/default.aspx

The draft review is also recommending an increase in the number of charging points for electric and hydrogen vehicles in the city.

It is worth noting the recent written evidence submitted in November 2017 by the City of Cardiff Council[14] (alone from Wales) to the unprecedented and scathing UK Parliament Environment, Food and Rural Affairs, Environmental Audit, Health and Social Care, and Transport Committees joint report on improving air quality, published in March 2018[15], and specifically the following comments by the Council:

"CCC has limited scope to effect significant change in the composition of the vehicle fleet."

"The Welsh Government anticipates a Clean Air Zone, with vehicle access restrictions, could be implemented in Cardiff during 2021, or earlier if possible."

"The UK Plan sets out a clear understanding for the next steps those highlighted LAs in England must take. The plan draws upon available funding to help aid those LAs to improve air quality;"

"The government will set up a £255m Implementation Fund to support local authorities to prepare their plans and deliver targeted action to improve air quality. This funding will support the immediate work to conduct feasibility studies and develop and deliver local plans. Further details will be announced later in the year. However, £40 million will be made available immediately to support local authorities to take action to improve air quality as quickly as possible. The plan does not detail whether this funding is being made available to Welsh LAs and clarification has been sought on this from Welsh Government."

While it is recognised that Cardiff Council is reviewing all low/zero emission transport options open to them including batteries, biomethane and hydrogen, it is perhaps worth noting the following comments[16] from a senior official at the 8 March 2018 Environmental Scrutiny Committee meeting:

"Cardiff has absolutely no hydrogen infrastructure. There are three fuelling stations in Wales. Without more infrastructure the hydrogen market won't grow."

2.2.2 Neath Port Talbot & Swansea Council

In February 2015, Neath Port Talbot County Borough Council and Swansea Council led the submission of a Swansea Bay City Region bid to the UK Government's Go Ultra Low City Scheme - a £35m competition to deliver a step-change in the uptake of Ultra Low Emission Vehicles (ULEVs) in those cities and administered by the Office of Low Emission Vehicles (OLEV)[17]. The bid included a strong emphasis on both hydrogen and electric vehicle infrastructure. Hydrogen bus operators were engaged in its preparation.

Although unsuccessful, the bid resulted in a follow-up visit from then UK Transport Minister, Baroness Kramer, who encouraged the bidding team to maintain contact with OLEV in advance of future opportunities. Many elements of the bid remain viable and perhaps even more relevant in 2018 given the proposals for a Swansea Bay Metro and the growing concerns on the limitations of the electricity grid in delivering charging infrastructure for battery electric vehicles BEVs.

14 http://www.parliament.uk/business/committees/committees-a-z/commons-select/environment-food-and-rural-affairs-committee/news-parliament-2017/joint-improving-air-quality-report-publication-17-19/

15 http://data.parliament.uk/WrittenEvidence/CommitteeEvidence.svc/EvidenceDocument/Environment,%20Food%20and%20Rural%20Affairs/Joint%20inquiry%20into%20improving%20air%20quality/written/73391.pdf

16 https://www.walesonline.co.uk/news/wales-news/ideas-being-put-forward-clean-14388139

17 https://www.gov.uk/government/organisations/office-for-low-emission-vehicles

2.2.3 Western Power Distribution, WPD

As part of a Welsh Government Smart Living[18] project at their Church Village depot near Pontypridd, Western Power Distribution aimed to host the development of an electrolyser to produce hydrogen for use as a vehicle fuel and associated heating scheme. Small fleets of commercial hydrogen vehicles were set to be deployed as part of the project.

A core aim of the work for WPD was to gain an understanding into the conversion of peak renewable electricity production to hydrogen (peak lopping) to enable the installation of further renewable generation without incurring the infrastructure cost of grid strengthening.

2.2.4 Hydrogen Trains

The emergence of hydrogen trains as a viable zero emissions alternative to conventional electrification has received much global attention in the last 12 months (see 3.1). The new Wales & Borders Rail Franchise and proposed Metros for Cardiff and the Valleys, Swansea Bay and North East Wales present excellent opportunities for the business case to be made for the introduction of hydrogen trains - and buses - in Wales.

There have been no specific government announcements on hydrogen trains in Wales. The Welsh Government appears to be maintaining a technology-neutral stance on sources of traction power for the Wales & Borders Rail Franchise for the time-being. Public comments and discussions have been limited to Plenary sessions, the Economy Infrastructure and Skills Committees and a special evidence session on hydrogen for the Climate Change, Rural Affairs and Environment Committee in 2017.

This contrasts with UK Government announcements and also from overseas which have been far more specific in encouraging and enabling projects (see 3.1).

In its evidence to the National Assembly for Wales' Economy, Infrastructure & Skills Committee's Rail & Metro Consultation in February 2017, Ynni Glan calculated that the entire Wales rail network could run on hydrogen produce from an achievable 117MW of wind capacity, see 5.1.

Industry looks to government for signals. Perhaps the new train manufacturing facility in Newport can provide a springboard for discussions with hydrogen train manufacturers on the development and manufacture of hydrogen trains in Wales for domestic and UK markets.

2.3 Wales' Manufacturers

Riversimple is in good company. Toyota, perhaps the leading global brand in the development of hydrogen cars, has an engine plant in Deeside. The plant could be re-aligned for the 2020s for the manufacture or local assembly of the anticipated new wave of hydrogen vehicles which Toyota will be introducing in Japan and global markets.

Wales has a strong automotive industry but concerns over BREXIT and the demise of petrol and diesel engines (sales of new diesel and petrol engines are to be banned in the UK from 2040) presents huge challenges in maintaining the industry's presence. In March 2018, the UNITE union called on the Welsh Government to help support the re-alignment of the Welsh car industry - including the Ford engine plant in Bridgend - towards the brave new world of low/zero emission vehicles[19].

Details of the Welsh Government's £100m automotive innovation park in Ebbw Vale remain sketchy but one of its core missions could be to nurture, develop and provide on-going support for the development of hydrogen vehicles.

18 http://gov.wales/topics/businessandeconomy/creating-a-sustainable-economy/smart-living/?lang=en
19 http://www.bbc.co.uk/news/business-43363539

2.4 Welsh Initiatives - Hydrogen Highway, Low Carbon Vehicle Expert Steering Group & European Hydrogen Road Tour

The new wave of interest in hydrogen is welcome although it should be noted that initiatives have ebbed and flowed on this matter in Wales for almost a decade.

The Welsh Government announced the Hydrogen Highway in 2010; and in 2014 established the Low Carbon Expert Steering Group, which included hydrogen in its brief and which reported with recommendations to the Welsh Government in September 2015[20]. But no resultant policy initiatives have been detected.

In this context, it is worth noting the speech of the First Minister in welcoming a Welsh and international audience to Cardiff for the European Hydrogen Road Tour in October 2012[21].

The Welsh Government has a recent track-record on the awareness of hydrogen for transport, which provides a platform for the rapid development of policy to address clean air and decarbonisation goals and to seize economic opportunities.

20 http://gov.wales/topics/businessandeconomy/creating-a-sustainable-economy/low-carbon-vehicle-expert-steering-group/?lang=en
21 https://www.youtube.com/watch?v=vKstC08S3hg&feature=youtu.be

3 UK and International examples of the use of Hydrogen in Transport

3.1 Rail

In addressing the urgent air pollution health crisis from toxic diesel fumes and in meeting decarbonisation goals, hydrogen for rail applications has witnessed a surge of interest in the last 12 months. This is largely as a result of the spiralling costs of conventional (overhead) rail electrification but also due to the limited operational performance of battery trains. Examples of recent international activity in the rail sector are provided in this section, as well as a commentary on recent UK Government announcements. The UK section (3.1.6) also refers to heat and industry applications which can be pursued in parallel to transport, so demonstrating hydrogen's versatility.

3.1.1 Germany

Lower Saxony is the pioneer regional Lander in Germany which is introducing a fleet of hydrogen trains to its regional rail network over the next few years[22]. 14 hydrogen trains will be in service by 2021 in Lower Saxony, which specified hydrogen trains as the preferred technology option for the network. Alstom's hydrogen train can reach 140 kmh, with a range of 600 to 800 km and accommodate up to 300 passengers

3.1.2 Austria

Austria's Zillertal Railway has opted for hydrogen trains on a 32km narrow-gauge line. Previous electrification plans were estimated to cost €156m including track upgrades and rolling stock but the hydrogen option is expected to cost €80m, including new rolling stock and hydrogen fuelling and production facilities which will use energy from local hydroelectric power stations. A specific tender to deliver the hydrogen trains was issued in March 2018 and won by Stadler in May 2018. The trains are scheduled for service from 2020.

22 http://www.alstom.com/press-centre/2017/11/14-coradia-ilint-in-salzgitter-for-lnvg/

3.1.3 Ontario

The Ontario Government recently commissioned a Hydrogen Rail (Hydrail) Feasibility Study[23] which found that it would be feasible to build and operate electrified rail service using hydrogen-powered trains at a cost comparable to conventional electrification using overhead wires.

Ontario is now engaging with train manufacturers Alstom and Siemens to produce concept designs that incorporate hydrogen fuel cells into bi-level trains; and an additional request for proposals for designs for a hydrogen fuel cell-powered locomotive.

"The potential benefit of hydrogen fuel cells compared to overhead wires makes exploring hydrogen rail technology worthwhile."

Kathryn McGarry, Ontario Minister of Transportation, February 18 2018

3.1.4 China

Tangshan Railway Vehicle Company (TRC) is trialling hydrogen trams on a new 14km line in Tangshan City, which is located in China's Hebei Province.

The TRC low floor tram consists of three cars with a total capacity for 336 passengers, a top speed of 70kmh and a range of 40km on a single 12kg tank of hydrogen.

3.1.5 Costa Rica

At his Inauguration in May 2018, the new Costa Rica President declared that the country would prepare for full decarbonisation of the economy and in support of this goal that a hydrogen plan to include rail would be produced within 6 months[24]. To underline this commitment, the President arrived at the Inauguration in a hydrogen bus accompanied by a cavalcade of bicycles.

23 https://news.ontario.ca/mto/en/2018/02/ontario-taking-next-steps-in-testing-hydrogen-powered-train-technology.html
24 https://www.independent.co.uk/environment/costa-rica-fossil-fuels-ban-president-carlos-alvarado-climate-change-global-warming-a8344541.html

3.1.6 UK

In recent months, the UK Government has made very positive comments in Parliament and through the media on hydrogen trains, urging a swift uptake of the technology in the UK. For example:

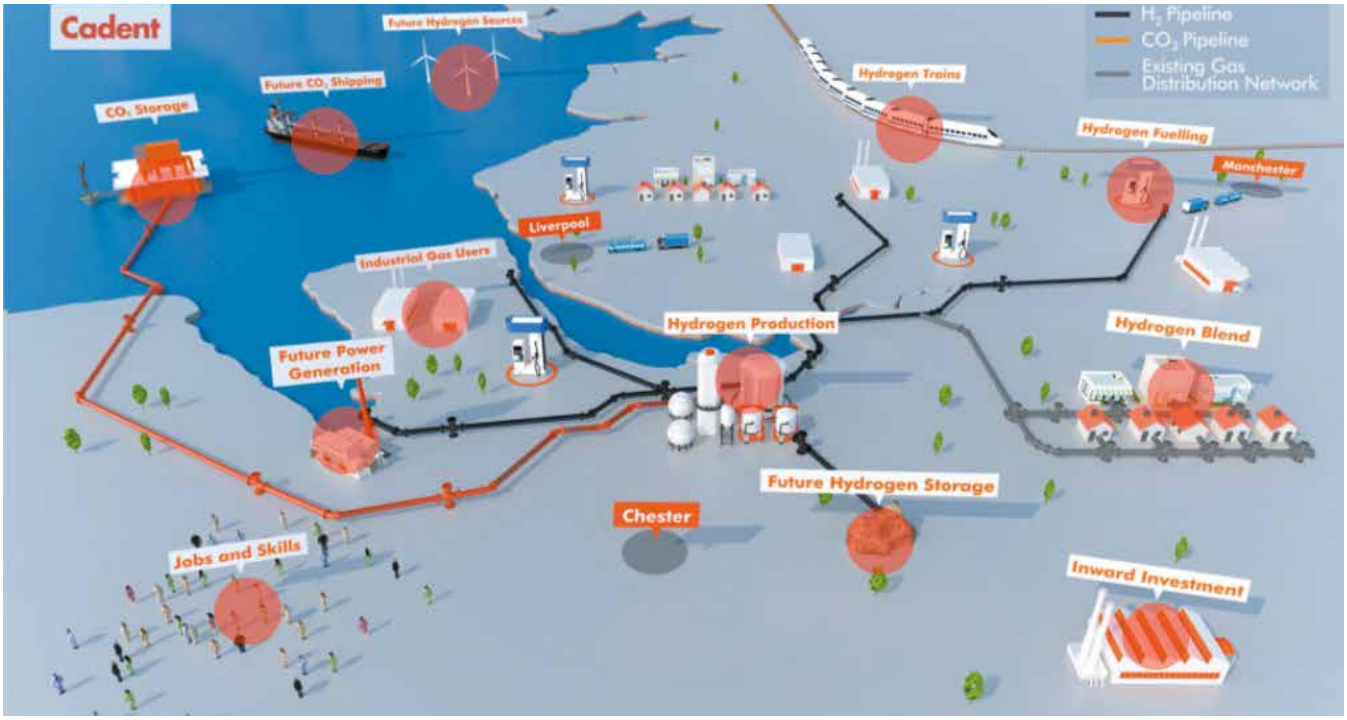
"Roll on hydrogen trains in the U.K."
"Hydrogen train to be tested in the UK by 2020."
Tweets by Jo Johnson, UK Government Transport Minister, February 18

French train manufacturer, Alstom, announced in May 2018 that it is developing specific hydrogen trains for the UK market at their factory in Widnes, to be ready by 2021. This builds on Alstom's introduction of hydrogen trains to Germany.

However, Alstom is not alone. Siemens is also developing hydrogen trains in a joint-venture with Canadian fuel cell manufacturer, Ballard25; and Stadler has won the tender for Austria's Zillertal Railway[26].

Further, clear signals towards a hydrogen economy emerged in May 2018 when the UK Government announced a £20m funding competition to investigate the development of low cost, low carbon hydrogen for industry, buildings and transport[27]. In the words of Energy and Clean Growth Minister, Claire Perry: "Clean, green and safe, hydrogen has an exciting role to play in powering the UK."

In the same week, Cadent, the gas utility for much of the Midlands and North of England presented details of the HyNet project[28], a £900m proposal involving hydrogen and Carbon Capture, Usage and Storage (CCUS) to reduce carbon emissions from industry, homes and transport and to support economic growth in the North West of England. Based around the Liverpool - Manchester area, transport (including trains and buses) forms an integral part of the project and, as the map below illustrates, the project extends to north east Wales.



25 https://www.siemens.com/press/en/pressrelease/?press=/en/pressrelease/2018/mobility/pr2018020172moen.htm&content[]=MO
26 http://www.railjournal.com/index.php/rolling-stock/zillertalbahn-orders-stadler-hydrogen-powered-trains.html
27 https://www.gov.uk/government/news/20-million-boost-for-business-innovators-powering-the-uks-hydrogen-economy
28 https://hynet.co.uk

Similarly, Northern Gas Networks, with support from Wales & West Utilities, is leading the H21 Leeds project to assess the transformation of the gas network at the Leeds city-scale from natural gas to hydrogen[29].

Hydrogen, whether on its own or as the feedstock for Synthetic Natural Gas (SNG), has obvious attractions for gas utilities as a pathway for decarbonising heat and extending to transport. But its merits for storing renewable energy and its cost advantages when compared with full-scale electrification and heat networks have also recently been highlighted in studies by the Institute of Mechanical Engineers, Energy from Gas: Taking a Whole System Approach[30]; and by E4Tech, Cost analysis of future heat infrastructure[31], for the UK's National Infrastructure Commission.

Expanding on the huge potential for industry, steelworks in Sweden[32] and Austria are developing pilot projects which will produce hydrogen from renewables instead of fossil fuels for their operations. Such developments open-up the prospect for another large-scale and global market for hydrogen.

3.2 Buses

A growing number of European cities are introducing hydrogen buses to their fleets in response to tougher air pollution regulations. Aberdeen, Birmingham and London are the leading UK cities with multiple hydrogen buses either deployed or ordered.

3.2.1 Aberdeen

Aberdeen anticipates major economic as well as environmental benefits of being a fast-mover in the development of a hydrogen economy, as part of a long-term strategy to re-skill the local economy's expertise from declining oil and gas.

In March 2017, Aberdeen City Council was awarded £3m of funding from the Scottish Government towards the deployment of an additional 10 hydrogen buses, taking the city's fleet to 20 (the largest in Europe)[33]. The Council also invested its own money and secured funding from FCH JU's JIVE programme (see 4.1.1) towards the costs.

And in 2018, using Aberdeen as the launchpad, the Scottish Cities Alliance - a partnership between the Scottish Government and all seven of Scotland's cities - is to focus on developing hydrogen technology in the North-east during 2018 with Dundee, for example, looking to deploy its own hydrogen buses[34].

29 https://www.northerngasnetworks.co.uk/wp-content/uploads/2017/04/H21-Report-Interactive-PDF-July-2016.compressed.pdf
30 http://www.imeche.org/news/news-article/uk-'should-store-excess-renewable-energy-storage-in-hydrogen
31 http://www.e4tech.com/e4tech-and-element-co-author-study-for-the-national-infrastructure-commission-assessing-the-cost-of-decarbonising-uk-heat/
32 https://www.euractiv.com/section/energy/interview/hybrit-ceo-our-pilot-steel-plant-will-only-emit-water-vapour/
33 https://www.eveningexpress.co.uk/fp/news/local/green-bus-fleet-to-double-as-government-pledges-3m/
34 https://www.insider.co.uk/news/scottish-cities-alliance-smart-cities-11763737

3.2.2 Birmingham

Birmingham City Council has won significant funding towards the £13.4m cost of introducing 20 hydrogen buses and new fuelling infrastructure to to its fleet from late 2018 onwards[35]. Funding sources include the UK Government's Office for Low Emission Vehicles (£1,474,000), the EU's Fuel Cells and Hydrogen Joint Undertaking (£4,080,800), the Greater Birmingham and Solihull Local Enterprise Partnership (£2,156,000) and a lease agreement with the bus operator. Each bus currently costs approx £500,000.

3.2.3 London

London has the oldest hydrogen bus fleet in Europe. To facilitate deployment in the city and for other cities, Transport for London (TfL) has established a protocol which invites potential suppliers of fuel cell buses to join a framework for the supply of single and double-decker vehicles to cities across the UK and potentially abroad. This bulk procurement of buses is intended to significantly increase order volumes in Europe and reduce costs for widespread commercialisation.

The procurement activity is part of the EU JIVE (Joint Initiative for Hydrogen Vehicles across Europe) project, which aims to deploy 142 hydrogen buses across 9 participating European cities.

3.2.4 Global Emergence

Several other European cities have introduced hydrogen buses to their fleets and further deployment is talking place in India (including Tata Motors), China and USA. Notably, after previously trialling 2 buses, the German cities of Cologne and Wuppertal have order 40 hydrogen buses to be operational from 2019[36]. This is the largest European order to date but such orders may soon be dwarfed by developments in China whose "blue skies" initiative seeks to aggressively tackle air pollution. A new manufacturing facility for fuel cell stacks in Guangdong Province[37] serves as a statement of intent towards an accelerated deployment programme in China. More details of international developments are provided in the following sections.

35 https://www.birmingham.gov.uk/news/article/178/cleaner_hydrogen_buses_to_be_given_green_light
36 https://uk.reuters.com/article/us-autos-renewables-buses/belgiums-van-hool-bags-large-german-order-for-hydrogen-buses-idUKKCN1GC1GV
37 http://ballard.com/about-ballard/newsroom/news-releases/2017/09/06/ceremonial-opening-of-ballard-s-china-stack-joint-venture-production-facility

3.3 Cars, Vans and other Vehicles - including Bikes

3.3.1 France - Zero Emission Valley and H2Mobilite France

ZEV is a flagship initiative for the French region of Auvergne-Rhône-Alpes which aims to create a bankable investment environment for hydrogen infrastructure investors by building stations for the captive fleet of this local cluster.

ZEV will deploy 20 stations, out of which 15 will be supplied by onsite electrolysers. It will also procure and lease 1,000 fuel cell vehicles.

The project also forms part of the Mobilité Hydrogène France programme, which aims to deploy 600 hydrogen refuelling stations in the country by 2030.

On 1 June 2018, the French Government launched a comprehensive hydrogen plan for transport and other applications.

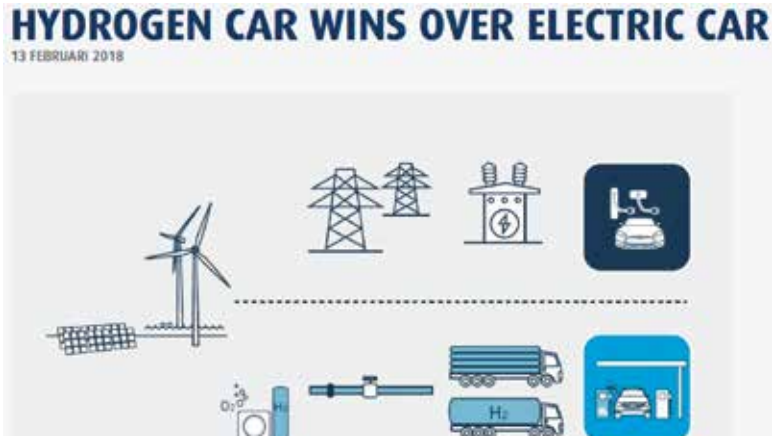
3.3.2 Germany and Central Europe

Germany has 50 hydrogen filling stations in a network which will expand into the hundreds, co-ordinated by the Clean Energy Partnership of government and industry[38].

Denmark has the first countrywide hydrogen station network in the world which will expand in the coming years to ensure that 50% of the Danish population is within15 km of a station[39].

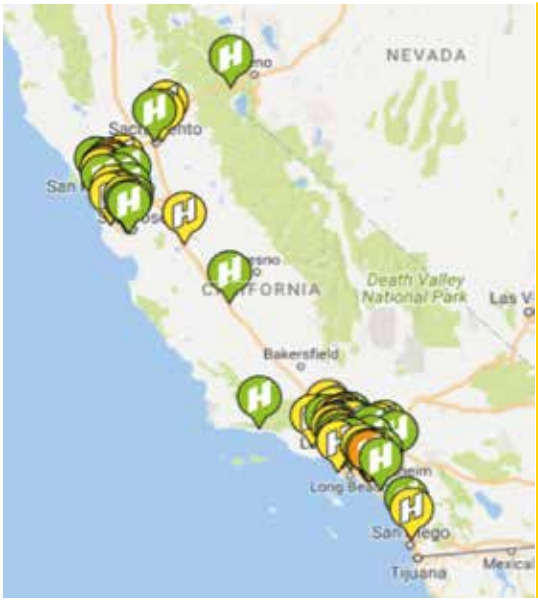
In the Netherlands, government investment of €15 million in the transport sector will go towards introducing hydrogen fuel-cell buses, lorries and vans and building seven hydrogen filling stations in 2018[40].

38 https://cleanenergypartnership.de/en/home/
39 http://h2logic.com/products-services/track-record/
40 https://www.government.nl/latest/news/2018/03/09/government-to-invest-€300-million-in-climate-measures



In February 2018, the Jülich Research Centre in Germany released a study[41] which assessed battery and hydrogen infrastructure costs. The study concluded that up to a fleet size of 100,000 vehicles, the scheduled costs for hydrogen mobility (FCEV) amount to around €450 million. For battery electric vehicles (BEV), the costs are around €310 million. However, once 1 million vehicles are on the road, the cost of H2 infrastructure totals ~€1.9 billion while battery charging infrastructure totals ~€2.8 billion.

3.3.3 USA



California's Hydrogen Highway is expanding[42] and spurring commercial hydrogen innovations. North America's largest power to gas project is being developed in Palm Springs. The 2.5MW plant will deploy highly efficient and responsive electrolyzers to convert wind and solar energy into 1,000kg of renewable hydrogen per day - enough to supply hundreds of cars and fleets of hydrogen buses and trains. The plant is modular and can be increased in size as demand grows.

Start-up Nikola Motor[43] is developing a long-range articulated hydrogen fuel cell lorry for the US/Canadian market by 2020 with European markets to follow.

Nikola's plans include the development of complementary and continent-wide hydrogen infrastructure to fuel the lorries and a $1bn manufacturing facility in Arizona.

41 http://h2-mobility.de/en/news-and-infos/battery-and-hydrogen-h2-juelich-research-center-and-h2-mobility-publish-comparative-analysis-of-infrastructure-costs/
42 https://cafcp.org
43 https://nikolamotor.com

3.3.4 Hydrogen Bikes

But perhaps the most appealing form of hydrogen transport will turn out to be the hydrogen bike - in reducing the waste, cost and pollution of car congestion and in promoting active travel.

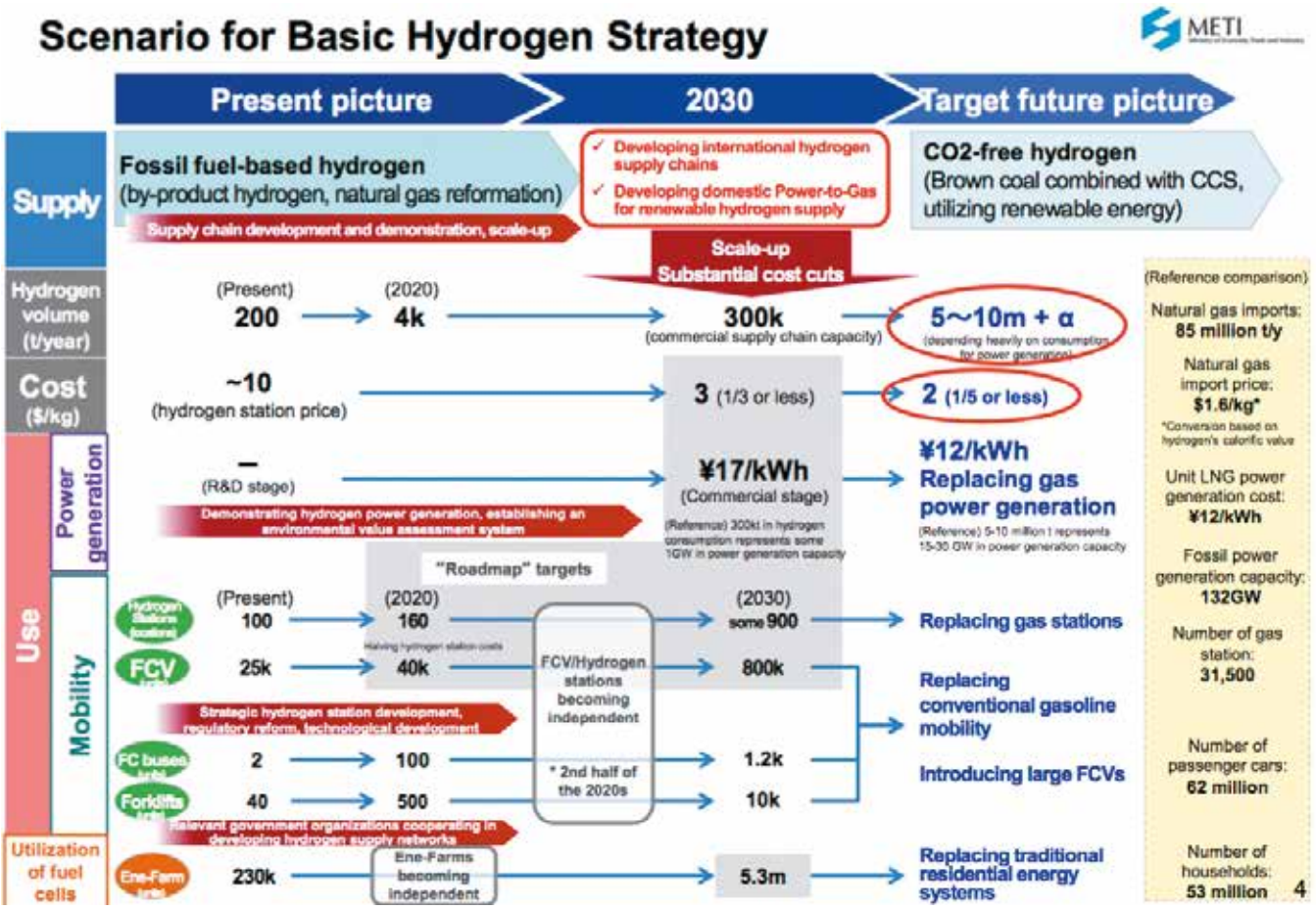
Municipalities in France are trialling the hydrogen bike.

3.4 Asia & Australia

East Asian countries have been amongst the earliest advocates and adopters of hydrogen for transport and building applications. Australia is also now in play.

3.4.1 Japan

Japan is perhaps the pioneer country for developing a hydrogen economy, in response to the Fukushima disaster and being heavily reliant on imported fossil fuels. In March 2018, the Japanese Government updated its hydrogen strategy[44] which is being led by the Ministry of Economy, Trade & Industry. Across all sectors, the strategy envisions "massive amounts of hydrogen" and an exponential increase in the deployment of vehicles, filling stations and power systems through the 2020s. Notably, Japan is nurturing an international supply chain in liquefied hydrogen involving supertankers as an evolution from LNG.



Japan will use the 2020 Tokyo Olympics as a global platform to showcase hydrogen and fuel cells.

44 http://www.meti.go.jp/english/press/2017/1226_003.html

3.4.2 South Korea

With a strong domestic car manufacturing base, South Korea is amongst the global leaders in the adoption of hydrogen-powered fuel cell vehicles, alongside Germany, Japan, and California. In February 2018, the South Korean Government announced plans to deploy 310 hydrogen stations across the country by 2022 in a public-private partnership[45].

In February 2018, South Korea hosted a meeting of the Hydrogen Council[46], which is a global initiative of leading energy, transport and industry companies with a united vision and long-term ambition for hydrogen. The Hydrogen Council was active at the recent Clean Energy Ministerial meeting in Sweden and at COP23 in Berlin in November 2017. It operates at the highest level in promoting hydrogen across the world.

3.4.3 China

In February 2018, China convened a National Alliance of Hydrogen and Fuel Cells with the aims of supporting China's hydrogen and fuel cell technologies to reach market maturity and international competitiveness. The Alliance is set to accelerate developments towards China's hydrogen society.

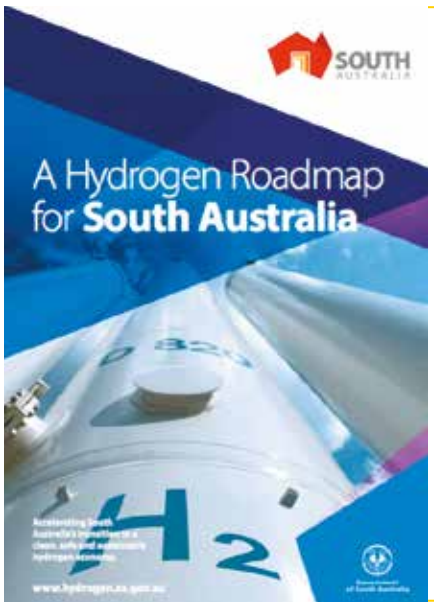
Wuhan, capital city of central China's Hubei province, is scheduled to become a world hydrogen city by 2025[47], with 3 to 5 world leading hydrogen enterprises and 30 to 100 hydrogen fuelling stations. A hydrogen energy industrial park is expected to be built in the city, gathering more than 100 fuel cell automakers and related enterprises. In a rapid scale-up, the city will initially build up to 20 hydrogen fuelling stations from 2018 to 2020 to support the running of about 3,000 hydrogen fuel cell-powered vehicles. The annual production value of hydrogen fuel cells in Wuhan alone is expected to exceed 100 billion yuan (~£11 billion).

Should China's pursuit of hydrogen mirror the incredible global rise of its solar PV industry, Great Wall Motors, SAIC and other Chinese car brands may become familiar on the roads of Wales in the near future.

45 https://energies.airliquide.com/korean-government-announces-deployment-310-hydrogen-stations-2022
46 http://hydrogencouncil.com
47 http://www.chinadaily.com.cn/a/201801/22/WS5a65538ba3106e7dcc135b88.html3.

4.4 Australia

Australia has abundant natural resources including coal which still dominates power generation. But vast renewable plants are now being deployed together with a surge of interest in hydrogen to bridge fossil fuels and renewables at state and federal level.



In September 2017, the South Australia Government published A Hydrogen Roadmap[48] with specific aims for hydrogen: to be exported as vehicle fuel; to release the full potential of renewables; to provide grid stability; and for renewable fertiliser production.

A call for proposals for hydrogen infrastructure projects under South Australia's $150M Renewable Technology Fund was also released. Projects include at least six hydrogen fuel cell buses for use by Adelaide Metro, as well as the supporting hydrogen production and refuelling infrastructure.

South Australia - "We're going to be the hydrogen capital of the world!" - realises that its huge renewables potential needs to be coupled with hydrogen production in order for energy to be stored at scale and over seasonal periods.

In 2016, Australia Capital Territories' Minister for the Environment and Climate Change outlined that international businesses will invest A$180 million to bring hydrogen energy storage and infrastructure to ACT[49], requiring them to make contributions to the government's vision as an internationally recognised centre for renewable energy innovation and investment. To underline its commitment, the ACT Government issued a mandate in April 2018 for all newly leased government vehicles to be zero emissions from 2021[50]. This means battery or hydrogen for all cars, vans and bikes.

Meanwhile, the central Australian Government views coal as having a major future in the production of hydrogen and is backing a coal-to-liquid hydrogen conversion trial in partnership with Kawasaki Heavy Industries, with a view to establishing a new, large-scale hydrogen export industry to Japan[51].

48 http://ourenergyplan.sa.gov.au/hydrogen
49 http://www.govnews.com.au/act-invests-hydrogen-technology/
50 https://reneweconomy.com.au/act-takes-lead-on-evs-all-new-government-cars-to-be-zero-emissions-78922/
51 https://www.reuters.com/article/us-japan-hydrogen-australia/australias-agl-to-host-coal-to-liquid-hydrogen-export-trial-for-japans-kawasaki-heavy-idUSKBN1HJ0ET

4 EU initiatives; any other mechanisms and sources of funding

Relevant sources of hydrogen funding from the EU and the UK Government are provided below. Applying for these sources of funding can be a major undertaking as well as the on-going project administration. However, the rewards can be substantial. Consideration should be given towards establishing a dedicated and co-ordinated team of bid writers and project managers (e.g. from amongst Wales universities and local authorities) who could pool resources in supporting project development including partner searches and in sourcing such funding.

It should be noted that additional funding - beyond those listed below - has been made towards the projects listed in Section 2 in response to specific project proposals put forward or the project - to include Aberdeen's hydrogen buses, Riversimple's hydrogen car, Germany and Austria's hydrogen trains and others.

There are no known dedicated sources of funding towards hydrogen transport schemes in Wales, although the Low Carbon Vehicle Expert Steering Group did recommend such funding in its September 2017 report to the Welsh Government. However, the new Wales & Borders Rail Franchise and the proposed Metros for Cardiff and the Valleys, Swansea Bay and North East Wales - together with the City Regions deals - may present opportunities to fund hydrogen transport. This could result in overall cost savings when compared to conventional rail electrification and by establishing hydrogen hubs for multiple transport users to reach economies of scale.

4.1 EU

4.1.1 FCH JU

The EU dedicates funding towards fuel cells and hydrogen technologies through the Fuel Cells and Hydrogen Joint Undertaking[52] (FCH JU) under the EU Horizon 2020 Framework Programme. The current phase (2014-20), has a total budget of €1.33 billion and targets a wide-range of aims including R&D, demonstration projects and commercialisation of technology.

FCH JU operates annual calls for proposals under which large scale consortium projects such as JIVE[53] (for the roll-out of hydrogen buses across European cities, see 3.2) are put forward.

FCH JU is the dedicated funding source for a hydrogen in the EU. But hydrogen projects have been funded and sources are available elsewhere within EU funding programmes.

4.1.2 Ireland Wales Programme

The updated Cross Cutting Themes Matrix for the Ireland Wales Cooperation Programme 2014 - 2020 was published in January 2017[54]. Listed within the Generic Actions across all Priorities is the following topic and detail:

Develop innovative technologies to promote sustainable transport.

Research into, and the application of, new technologies to promote more sustainable transport (such as hydrogen fuel cells or biogas/biodiesel systems), would provide environmental benefits as well as potentially significant future economic benefits.

52 http://www.fch.europa.eu
53 http://www.fch.europa.eu/project/joint-initiative-hydrogen-vehicles-across-europe
54 http://www.irelandwales.eu/sites/default/files/2017-05/CCTIrelandWalesGuidanceeEnglishMatrix%20-%20VERSION%20CONTROL%20DEC%20 2016%20-%20RP-B%20NC.pdf

4.1.3 INTERREG NWEurope

INTERREG NWEurope has funded two specific hydrogen projects.

H2-SHare[55] is a €3.52m project involving partners in Belgium, the Netherlands and Germany to reduce emissions from heavy-duty transport in NWE through hydrogen solutions.

GENCOMM[56] - Led by Belfast Metropolitan College, the €5.63m GENerating energy secure COMMunities through Smart Renewable Hydrogen project includes assessment of transport as an end-use application for hydrogen.

4.1.4 Connecting Europe Facility

In 2013, the Connecting Europe Facility (CEF) was adopted as a successor to the former TEN-T Programme (2007-2013)[57]. The main objective of the CEF Transport Programme, as set out by the TEN-T Guidelines, is to help complete the Core Network and its nine TEN-T Core Network Corridors by 2030. To achieve this objective, a total budget of €24 billion has been made available for TEN-T projects for the 2014-2020 period.

CEF has funded €10,131,800 towards the overall €50,659,000 project costs of France's Zero Emission Valley project from 2018 to 2024, see 3.3.1.

4.2 UK Government, OLEV

The main focus of funding attention for low/zero emission vehicles - at UK and Welsh Government level - is currently battery vehicles. However, the following dedicated funding is being made available from OLEV towards hydrogen transport.

4.2.1 Hydrogen for Transport Program

In support of the UK H2 Mobility industry-government partnership, the UK Government's OLEV has established Hydrogen for Transport Programme (HTP) in order to develop the UK hydrogen vehicle market[58]. It is providing up to £23m of new grant funding until 2020 to support the growth of refuelling infrastructure alongside the deployment of new vehicles.

USW were amongst the projects to win funding under Stage 1 while Stage 2, which is scheduled to begin in December 2018, will commit up to £14m to fund up to ten hydrogen filling stations plus captive fleets.

4.3 Regulatory Mechanisms

Air Pollution and clean air zones are explored elsewhere in this report but there is new legislation and emerging regulatory mechanisms which are either directed at or can influence hydrogen transport.

55 http://www.nweurope.eu/projects/project-search/h2share-hydrogen-solutions-for-heavy-duty-transport/

56 http://www.nweurope.eu/projects/project-search/gencomm-generating-energy-secure-communities/

57 https://ec.europa.eu/inea/sites/inea/files/cef_blending_call_brochure_alltogether_20171205_final_web.pdf

58 https://ee.ricardo.com/htpgrants

4.3.1 Modern Transport Bill

The UK Government is preparing proposals[59] to force service stations to offer hydrogen for sale at dedicated filling stations under the Modern Transport Bill.

4.3.2 Renewable Transport Fuel Obligation Order (RTFO)

This 2016 consultation[60] sought views on the proposed changes to the RTFO including increases to the use of advanced renewable fuels, such as hydrogen. The proposals are intended to increase the supply and sustainability of renewable transport fuels in order to meet national and international climate change commitments.

4.3.3 Green Gas Certificates

Green Gas Certificates[61] track green gas through the supply chain, providing certainty for consumers who buy it and an incentive for gas producers to inject green gas into the grid instead of using it to generate electricity. Green Gas Certificates can be accounted for at a zero carbon emissions rate and applied to gas combusted or used in a non-combustion fuel cell by a reporting company.

Green Gas Certificates can be used to report Scope 1 emissions under the international Greenhouse Gas (GHG) Protocol[62] and Renewable Heat Incentive sustainability rules mean that Scope 3 emissions can also be accounted for under the GHG Protocol.

59 https://www.gov.uk/government/consultations/proposed-ulev-measures-for-inclusion-in-the-modern-transport-bill
60 https://www.gov.uk/government/consultations/renewable-transport-fuel-obligation-proposed-changes-for-2017
61 http://www.greengas.org.uk
62 http://www.ghgprotocol.org5The cost and benefit of using hydrogen to decarbonise the transport sector, for example, the financial cost of hydrogen and the clean air and carbon impact

5 The cost and benefit of using hydrogen to decarbonise the transport sector, for example, the financial cost of hydrogen and the clean air and carbon impact

Two of the main arguments put forward against using hydrogen for transport are:

i) the inherent inefficiencies in production, storage and use, especially when compared with Battery Electric Vehicles; and

ii) the additional carbon emissions if the hydrogen is produced via Steam Methane Reformation - so called brown hydrogen.

However important, efficiency is just one of the metrics which should be taken into account when promoting zero emission transport - for both decarbonisation and air pollution goals. Other metrics include: customer acceptance; range; charging/filling time; weight/performance ratios; infrastructure costs and upheaval (see Julich Report 3.3.2); the impact on the electricity grid; practical application (especially in crowded cities); resource implications (e.g. lithium and cobalt); and the use/waste of toxic materials. For the complete picture and for a circular economy, all metrics should be taken into account.

And assuming that electrified transportation is the way forward to meet zero emission goals, this essentially narrows the field to 3 available options based on current available technology:

a) Battery Electric Vehicles (BEV) - trains also.
b) Fuel Cell Electric Vehicles (FCEV) - trains also.
c) Overhead Electrification (for trains, trams, large transportation)

There are not many tools in the box. Therefore, it would be wise to keep all options open and not to dismiss any (of only three options) on the grounds of efficiency alone. Besides some of the other above metrics may ultimately prove far more decisive. And, by definition, in a renewable world is efficiency of prime importance?

Moreover, the efficiency argument is being challenged by some in the FCEV industry such as Riversimple who argue that a complete understanding of efficiency is required in order to avoid making false comparisons[63].

And if both BEVs and FCEVs have a role to play, their development is perhaps best served by making comparisons with petrol and diesel engines. A US Department of Energy study concluded that hydrogen fuel cell bus fuel economy was 1.4 times higher than diesel[64]. And after over 100 years of domination, almost every last drop of efficiency has been squeezed out of engines; whereas fuel cells and hydrogen technologies' are only in their infancy meaning efficiencies will improve.

In Germany, steam methane reformation (SMR) is currently the main predicted source of hydrogen for their transport applications (vehicles and trains) in the short term due its lower cost and its availability, for example, as a by-product of industry. However, Germany's aim is to source increasing volumes of hydrogen from renewables via electrolysis (green hydrogen). The Austrian Zillertal railway has already made this commitment to source green hydrogen from the very beginning of its operation, see 3.1.2.

Brown hydrogen (from SMR) can therefore be viewed as a transition to green hydrogen (from electrolysis) and a European standards and certification process is being established under the Green Hydrogen Certificates system.

63 https://www.riversimple.com/batteries-hydrogen-wrong-question/
64 https://www.energy.gov/eere/fuelcells/articles/doe-fuel-cell-bus-analysis-finds-fuel-economy-be-14-times-higher-diesel

5.1 Cost of Hydrogen - Kick-started by Large Users?

The market for hydrogen in transport is at the very early stage and there is, therefore, no settled and competitive market price. As hydrogen infrastructure technologies are also relatively new, there is still a premium on their capital costs until economies of scale bring down prices.

However, in the UK a figure of £10/kg has been applied as the typical, nominal price for hydrogen at the dispenser in the few existing filling stations in operation.

Using this figure, it is possible to apply a nominal cost for the supply of green hydrogen to fuel a fleet of hydrogen trains to cover the entire Wales & West Rail network, as illustrated in Table 1.

Table 1 Hydrogen to Fuel the Entire Wales Rail Network

Measure	Value	Unit	Notes
Hydrogen	**1**	kg	
Hydrogen Train Capacity	**188**	kg/H2	
Electricity required to produce hydrogen for train	**11,280**	kWh	Assumes 60kWh of renewable electricity to produce 1kg of H2 via electrolysis
Train Range	**800**	km	
Total Wales Rail Network	**24,000,000**	km	
Hydrogen required for Wales Network	**5,640,000**	kg/H2	
Annual cost of Hydrogen for Wales Network	**50,640,000**	£	Assumes £10/kg
Electricity required for Wales Network	**338,400,000**	kWh	
Equivalent Wind Capacity required for Wales Network*	**117**	MW	Assumes 33% capacity factor
*In practice, a combination of wind and solar could be developed in clusters across Wales to spread the wealth, according to the practical challenges of installation and the strategic benefits.			

The above may be a hypothetical scenario but serves to illustrate that a relatively modest increase in renewable energy capacity could fuel the entire rail network (equivalent to approximately 50% of the Pen y Cymoedd windfarm).

The cost of hydrogen at over £50m per annum is high but is based on today's nominal unit price of £10/kg - and the price will fall with economies of scale. (To put £50m in context, this is the order of annual revenue which a large windfarm developer can currently expect from selling to the grid.) And this price factors-in a cost for electricity, whereas at times of maximum renewable generation - a windy, sunny day in Summer - the cost of electricity can be negative (and large constraint payments are paid to developers to curtail generation to avoid impact on the electricity grid). Flexible hydrogen production from electrolysers can deliver very useful fuel and provide grid-balancing services, so reducing the cost burden on the electricity grid.

Importantly, the local production and supply of hydrogen presents significant economic opportunities for Wales' communities. The £50m cost now turns into a revenue benefit and keeps this wealth in Wales. The cost of producing hydrogen is largely sunk into capital assets for production, storage and transportation, delivering a payback and an economic opportunity; as opposed to paying for external electricity/diesel over which there is less or no control and which may also be less resilient due to power supply issues or weather-related incidents.

Such economic opportunities can help spread the wealth of the Rail Franchise and Metro by sourcing hydrogen from, for example, rural areas which have plentiful wind or solar resource, especially when involving community energy enterprises.

The local production of hydrogen could extend to other applications including: injection into and decarbonisation of the gas grid; dedicated hydrogen grids for communities; electricity grid-balancing services; the sustainable production of ammonia (NH3) for agriculture; and for use in industry (chemicals, refineries, steel etc). The Rail Franchise & Metro opportunity could provide the kick-start and at the scale which is required to propel such complementary hydrogen-based innovations to sustainably grow the Welsh the economy.

The high and difficult to predict costs of conventional electrification should serve as a caution to the electrification aims of the Rail Franchise and the Metro; especially given the many tunnel, bridge and topography challenges of laying-down electrification infrastructure within Wales' towns and cities, in rural areas and in the Valleys. Some lines on the rail and Metro network may be better suited to hydrogen trains or trams than conventional electrification on the grounds of infrastructure costs, civil engineering upheavals, appearance and power-supply constraints. The same zero emission goals are reached but with on-board generation of electricity rather than external supply. Germany, Austria and Ontario are reaching the same conclusions, see 3.1.

Hydrogen trains may have a cost premium when compared with conventional electric trains but these costs could be more than compensated for by avoiding expensive electrification infrastructure. i.e taking a whole-systems look at costs.

Additionally, social, health and environmental factors should be costed-in to public transport decisions to provide the full-cost picture and to cover the cost to society of air pollution, carbon emissions and noise pollution; all of which can be mitigated by hydrogen trains and vehicles.

Kick-starting the hydrogen economy may be best served in Wales by focusing on large transport such as trains and buses - by matching and sharing large supply with large captive demand - in order to facilitate more widespread adoption amongst car and van users. Large users of hydrogen can reach economies of scale more quickly and drive down infrastructure and equipment costs for others.

And large public and private sector organisations could and should play a significant role by decarbonising their fleets and establishing and sharing refuelling infrastructure at their depots and core locations. These fuelling stations could also be shared with bus operators and made open to personal users, where appropriate.

One of the great benefits of hydrogen is its simplicity and its "one-grade only" nature as a fuel. The hydrogen grade which would fuel a train is the same as that which would fuel a bike.

Research into a multi-modal approach for the rail industry is now being commissioned by Shift2Rail & FCHJU[65]. Shift2Rail is the EU funded European rail initiative to seek focused research and innovation and market-driven solutions by accelerating the integration of new and advanced technologies into innovative rail product solutions. The research will prepare the business case and case studies for up to nine different rail applications, including 'shunting locomotives, freight/last mile locomotives and regional trains', looking at both the concept design and potential opportunities.

65 https://shift2rail.org5.2

5.2 Water

Producing green hydrogen via electrolysis requires renewable electricity and water. In plentiful supply in Wales, it is worth assessing the value of water in the production of green hydrogen if the market increases in lines with the predictions and global initiatives presented in this report.

Consider using the water in the Elan Valley reservoir system and under the control of Dŵr Cymru for the production of hydrogen. Elan Valley holds nearly 100,000,000m3 of water and should all this be converted to hydrogen at £10/kg, its value would be in the order of £100,000,000,000 (£100bn).

Such thought experiments may be fun and it may be far-fetched to use all of the Elan Valley system's H2O for H2 production. But there are serious plans to develop hydrogen production, distribution and transportation facilities at vast and continental scale in the North Sea, Australia, Japan and the US, for example.

The value of hydrogen in water far exceeds the value of water on its own. And Elan Valley lies in the heart of mid-Wales' constrained wind country.

We may need to develop more on-shore wind and solar at scale (as well off-shore wind) in Wales to meet our targets and these developments will have landscape implications. But the hydrogen route now provides a viable alternative to the default option of using huge electricity transmission lines to move renewable energy from production sites to end-use, which comes with vast cost, visual impact and inefficiencies.

And moving a gas is cheaper than moving electricity. According to TenneT, the leading European electricity transmission system operator based in The Netherlands and partners in the giant, hydrogen-included North Sea Wind Power Hub[66]. "The costs of energy transmission and long-term storage in gas form are considerably lower per unit of energy than if the energy is transmitted and stored in the form of electricity."

Given the vast hydrogen production facilities being proposed globally, Elan Valley's contribution may one day be viewed as merely a drop in the ocean.

5.3 Power to Gas Costs

A research paper published by University College Cork (UCC) in February 2018 assessed the cost of producing hydrogen from renewables[67], so called power to gas (P2G).

UCC found that the levelised cost of energy (LCOE) for P2G to ranges from €124/MWh in 2020, €105/MWh in 2030, and €93/MWh in 2040.

Electricity is by far the largest contributor to the LCOE of the system and reductions over time take into account the falling cost of renewable electricity (which is as low as c1 per kWh in Mexico) and reductions in the capital cost of electrolysers through economies of scale

This compares with diesel currently retailing at €105/MWh in Ireland excluding value added tax (VAT).

However, Ireland does not produce any of its diesel or primary oil and, except for the filling stations, the vast majority of the value in diesel and oil flows out of the country. By contrast, the value and wealth generation potential of producing and using hydrogen could all stay in Ireland - or Wales.

Neither do the figures take into account the health and social costs of air pollution from diesel. The March 2018 UK MPs report on air pollution (see 1) has served to underline the staggering health and social costs of our reliance on diesel and other dirty fuels. These costs can be avoided by a large-scale shift to available zero emission technologies.

66 https://www.tennet.eu/news/detail/gasunie-to-join-north-sea-wind-power-hub-consortium/
67 https://www.researchgate.net/publication/323276987_Modelling_of_a_power-to-gas_system_to_predict_the_levelised_cost_of_energy_of_an_advanced_renewable_gaseous_transport_fue

6 What is the Welsh Government currently doing to assist the hydrogen economy; what are the barriers; what more could be done?

There is no Welsh Government strategy on the hydrogen economy. Projects are supported on individual merit such as Riversimple (see 2.1.1), or via FLEXIS and Smart Living (see 2.2.3) but there does not appear to be a coherent, single/multi-sector strategy of the kind which other countries and regions have adopted.

There is recent history of strategic announcements and policy work either directly from or sponsored by the Welsh Government - e.g. H2 Wales, H2 Highway, Low Carbon Vehicle Steering Group (see 2.4) - but these have lacked continuity and/or further development and do not reflect the new, global interest in hydrogen and the major role it has to play in decarbonisation goals across a vast swathe of the economy and in tackling urgent air pollution.

New Dawn

This stop-start nature of past developments may serve as a barrier to new impetus; set-against a backdrop of previous false dawns on the hydrogen economy. And hydrogen may still be wrongly perceived as a novel, future technology which sits most easily in the R&D mindset.

But with global demonstration, deployment and commercialisation accelerating (China needs to be watched closely in this regard); with many of the world's largest companies re-aligning their business models to take account of hydrogen; and governments - UK Ministers included - making bold announcements, there is clearly new momentum behind hydrogen.

Hydrogen has physical, versatility and practical application benefits which in themselves are highly useful. But when the failings of other energy technologies and the limitations of existing infrastructure are taken into account, this usefulness is magnified. It is also difficult to think ahead to any damaging, unintended consequences of pursuing hydrogen - compare this with the resource availability and pollution implications of biomass and lithium/cobalt mining, for example - especially when the green hydrogen route is pursued.

Cost

Cost is perhaps the greatest barrier to progress. In keeping with all new technologies, there is a premium on the cost of hydrogen technologies at this early market stage. But their cost profiles are falling and expected to follow those of solar and wind as economies of scale are reached. The cost premium predominantly applies to capital costs since operational costs can be lower than those of engines, for example, as there are no moving parts or oil changes required in hydrogen technologies.

Hydrogen technologies would stand a better chance if whole-life costs were assessed in financial decisions, instead of procurement exercises which are weighted towards the lowest capital cost option. Better still if whole-system costs are considered, as detailed for hydrogen trains in 3.1.

In issuing tenders, proposed comparisons should therefore include all costs to include: vehicle + complete charging/refueling infrastructure + fuel + civil engineering infrastructure + grid upgrades.

And if value for money is the main determining factor in procurement, then social and health impacts and costs should be accounted for in any true value for money exercise.

Innovation

The perceived novelty factor of the technologies is a barrier to rapid progress. Although there are plentiful and commercially mature projects elsewhere in the world, this does not necessarily translate into sufficient evidence in order to promote projects in Wales. Seeing closer to home is believing.

Business as usual is a difficult nut to crack when introducing new technologies to the market. Long-established practices and project gatekeepers rely on tried and tested templates which dictate the development of a project to a client. Despite the benefits of new technologies, including hydrogen, the perceived risks of introducing a new technology outweigh the known downsides of incumbent technologies.

Everyone seems to be in favour of innovation - but not necessarily in terms of deployment in their back yard.

Regulations

There are no regulatory barriers to introducing hydrogen buses and cars in the UK and the rail industry is working with the UK Government towards standards for hydrogen trains. There are regulations which must be adhered to in developing hydrogen infrastructure including filling stations - and these may be onerous but they do not form a barrier.

From a different perspective, regulations could be strengthened against polluting technologies in order to accelerate the deployment of cleaner technologies. The Clean Air Act in California has been the main policy instrument - with supporting incentives - towards the growth in both BEV and FCEV. It has also been instrumental in reducing or avoiding pollution from other sources, including ports and industry. And while the WBFG Act is welcome, it is perhaps difficult to define in practice and avoids the specific and strict limits and definitions of, for example, California's air regulations.

However, although there is no strategic focus in Wales to date; there is an existing body of work to use as a platform; there is a growing knowledge base amongst companies, government and universities; but perhaps most importantly we can learn from and adapt the strategic work of other countries and regions (e.g. Denmark, California, South Australia) and adapt them to our own circumstances.

7 The feasibility of using hydrogen to decarbonise different aspects of the transport sector, for example, buses, trains and freight

Previous sections have illustrated not only the feasibility but the widespread adoption of hydrogen in the rail and road transport sector, gaining traction amongst both large users such as Alstom's hydrogen trains and cascading down to the small-scale such as the 2-seater Riversimple hydrogen car and the hydrogen bike.

But attention is also being directed towards shipping and aviation whose carbon and pollution impact is equally concerning and can be severely concentrated at ports and airports. Shipping currently accounts for 2-3% of global greenhouse gas emissions and a single cruise liner can emit as much particulate matter in a day as a million cars[68].

As ships sail close to land and reach ports, the air pollution can be acute and legislation will be introduced in the EU. Vehicle movements exacerbate the problem and the Port of Los Angeles is addressing the issue by introducing zero emission technologies including hydrogen.

Meanwhile, Norway is piloting the use of hydrogen in ships[69].

And then Kawasaki heavy industries in Japan is building a hydrogen supertanker to ship hydrogen from Australia to energy hungry markets at home[70]. Could we one day see Wales exporting hydrogen in such ships from reconfigured terminals in Milford Haven?

Aviation presents its own unique safety challenges but Airbus, with a base in Broughton, views hydrogen as playing a role in the aircraft of the future. In the short term in the form of fuelling Auxiliary Power Units (APUs), which can alleviate pollution at airports while aircraft are standing or taxiing, but in the longer term as a fuel for propulsion itself[71].

An insight into UK-scale thinking has been provided by National Grid[72] who are assessing how to reconfigure the gas transmission and distribution network to carry hydrogen in order to decarbonise heating and to supply hydrogen as a transport fuel.

The implications of these comments by National Grid extend to Wales & West Utilities as the local gas network operator in Wales and whose pipelines - and others' - could be refashioned to carry hydrogen to not only decarbonise heat (see 3.1.6) but to distribute hydrogen as a transport fuel. WWU is a licensed carrier of gases - not limited to natural gas but to also include hydrogen.

68 https://www.euractiv.com/section/air-pollution/news/daily-emissions-of-cruise-ships-same-as-one-million-cars/
69 https://www.sdir.no/en/news/news-from-the-nma/norway-may-get-the-worlds-first-hydrogen-powered-cruise-ship/
70 http://global.kawasaki.com/en/hydrogen/
71 https://apex.aero/2018/02/05/fuel-cell-systems-power-commercial-aircraft-cabin-parts….
72 https://about.bnef.com/blog/national-grid-eyes-decarbonizing-gas-using-hydrogen-qa/.8Recommendations

8 Recommendations

Wales can take a leading, strategic role in the emerging hydrogen economy, which, as this report illustrates, is accelerating quickly across the world.

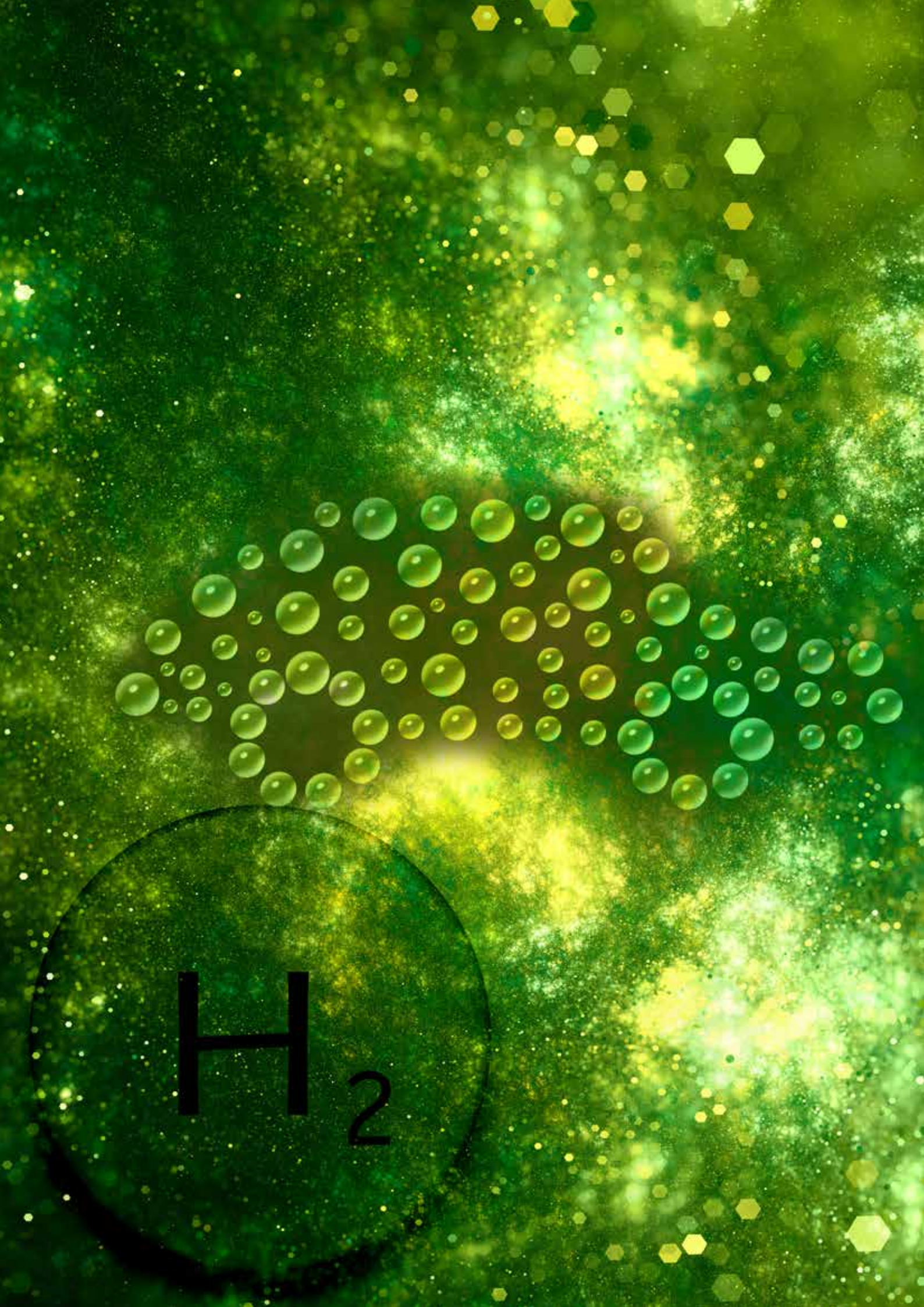
There is a growing body of evidence from research, industry and governments across the world which can guide policy initiatives in Wales; and swiftly lead to the replicating and tailoring of best-practice from other countries to suit Wales' circumstances.

The Welsh Government should provide leadership in creating the appropriate project support mechanisms and governance to help overcome barriers and to accelerate developments across Wales.

The global hydrogen community is still relatively small and well-connected. By joining the fast-lane of those countries and regions which are rolling-out the technologies, Wales has the opportunity to make rapid progress towards environmental, social and economic goals.

Specifically:

1. The Welsh Government should consider opportunities for supporting the local production and supply of hydrogen.
2. The Welsh Government should provide a dedicated source of funding towards hydrogen transport schemes in Wales.
3. The Welsh Government should use the opportunity presented by the new Wales & Borders Rail Franchise and proposed Metros for Cardiff and the Valleys, Swansea Bay and North East Wales to make the business case for the introduction of hydrogen trains - and buses - in Wales.
4. The Welsh Government should consider establishing a dedicated and co-ordinated team of bid writers and project managers (e.g. from amongst Wales universities and local authorities) to pool resources in supporting project development including partner searches and sourcing funding.
5. The Welsh Government should encourage and enable large public and private sector organisations to decarbonise their fleets and establish and share refuelling infrastructure at their depots and core locations and for public use.
6. The Welsh Government should monitor predictions and global initiatives to assess the value of water in the production of green hydrogen as the market increases.
7. The Welsh Government should develop a coherent, multi-sector strategy on the hydrogen economy.
8. In considering the business case for transport and other infrastructure projects, whole-life costs or whole-system costs, along with social and health impacts and/or benefits, should be assessed, rather than weighting decisions towards the lowest capital cost option.
9. The Welsh Government should make use of strengthened regulations against polluting technologies in order to accelerate the deployment of cleaner technologies including hydrogen.
10. The Welsh Government should reach out to the Hydrogen Council and co-organise a major event in Wales which communicates Wales' ambition on the hydrogen economy to a global audience. Such an event should also celebrate the life of William Grove of Swansea, who invented the hydrogen fuel cell in 1842.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