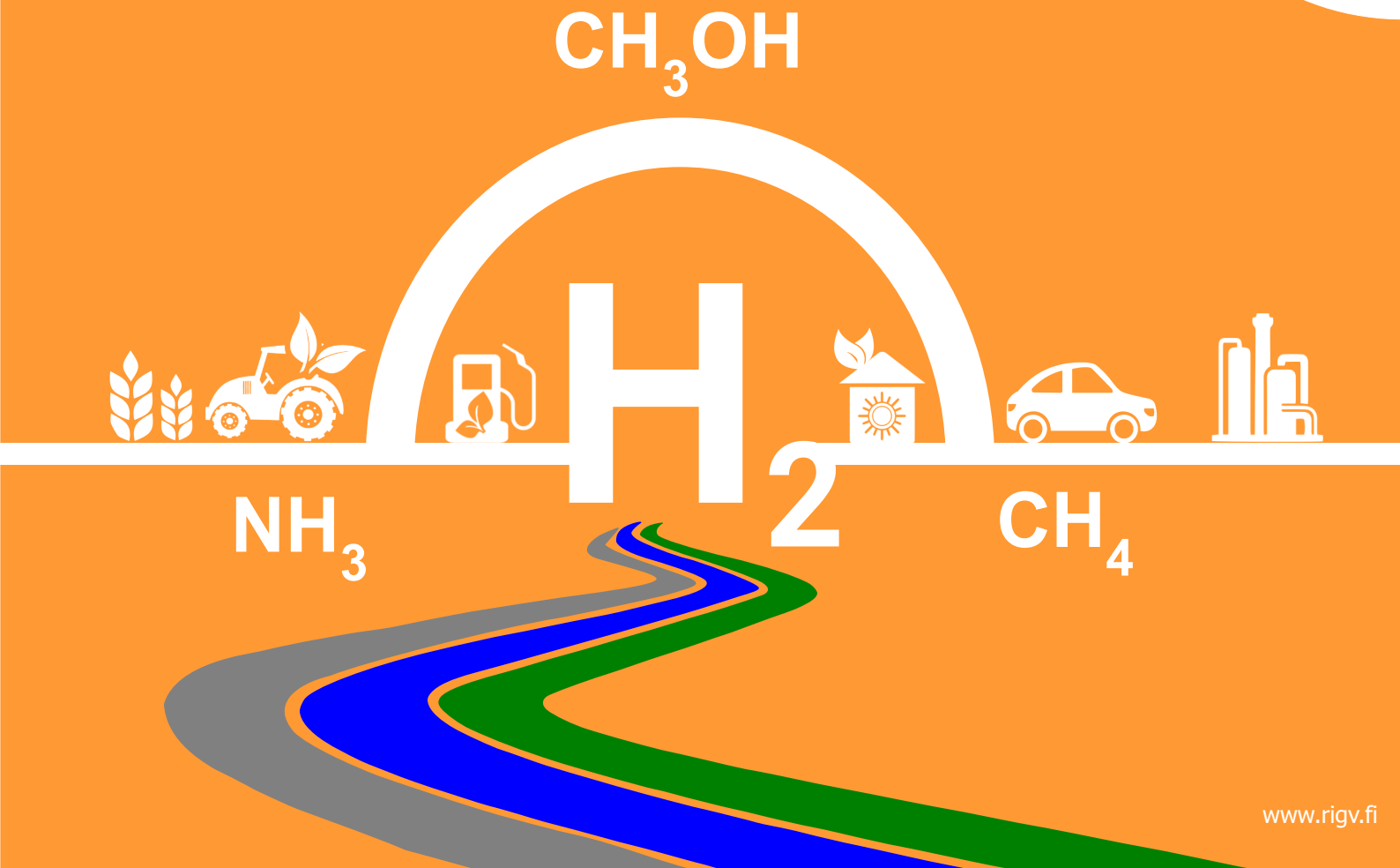
MID WALES HYDROGEN STUDY

RADICAL INNOVATIONS GROUP
2021



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Executive summary

This report is an outcome of the work commissioned by the Growing Mid Wales (GMW) Board in partnership with Ceredigion and Powys County Councils. Radical Innovations Group AB, Finland strategically partnered with GMW Board to carry out this work in two stages – opportunities assessment and feasibility study phase.

Hydrogen and hydrogen-based fuels are increasing in popularity, thanks to the growing interest and increasing ambitious commitments from public and private sectors across the world. We have seen several ambitious targets set by UK government over these years in this direction. That being said, we have several reasons to believe that there is still a huge gap between ambitious targets and ground reality. Welsh and UK governments must act decisively and provide clear political support to position itself at the forefront of a growing global industry. Though decisive policy and regulatory push is currently emerging, thanks to strategic developments at the local- and national-level in the UK, detailed short-, medium-, and long-term action plans on "how" to go ahead are left to interpretations and capabilities available in the region. It is our humble and sincere opinion that without such realistic action plans and support in the form of policy and regulation, we will still be only talking about hydrogen even in 2030. Hence, we aim that our present work will address this gap at the county-level providing actionable roadmap in short- and medium-terms by creating market opportunities and decarbonising the local public assets. Furthermore, strong and clear signals are also required from policy makers to encourage industries to confidently increase investments in this direction. Such private sector investments will form the evidence base that will set the long-term direction for growth in this sector.

That being said, politicians, policy makers, technocrats, project developers, and businesses across sectors have one thing or the other to say about hydrogen and hydrogen-based fuels and their potential in decarbonizing various sectors of the UK economy. Like with all new technologies, there are groups within UK fully advocating for hydrogen and the others who are not convinced with the potential of hydrogen as a viable energy vector for the UK. While the former groups see huge potential in hydrogen in many applications, the latter group believe hydrogen is just another "hype" promoted by big corporate lobbies.

Hence, we have strong reasons to believe that the overall scale of hydrogen deployment in the energy system is largely uncertain and will heavily depend on the commercialisation of technologies for electrification, hydrogen, and other hydrogen-based fuel options. There will be an increase in electrification across UK. Especially in the region of Mid Wales, where grid capacity is a huge bottleneck, we cannot talk about development of any sort without significant increase in grid capacity. For regions with limited grid capacity, it is likely that other energy carriers will be required to enable a more flexible, resilient and integrated system. Our opportunities assessment has revealed that hydrogen and hydrogen-based low- and zero-carbon fuels such as methanol and ammonia can complement electricity.

Hydrogen (green or blue) as the way it is being positioned might very well be a wishful thinking or a miracle fuel of the future. Presently, direct hydrogen has only limited market opportunities within Mid Wales and developments outside Mid Wales are still evolving. Many of the applications are not yet ready for green fuels. One has to think about a transitory period to create a pathway if green fuels have market opportunities. In this period, Mid Wales need to find realistic market opportunities as a way to support the organic growth within the region. There should be transition fuels specific to applications that can serve as a bridge between current fossil-fuels and the future green fuels. The transitory fuels should be easily usable with current infrastructure and machineries with minimum or no change. That being said, pure hydrogen has some niche market opportunities in the heavy goods vehicles and public transportation such as buses and trains. Synthetic methane, methanol, and ammonia could be seen as transition or ideal green fuels for many of the applications.

Given the lack of infrastructural support, supply chain challenges, and policy and regulatory gaps, the market developments can go either way as strategic goals are not linked to clear actionable plans in short-, medium- and long-term for hydrogen and hydrogen-based fuels. With these uncertainties, Mid Wales can best prepare by cleverly planning and positioning itself as a strategic partner to other regions that are acting as first movers. In doing so, Mid Wales region can also greatly benefit from the learnings derived from "others'

mistakes" before venturing into long-term large-scale investments. This way, Mid Wales can align itself as a strategic partner to North and South Wales and the rest of UK to create new market opportunities inside and outside Mid Wales.

We have shown in our opportunities assessment report how the "first procure, later produce" strategy can be effectively implemented in the Mid Wales region. Our strategy is built on the basic premise that it would be a clever approach for the region to first create a market ecosystem for the low- and zero-carbon fuels identified in this study by first procuring these fuels in short- and medium-term (up to 2030) and in long-term partner with relevant stakeholders to locally produce these fuels in the region. To this end, we have explored ways to implement this strategy at business-, industrial-cluster-, industry-, and public-sector-level highlighting the **relevance**, **challenges**, **opportunities**, and **limitations** at different levels.

We have also addressed the skills and capacity building challenge in the cleantech and renewable energy sectors, particularly in the hydrogen and hydrogen-based low- and zero-carbon fuel economy. In this feasibility study, we gathered insights that there is a significant skills gap in this sector in Wales, particularly in Mid Wales. This issue needs to be addressed strategically at the same time to ensure that the right talent is available at all levels, which includes an inclusive and diverse mix of people. We need to work with educational institutions at all levels to ensure that the right skills developed at all levels in the coming years – from schools and apprenticeships, to higher education and vocational training. We have already initiated dialogues with relevant government agencies and vocational and university educational institutions in Wales and Mid Wales during the course of this feasibility study to highlight and elevate this issue. More discussions should follow in this direction to initiate and develop relevant courses and training programmes at all levels from vocational training schools to research institutions to fill this gap in the coming years.

Last but not the least, we have also carried out broad-brush financial assessment to get a preliminary overview of investments needed in the short- and medium-term to pursue first procure part of the strategy. The aim of the financial assessment is to serve as starter for further discussions with the decision makers and initiate various actions that are recommended in the short- and medium-term strategy implementation section. We have provided rough estimates for the capital and operational expenditure required for relevant technologies based on available data and for procuring low- and zero-carbon fuels as an effort to decarbonize the public-sector assets in Mid Wales region. We have also included estimates for the environmental cost of emissions for the as-it-is (baseline) scenario and compared it with various low- and zero-carbon fuel options discussed in this feasibility report.

During the feasibility study, we found that many of the national and regional funds for developments related to hydrogen are mainly distributed in the North and South Wales region. That being said, contrary to the proverb, "hydrogen is not always greener on the other side!" This is probably the main "potential strength" of Mid Wales, which needs to be properly used at the right time. The decision makers in the region should prepare the region accordingly to attract investments through short- and medium-term actions.

As a final thought, we strongly believe this feasibility report will stimulate further discussions among stakeholders and decision makers in the region to drive change and to implement various recommendations made in this report. We take this opportunity to thank the Growing Mid Wales Board, Powys and Ceredigion Counties, and the funding agencies for giving us the opportunity to carry out this feasibility study.

Introduction and motivation

The ambitious targets set by the UK Government (UKG) to rapidly move towards low-carbon sources based on renewables and nuclear emphasize the importance, urgency, and timeliness of our efforts in the Mid Wales region. Various countries, particularly the UK, have been looking for the holy grail of low- or zero-carbon energy source over these years. Though there are many fads that come and go depending on the priorities of the times, the obsession for the low- or zero-carbon holy grail remains obviously for the right reason – climate change. Today, the buzzword is "hydrogen."

Politicians, policy makers, technocrats, project developers, and businesses across sectors have one thing or the other to say about hydrogen and its potential in decarbonizing various sectors of the UK economy. Like with all new technologies, there are groups within UK fully advocating for hydrogen and the others who are not convinced with the potential of hydrogen as a viable energy vector for the UK. While the former groups see huge potential in hydrogen in many applications, the latter group believe hydrogen is just another "hype" promoted by big corporate lobbies.

Hydrogen fuel, based on its production process, can be termed as grey, blue, and green hydrogen which corresponds to non-zero, net-zero, and zero carbon emissions, respectively. Apart from these direct hydrogen options, there are also other high-density hydrogen-carrier fuels, especially, ammonia and methanol. That being said, at the point of departure in this study, we have taken a neutral stand and listened to all stakeholders to build a reasonably balanced picture about the true potential of hydrogen, hydrogen-carrier, and other low-carbon fuels in the Mid Wales region. In the opportunities assessment phase, we summarized our initial findings addressing

- why Mid Wales region should pursue realistic low- and zero-carbon fuels market opportunities?
- what potential application areas and sectors should Mid Wales region target?
- how to prepare and pursue the identified market opportunities within and outside Mid Wales?

We have gathered solid evidence-based answers to above three questions and presented the initial learnings to the steering board, namely,

- the energy landscape of the region exploring the ideal (mix of) energy vector(s) that can be used to create value to the Mid Wales region,
- relevant applications areas and target sector where Mid Wales should focus
- ideal strategy for Mid Wales to pursue in short- and medium-term given the various developments in and around the region.

In the following, we have summarized only the essential information distilled from our assessment study report to build the narrative for our feasibility study. Mid Wales, in the context of green energy potential, is resource rich. Assets include availability of fresh water, renewable energy assets in the form of wind, hydro, and solar. There is also considerable amount of biomass in the region – thanks to the region's forests and farms.

Mid Wales is considered for most part as "under-developed" due to poor, or lack of, infrastructure and mostly rural in the context of development opportunities. The lack of infrastructure, as we pointed out in the opportunities assessment report, has not only severely affected growth in the region, but also isolated the region from its regional siblings – North and South Wales. Efforts to improve the infrastructure in the region in the past were dealt with local oppositions for any such improvements were not seen to truly add value to the livelihoods of local population. For example, initiatives to improve grid infrastructure were seen as a way for big firms to make money for themselves milking the regional resources without giving back to the region. Number of companies, local job opportunities in sectors other than agriculture and forestry, quality of home and public infrastructure for heating, electricity, transport, etc. compared to regional neighbours – North and South Wales – and rest of the UK highlights the reasons for concerns regarding development in the region.

That being said, we are not clear about the status and the nature of any local opposition for development in present times. Highlighted challenges, however, make one thing clear. Any development pursued in the region should win the local support and truly create value in the region at least in medium- and long-term.

In other words, those who want to milk the regional resources should be prepared to share the benefits locally in the region. Any kind of value creation in the region requires reactivating the Mid Wales region's energy landscape in terms of choice of low-carbon energy vectors, improving grid connectivity, ramping renewable energy assets, creating new job opportunities, improving quality of heating, electricity, and transport infrastructure, etc. Without creating local market opportunities that can benefit from these improvements and focusing only on export potentials of the region's resources, we believe, there will hardly be any significant progress in the region. We have derived some important clues on where are the best bet for Mid Wales and what role Mid Wales could play in the larger scheme of things considering the developments in North and South Wales, and the rest of UK.

Based on the outcomes of the assessment study phase, our goal in the feasibility study phase is to evaluate different market opportunities for Mid Wales region to pursue involving hydrogen, hydrogen-carrier, and other relevant low-carbon fuels such as biogas and methane. Our insights are derived from qualitative and evidence-based assessments taking into account various ongoing developments in North, South, and Mid Wales aligning to the overall UK government priorities.

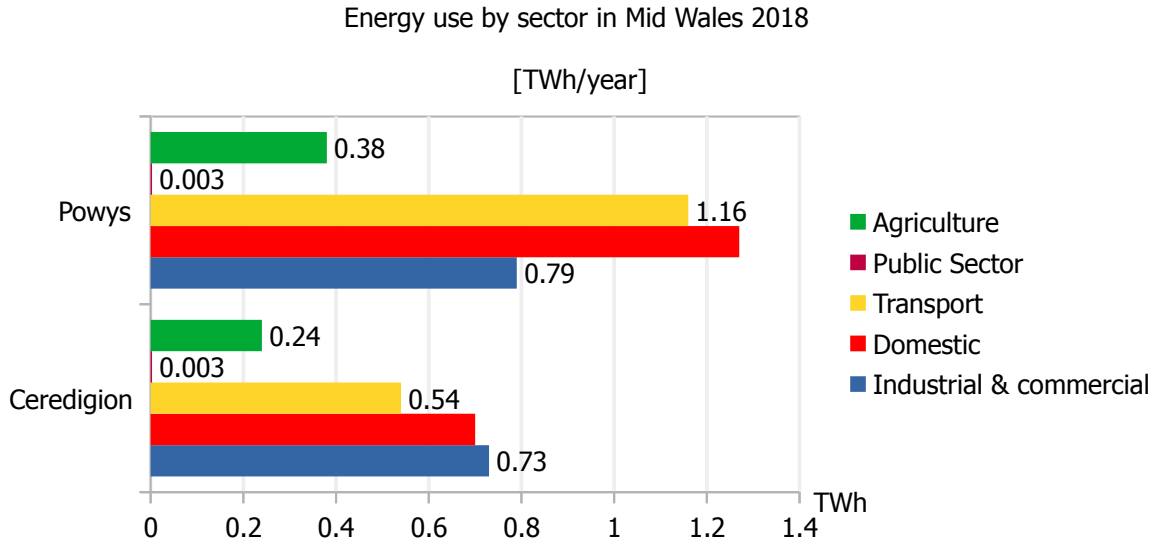
We have interviewed more than 50 key stakeholders in and outside Mid Wales region in the form of one-on-one meetings and focus-group discussions. We have gathered insights about challenges and opportunities through these interactions and comprehensive desk-research. Following this, we carried out a systematic and comprehensive feasibility study to develop an actionable roadmap based on suitable strategy for the region. In sum, through the outcomes of this study, we want to inform and prepare the decision makers in the region what role can Mid Wales play in short-, medium-, and long-term, how Mid Wales can prepare for the low- and zero-carbon energy future developments, and what are relevant actionable next steps.

Opportunities assessment findings

In the opportunities assessment, we have reviewed and evaluated the energy landscape of Mid Wales taking into account different sectoral energy demands and types of fuels currently in use in the region.

Energy landscape of Mid Wales

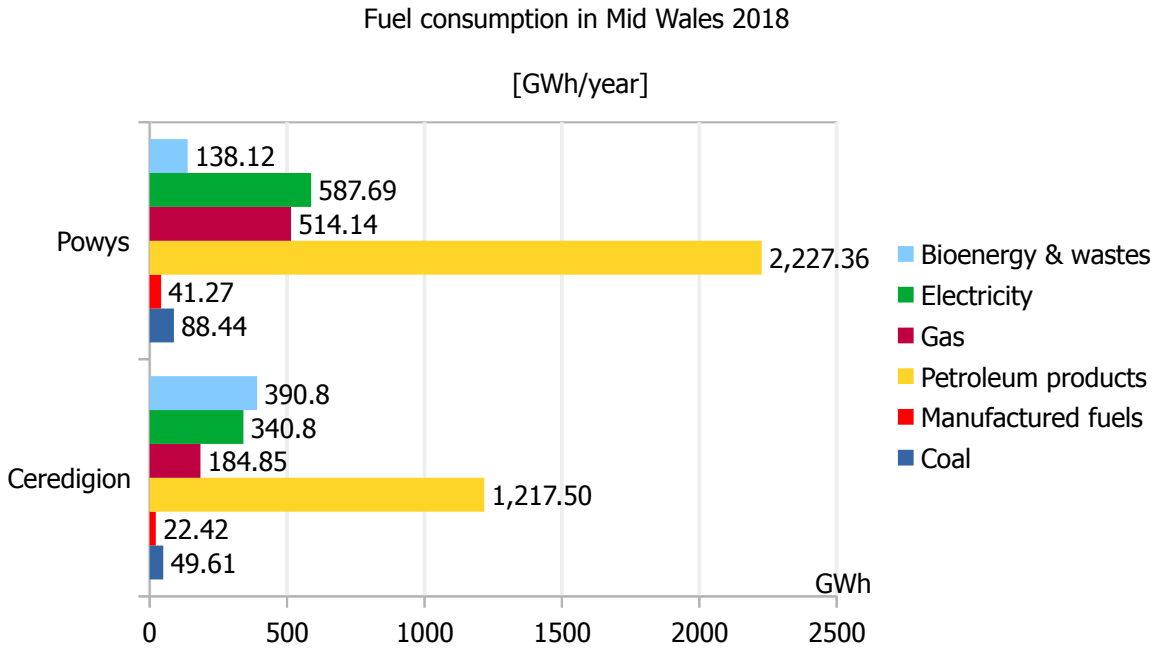
As of 2018, the overall energy (electricity and fuels) consumption in Mid Wales is split between the commercial and industrial (26%), the domestic (34%), the transport (29%), and the agricultural (11%) sectors. Annual energy consumption [TWh] across different sectors in Mid Wales is given in the figure below.



It is worth noting that almost all of the region's electricity consumption (97%) is catered by local renewable energy sources. Local renewables constitute predominantly onshore wind (~ 285 MW), hydro (~ 78.7 MW) and solar photovoltaic (PV) (~ 55 MW) supplying 66%, 18%, and 13% of renewable generation capacity, respectively. The region's annual electricity demand as of 2018 is 0.93 TWh. More than 50% of this is consumed by the commercial and industrial sector. Decarbonisation of the UK's electricity grid has led to decrease in the industrial energy demand (down by 10%) and emissions (down by 37%) compared to 2005-level. Though this is a good thing for the environment, there are some concerns among electricity firms as these developments has also led to drop in their revenue over these years.

We evaluated the energy use [GWh] by the type of fuel used in Mid Wales in order to understand the consumption patterns and market price sensitivities. In the figure below, we have highlighted the annual consumption of different fuels in Mid Wales.

These figures show that about 12% of commercial and industrial demand is met by gas, reflecting the off-gas nature of the region – highest proportion of off-gas grid properties in Wales (62%). For example, in Powys, off-grid public sector housing stock is approximately 20% as per previous studies commissioned by Growing Mid Wales Board. According to UKG statistics, domestic and non-domestic sectors in Powys region use more petroleum products and electricity. Their usage levels is more than the average for Wales. Similar trends are noticed also in Ceredigion region. The industrial and commercial sector in Ceredigion uses very high proportion of bio-energy from waste, ranking third largest in Wales.



About 17% homes in Ceredigion and 14% in Powys experience fuel poverty due to relatively poor domestic energy efficiency. This is in spite of the fact that Powys having the highest biomass heat capacity in Wales (total thermal capacity 132 MW) and Mid Wales as a whole having highest deployment of renewable heat installations in Wales with nearly 2% of homes having a heat pump or biomass boiler. These facts hint that heat pumps and biomass are not ideal choice for domestic heating in the region largely due to poor insulation and efficiencies of houses.

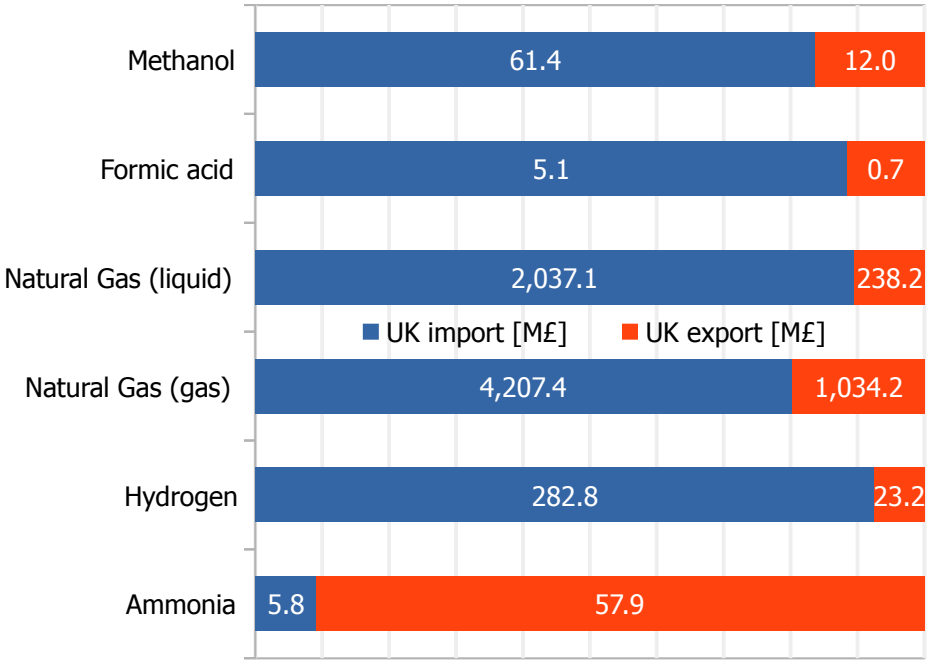
Furthermore, tackling the decarbonisation of off-gas homes, representing circa 22% of Welsh homes, is one of Mid Wales' key challenges. The relatively high upfront cost of heat pumps remains the main barrier to widespread deployment. This is one of the potential area where huge market opportunity lie for low-carbon energy vectors provided clever supply chain and infrastructural solutions can be developed.

Transport sector in Mid Wales consumes about 1.7 TWh of energy mostly contributed by petroleum (1.67 TWh). Large portion of this is personal vehicles running on diesel followed by gasoline. In freight vehicles, we have heavy goods vehicles (HGV) and light goods vehicles (LGV) running on diesel and gasoline. UKG has set an ambitious target to ban fossil fuel vehicles by 2030. This presents a compelling opportunity for hydrogen-based vehicles and electric vehicles in the region.

Agriculture sector forms the main economic driver of the region. Presently, petroleum is the primary choice of fuel with around 0.62 TWh of annual consumption in agriculture sector. It is one of the most difficult sector to decarbonize given its nature of operations, equipment, and infrastructure.

Relevant low- and zero-carbon energy vectors

The overall market opportunity in the UK for low- or zero-carbon energy vectors like hydrogen, ammonia, methanol, and bio-methane in comparison with natural gas for the year 2019 is given in the figure below.



Hydrogen

North and South Wales have started several activities to produce hydrogen in a large industrial scale benefiting from various existing infrastructure and industrial activities in their region. Several ongoing activities in the rest of UK are also gearing up to produce blue and green hydrogen based on available infrastructure and ongoing large industrial-scale activities. As of 2019, UK imports about £ 61.4 Million [1] and exports about £ 23.2 Million worth of hydrogen. This figure is meant to increase both in terms of import and export. Availability of cheap electricity, man power, and raw materials are going to reduce global hydrogen price in the coming years. As far as UK is concerned, there is no standard reference price for hydrogen like in the case of petroleum products. Hence, the market dynamics in short-term is heavily volatile with price variations in the range of 50-70%. One can compare this with the short-term price variations in petroleum products which lie in the range of 5-10%. One of the reasons for this is both demand and supply levels are low. As the market demand picks up, there will be more stability and regulations in the prices.

Currently hydrogen is partly used in metal processing to yield iron reduction. Hydrogen is also employed to prevent partial oxidation of iron ore while the ore is still in the furnace. Steel industry is a particularly interesting area for green hydrogen because of the process's high carbon emissions and the relative lack of viable alternatives. Green hydrogen can be traded for producing methanol or synthetic methane as a way in the carbon capture and utilisation strategy. Other segments of interest for hydrogen is the food industry and glass industry. Hydrogenation of fats is the core area of application in the food industry. Other applications include use of green hydrogen in the semiconductor industry as a heat transfer fluid (when kept in a vacuum) and as fuel in the aerospace industry.

Power-to-gas (P2G) involves the use of renewable electricity to produce green hydrogen through water electrolysis. In some cases, the hydrogen is then converted to synthetic methane gas using captured carbon dioxide. Since there are likely to be increasing amounts of wind and solar capacity, there will at times be excess output over demand. Converting that surplus to hydrogen, or other hydrogen-based fuels like methane makes more sense than curtailing the output of wind and solar plants.

1 All figures are converted from US$ or other foreign currencies to £ equivalent.

Other hydrogen-based fuels

We will briefly summarize relevant hydrogen-based fuels that have significant potential in Wales and the UK markets. Some of these fuels are already being considered by various actors outside Mid Wales, particularly, in the industrial clusters in North and South Wales.

Ammonia

As given in the figure, the UK is a net exporter of ammonia. The market is mostly in agricultural and industrial raw material sectors. The primary interest in ammonia is due to its use as a fertiliser. However, it can also be used as storage and carrier medium for hydrogen. It is cheap (30 to 40 p/kg) and offers long-term hydrogen storage capabilities. However, this process of storing hydrogen in the form of ammonia and recovering hydrogen from ammonia has a round-trip efficiency of 20–30% depending on the initial efficiency of the electrolyser technology or SMR process used. Many efforts are currently ongoing in the universities in Wales and the UK to directly use ammonia as a fuel in engines and solid oxide fuel cells. Furthermore, ammonia can also be cracked on-site to recover hydrogen that can be fed into hydrogen fuel cells. Companies such as Mitsubishi, Siemens, Baker Hughes and MAN Group have been working to develop and commercialise turbine technology that could generate energy from 100% ammonia fuel. This is being closely monitored as it is a remarkable opportunity for countries with several operating natural gas turbines. Green ammonia is increasingly seen as a convenient hydrogen-derived fuel for zero-carbon-emission power.

The market opportunity for ammonia is growing as it is a better carrier of hydrogen and provides excellent hydrogen storage features. As a material, ammonia has a long history in the industrial sector and hence the supply chain is well established both in the UK and abroad.

Methanol

Currently, UK is net importer of Methanol with about £ 61.4 Million and exports about £ 12 Million. As technological advances are made in alternative fuels and fuel cells, methanol is increasingly used in many applications in the UK. It is worth mentioning that South Wales Industrial Cluster (SWIC) is looking at decarbonization schemes using carbon capture and utilisation methods to produce methanol using industrial emissions and green hydrogen in South Wales. Moreover, methanol in an interesting raw material for the chemical industry as it is highly versatile building block for manufacturing countless everyday products such as paints, carpeting, plastics and more. There are commercialising efforts to use methanol as a fuel for cars and trucks, marine vessels, boilers, cook stoves and kilns. If there is a cash-cow, this surely is one of the interesting ones.

Synthetic methane

Another valuable hydrogen-based fuel, particularly for European countries and policy makers who are exploring renewable hydrogen applications, is **synthetic methane**. When synthesized using carbon capture methods or using biomass synthetic methane can be highly appealing because it allows for the continued use of current natural gas infrastructure and avoids the need to replace or retire existing natural gas assets. Synthetic methane also has the added advantage of being easier to generate at larger scales and across a wider range of locations than biogas or bio-methane, which has long been seen as a means of "greening" the gas supply.

Only a few pilot projects are currently generating synthetic methane. Most of them extract their carbon from anaerobic digesters linked to agricultural or land fill waste. A demonstration project in Italy, however, sources its carbon from directly through air capture technology. It should be remarked that whether sourced through biomass, waste or captured from air, all these options can be considered carbon-neutral. Another interesting project is that of Uniper's "STORE&GO" in Germany, which uses wind-powered electrolysis and carbon from biomass to produce up to 1 400 m^3 of synthetic methane a day – approximately 14 500 kWh of energy.

Bio-methane and biogas

Bio-methane and biogas production in the region is highly distributed and small-scale. In the Mid Wales region, anaerobic digester (AD) plants contribute roughly 4.4 MW electric and 3.6 MW thermal capacities. Most of the available capacity from AD for heating applications in Wales is in Mid Wales. Though there are many ways in which bio-methane and biogas can drive the decarbonisation activities in the region, AD deployment and bio-methane production are very limited in the region. As a renewable fuel, bio-methane has many market opportunities but local production is highly limited by availability of raw materials (waste and biomass).

According to Anaerobic Digestion & Bioresources Association (ADBA), there were circa 90 agricultural biogas plants injecting bio-methane in the gas grid in the UK in early 2017. This had an effect in reducing the UK's natural gas demand by 0.6%. When biogas is refined into bio-methane, it is chemically identical to natural gas and hence it is gas-grid ready and can power all applications like conventional gas.

However, UKG has reduced subsidies for bio-methane and biogas injection into the grid under the non-domestic Renewable Heat Incentive (RHI). The most recent cut effective from April 2017 resulted in 10% reduction in bio-methane injection tariff, and a 5% reduction to the small, medium, and large-scale biogas tariffs. Adding more twist to the story, in December 2017, UKG also announced new biogas and bio-methane plants would only receive support if at least 50% of the gas comes from feedstocks that are wastes or residues – reflecting growing concern that crops are being used as feedstocks resulting in agricultural lands used for cultivating energy crops and directly competing with food crops cultivation. The Renewable Energy Directive further planned to increase the biofuel carbon savings compared to fossil fuel equivalents from 35% to 70% in 2020. This measure is aimed to exclude many energy crops from the biogas or bio-methane production.

Adding more salt to the injury, we believe that the biogas and bio-methane producers in the UK will not be cost-competitive as the present production cost for bio-methane are likely to stay around £50–105 per MWh, which is quite some way current UK wholesale gas prices of around £40 per MWh.

That being said, synthetic methane discussed above can come to rescue methane industry if can align with Carbon Capture and Utilization (CCU) strategies of industries that are presently large-scale CO_2 emitters. In this context, synthetic methane can become more relevant and price-competitive when carbon emission and pollution taxes are introduced that can incentivise production.

Table below shows the comparison between zero- or low-carbon fuels using various key parameters.

Compared to LPG / domestic heating oil / Gasoline / Diesel	Hydrogen	Ammonia	Methanol	Synthetic methane and bio-methane
energy content [MJ/kg] Diesel / Gasoline (42 – 46) Domestic heating oil (43 – 47) LPG (46 – 51)	120 – 142	22.5	22.7	45.4 – 55.1
Price [£ / tonne] LPG (900 – 1000) Domestic heating oil (300 – 550) Diesel / Gasoline (1500 – 2000)	Low: 1500 High: 7000 *	Low: 300 High: 400	Low: 350 High: 400	Low: 200 High: 700 **
direct usage in existing (installed) machineries and applications	low	medium	high	very high
storage and transport challenges	high	low	low	low
health and safety concerns	medium to high	medium to high	medium to low	medium to low
environmental concerns	low	medium	medium	medium

* this range includes for both SMR and Green hydrogen

** on lower extreme the price depends on Natural gas prices and on the higher extreme depending on the pathway used to produce bio or synthetic methane (Anaerobic Digester or green hydrogen + CCU pathway)

From the above discussions, we get an overview of different low- and zero-carbon energy vectors that are relevant for the region. As previously highlighted, the scope of biogas and bio-methane is very limited, regional and ad hoc in nature.

Applications suitable for hydrogen and hydrogen-based fuels

Having evaluated different low- and zero-carbon energy vectors in the opportunities assessment study, we have gathered insights into specific energy applications where direct hydrogen and other hydrogen-based fuels can be commercially viable and where will be not viable. We have briefly highlighted those applications areas in the following:

On demand electricity generation and renewable energy storage: Storing renewable energy in the form of fuels is increasingly recognized. Green hydrogen produced from renewable resources like wind, solar, or hydro is an excellent value proposition for region like Mid Wales provided we understand the market opportunities thoroughly and create strategic partnerships in the supply chain (industries, consumers, grid supplier, etc.) Storing hydrogen is energy intensive, hence, other fuels like ammonia and methanol are increasingly recognized as cost effective carriers of hydrogen.

Heating applications: Hydrogen can be competitively used for space and water heating only in the case of district heating networks under current price levels and grid infrastructure limitations. International Energy Agency emphasizes retrofitting buildings with insulation to make them energy efficient and switching boilers for heat pumps as the most promising route for the vast majority of buildings. That being said, hydrogen should be reserved for applications where there are few or no green alternatives available. However, other hydrogen-based fuels such as ammonia, synthetic methane, and methanol are good contenders for this application with or without grid infrastructure. In the case of Mid Wales and other places where gas-grid infrastructure is limited these hydrogen-based fuels will be the best options for heating applications that can reduce the carbon footprint and also cost for the end user.

Fuel for transport: For transport applications using internal combustion technologies direct hydrogen is not a viable option given its high cost compared to petroleum-products and resulting NO_x emissions. However, ammonia, synthetic methane, and methanol are price competitive alternatives. Ammonia has some concerns due to NO_x emissions. But this issue is well studied and can be handled with appropriate catalytic reduction techniques. Fuel system developers such as Alfa Laval and engine developers such as Japan Engine Corporation have announced plans to include ammonia in their offerings. Furthermore, as already mentioned above, several companies including MAN Energy, Mitsubishi, and Siemens have announced efforts to produce ammonia-powered marine engines. Methanol and synthetic methane are already commercially used as fuels for many transport applications. The best way to use direct hydrogen is using fuel cells which does not have any NO_x emission issues. Vehicles powered by hydrogen fuel cells have a similar driving range and can be refuelled as quickly as internal combustion engine vehicles running on petroleum products. This is another important reason for using direct hydrogen for long-haul and heavy-duty transport. With the UK government planning to ban fossil fuel vehicles from 2030, hydrogen fuel cells potentially can help in decarbonising freight and public transport segment. It is expected that majority of hydrogen demand within the transport sector in the UK will come from heavy goods vehicles (HGV) and public transport. The market success for direct hydrogen in private vehicles depends on the retail price of hydrogen, availability of fuelling infrastructure, and price levels of fuel cell vehicles. From our discussion with the Global Centre of Rail Excellence (GCRE), we gathered that they have acquired around 700 hectares of land, which used to be a coal mining area. Within GCRE, we are informed that, there are still many uncertainties about the choice of ideal fuel for transport. There are parties who are very much convinced about the potential of hydrogen. At the same time, there are people within GCRE who deny this about hydrogen, however, they strongly support electric batteries. Regarding hydrogen, they confirm that there are still many uncertainties. That being said, we can clearly see that, there is a huge push for hydrogen in the heavy transport segment. But for things to really take off in a commercially successful way, we have to wait still another 10 to 15 years.

Industrial furnaces and heating: Heavy industry represents second most polluting sector in the UK after transport accounting for 21% of the UK's total carbon emissions. Major contribution to these emissions come from industrial furnace and kiln applications that require very high temperatures. Furnaces in the steel industry are generally powered by fossil fuels. Heating in industry is mostly fuelled by natural gas. If we have to decarbonize industrial sector, both petroleum products and natural gas have to be replaced with low or zero carbon alternatives. Direct hydrogen and hydrogen-carrier fuels can be ideal for such applications. However, clever design of furnaces, nozzles, spark injections are required to reduce NO_x emissions. However, Ammonia oxidation catalyst and catalytic reduction can be applied in order to reduce NO_x emissions. There are different NO_x reduction technologies becoming increasingly available in the market.

Other industrial applications: Presently, hydrogen is used in oil refining to react with and remove unwanted sulphur compounds. Most of the hydrogen used in the UK is derived from steam methane reforming (SMR) or other fossil fuels. It is important to increase the production of green hydrogen using renewable resources to replace the high-carbon fuels powering industrial processes.

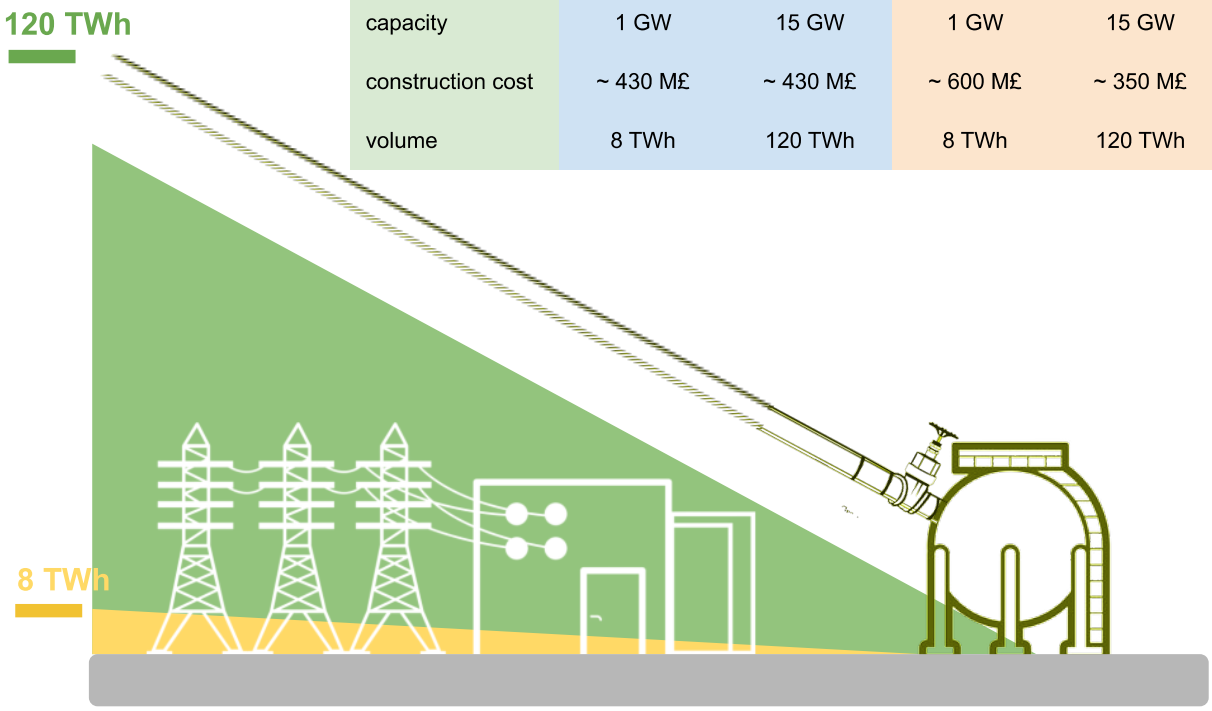
Fuels for machineries: Many of the machineries in rural and urban systems such as agricultural equipment, tractors, trucks, etc. are heavily dependent on fossil fuels. Immediate shifting to direct hydrogen-base fuels will be challenging given the high cost of hydrogen and safety concerns related to handling hydrogen. Furthermore, present equipment and machineries that run on fossil fuels are incompatible with pure hydrogen. Other hydrogen-based fuels such as methanol and ammonia could be more cost competitive and are easy to handle.

Gas pipelines vs. electricity grids

Before delving into potential pathways, we want to take a short detour to highlight "underlying" debates between lobbies supporting gas pipelines and electricity grids.

Essentially, there are two contrasting viewpoints. One based on electricity-demand-boosting agenda and the other based on positioning gas grid as an ideal solution. Gas grids, when they exist, are more efficient and less costly than electricity for heating, and possibly also for other purposes. While this is not the case for Mid Wales where most of the properties are off-grid, the narratives are still very relevant to understand where the best bets are both within and outside Mid Wales. For sure, it is easier to transmit gas with lower energy losses compared to electric power lines. We were interested in knowing about overall cost levels and capacities. We have gathered data to put things into perspectives using four example cases. The first and second examples are that of underwater (submarine) deployments running about 250 km between UK and Netherlands. In the first case, high voltage direct current (HVDC) cables are used to transmit electricity and in the second case natural gas is supplied using pipeline. We have contrasted these with same distance deployment of HVDC overhead cables and gas pipelines deployment on the land. The differences between these cases are illustrated in the figure below.

	Submarine		On land	
	HVDC Cable (Britned)	Gas Pipeline (BBL)	HVDC Cable	Gas Pipeline
capacity	1 GW	15 GW	1 GW	15 GW
construction cost	~ 430 M£	~ 430 M£	~ 600 M£	~ 350 M£
volume	8 TWh	120 TWh	8 TWh	120 TWh



REMARK: *BritNed is a 1 GW HVDC submarine power cable between the Isle of Grain in Kent in the UK and Maasvlakte in Rotterdam in the Netherlands. The BBL Pipeline (Balgzand Bacton Line, BBL) is a natural gas inter-connector between the Netherlands and the United Kingdom. The land deployment examples for electricity and gas pipeline are based on £/km standard price level back-of-the-envelope calculations.*

Gas is the main source of heat in the UK. The UK gas grid carries about four times more energy than the electric power grid with heating demand being high at times. Supporters of gas grids argue that it is foolish to try to switch over to electric heating as the power grid could not cope without massive expansion. Such massive expansions in the Mid Wales have received oppositions from the anti-pylons protesters for various reasons discussed earlier in our opportunities assessment report.

However, the supporters of electricity take the argument of climate change in their favour conveniently. They argue that the energy system can best be decarbonized connecting power from wind, solar and other

renewables to end users by wires. In other words, they believe the only way to go ahead is electrification of everything – heating, cooking, transport, etc. Against this, the gas lobbyists stress that, for heating, it makes more sense to stay with the gas grid and standard appliances but switch over to green gas. In the context, green hydrogen, ammonia, methanol, synthetic methane all makes sense. One can employ most of these green alternatives with almost no change except in the case of 100% hydrogen as explained in the earlier sections. In comparison, to use electricity efficiently you would have to install expensive heat pumps in every house. Furthermore, green gas can also be used for vehicles, as compressed natural gas is already used for transport purposes.

The situation becomes more complicated when we have another pipe option, namely, district heating network that can supply heat directly to users. Though this is not relevant in the present situation to most of Mid Wales, it is important in high-density urban environments in other parts of Wales and the UK. We have to consider this as an option to find potential partners for green gas that may be produced in the Mid Wales region. District heating can make more sense than individual domestic boilers, and heat networks could supply perhaps half of UK heat. Local gas-fired Combined Heat and Power (CHP) plants can supply heat much more efficiently than small domestic heat pumps. Heat pumps can have a coefficient of performance (COP) around 3 to 4. This means heat pumps can deliver three or four times more useful heat out of the input electricity. However, CHP plants have a COP ratings about 9 or more. Importantly, they use heat from burning fuel that would otherwise be wasted. Most CHP plants use fossil gas with high efficiencies in the range of 70–80% or more. It is worth noting that increasing the use of hydrogen, synthetic methane, methanol, or ammonia can help in drastically reducing the carbon footprint of CHPs.

Potential pathways

Having looked into potential for various green fuels, target sectors and applications, we would like to present three potential pathways as a way forward to Mid Wales. Each of these pathways differ in their short-term goals. However, all of them have similar or same medium- and long-term goals for the Mid Wales region. The pathways are namely,

- first procure, later produce scenario
- grid-connected-production scenario
- isolated-production scenario

First procure, later produce

priority:

In this strategy, priority is to align Mid Wales as a strategic partner to North and South Wales and the rest of UK to create new market opportunities inside and outside Mid Wales. Identify how Mid Wales can best support North and South Wales in creating pan-Wales hydrogen economy. Decarbonise local energy applications by procuring green fuels produced outside Mid Wales.

goals:

Short-term establish local market for green hydrogen and other hydrogen-based fuels produced outside Mid Wales in an effort to decarbonize and create sizeable local market. Learn from others' mistakes before venturing into long-term large-scale investments in Mid Wales.

rationale:

The real potentials for green hydrogen and other hydrogen-based fuels are unclear. Given the lack of infrastructural support, supply chain challenges, and policy and regulatory gaps, the market developments can go either way as strategic goals are not linked to clear actionable plans in short-, medium- and long-term for hydrogen and hydrogen-based fuels. Grid developments are slow and might take several years to materialize. With these uncertainties, Mid Wales can best prepare itself by playing safe but clever and position itself as a strategic partner to other regions that are acting as first movers.

remarks:

In the short-term, Mid Wales will be aiming to become strategic partner connecting North and South Wales and the rest of UK. As there are a lot of industrial developments happening in North (HyNet) and South Wales (SWIC). If we want to grow hydrogen economy in Mid Wales, we could find ways to expand HyNet to the south and SWIC to the north by using their infrastructure and creating market opportunities in Mid Wales. Given the huge potential for renewable energy in the region, Mid Wales can attract investments to produce locally various green fuels in the medium- and long-term. These investments can further be used to improve infrastructure and develop grid connectivity in the region, at the same time create new job opportunities. This strategy can be win-win in the long-term with low risk exposure in the short-term as the real potential for green hydrogen and other hydrogen-based products to decarbonise various sectors inside and outside Mid Wales is still uncertain and evolving. Mid Wales can prepare the ground to decouple previous local opposition against wind farms and pylons by strategically introducing various developments by creating local demand for different green fuels. If the market for green hydrogen is not picking up, Mid Wales can play safe with minimum risks. In this strategy, if Mid Wales can position itself as a strategic partners, other regions will require Mid Wales in medium-, and long-term.

Produce with existing grid spare capacity

priority:

The priority is to maximise existing grid spare capacity to create local value.

goals:

Immediately tap into existing grid spare capacity to locally produce green hydrogen and identify market opportunities mainly outside Mid Wales. Also explore the possibility to produce other hydrogen-based fuels like ammonia, methanol, and synthetic methane considering the market demands.

rationale:

There are some spare capacity in the existing electricity grid in Mid Wales. We are sure this is very limited and the range needs further investigation. This can be used to produce green hydrogen without building any new renewable infrastructure and supply to market opportunities outside Mid Wales. Align with electricity grid operators and create long-term fixed contracts with potential clients outside Mid Wales. Given the huge fluctuations in market prices for hydrogen, potential clients may be willing to take the risk of fixing the price.

remarks:

Mid Wales will be one of the minor production regions for green hydrogen and other hydrogen-based fuels. Production capacity, however, will be limited by the available grid spare capacity of ~100 MW. Green hydrogen produced will not be cost competitive compared to open market prices. Risk will be high as the market is very sensitive to prices. Mid Wales will be competing with North and South Wales, and the rest of UK. None of the clusters "need" Mid Wales for their activities, but Mid Wales will need other regions to find market opportunities.

Produce without depending on existing grid

priority:

Maximum tap into the potential renewable resources in the region independent of the grid to increase green hydrogen production capacity.

goals:

Produce at the highest capacity using maximum renewable resources in the region to be cost competitive in the entire green hydrogen UK market. Also explore the possibility to produce other hydrogen-based fuels like ammonia, methanol, and synthetic methane considering market demands.

rationale:

Mid Wales can only be cost competitive if it uses maximum renewable resources in the region to produce green hydrogen at large scale. Aim for establishing long-term contracts at best price levels with potential clients outside Mid Wales.

remarks:

Mid Wales will be aiming to become one of the major production regions for green hydrogen and other hydrogen-based fuels in the UK. However, huge upfront investments will be required for creating new large-scale renewable infrastructure. Actual production may happen only after several years (typically 5 to 10) as it involves getting project approvals, planning, and construction stages typical for new large-scale renewable infrastructure development projects. Potential local opposition may also oppose and delay construction of new renewable infrastructure in the region. If the market for green hydrogen is not picking up there will be a huge sunk-cost which might be difficult to recover. These market risks can be partially mitigated by producing other hydrogen-based fuels like ammonia, methanol, and synthetic methane. This strategy will be good for Mid Wales provided the above challenges can be overcome as it can strongly position Mid Wales price competitive compared to other producers in North and South Wales, and the rest of UK. That being said, Mid Wales will still need other regions to find market opportunities.

Interlude

During the course of the feasibility study, we have reviewed various past and ongoing work related to the topic of this study. Some of these reports and links are referred by project steering board members and key stakeholders given the relevance of these work to our present work in Mid Wales. We have extracted some of the relevant remarks from these references in the table below.

Document name **Link / Contracting authority**	**Remarks**
UK Hydrogen Strategy Department of Business, Energy and Industrial Strategy (BEIS), UK Government	BEIS, UKG recently released their UK Hydrogen Strategy document. We have taken time to review this important document, although it was published towards the end of our feasibility study work. Though in this document, Wales region is recognised to have significant opportunities for low-carbon hydrogen production and use, no specific mention is made about the possibilities in the Mid Wales region, except for the mention about RiverSimple. That being said, they have talked about the potentials in South and North Wales. For example, the document highlights a project in South Wales, Dolphyn FLOW study, which is exploring the feasibility of a 100-300MW commercial hydrogen wind farm off South Wales, to be expanded in future, with hydrogen pipelines to strategic locations along the Milford Haven waterway for transport and heat applications, and potentially to Pembroke Dock for marine operations. Similar mentions are made about Holyhead Hydrogen Hub and funding the government is pushing to support hydrogen fuels production in the region to support transport and related applications. This strategy document provides a clear timeline and what needs to be completed during this period. However, as this is a strategy document, there are no mentions about "how" we have to achieve "what" we need to achieve. This is left to our interpretation, ability, and willingness to take risks and proactive steps to create actionable plans at the regional and county levels. In our opinion, we need to elevate our ongoing activities in Mid Wales, especially this present work, to the UKG so as to attract more funding opportunities and support through projects such as SBRI. We have separately presented an overview of one demonstration project in Mid Wales to Powys and Ceredigion Counties. We find that lack of proactive and agile decision making, and willingness to push the organisational barriers in the Mid Wales region only reduce the region's chances of playing an important role in the coming years. This is especially true when North and South Wales are already highly visible and there is a risk of leaving out Mid Wales, if we are not more proactive and agile. We have also briefly highlighted these points in our report in the strategy implementation challenges section. We have made some suggestions on how to engage and partner with the neighbouring regions to increase the chances and role for the Mid Wales region in the future energy scenario.
Midlands Regional Transport Hubs – Midlands Energy Hub Coventry City Council	**Highlights**: Ongoing discussions about suitability of sites for constructing a multimodal transport hub. This is proposed to include a Park & Ride, a freight consolidation centre, an extension to the Coventry Very Light Rail Scheme, and EV charging (for private and commercial vehicles, and buses). The site has scope to attract companies to invest in transport services as well as

	supporting infrastructure, such as EV charging, renewable electricity generation, battery energy storage, catering and retail services, and the potential for other alternative fuels storage and retail. There is a lot of development planned in the area with several large employment sites nearby. **Topical relevance**: sites identified will attract companies that have potential interest in large-scale hydrogen and hydrogen-based low- or zero-carbon fuels. See industrial-cluster-level discussions in the strategy implementation plan of this report to see how we can potentially cooperate and engage with these developments in the future.
Unicorn or Silver Bullet? Filling evidence gaps on decarbonising heat Department of Business, Energy and Industrial Strategy (BEIS), UK Government	**Key activities**: Hydrogen for Heating (Hy4Heat), Electrification of Heat, Smart ENergy Savings Competition (SENS), Demonstration of Energy Efficiency Potential (DEEP), Cost Optimal Domestic Electrification (CODE), Heat Distribution Systems **Highlights:** Aim to establish, if it is technically possible, safe and convenient replacement for natural gas (methane) using hydrogen in residential and commercial buildings and gas appliances. This work aim to help in enabling the government to determine whether to proceed to a community trial of hydrogen. **Topical relevance**: See specific-industry-level discussions that aim to transform applications such as heating, electricity to hydrogen and hydrogen-based fuels. In the strategy implementation plan of this report, we can see how to engage actors in specific applications or industry.
Marches, Mid Wales and Cheshire – West Midlands Rail Connectivity West Midlands Rail Executive	**Highlights**: The West Midlands Rail Executive is preparing an updated 30-Year Rail Investment Strategy (West Midlands Rail Investment Strategy – WMRIS). The geographical limits of this strategy reach as far as Shrewsbury in the west and Stafford / Crewe in the north. The consequence of the sheer scale of investment needed to accommodate the potential capacity investment and electrification alongside the major HS2, Midlands Rail Hub and Northern Powerhouse Rail project means that Marches Strategic Rail Group stakeholders will need to focus on the agendas most likely to succeed. **Topical relevance**: See specific-industry-level discussions that aim to transform applications such as transport using hydrogen and hydrogen-based fuels. In the strategy implementation plan of this report, we can see how to engage actors in specific applications or industry.
Mid Wales Energy Strategy Growing Mid Wales Partnership, Powys County Council and Ceredigion County Council	**Highlights**: The higher level of effort related to decarbonisation and the energy transition in the energy system vision scenario requires more investment/spending when compared against the business as usual scenario. The economic analysis demonstrates that almost £1 billion of additional investment/spending is needed to achieve the energy efficiency, electricity generation, and heat aspirations described in the energy vision between now and 2035. This represents approximately £66 million per year and will need to be financed from a range of sources including the private sector,

	households, and national and local government. **Topical relevance**: See public-sector- and specific-industry-level strategy implementation discussions in this report.
Social research with installers of heating systems in off gas grid areas of England and Wales Department of Business, Energy and Industrial Strategy (BEIS)	**Highlights**: For the two-thirds of installers who currently have no heat pump experience, changes in the market may be more impactful. This group were understandably far less confident in their ability to identify the right heat pump for different types of building, or in their ability to install heat pumps. To transition their businesses would require training, but a key consideration for some non-heat pump installers was their proximity to retirement. Some of the most experienced installers of this type did not see the value in upskilling, as they could foresee a sufficient volume of maintenance, repair and servicing of traditional heating systems to support their business for the remainder of their career. There is significantly more doubt around the extent to which heating installers might transition their business to enable them to retrofit properties in order to make them suitable for heat pumps. This was perceived as a barrier to uptake, not just from a consumer demand perspective, but also because installers did not feel they had the level of expertise to make changes to insulation or it was seen as beyond the scope of heating replacement quotes. **Topical relevance**: skills and capacity building aspects discussed in this report.
Hydrogen in Wales – A pathway and next steps for developing the hydrogen energy sector in Wales Welsh Government	**Highlights**: With Wales set to see a significant increase in renewable energy project development over the coming decades, it is absolute necessary that a hydrogen pathway is developed concurrently to ensure that an energy system dominated by renewable power can capitalise on the flexibility and system balancing opportunities afforded by wide scale development of green hydrogen. In addition to the contribution to the Energy system, a coherent strategy is vital to link hydrogen production and end-use value chains through, for example, training and skills, high added-value activities in R&D, legal services, planning, professional consultancy, and financial services. Most broadly, the Energy Transition is characterised by the pace at which it is moving, and so Wales must be alive to first mover opportunities which drive export opportunities and influence within the hydrogen value chain. In terms of specifics, grid strengthening will be highly important factor in ensuring Wales capitalises on the hydrogen opportunity. In addition, Wales will need to assess whether it has sufficient control over the legislative and regulatory levers to pursue the opportunity in the most appropriate way, while continuing to influence and benefitting from UK Government plans. **Topical relevance**: See public-sector-, industrial-cluster-, and specific-industry-level strategy implementation discussions in this report.
Batteries or Hydrogen? RiverSimple	**Highlight**: Key observations on the drivers of vehicle efficiency: • vehicle efficiency is highly dependent on vehicle weight • powertrain efficiency is not dependent on vehicle weight – and is

	therefore not very well correlated to vehicle efficiency • weight is dependent on ◦ choice of power train, and ◦ designed vehicle range Battery electric vehicles (BEVs) have two key advantages; they can be very efficient for short range applications and can contribute to stabilising the grid by charging off-peak at night. They have a key role to play in an integrated approach to transport and energy. However, if used for long distance applications, not only does the BEV become inefficient but it also relies on fast charging in peak demand hours. The misapplication of a critical technology – an inefficient car that destabilises the grid – not only weakens but reverses the benefits. It is time to put the batteries or hydrogen question to rest. The challenge now is to use both clean technologies appropriately so that we can cut carbon emissions as quickly as possible. **Topical relevance**: See business- and specific-industry-level strategy implementation discussions and transport application sections in this report.
Green hydrogen is vital in decarbonising the hard-to-abate sectors https://foresightdk.com/green-hydrogen-is-vital-in-decarbonising-the-hard-to-abate-sectors/	**Highlights:** The paper "navigating through hydrogen" published by European think tank Bruegel in April 2021 looks at the potential use of hydrogen in regards to shipping, aviation and heavy-duty vehicles, steel- Experts highlight the price of green hydrogen as a significant barrier in terms of accelerating its use. green hydrogen costs between about $3/kilogram and $6.55/kilogram, according to the European Commission's hydrogen strategy and fossil-based hydrogen costs about $1.80/kilogram. To accelerate the expansion of the necessary infrastructure and encourage sector coupling through electrification, we can maximise the value of renewable energy, the electrolysis process and also distribute the energy efficiently throughout the energy system. **Topical relevance:** See public-sector- and industrial-cluster-level strategy implementation discussions section in this report.

Stakeholder engagements

We have interviewed more than 50 key stakeholders in and outside Mid Wales region in the form of one-on-one meetings and focus-group discussions. We have highlighted only some of the organisations whom we have engaged in this process over the last 4 months below.

Way forward

Having carefully reviewed 3 potential strategies for Mid Wales, we have identified that **"first procure, later produce" strategy** will be the best option for the region in short- and medium-term going forward. We will discuss this strategy in more detail in the following.

First procure, later produce strategy

Having interviewed and engaged several stakeholders in and around Wales, we strongly believe that the real opportunity for hydrogen and other hydrogen-based fuels is still largely unclear. There are certainly opportunities for these hydrogen and hydrogen-carrier fuels in some sectors and applications as highlighted before. Given the lack of infrastructural support, supply chain challenges, and policy and regulatory gaps, the market developments can go either way as strategic goals are not linked to clear actionable plans in short-, medium- and long-term for hydrogen and hydrogen-based fuels. Particularly in Mid Wales, grid developments are slow and might take several years to materialize. With these uncertainties, Mid Wales can best prepare by cleverly planning and positioning itself as a strategic partner to other regions that are acting as first movers. In doing so, Mid Wales region can also greatly benefit from the learnings derived from "others' mistakes" before venturing into long-term large-scale investments. This way, Mid Wales can align itself as a strategic partner to North and South Wales and the rest of UK to create new market opportunities inside and outside Mid Wales.

This strategy is based on the basic premise that it would be a clever approach for the region to first create a market ecosystem for the low- and zero-carbon fuels identified in this study by first procuring these fuels in short- and medium-term (up to 10 years) and in long-term partner with relevant stakeholders to locally produce these fuels in the region.

Benefits of first procure, later produce strategy

The benefits of this strategy can be understood by splitting the strategy implementation process into two parts, namely, procurement part and production part. In terms of timescale, the procurement part will be addressed by short- and medium-term actions and goals. The production of green fuels will be addressed in the long-term goals.

In the short-term, Mid Wales will be aiming to become strategic partner connecting North and South Wales and the rest of UK. As there are a lot of industrial developments happening in North (HyNet) and South Wales (SWIC). If we want to grow hydrogen economy in Mid Wales, we could find ways to expand HyNet to the south and SWIC to the north by using their infrastructure and creating market opportunities in Mid Wales. Given the huge potential for renewable energy in the region, Mid Wales can attract investments to produce locally various green fuels in the medium- and long-term. These investments can further be used to improve infrastructure and develop grid connectivity in the region, at the same time create new job opportunities. This strategy can be win-win in the long-term with low risk exposure in the short-term as the real potential for green hydrogen and other hydrogen-based products to decarbonise various sectors inside and outside Mid Wales is still uncertain and evolving. Mid Wales can prepare the ground to decouple previous local opposition against wind farms and pylons by strategically introducing various developments by creating local demand for different green fuels. If the market for green hydrogen is not picking up Mid Wales can play safe with minimum risks. In this strategy, if Mid Wales can position itself as a strategic partners, other regions will require Mid Wales in medium- and long-term.

No major land-use related actions are foreseen in the short- and medium-term actions as we are mainly focused on procuring relevant low- and zero-carbon fuels. The energy systems currently in place in public sector assets have already established electricity and heat production processes that includes equipment, buildings, supply chain including storage, etc. The low- and zero-carbon solutions discussed in this feasibility report aim to reuse the existing infrastructure with minimum changes including land-use modifications. When it comes to long-term part of the strategy, where we aim to locally produce green fuels in the region, appropriate land identification, selection, and deployment will be made as per the land-use guidelines of the region.

Following our first procure, later produce strategy, the overall cost of the fuels can be reduced compared to as-it-is baseline scenario. The environmental cost of emissions have to be also considered as we are aiming for step-by-step decarbonisation of public-sector assets. If environmental emission costs are to be mainly prioritized, then we have the option of fully using zero-carbon fuels such as ammonia or hydrogen. However, using hydrogen is not commercially feasible in the short-term as the cost of hydrogen is quite high. Using ammonia is always a good option as it is price-wise much cheaper than other alternatives. But we have to blend it with other fuels to use it in commercially available machineries. For a balanced overview, we have considered both fuel and environmental costs as overall fuel-related cost as shown in the table below.

[k£]	as-it-is	CH_4	$NH_3 + CH_4$	CH_3OH	$NH_3 + H_2$	$H_2 + CH_4$
fuel costs	828	698	736	979	1417 to 1762	2383
emission costs (presently not accounted)	280	169	156	190	2 to 6	68
Overall fuel-related cost	1108	867	892	1169	1419 to 1768	2451

Strategy implementation challenges

In implementing this proposed first procure, later produce strategy, we anticipate some systemic challenges. First, we believe that the level of appetite for changes in the region is rather low compared to other regions in the UK. This could be one of the biggest challenge to overcome. Especially, for big changes in the region, for example, decarbonisation, require strong commitment and backing of the senior decision makers in the public offices at county level. Without such support, we can only talk about changes without changing anything on the ground. During our stakeholder engagement process, we found that there is a lack of real interest among stakeholders because of the systemic constraints, which we discussed in the opportunities assessment report. This could be one of the biggest challenges to overcome in the region. The mindset change and decision makers' commitment are fundamental to progress in the region.

Last but not the least, we noticed that lack of relevant skills and expertise will be one of the challenges to overcome to make progress with the first procure, later produce strategy. Especially at county level, we need to train existing staffs and recruit potentially new staffs to deal with sustainability, energy, and decarbonisation related themes. Though this is not a huge risk or challenge, one has to address this completely before venturing into strategy implementation process. Short-term and medium-term, we have expressed interest in support the region in addressing these challenges and risks.

Strategy executions levels

We are interested in exploring ways to implement this strategy at business-, industrial-cluster-, industry-, and public-sector-level. Let us now look how to implement this strategy highlighting the **relevance**, **challenges**, **opportunities**, and **limitations** at different levels one-by-one.

Business-level

- **why this is relevant (or not relevant)?**

  Though there are companies in Wales that are pushing the agenda for hydrogen or hydrogen-based fuels, we believe that this strategy on a business level has less impact for the entire region in short- and medium-term. We have couple of reasons to believe why this is the case. Firstly, there are not many companies in the Mid Wales region that are driving the hydrogen agenda. RiverSimple is the only company where we noticed a push for hydrogen-based solutions among other sustainability solutions such as electric vehicles (EVs). That being said, there is no economy of scale for individual companies to make systemic changes that we are expecting at a regional level.

- **are there opportunities to implement and support?**

  Mid Wales region do not have individual business-level opportunities to implement this strategy on a scale that is required in a sustainable way. However, there could be a way to create a consortium of two or more companies who would be willing to implementing this strategy. Individual companies might be interested in procuring hydrogen or hydrogen-based fuels for their own consumption. By themselves they might neither have the interest nor the capacity to produce hydrogen locally. However, when we are able to create a consortium of businesses in and around Mid Wales this strategy will become more interesting given the fact that we can only produce hydrogen cheaply in the region if we have the economy of scale. Hence, this strategy could help in building the consumption base for pushing this agenda in a commercially feasible way.

  To implement this strategy, we have to bring companies together who are currently using hydrogen or hydrogen-based fuels or could be the potential users of these low- or zero-carbon fuels. The first step could be is to bring these companies together to discuss potential opportunities to jointly procure these fuels and explore opportunities for producing them locally addressing the capital and economy of scale requirements. GMW Board through Welsh and UK government could support such consortiums with required financial, policy, and regulatory support.

- **what are the advantages in general and in specific to Mid Wales?**

  The main advantage of this approach is to create industrial clusters locally in the region and to partner with existing companies, consortiums, and clusters in other regions. This way we can create an opportunity for businesses to drive the hydrogen or hydrogen based fuel agenda in a sustainable way. Specifically for Mid Wales this could be a way to create consortiums of small companies which could potentially become a bigger cluster when we are able to locally produce hydrogen at a later stage.

- **what are the limitations and challenges?**

  This strategy on a business level will require a multiple step process which could be time consuming and require several levels of discussions and matchmaking. The potential risk is minimum as companies will not value such a process if they don't see commercial value in short-, medium-, and long-term. Hence, it is worth the effort to create the space for such discussions and joint efforts to take place. The limitations are only related to availability of companies in the Mid Wales region who are interested to engage. However, if we are able to tap into potential companies also in North and South Wales and the rest of UK there might be better chances of creating a **Mid Wales Hydrogen Consortium**.

Industrial-cluster-level

- **why this is relevant (or not relevant)?**

  There are existing industrial clusters in North and South Wales such as HyNet, SWIC, etc. who are already having interest for hydrogen and hydrogen-based fuels. Partnering with such clusters could create a way forward for Mid Wales to jointly produce hydrogen or hydrogen-based fuels using the available extensive resources in Mid Wales.

- **are there opportunities to implement and support?**

  Mid Wales region do not have currently any industrial clusters in the region that could be interested in locally producing green hydrogen in the region. Furthermore, as mentioned above in the business-level implementation discussion, individual companies might be interested in procuring hydrogen or hydrogen-based fuels for their own consumption. But their demand will not be sufficiently large for producing hydrogen locally in a commercially feasible manner. Hence, we need to align or partner with existing industrial clusters around Mid Wales to create the minimum required demand for locally producing green fuels in Mid Wales. To implement this strategy, we have to bring companies together who are currently using hydrogen or hydrogen-based fuels or could be the potential users of these low- or zero-carbon fuels. Such industrial clusters could be invited to explore the possibility to invest in production ecosystems in Mid Wales.

The first step could be is to bring these companies together to discuss potential opportunities to jointly procure these fuels and explore opportunities for producing them locally addressing the capital and economy of scale requirements. GMW Board through Welsh and UK government could support such consortiums with required financial, policy, and regulatory support.

- **what are the advantages in general and in specific to Mid Wales?**

  The main advantage of this approach is to create industrial clusters locally in the region and to partner with existing companies, consortiums, and clusters in other regions. This way we can create an opportunity for businesses to drive the hydrogen or hydrogen based fuel agenda in a sustainable way.

  Given the present condition that there are no reference prices for hydrogen, any effort to bring companies together to jointly procure at large scale will create a good market opportunity for stabilizing and standardizing hydrogen price in the region and hence, also create pathways for new applications and sectors to switch to hydrogen or hydrogen-based fuels.

  Specifically for Mid Wales this could be a way to create consortiums of small companies which could potentially become a bigger cluster when we are able to locally produce hydrogen at a later stage.

- **what are the limitations and challenges?**

  This strategy on a business level will require a multiple step process which could be time consuming and require several levels of discussions and matchmaking. The potential risk is minimum as companies will not value such a process if they don't see commercial value in short-, medium-, and long-term. Hence, it is worth the effort to create the space for such discussions and joint efforts to take place. The limitations are only related to availability of companies in the Mid Wales region who are interested to engage. However, if we are able to tap into potential companies also in North and South Wales and the rest of UK there might be better chances of creating a **Mid Wales Hydrogen Consortium**.

Industry-level

- **why this is relevant (or not relevant)?**

  Specific-industry-level changes require strong policy and regulatory support and push. For example, transport industry is proactively pushing the technologies and infrastructure in this direction. Similarly manufacturing and process industries could work together to create a hydrogen or hydrogen-based fuel consortium for procuring and producing these fuels in the region. Not all industries are prepared or capable of the shift to these fuels. Some are more likely to resist the change until the last minute as the change to green fuels cost more and the technology readiness level is closer to the research and development stage than commercial stage.

- **are there opportunities than can be implemented and supported?**

  Mid Wales region do not have much industry-level opportunity other than heavy-goods vehicle and rail transport industry. It would be a good idea to work closely with the centre rail excellence and other similar industry excellence centre to develop potential future opportunity. Also one has to work closely with the policy and regulatory body for making industry-level impact or changes.

- **what are the advantages in general and in specific to Mid Wales?**

  Specific-industry-level strategy implementation depends on various factors including policy and regulation. To create impact on industry-level and drive strategy, we have to act on Welsh and UK government level. Mid Wales region by itself do not have much industries, other than agriculture, forestry, and related industries. These rural sector industries in the region are very slow and not proactive to bring changes.

- **what are the limitations and challenges?**

  Not a good starting point to make strategic impact for Mid Wales region.

Public-sector-level

- **why this is relevant (or not relevant)?**

  Public-sector-level actions are one of the most relevant and urgent need for the region. The ambitious carbon neutral by 2030 goal set by the Welsh government for whole of the public sector requires strong commitment and dedicated actions in all fronts. We see this feasibility study as a step towards building an actionable route map for achieving this ambitious target over the next 9 years. Public sector assets' energy requirements are mainly due to heating, electricity, and transportation needs.

- **are there opportunities for implementing the strategy?**

  Mid Wales region have a lot of public-sector assets. These include county council office buildings, libraries, hospitals, schools, universities, and other training centres, other public assets such as castles, museums, etc., transportation vehicles, other relevant infrastructural assets. All these assets are predominantly, if not only, run on fossil-fuels. Together there is an economy of scale for procuring low- or zero-carbon fuels, mainly, hydrogen, ammonia, bio- or synthetic methane, and methanol. One way to go ahead is to create procurement and supply logistics entity that can procure these fuels for public-sector consumption. We have also presented an initial idea to implement this strategy in the Powys and Ceredigion Counties. Such a platform could be used to decarbonize public-sector assets in the Mid Wales in a systematic manner in the next 10 years period by first procuring fuels and later exploring opportunities for producing these fuels locally in the region.

- **what are the advantages in general and in specific to Mid Wales?**

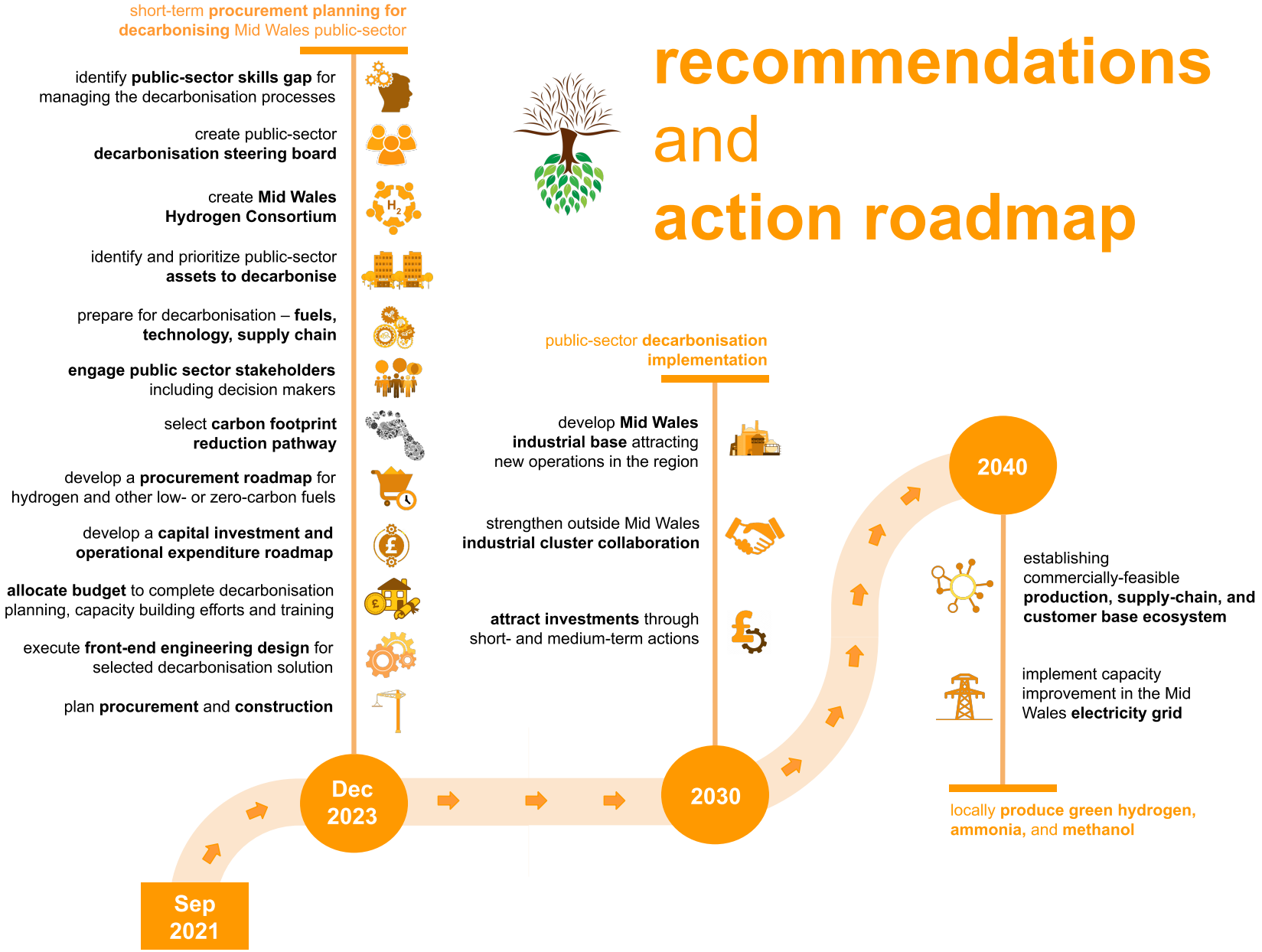
  The advantages of this approach to implement strategy in public-sector-level are many. Firstly, we can drive on the momentum set by the Welsh and UK government to fully decarbonise public sector in the UK by 2030. Secondly, there we can create staged approach to move towards fully green or zero-carbon solutions by initially transforming the fossil-fuel driven public sector assets to low carbon solutions. Moving to low carbon solutions have long-term commercial advantage for public sector as we can cut down on the fuel costs substantially compared to fossil fuels. It will create potentially new job opportunities. Particularly for Mid Wales, these are good news, if they are willing to go in this direction.

- **what are the limitations and challenges?**

  The limitations of this approach are mainly due to the willingness and readiness of public sector actors to move in this direction. Given the fact that there is a ticking time bomb set to 2030, not acting also does not help. Challenges are related to convincing the public sector decision makers. In the case of Mid Wales, we have initiated the first step by presenting the strategy implementation roadmap, which will also be discussed later in this report.

Short- and medium-term targeted actions

Let us briefly discuss the targeted short- and medium-term actions that can form the basis for the long-term targeted goals for the Mid Wales region. The figure below highlights important milestones and actions.



Short-term target actions (up to 2023)

In short-term until 2023, we suggest that the region should invest in various planning and support processes that are required. This goes along the line of the ambitious target set by the Welsh Government in 2017 of achieving a carbon neutral public sector by 2030. In doing so, Welsh Government recognised that the public sector is uniquely placed to influence emissions far more widely than its own, relatively small direct emissions in areas such as transport, energy and land-use. Hence, we strongly believe that targeting public sector for initial transformation will set the basis for future developments in the region.

The ambitious carbon neutral by 2030 goal set by the Welsh government for whole of the public sector requires strong commitment and dedicated actions in all fronts. To this end, we want to present an actionable route map for achieving this ambitious target over the next 9 years in two distinct phases:

- short-term
  - 2021 – 2023: first procure planning
- medium-term
  - 2023 – 2030: implementing first procure solutions

In the following, we will discuss a suggestive implementation plan for the first procure, later produce strategy focusing on public sector assets. We believe that public sector is rightly positioned for the transformation given various targets set by the Welsh and UK governments. As mentioned before, there is a clear target for complete decarbonisation of public sector before 2030. This could be a blessing for pushing the agenda for hydrogen and other low- or zero-carbon fuels in the region.

First procure planning

This preliminary assessment should be used as a starting point for further discussions with the decision makers in the region. Our emphasis in this first procure planning phase is to "step-by-step" decarbonise public sector assets using the optimal choice of low- or zero-carbon fuels. Based on this, we have evaluated the options to replace LPG, domestic heating oil, and wood pellets currently in use in various public sector assets by natural gas, hydrogen, methanol, and ammonia.

The pathways we have discussed in the future scenarios highlight the cost of transition (CAPEX and OPEX), level of emission reduction, and environmental cost of emission for these pathways. These estimates are presented mainly to guide the thinking and decision-making process at the county and regional level in the short-term. In short-term, we have identified various actions that are required for planning including stakeholder engagement. The activities include,

- identify public-sector skills gap for managing the decarbonisation processes
- create public-sector decarbonisation steering board
- create Mid Wales Hydrogen Consortium
- identify and prioritize public-sector assets to decarbonise
- prepare for decarbonisation – fuels, technology, supply chain
- engage public sector stakeholders including decision makers
- select carbon footprint reduction pathway
- finalize suitable technologies and fuel choices
- execute front-end engineering design for selected solutions
- develop a procurement roadmap for hydrogen and other low- or zero-carbon fuels
- develop a capital investment and operational expenditure roadmap
- allocate budget to complete decarbonisation planning, short-term capacity building effort, training and development

- **identify public-sector skills gap for managing the decarbonisation processes**

  As highlighted in the skills and capacity building section, there are some gaps in energy-related responsibilities in the public-sector operations in the region. Presently, energy-related questions are answered by people who have also other responsibilities. There is no single-point contact at the county council-level who manages all energy, sustainability, and carbon footprint related issues. If we have to take decarbonisation in the region seriously, we need to fill this gap by developing new roles in the county level and also train existing personnel on important thematic such as carbon footprint mapping, lifecycle assessment, cost of decarbonisation, etc. We can support the Growing Mid Wales Board and the Counties in this process.

- **create public-sector decarbonisation steering board**

  We have to create a steering board who will be overseeing the progress made in the short-term. As a suggestion, this could be made of members already in the Growing Mid Wales Board with a few industrial representations from the region. We have also identified relevant businesses that might be interested in joining the regional decarbonisation steering board.

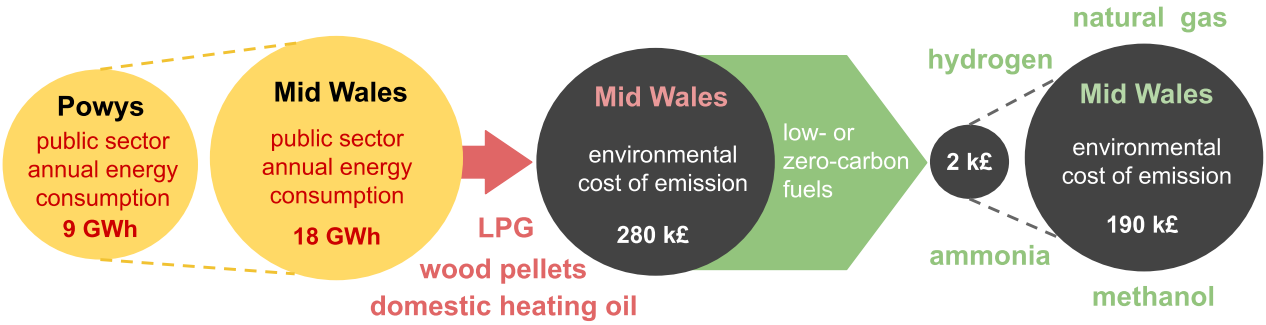
- **create Mid Wales Hydrogen Consortium**

  Identify members from the public-sector offices with energy and sustainability responsibilities and members from the local companies in the region who are currently using fossil fuels such as diesel, gasoline, domestic oil, etc. for their operations. These people will have primary interest in the decarbonisation plan and hence, would be an ideal starting group for developing a consortium for hydrogen in the region.

- **identify and prioritize public-sector assets to decarbonise**

  Based on the overall energy consumption data related to Powys County Council assets, we believe there is scope for decarbonising roughly 9 GWh of energy use annually using low- or zero-carbon fuels. For Ceredigion County Council assets the scope for decarbonisation is roughly 7 GWh annually. We have taken the net scope for decarbonisation for the entire Mid Wales using first procure, later produce strategy to be roughly 18 GWh annually. This is double of the Powys County Council assets consumption as a safe estimate.

  Based on this safe estimate, the total environmental cost of emission presently is roughly 280 k£ which is due to combustion of LPG, domestic heating oil, and wood pellets as shown in the figure below. Depending on the choice of low- and zero-carbon fuels, we can reduce this environmental emission cost to minimum 190 k£ and maximum 2 k£ annually. More details are presented in the financial assessment section. Using this as a starting point, we should identify and prioritize public-sector assets that we will step-by-step decarbonise in the region. This will feed into the next step related to procurement planning.



- **preparing for decarbonisation – fuels, technology, supply chain aspects**

  Energy auditing of the public assets county council office buildings, libraries, schools, workshops and other wider public sector assets such as castles, museums, hospitals, universities, training centres. This is done to get a clear overview of current energy consumption pattern, choices of fuels, and technologies in place. We have to do a reality check of these assets compared to the data derived

from the regional energy statistics. Also we have to investigate how the present fuel supply chain operates and if there are flexibility to transform the existing supply chain and logistics for hydrogen or other low- and zero-carbon fuels.

We have to identify suitable commercially available technologies that can handle low- or zero-carbon hydrogen and hydrogen-based fuels with minimum adaptations and changes to the existing infrastructure. Based on the capacity requirements of the public sector assets, thorough mapping of different commercially available technologies should be carried out to finalize the technologies and fuels. The choice of the fuels will feed into the supply chain and procurement plan discussed below.

We have looked into commercially available combined heat and power (CHP) units running on blended fuels made from natural gas and ammonia or natural gas and methanol. Commercial vendors include Turbec, Capstone Green Energy Corporation, General Electric. Some of the CHP units can also run only on natural gas or on methanol. Many other companies including MAN, Mitsubishi, Siemens, etc. are competing to bring engines that will fully or partially run on ammonia, hydrogen, methanol, and natural gas.

Technically speaking, hydrogen, when added to ammonia in small quantities, acts as a combustion promoter in accelerating the burning of ammonia. The engine modifications involved when replacing gasoline with ammonia appear to be straightforward. Some concerns are due to auxiliary equipment and controls. The development of these control and auxiliary systems would possibly follow along the lines of similar LPG system developments. To run CHP units for the same energy requirements, at least 2.8 times by volume and 2.35 times by weight as much ammonia as gasoline will be required. Hence, the fuel system in an ammonia-fuelled CHP will be bulkier than that in a conventionally fuelled ones. But these challenges are not a huge ones to overcome and many new developments are happening as we are writing this report.

- **public sector stakeholder engagements including decision makers**

  From our past engagements in carrying out similar tasks, we have learnt how involving various relevant stakeholders and decision makers at an early stage is critical to the overall success of the strategy implementation. Hence, we need to gather insights about the priorities, preferences, and constraints of key public sector stakeholders and decision makers. This is done to identify both conflict of interests and constructive alignments to understand the systemic constrains for implementing the solution in Mid Wales. For gathering the relevant data one needs to engage key individuals with roles such as

  - energy manager,
  - sustainability manager,
  - facility manager responsible for waste and recycling,
  - procurement manager,
  - transport / fleet manager,
  - finance manager,
  - human resource manager,
  - risk & resilience manager.

  We noticed that some of these key roles do not exist currently in the public sector ecosystems in the region. This gap needs to be systematically addressed, either by training existing personnel on relevant skills highlighted above or recruiting new people who will be responsible for those areas which are not presently covered in the region. More details are presented in the skills and capacity building section below.

- **carbon footprint reduction pathway selection**

  Collecting critical information regarding various energy and resource usage from public sector assets to assess the carbon footprint using the Welsh government carbon calculator. This is done to critically evaluate the constraints and challenges along with the opportunities to select a suitable pathway. Finally, one can develop a detailed decarbonisation action plan for the public sector assets using hydrogen and hydrogen-based low- or zero-carbon fuels.

- **procurement roadmap for hydrogen and other low- or zero-carbon fuels**

  Based on the choice of fuels for different public sector assets and applications, we have to explore ways to transform existing supply chain and logistics for future hydrogen or other low- and zero-carbon fuels. If the existing fuel supply chain does not provide the flexibility to procure and supply hydrogen or other low- or zero-carbon fuels, then public sector organisations can invite private sector actors to bid for procurement process that will help in establishing new fuel supply chain ecosystem.

- **capital investment and operational expenditure roadmap**

  One has to evaluate the possibility for retaining ancillary services and reusing of assets (lower initial investments) to efficiently estimate the preliminary cost – CAPEX, OPEX, RoI – based on capacity and storage requirements of the public sector assets. This is done to compare cost-benefit of green fuel procurement ecosystems (hydrogen, methanol, and ammonia) with market developments and scale-up potential from late 2020s to 2050 in Mid Wales.

  One needs to assess the techno-economic feasibility to convert some of the existing fossil fuel-powered technologies to run on direct hydrogen, ammonia, or methanol. For this, techno-economic model (TEM) should be used to assess technology readiness and compliances, evaluate benefits to switch to net-zero carbon fuel choices, economy of scale evaluation based on anchor heat demand for hydrogen supply and compare it with other net-zero carbon fuel options. One also needs to evaluate the storage and balance of plant requirements and assess the modification requirements while shifting to low or zero carbon fuels, particularly hydrogen, ammonia, and methanol.

- **front-end engineering & technologies and fuels selection**

  The outcomes of the above techno-economic feasibility study will directly feed into development of a roadmap to establish realistic timescales and costs to above options, including potential identification of a pilot site for immediate Front-End Engineering Design (FEED). One parallel track in the study could also be to study the medium- and long-term feasibility for producing, distributing, and storing low or zero carbon hydrogen, ammonia, and methanol locally in the Mid Wales region. The FEED model could be used to calculate various CAPEX, OPEX, and REPEX (replacement expenditure) and to develop innovative business models showcasing strong case for future demonstration.

  One needs to select relevant low- and zero-carbon technologies and fuels based on the feasibility report recommendations and initiate the front-end engineering design processes. The choice of technologies will influence what we do with the existing energy ecosystem. Retrofitting options have to be first explored before resorting to complete replacement of the existing machineries. Some of the low- or zero-carbon fuels can be used also in the existing machineries, hence, this step have to be properly evaluated on a case-by-case basis. The choice of low- or zero-carbon fuels will guide the next steps regarding procurement and supply chain.

- **procurement and construction planning**

  based on the earlier step, initiate the procurement and construction planning process. Reach out to original equipment manufacturers to discuss relevant options for retrofitting or replacement. Get preliminary quotes for the overall process including capital equipment, accessories, and overall process costs. Include these in the reporting process to the decision makers to get the relevant approval.

- **allocate budget to complete decarbonisation planning, short-term capacity building effort, training and development**

  In order to prepare the region for the decarbonisation and net-zero carbon transition, we need to build capacity in the region which includes training and development of existing personnel and filling the gaps by recruiting new people with required skills to manage energy and sustainability-related topics in the region. In short-term, we will be able to support Mid Wales Counties and Growing Mid Wales Board in this strategic process.

Medium-term target actions (up to 2030)

While in the short-term we carry out the overall planning for the solution implementation, in the medium-term, we should incorporate recommendations and implement solutions identified by our first procure, later produce strategy. After finding the suitable hydrogen or hydrogen-based low- or zero-carbon fuels for the region and the relevant machineries (technologies) through the short-term actions, we will focus on solution implementation in the medium-term.

public-sector decarbonisation solution implementation

Based on the short-term actions, choice of machineries (technologies), and low- or zero-carbon fuels procure and implement solutions for the public-sector assets following the engineering, procurement, and construction processes. These actions are aligned with the stipulated Welsh government deadline to decarbonize public sector assets in Wales by 2030. We have carried out broad-brush financial assessments for 6 different solution pathways for procuring and implementing in the region. We have provided preliminary estimates for the CAPEX and OPEX for 6 different low- and zero-carbon energy transition options in the financial assessment section below. Secure the buy-ins from the decision makers in the region to implement the solutions in the region and establish supply chain processes for the choice of solutions.

develop cooperation and attract investments

Socio-economic development in the region cannot happen without attracting new industrial operations to the region and developing new job opportunities. In the medium-term, we have to create new opportunities for dialogues and discussions between companies and government stakeholders in and around the Mid Wales region. The goal for such dialogues and discussions should be to further build on the insights derived from this feasibility report. For example, to create business-, industrial-cluster-, and industry-level interactions. Such interactions can strengthen potential collaboration with stakeholders both inside and outside Mid Wales region.

During the feasibility study, we found that many of the national and regional funds for developments related to hydrogen are mainly distributed in the North and South Wales region. That being said, contrary to the proverb, the hydrogen is not always greener on the other side! This is probably the main "potential strength" of Mid Wales, which needs to be properly used at the right time. The decision makers in the region should prepare the region accordingly to attract investments through short- and medium-term actions.

Preparing for the long-term (2040)

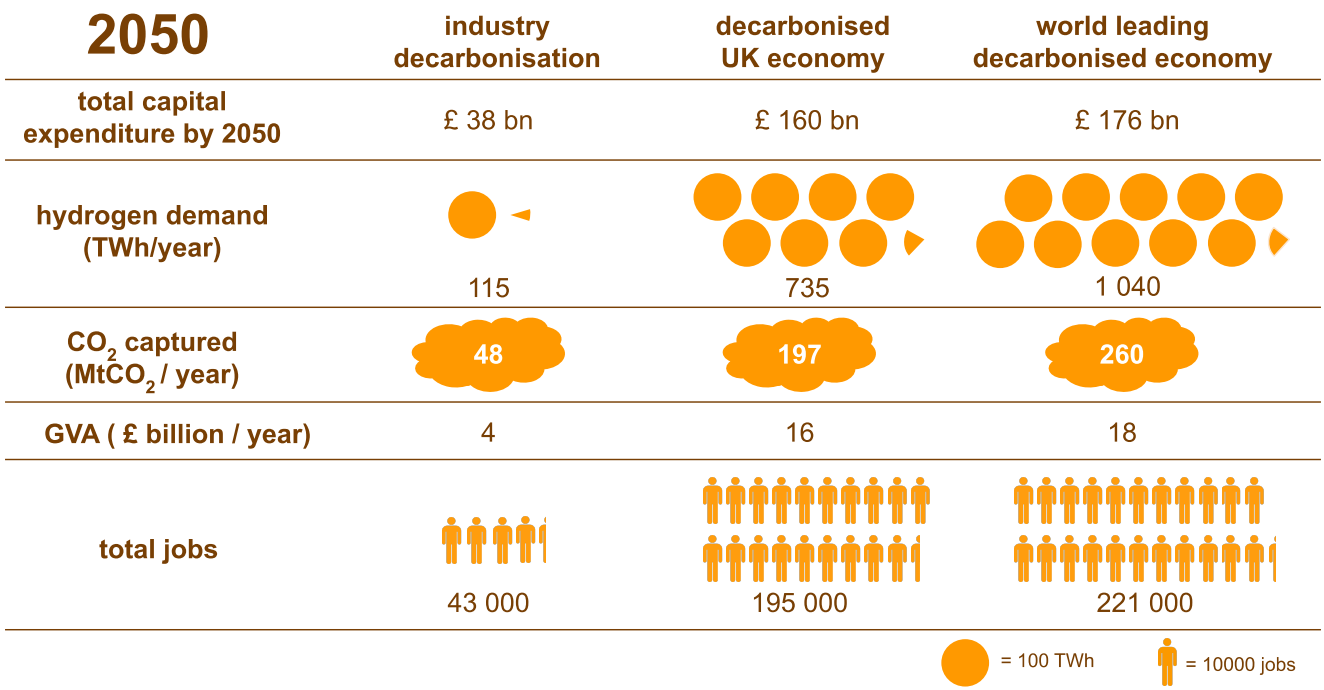
The short- and medium-term goals discussed before form the basis for fully executing the first procure, later produce strategy. As part of this strategy, we aim to position Mid Wales region in long-term as a commercially attractive region for producing low-cost green hydrogen, ammonia, and methanol. This can be achieved only by systematically implementing the short- and medium-term actions discussed above. The most important goal for the region by 2040 is to improve the electricity grid capacity in the Mid Wales region. As electricity is fundamental not only for producing green fuels, it is also the basis for socio-economic development in the region. By creating the space for investment related discussions in the short- and medium-term with relevant stakeholders from industries, industrial-clusters, governments, and relevant organisations, we will be able to attract potential investment opportunities to the region. This will create the basis for establishing commercially-feasible production, supply-chain, and customer base ecosystem in the region. Such an ecosystem is crucial for creating and sustainably operating local green fuels production units in the region.

As most of the long-term goals depend on the short- and medium-term actions, it would not be prudent to talk about long-term financial assessment and investment goals at this point. We will be able to "cross that bridge" when we "get there" by preparing ourselves to march in that direction. Hence, we have made conscious decision to focus only on the short- and medium-term goals and related investment assessment. Before going into the financial assessment, we would like to highlight some of the gaps mentioned in the skills and capacity of human resources in the region. It would be prudent to discuss these gaps briefly as they are also going to be relevant for the investments required in the region in short- and medium-term.

Skills gap and capacity building

We have been closely monitoring the state of the renewable energy skills shortage, particularly in relation to hydrogen and hydrogen-based low and zero carbon fuels. We will add some specifics on the hydrogen energy market. As an industrial member of the European Commission funded Open Innovation and Training Project, we are focusing our efforts on supporting governments and industries to close the skills gap in the cleantech and renewable energy sectors.

UKG is committed to achieving net-zero energy by 2050, and hydrogen and hydrogen-based fuels will play an important role in getting there. The figure below highlights the overall developments in the coming years in this sector.



It is estimated that the capital requirement for decarbonisation by 2050 is around £40 billion in the UK. The above investments will potentially create more than 70,000 jobs in infrastructure development, operations and indirect opportunities across the supply chain of this advanced fuel economy. This includes the jobs that will be created in the production of fuel cells and the necessary components.

With the UK leading the way in investment in the sector, recently approving £28 million for five hydrogen production projects, there is an obvious need not only to recruit workers now, but also to consider the future needs of the market. To recruit this workforce, the industry needs to work with the education system to ensure that the right skills and talent are developed at all levels in the coming years – from schools and apprenticeships, to higher education institutions and vocational training centres for those interested in moving into the industry.

Public-sector decarbonisation requires systematic data collection and planning. From our experience, we have found that we need to involve various individuals with the following skills

- energy management,
- sustainability,
- facility management including waste and recycling,
- procurement management,
- transport / fleet management, and
- risk & resilience management.

In this feasibility study, we gathered insights that there is a significant skills gap in this sector in Wales, and particularly in Mid Wales. This issue needs to be addressed strategically at the same time to ensure that the right talent is available at all levels, which includes an inclusive and diverse mix of people. Presently, energy-related questions are answered by people who have also other responsibilities. There is no single-point contact at the county- or council-level who manages all energy, sustainability, and carbon footprint-related issues. If we have to take decarbonisation seriously in the region, we need to fill this gap by training existing personnel to comprehensively handle these topics in the region or develop new roles in the region.

We have already initiated dialogues with relevant government agencies, vocational training centres, and educational institutions in Wales during the course of this feasibility study to highlight and elevate this issue. More discussions should follow in this direction to develop relevant courses and training programmes at all levels from vocational training schools to research institutions to fill this gap in the coming years. We can support the Growing Mid Wales Board and the Counties in this skills and capacity building process.

Financial assessments

We are presenting our financial investment assessment for the medium-term public-sector decarbonisation action, which involves only the procurement part of the first procure, later produce strategy. We have carried out broad-brush financial assessment based on the limited data that was available related to public-sector energy consumption pattern in Powys. In building the financial assessment, we have based the calculation on the energy consumption data of the public sector in Powys County. We could not get any relevant data for the Ceredigion County. So we have assumed that it is comparable to Powys region.

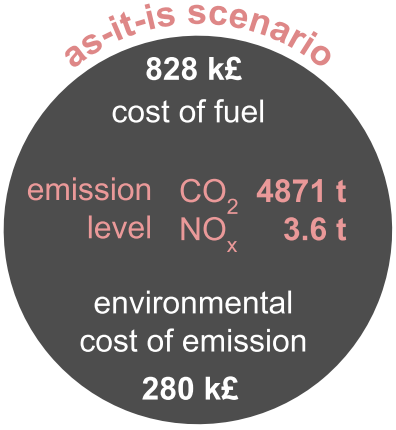
Presently there are 4 main fuels used for the public sector assets. We have not considered the emissions from the production of electricity, which is also used as an energy source for public sector assets in Powys. We have only considered fuels that are used in the region for energy production. For example, Powys public sector energy consumption is mainly based on natural gas (CH4), liquefied petroleum gas (LPG), domestic oil, and wood pellets other than electricity. Of these 4 fuels, we have aimed to decarbonise only those applications currently run on LPG, domestic oil, and wood pellets. Those which are using natural gas are already at the best level of decarbonisation possible in the region given the constraints and limitations. In that sense, natural gas-based decarbonisation will be used as a benchmark for our calculation, where we will assess the pathway emission efficiencies in comparison to that of fully natural gas-fuelled system.

Based on these assumption, we have proposed **6 potential pathways** to reduce the current carbon emissions resulting from the use of LPG, domestic oil, and wood pellets. As mentioned above, we have not considered natural gas-fuelled applications as it is already at the optimal level of emission for the region.

Each of these pathways will have different financial implication in terms of CAPEX, OPEX, and reduction in costs of emissions. CAPEX is calculated based on investment required for capital equipment, construction costs for buildings, piping, and related auxiliary facilities. OPEX is related to operation expenses required to run the new setup especially taking into account direct and indirect costs including the cost of alternative low-carbon fuels. The cost of emission is to be considered because we have to account for the environmental damage resulting from the emission of GHGs. We have to evaluate how our pathways' cost-efficiency (CAPEX & OPEX) and cost of emissions generated compared with the existing as-it-is scenario using 3 fuels LPG, domestic oil, wood pellets.

Baseline:
We have calculated the current OPEX, level of emissions, and cost of emissions for the public sector data from Powys as-it-is today running on 4 fuels, namely, natural gas, LPG, domestic oil, wood pellets. The as-it-is baseline scenario data are given in the table below.

as-it-is scenario					
Fuels	**Consumption [t]**	**Emissions [t]**		**Fuel cost [k£]**	**Emissions cost [k£]**
		CO_2	**NO_x**		
Natural gas	1 740	4786	1.7	1058	257
LPG	195	647	0	186	32
Domestic heating oil	1 113	4068	3.3	473	237
Wood pellets	367	156	0.3	169	10
Total [Powys] as per Powys data		**9 657**	**5.3**	**1 886**	**536**
Total [Mid Wales] assumed		**19 314**	**10.6**	**3 772**	**1 072**



As you can see in the above table, we have used actual data from Powys public sector energy consumption to derive the overall MW region public sector energy scenario assuming that Ceredigion has comparable consumption to that of Powys region. The baseline scenario using LPG, domestic heating oil, and wood pellets provides the as-it-is cost of fuels, emission level, and related environmental cost as shown in the figure.

The baseline data will be used to compare the 6 potential low- or zero-carbon pathways described below.

- **Pathway 1 (CH_4)**: natural gas only
- **Pathway 2 (CH_3OH)**: methanol only
- **Pathway 3 (H_2 + CH_4)**: hydrogen blended with natural gas (50:50)
- **Pathway 4 (NH_3 + CH_4)**: ammonia (20%) blended with natural gas (80%)
- **Pathway 5 (NH_3 + H_2)**: ammonia (98%) blended with hydrogen (2%)
- **Pathway 6 (NH_3 + H_2)**: ammonia (94%) blended with hydrogen (6%)

For these 6 pathways, we have derived the financials highlighting capital expenditure (CAPEX), operational expenditure (OPEX), level of emissions, and the cost of emissions.

CAPEX: This includes the capital investments due to the cost of equipment, building work, electrical work, gas works, plumbing (water connect / ventilation / exhaust), meters, and other miscellaneous costs.

OPEX: This includes direct and indirect operational costs. Direct costs include direct labour cost (DLC), admin and general overhead costs, annual operation and maintenance, insurance, and local taxes and fees. Indirect costs include the raw material and fuel costs.

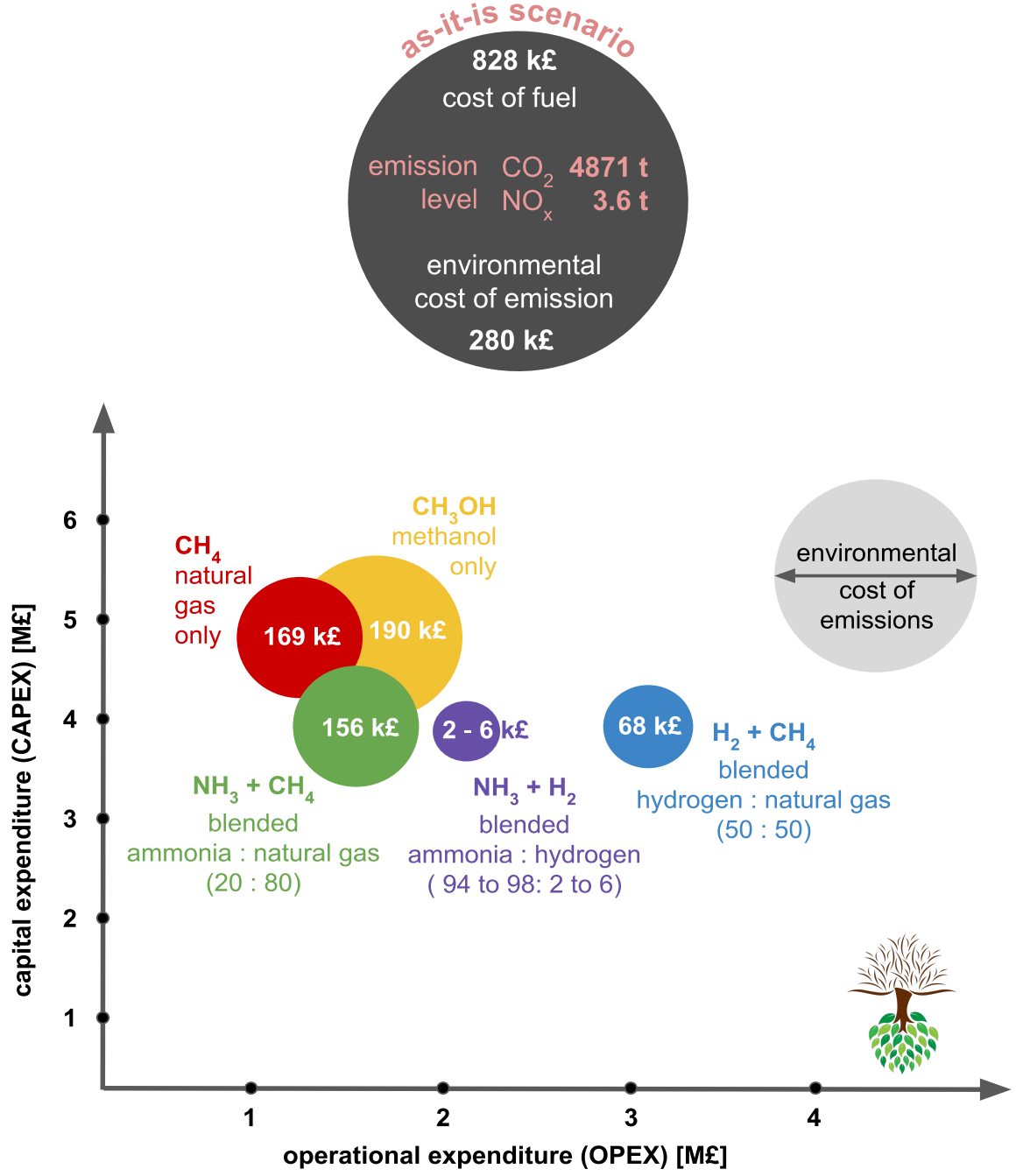
Level of emissions: This is an important parameter to understand the emissions resulting from the choice of fuels in our pathways. This includes mainly the CO_2 and NO_x emissions. We have not considered the carbon monoxide (CO) emissions in this calculation as we assumed the fuels are fully burnt in the system and there is negligible amount of CO emissions. Other emissions such as sulphur oxide, particulate matters, etc. are not considered in the calculation as they do not affect the outcomes of our assessment.

Cost of emissions: Cost of emissions is also an important parameter, which is not considered normally in many calculations. Going forward, there will be implications for polluters who are using fuels that emit GHGs. We have considered this in our calculations to rightly price the overall cost of our pathways considering the environmental damages of such emissions. For this, we have used a basic tariff for CO_2 emissions used in European Union emission trading system (EU ETS). This is presently, 50-60 € per tonne, which corresponds

roughly 50 £ per tonne of CO_2 emitted. We have used the 200-to-300 year period NO_x global warming potential (GWP) value to calculate the environmental cost of NO_x emission. This is roughly 200 times that of CO_2 and taken as 10 k£ per tonne of NO_x emitted.

If we assume the diameter of the bubbles in the chart as an indicator for the environmental cost of emissions, then we can compare these with 6 pathways suggested in this assessment.

Overall pathway impacts in terms of CAPEX, OPEX, level of emissions, and cost of emissions in given in the figure below. Please note that the baseline is the as-it-is scenario for entire Mid Wales region public sector energy consumption only using 4 fuels – natural gas, LPG, domestic heating oil, and wood pellets. As mentioned above, direct grid electricity and renewables generated electricity are not considered in this calculation as they remain the same in all the pathways.



Summary and future outlook

Over the last 6 months, we have been investigating the potential for development market opportunities in the Mid Wales region for hydrogen and hydrogen-based low- and zero-carbon fuels. We have carried out this work in two stages – opportunities assessment and feasibility study phase.

Hydrogen and hydrogen-based fuels are increasing in popularity, thanks to the growing interest and increasing ambitious commitments from public and private sectors across the world. We have seen several ambitious targets set by UK government over these years in this direction. That being said, we have several reasons to believe that there is still a huge gap between ambitious targets and ground reality. Politicians, policy makers, technology experts, project developers, and businesses across sectors have one thing or the other to say about hydrogen and hydrogen-based fuels and their potential in decarbonizing various sectors of the UK economy. Like with all new technologies, there are groups within UK fully advocating for hydrogen and the others who are not convinced with the potential of hydrogen as a viable energy vector for the UK. While the former groups see huge potential in hydrogen in many applications, the latter group believe hydrogen is just another "hype" promoted by big corporate lobbies.

Our investigation has revealed that presently direct hydrogen has only limited market opportunities within Mid Wales and developments outside Mid Wales are still evolving. Many of the applications are not yet ready for green fuels. One has to think about a transitory period to create a pathway if green fuels have market opportunities. In this period, Mid Wales need to find realistic market opportunities as a way to support the organic growth within the region. There should be transition fuels specific to applications that can serve as a bridge between current fossil-fuels and the future green fuels. The transitory fuels should be easily usable with current infrastructure and machineries with minimum or no change. That being said, pure hydrogen has some niche market opportunities in the heavy goods vehicles and public transportation such as buses and trains. Synthetic methane, methanol, and ammonia could be seen as transition or ideal green fuels for many of the applications.

Given the lack of infrastructural support, supply chain challenges, and policy and regulatory gaps, the market developments can go either way as strategic goals are not linked to clear actionable plans in short-, medium- and long-term for hydrogen and hydrogen-based fuels. With these uncertainties, Mid Wales can best prepare by cleverly planning and positioning itself as a strategic partner to other regions that are acting as first movers. In doing so, Mid Wales region can also greatly benefit from the learnings derived from "others' mistakes" before venturing into long-term large-scale investments. This way, Mid Wales can align itself as a strategic partner to North and South Wales and the rest of UK to create new market opportunities inside and outside Mid Wales.

We have evaluated how the "first procure, later produce" strategy can be effectively implemented in the Mid Wales region. We have built our strategy based on the basic premise that it would be a clever approach for the region to first create a market ecosystem for the low- and zero-carbon fuels identified in this study by first procuring these fuels in short- and medium-term (up to 10 years) and in long-term partner with relevant stakeholders to locally produce these fuels in the region. To this end we have explored ways to implement this strategy at business-, industrial-cluster-, industry-, and public-sector-level highlighting the **relevance**, **challenges**, **opportunities**, and **limitations** at different levels.

We have also addressed the skills and capacity building challenge in the cleantech and renewable energy sectors, particularly in the hydrogen and hydrogen-based low- and zero-carbon fuel economy in the region. In this feasibility study, we gathered insights that there is a significant skills gap in this sector in Wales, and particularly in Mid Wales. This issue needs to be addressed strategically at the same time to ensure that the right talent is available at all levels. We have initiated discussions along this direction with relevant government agencies, vocational training centres, and educational institutions in Wales during the course of this feasibility study to highlight and elevate this issue. More discussions should follow in this direction to develop relevant courses and training programmes at all levels from vocational training schools to research institutions to fill this gap in the coming years.

Last but not the least, we have presented a broad-brush financial assessment for investments needed in the short- and medium-term to pursue first procure part of the strategy. The aim of the financial assessment shall serve as starter for further discussions with the decision makers and initiate various actions that are recommended in the short- and medium-term strategy implementation section. We have also included estimates for the environmental cost of emissions for the as-it-is (baseline) scenario and compared it with various low- and zero-carbon fuel options discussed in this feasibility report. We believe the outcomes of this feasibility report will strongly resonate with the stakeholders and decision makers in the region to drive change and progress in the Mid Wales. We take this opportunity to thank the Growing Mid Wales Board, Powys and Ceredigion Counties, and the funding agencies for giving us the opportunity to carry out this feasibility study.

Glossary

AD	Anaerobic Digester	**H_2**	Hydrogen
ADBA	Anaerobic Digestion & Bioresources Association	**HVDC**	High Voltage Direct Current
BEV	Battery Electric Vehicle	**kWh**	Kilowatt Hour
CAPEX	Capital Expenditure	**LGV**	Light Goods Vehicle
CCU	Carbon Capture and Utilization	**LPG**	Liquefied Petroleum Gas
CH_4	Methane (natural gas contains 70 – 90% methane)	**MWh**	Megawatt Hour
CH_3OH	Methanol	**NH_3**	Ammonia
CHP	Combined Heat and Power	**NO_x**	Nitrogen Oxides
CO	Carbon Monoxide	**OPEX**	Operational Expenditure
CODE	Cost Optimal Domestic Electrification	**P2G**	Power-to-gas
CO_2	Carbon dioxide	**REPEX**	Replacement Expenditure
COP	Coefficient of Performance	**RHI**	Renewable Heat Incentive
DEEP	Demonstration of Energy Efficiency Potential	**ROI**	Return On Investment
EU ETS	European Union Emission Trading System	**SENS**	Smart ENergy Savings Competition
EV	Electric Vehicle	**SMR**	Steam Methane Reforming
FEED	Front-End Engineering Design	**SWIC**	South Wales Industrial Cluster
GCRE	Global Centre of Rail Excellence	**TEM**	Techno-Economic Model
GMW	Growing Mid Wales	**TWh**	Terawatt Hour
GWh	Gigawatt Hour	**UK**	United Kingdom
GWP	Global Warming Potential	**WMRIS**	West Midlands Rail Investment Strategy
HGV	Heavy Goods Vehicle		

Orders of magnitude	Explanation
W	1 watt = 1 watt
kW	1,000 watts = 1 kilowatt
MW	1,000,000 watts = 1 megawatt
GW	1,000,000,000 watts = 1 gigawatt
TW	1,000,000,000,000 watts = 1 terawatt

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