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LOT 3 - Energy Strategy: Transport Research Project 3 - Alternative fuels for vehicles

Technical Report

Developed by Atkins and Cenex for the Department for Infrastructure of Northern Ireland

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Contents

Figures Page

Glossary of Terms

AD	Anaerobic Digestion
BEIS	Department for Business, Energy & industrial Strategy (UK)
BEV	Battery Electric Vehicles
Bio-CNG/ CBM	Compressed biomethane
Bio-LNG/LBM	Liquid biomethane
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
DAERA	Department of Agriculture, Environment and Rural Affairs (NI)
DECC	Department of the Environment, Climate and Communication (RoI)
DfE	Department for the Economy (NI)
DfI	Department for Infrastructure
DfT	Department for Transport (UK)
DoT	Department of Transport (RoI)
EC	European Commission
ERS	Electric Road System
ES	Electricity Storage
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GB	Great Britain
GHG	Greenhouse gases
H_2	Hydrogen
HGV	Heavy Goods Vehicle
HRS	Hydrogen refuelling station
LNG	Liquid Natural Gas
MPV	Medium Passenger Van
NDC	Nationally Determined Contributions

Glossary of Terms

NI	Northern Ireland
O&G	Oil and Gas
OLE	Overhead Line Equipment
OLEV	Office for Low Emission Vehicles
PHEV	Plug-in Hybrid Electric Vehicle
RAG	Red-Amber-Green
REEVs	Range Extender Electric Vehicle
RE-FCEV/ H2-REX	Hydrogen range extender
RoI	Republic of Ireland
STK	Single track kilometre
TRL	Technology Readiness Level
TTW	Tank-to-wheel emissions
ULEV	Ultra Low Emission Vehicle
WAV	Medium Van
WTT	Well-to-tank emissions
WTW	Well-to-wheel emissions
ZE	Zero Emissions

At the time of production of this report the Department for Transport (United Kingdom) had not published the Transport Decarbonisation Plan, and Northern Ireland Assembly had not committed to any specific climate change targets in line with Committee on Climate Change advice which might make specific suggestions that differ from those proposed by this commission.

The UK Department for Transport (DfT) published the Transport Decarbonisation Plan on 14th July 2021, after the production of this report. It is recommended that the Department for Infrastructure (DfI) review the implications of the Transport Decarbonisation Plan on the conclusions of this report as it develops its strategy for alternative fuels in Northern Ireland.

Executive Summary

This study provides a pre-assessment of the energy demand required by the future alternative fuelled heavy goods vehicles (HGVs), buses, taxis and rail in Northern Ireland (NI). The key messages shared by this study will inform the draft Energy Strategy developed by the Department for the Economy which will be published by the end of 2021 [1].

This report mirrors the relative uncertainty in the energy transition, driven largely by technological development and market forces as well as political economy. These trends are driving continuing declines in the cost of renewable energy and leading to tipping points in those areas where demand for fossil fuel energy is peaking.

The diagram below (Figure 1-1) presents the complexity of decarbonising the NI transport sector. The study involved analysing the potential scenarios of uptake of alternative fuels for HGVs, buses, taxis and rail and the implications of this alternative energy demand on production, storage and energy distribution in the NI context.

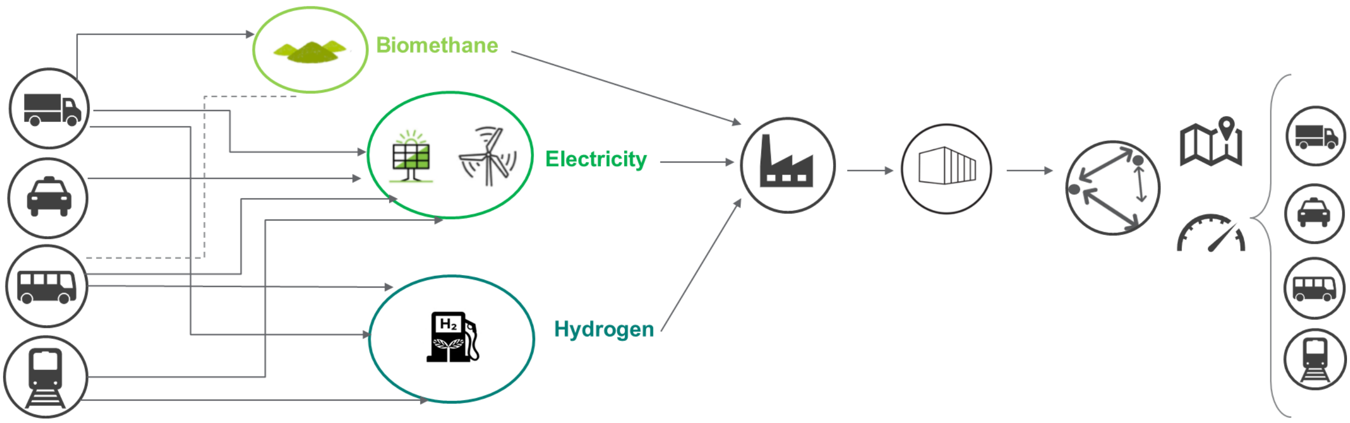


Figure 1-1 - Research problem diagram

In this project we investigated transport solutions that adopt electricity, hydrogen or biomethane as the alternative fuel.

It is fundamental to stress that low carbon fuels are useful to decarbonise other sectors, such as the heating sector. Limited production and storage capacity developed to date may pose a limit on the extent to which low carbon fuels can meet energy demand across all sectors.

When defining what alternative energy each transport sector should adopt, consideration should be given to a 'whole systems' approach for greenhouse gas savings and overall emissions savings across all sectors.

In this project we explored the options and solutions to decarbonise HGVs and passenger vehicles in Northern Ireland, with the target goal of reducing by 70% all greenhouse gases in Northern Ireland by 2040 and net zero for CO_2 emissions by 2050. A holistic approach to the energy demand cross-sectors is fundamental to achieve the highest carbon abatement levels and further greenhouse gases emissions reduction.

In the following section we summarise the key messages from this research project starting with setting the scene around alternative fuelled transport and energy in United Kingdom (UK) and Europe and how Northern Ireland stands in these sectors. We also highlight the most relevant suggestions on what the future of alternative fuelled transport could look like in Northern Ireland, and the implications for the energy system.

Key Messages from the Research Project

Alternative Fuelled Vehicles in UK and Europe – Setting the Transport Scene:

HGVs: In this study we considered the potential viable alternatives for decarbonising the road freight sector in a two-fold approach: rigid HGVs (up to 25 tonne) and heavy duty articulated HGVs (over 25 tonne). Currently there are limited technology solutions to serve heavy duty vehicles. Electric vehicles have limitations on mileage due to the size and weight of batteries required. Hydrogen technology is still in its infancy and in early trial phase. Biomethane vehicles are available now but can only contribute a reduction of up to 70% of the carbon emissions from the sector. Proven solutions for heavy duty vehicles are not thought to be feasible until 2030 however action needs to be taken now in trialling zero emission vehicles in preparation for large wholesale changes in the next decade, particularly in having the distribution infrastructure in place.

Taxis: Solutions exist now in the electric market for various sizes of vehicles. Technology maturity is high for smaller vehicles with whole life savings over conventional fossil fuel vehicles due to lower running costs for electric vehicles. Wheelchair accessible vehicles (WAVs) and hackney carriage style taxis are still limited at the moment with WAVs primarily utilising the van market options at present. It is expected that in the next 5 years more of these vehicles will be produced by manufacturers with costs reducing due to economies of scale.

Buses: Technology solutions already exist for electric and hydrogen buses though they are still in their relative infancy. Capital costs are very high for these vehicles at present. Electric buses are limited in range at present up to 300km which will suit a high number of daily routes without the requirement for top-up charging. Hydrogen buses are able to cover much larger ranges with refuelling taking a matter of minutes rather than hours, although there are limited numbers of vehicles on the road at present. The purchase costs of hydrogen buses are significantly higher than diesel with the costs of hydrogen fuel also high resulting in no savings in the whole life costs (at present) of the vehicles. It is expected that fuel costs will drop, however they may not drop sufficiently to offer lower total cost of ownership vs conventional fossil fuelled vehicles.

Rail: The key options for a low and zero carbon rail system range from electric traction and battery-powered traction to hydrogen-powered traction and traction combinations (bi-mode). An important reference case for decarbonising the Northern Ireland rail sector is the work carried out by Network Rail on UK Traction Decarbonisation Network Strategy and Scotland's Railway investment in zero carbon solutions, which employ a combination of the four solutions to address specific geography and demand needs.

Distribution, Production and Storage of Alternative Fuels in UK and Europe – Setting the Energy Scene:

Electricity: The UK aims to increase interconnector capacity from 4GW [2] to 18GW [3] by 2030 to enhance the flexibility of the UK's energy system. This is extremely important to the UK nations renewable energy mix, as generation from variable sources becomes more stable as the geographic boundary of that generation expands. The UK government targets require the electricity system to grow and double in size by 2050 to meet the demand for low-carbon electricity.

Hydrogen: Hydrogen is a highly versatile low carbon fuel, that can help to reduce CO_2 emissions from otherwise hard to decarbonise sectors. Significant demonstration of H_2 production, distribution, storage and end-use cases has been shown in recent years, and the UK has several projects ongoing to reduce deliverability risk. The UK Government has not yet published its Hydrogen Strategy but has a 10-point plan for a Green Industrial Revolution, which aims for 1 GW of hydrogen production capacity by 2025 and 5 GW of hydrogen production capacity by 2030. Scaling of hydrogen across the full supply chain is therefore needed at an unprecedented speed.

Biomethane: Biomethane is an important fuel to decarbonise hard to otherwise decarbonise transport vehicles. Scale up of production is needed, and prioritising this fuel for transport use cases is recommended. Biomethane comes in many forms, from various feedstocks. Its ability to scale as a clean fuel is hindered by lack of regulation supporting grid injection. This is critical if it is to displace fossil fuel use.

Current Transport, Distribution Infrastructure and Energy Production and Storage in Northern Ireland

HGVs: Northern Ireland has a significant role to play in developing policies and actions to encourage the uptake of low and zero emission HGVs. Road freight represents the greatest proportion of all freight trips, partially as an extension of roll-on and roll-off activity but also through the cross-border connection with the Republic of Ireland (RoI). The majority of the cargo is moved by heavy duty articulated vehicles for which a zero emissions solutions does not exist in the market; at present for articulated HGVs only low emissions solutions are commercialised at scale making use of biomethane and other biofuels, which still emit a small amount of carbon, but overall considerable less harmful when comparing with fossil fuelled solutions

Taxis: Further segmentation of the taxi market due to the four categories of licence, including ride-hailing companies, means that external policies are likely to be required in order to encourage investment. Northern Ireland currently does not have any specific targets for decarbonising the taxi fleet, beyond the national government commitments to decarbonise the car fleet. Offering grants to support the upfront costs of acquisition similar to what is being rolled out by Office for Low Emission Vehicles in the UK and by the Sustainable Energy Authority in Republic of Ireland can support a greater take-up of zero emissions taxis.

Buses: Northern Ireland has been progressing the trial and uptake of zero emissions buses in a remarkable effort to decarbonise urban services in the first instance. Translink has committed to replace the fossil fuelled bus fleet with zero emissions vehicles by 2040, and has recently confirmed the direction of travel with a £ 66 million funding programme involving the collaboration between Translink and Wrightbus. Bus decarbonisation is also a key area of decarbonisation in the Republic of Ireland, though trials of zero emissions buses are yet to be undertaken with plans to start the operation of urban electric buses in 2021.

Rail: Translink is targeting a zero-emission fleet by 2040. Although there is no specific imperative from Northern Ireland Executive to achieve this, the aim aligns with the wider UK and EU targets. The existing rail network is approximately 330km in length and is serviced by a combination of Class 3000 and Class 4000 diesel multiple units, with the fleet currently being expanded with new 6-car units. The Enterprise service between Belfast and Dublin has been specifically identified in the all-Ireland review and it is understood that electrification would be considered in this review.

Electricity: NI operates under the single energy market, and so generation and import is treated as a whole. The current and planned interconnectors are critical to meeting Net Zero targets for both NI and ROI.

Hydrogen: Belfast is uniquely positioned with geography favourable for salt cavern storage of gas, including hydrogen. This opportunity is significant, but not yet explored; and would provide the means to store hydrogen at scale, at the lowest cost per unit.

Biomethane: Biomethane is not currently incentivised or supported for scale up, and as such a number of possible feedstocks are not being used to produce fuel. A whole system and 'circular economy' thinking is needed to upscale the end-to-end supply chain.

The Future Alternative Fuels Demand for Transport in Northern Ireland

HGVs: It is still unclear which direction the fleet will follow due to low emission technology being at an early stage of development. It is likely that lighter vehicles will electrify and heavier vehicles will move towards the hydrogen option, with a potential stepping stone of biomethane as an interim solution for heavier duty vehicles.

Taxis: Due to the smaller nature of these vehicles, and electric vehicles already being available on the market, all taxis are expected to electrify. The rate of uptake will rely heavily on policy from NI and an indicative target date of 2035 has been proposed based on local authority targets in some areas of the UK.

Buses: Though proven technology solutions exist for zero emission buses it is unclear as to whether electric vehicles will be capable of achieving long distance routes in the future which only hydrogen vehicles can meet at present. Hydrogen vehicles have inherently higher upfront acquisition costs and are more expensive to run than electric vehicles. Hydrogen refuelling infrastructure is also more complex than electric charging. The future split between electric and hydrogen vehicles should not be set in stone and it is recommended that a review of the latest technology advancements should take place every 2-3 years to ensure the most economical option is selected, route dependant.

Rail: Recognising the general preference for rail electrification, we assumed a move towards that but have looked at different scenarios in the medium-term to enable full decarbonisation of the network by 2035. As such, the option that we take forward is 50% electrified network by 2035 and the remaining 50% using battery-electric hybrid trains.

The Future of Alternative Fuels Distribution Infrastructure in Northern Ireland

HGVs: Refuelling and recharging points should be placed at strategically significant points with high traffic flow of HGVs and a concentration of logistics activities. Charge points, though rapid and ultra-rapid, will still take several hours to recharge vehicles and this should be considered when placing infrastructure. Supercharger recharging points with over 100kW are still under development and will reduce the charging time considerably. Hydrogen and biomethane refuelling can be completed quickly hence the placement can follow a similar distribution network to that of conventional diesel refuelling stations. It should be noted that hydrogen refuelling stations can take a long time to build due to strict safety and policy measures (often up to 2 years).

Taxis: Primarily charging from home with some public infrastructure required to support charging within a typical working shift that should provide rapid charging.

Buses: Refuelling to be placed at depots with electric rapid chargers serving vehicles on a 1:1 basis. Due to the expensive nature of hydrogen refuelling, strategically beneficial stations should be deployed at depots where hydrogen vehicles are the only viable solution. There is also the opportunity to consider the use of public infrastructure for HGVs as it is unlikely that it will be economically viable to install this infrastructure in all depots in the first decade of operation.

Rail: For full electrification, overhead line equipment provides power directly to the electric trains, whereas battery-electric bi-mode traction would draw power from the wires where available and be self-powered by battery where not.

The Future of Alternative Fuels Production and Storage in Northern Ireland

Electricity: Significant increase in clean electrical generation is needed, with an accelerated ramp up from 2030 to 2035 (of 175,520MWh to 632,650MWh[1]). This is needed in both capacity and peaking generation and would likely be achieved through a balance of oversized renewables and interconnectors. Forms of energy storage should be reviewed as a priority, as in all future energy cases, a ramp up of storage is needed. This is particularly relevant to transport use cases where security of supply may be a critical project factor.

Hydrogen: To meet the NI transport demand cases it is likely a majorated green H_2 production route could be taken, however the demand case for transport should be considered in the wider energy context, as a whole systems approach to H_2 production and storage will offer the lowest system costs.

Biomethane: The biomethane demand cases could be achieved through a combination of redirecting and prioritising existing production but supported by scaling up and new AD production plants. In addition, a regulatory barrier must be overcome to allow biomethane injection to the national gas grid.

[1] Excludes rail transport demand from estimate

1. Methodology

The report structure follows the methodology developed where each chapter describes the key activities performed to meet the objectives identified in the project brief. A short description of the content of each chapter is presented below.

Literature Review

Drawing on our previous experience, we undertook a desktop review of international literature on the suitability of alternative fuels for HGVs, buses, taxis and rail. We investigated how the alternative fuels under analysis in this study – hydrogen, electricity and biomethane – are distributed across UK and Europe and the implications of each vehicle type in shaping the distribution infrastructure. We also reviewed existing research and project case studies in the production and storage of new types of fuels.

The international literature review was concentrated on collecting policy recommendations, best practice, case studies with practical experience and lessons learned on each part of the process from vehicle adoptions, distribution infrastructure deployment, production and storage of alternative fuels.

We gathered evidence on benefits of adopting the best practice, highlighting caveats and uncertainties around the solution and how it contributes to moving the alternative fuels for transport agenda forward and whenever publicly available we explored the costs associated with the deployment of the solution.

Throughout the literature review we directed the reader to the reference consulted; a full reference list of the literature reviewed can be found in chapter 8 References.

From this literature review we gathered the evidence base in terms of technology options and readiness to inform the forecast scenarios in chapter 5 - Alternative Fuels Potential Achievable Take-up. This research allowed us to identify key aspects that will need to be addressed in the future alternative fuels' energy strategy.

Benchmarking Northern Ireland

Building on the findings of the literature review, we examined key publications relating to investment in and use of alternative fuels technology and infrastructure in Northern Ireland.

We presented a broad overview of the transport and energy system in Northern Ireland, identifying the key characteristics of each mode that will influence the future adoption and development in the distribution, production and storage of electricity, hydrogen and biomethane in Northern Ireland.

In order to complement the analysis with a high level appreciation of an all island perspective we also reviewed evidence on Republic of Ireland (RoI), both on the policies and developments of the transport and distribution infrastructure but also on how the energy system operates in the RoI.

Barriers and Opportunities

Drawing on the evidence from the previous tasks, we undertook a detailed SWOT (Strengths / Weaknesses / Opportunities / Threats) analysis of the alternative fuelled vehicle solutions for HGVs, rail, buses and taxis in the context of Northern Ireland and the respective implications to the energy system in terms of alternative fuel infrastructure. We also identified the benefits and barriers to deploying several production and storage solutions.

Alternative Fuels Potential Achievable Take-up

We assessed and proposed potential take-up of alternative fuels across the HGV, buses, taxis and rail sectors until 2035. We developed forecasts scenarios by adopting the most up-to-date industry trends and adapted to the context of different parts of NI, considering the inferences of a mixed territory with urban and rural areas. In some cases, we adopted a proportionate approach supported by desk-based review of best practice case studies and general recommendations for increasing the uptake of alternative fuels.

Based on the future vehicle forecasts we established an approach to identifying the potential energy requirements for each transport mode; due to the uncertainty around the most suitable solution for HGVs we proposed two forecast scenarios. For rail we provided a high-level view of the scale of energy demand required for the future electrified railway.

From the energy demand for each mode we estimated the respective distribution infrastructure requirements.

For each alternative fuel the highest transport demand case informed the production and storage capacity required in Northern Ireland. From this we proposed and assessed several production and storage solutions to support the increase in alternative fuels demand along the timeframe 2020-2035.

Action Plan and Assessment Framework

Based on the knowledge gathered throughout this research study and through extensive engagement between the subject matter experts in the transport and energy sector we proposed an Action plan setting the critical path in the 2021-2035 timeline for the adoption of alternative fuels for HGVs and passenger vehicles in Northern Ireland.

We built a complementary assessment framework to distinguish the key characteristics of each action/measure to support DfI prioritising the most relevant measures.

We used the evidence from the previous tasks to develop a comprehensive understanding of the opportunities, barriers, benefits and costs of the use of alternative fuels in comparison with the use of traditional fossil fuel vehicles.

We created the Action Plan and Assessment Framework so that it can address uncertainties about future market demands for alternative fuelled vehicles, future technology developments and infrastructure delivery and it can be refined when more detailed information is available.

Recommendations

Throughout the study we identified further work that will be required to tackle the gaps in existing evidence and refine the initial estimates of demand and infrastructure requirements.

Through the Action plan we identified a pathway of actions to support the transition to an alternative fuelled transport system and assessed the actions against the benefits and costs of implementing the solutions for HGVs, taxis, buses and rail. This pathway covers the key areas where the public sector can exercise greater influence in moving the alternative fuel agenda for transport forward.

2. Literature Review – UK and Europe

In this chapter we have compiled the literature review that covers the best practice in the uptake of the alternative fuels for transport in the UK (e.g. GB: DfT, BEIS, Scotland, Wales) and Europe (e.g. European Commission, Northern Europe, Germany) highlighting some of the most relevant developments made in this area.

We have conducted the literature review in a three-fold approach:

- Alternative fuelled transport - we started by collecting evidence on the state-of-the-art of alternative fuelled vehicles for each transport mode considered in this research study – HGVs, Taxis, Buses and Rail.

- Distribution infrastructure for alternative fuelled vehicles - we then evaluated the implications of these alternative fuelled vehicles in terms of required distribution infrastructure and presented some of the most apposite solutions for recharging and refuelling each mode.

- Production and storage of alternative fuels - finally, we explored the energy production and storage market across the UK and Europe, and how the energy system is operated.

We gathered supporting evidence of policies (funding, planning, strategies) in the UK and Europe to stimulate the adoption of alternative fuels, providing reference to respective responsible institutions and authorities. Whenever publicly available for each technology solutions presented, we complemented with the indicative cost and benefits, highlighting caveats and uncertainties around the implementation of each solution.

We focused our research on the following evidence:

- UK experience – drawing on the best practice in UK we explored the most relevant publications in Great Britain (GB) through the Department for Business, Energy & Industrial Strategy (BEIS), Department for Transport (DfT), and corresponding transport bodies in Scotland and Wales and other UK governmental bodies such as Office for Zero Emission Vehicles. We made use of publicly available governmental studies, data, and statistics.

- Industry publications - we analysed strategic documents developed by industry associations such as Network Rail, or reputable industry players such as Volvo, Cenex and Ofgem.

- European experience – in the European context we explored material published by the European Commission, and country specific information to include Germany, Netherlands and France.

- Case studies implemented – mainly focused in UK-based projects delivered by private and public institutions such as Local Authorities, infrastructure providers (e.g. Gas networks), consultants (e.g. Ricardo Energy and Atkins).

- Relevant institutions in the decarbonisation agenda such as the Committee on Climate Change or The Centre for Sustainable Road Freight.

This chapter forms the evidence base that was used to inform the technology options and readiness in order to form robust forecast scenarios in chapter 5 - Alternative Fuels Potential Achievable Take-up.

2.1. Alternative Fuelled Transport

In this study we focused the analysis of alternative fuelled vehicles with the highest potential to reduce the Tank-to-Wheel emissions.

Although electric and hydrogen vehicles are classified as zero emission vehicles carbon may still be produced during the creation of the fuel and the manufacturing of the vehicles. The full life cycle of the fuel, from creation to use, is known as well-to-wheel although there are other important definitions to understand. The definitions are given below for some common terms to help bring this into context:

- **Tank-to-wheel (TTW)**, commonly called tailpipe emissions, are the emissions produced from the fuel itself, from the tank to making the wheels move. For electric and hydrogen fuels this is zero. For biofuels, such as biomethane, the emissions are also zero, or rather, carbon neutral because the combustion of the fuel is releasing carbon that is part of a sustainable cycle so is discounted for emission reporting requirements.

- **Well-to-tank (WTT)** emissions are the total emissions generated when producing the fuel, extracting, processing, transporting and dispensing the fuel, from the well to the tank of the vehicle. For electricity, hydrogen and biofuels this will be positive due to the carbon dioxide produced from the energy required to carry out these processes.

- **Well-to-wheel (WTW)** emissions are the combination of both the well-to-tank and tank-to-wheel, the full lifecycle.

Tailpipe emissions do not take into account the source or sustainability of the fuel. Tailpipe emissions simply report the actual gases and other pollutants that are realised from the vehicle. On the other hand, **lifecycle emissions** take into account emissions embedded into the vehicle. These are the emissions produced when manufacturing the vehicle, both the raw material and the energy required to make the vehicle, the emissions during use, and also the emissions when the vehicle comes to the end of its life and is scrapped or recycled.

From Figure 2-1 we can appreciate that when moving from tailpipe emissions, to well-to-tank and then to the Life cycle analysis, the carbon abatement can be achieved not only with full electric solutions but also with other alternatives.

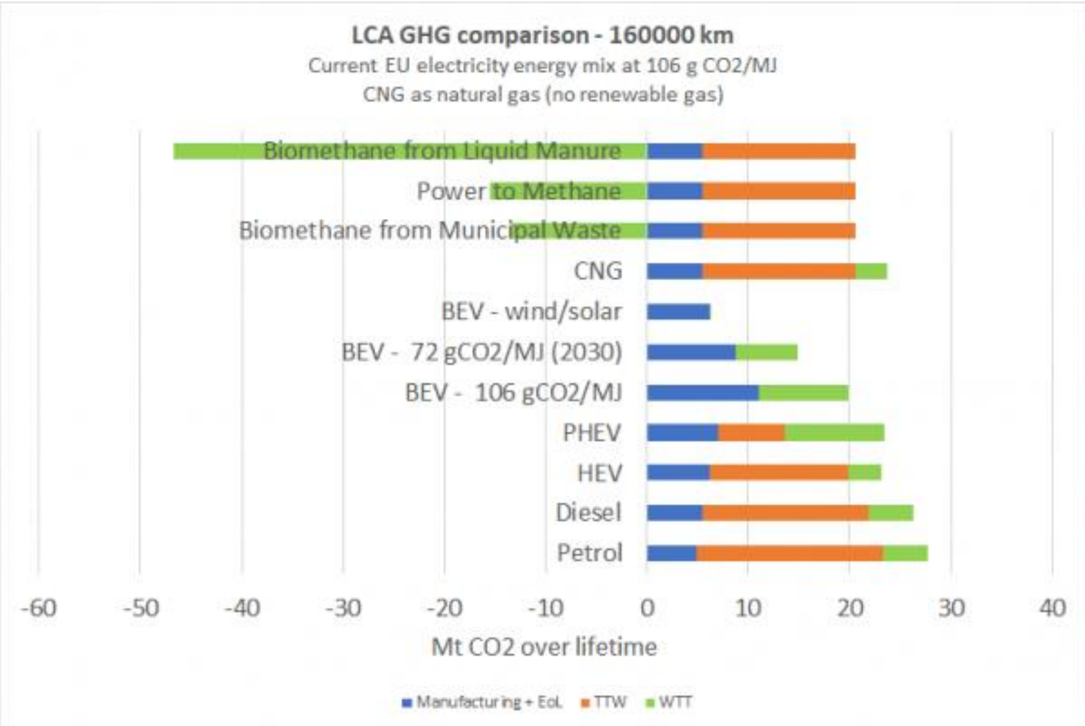


Figure 2-1 - Lifecycle GHG comparison of alternative fuels (source: NGVA Europe [4])

When looking towards net-zero targets, it is recommended that a comprehensive analysis of the carbon abatement of the alternative fuel solution is carried out for the whole life of the vehicles. Nonetheless, the relative contribution of Tank-to-Wheel emissions to the overall lifecycle emissions as shown in Figure 2-1 confirms the importance of understanding Tank-to-Wheel as a first step to reduce the carbon emissions in the transport sector.

In section 2.3 consideration has been given to the use of lesser carbon intensive fuels and also renewable energy.

2.1.1. HGVs

In 2018, the transport sector as a whole accounted for 33% of all UK carbon dioxide emissions, and the large majority corresponded to road transport [5]. HGVs alone accounted for 17% of the total Transport greenhouse gases emissions in 2018 [6], a figure that is rising in absolute and relative terms. Supporting the development of alternative fuels and clean vehicle technologies is fundamental to decarbonise the freight sector.

The literature largely agrees that the decarbonisation pathway of heavy duty vehicles, particularly long-haul articulated vehicles is not yet clear, with battery electric and hydrogen pointed out as potential long-term options [7] [8]; in contrast there is a consensus in the sector that light-duty vehicles decarbonisation will be achieved by the uptake of battery electric vehicles (BEV). However, unlike for light vehicles or buses, there is no agreement on the most cost-effective solution to be adopted by the freight industry.

When planning for the future heavy goods fleet composition policy makers and fleet owners should take into account for each vehicle type, rigid and articulated vehicles, which serve distinct purposes and have distinct characteristics. In the diagram below (Figure 2-2) we summarised six key considerations that may influence the implementation of alternative fuelled vehicles.

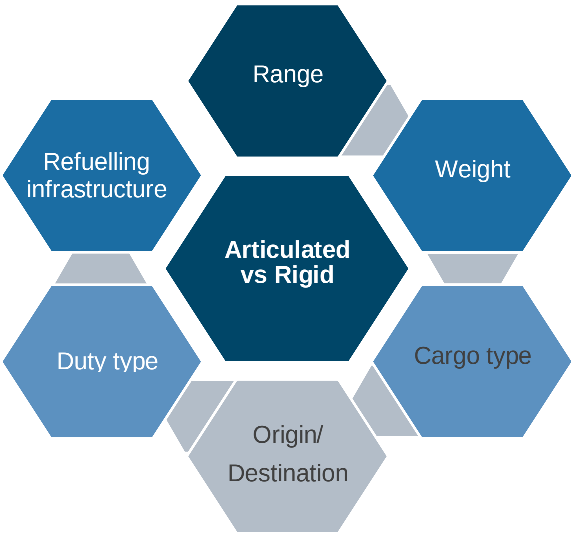


Figure 2-2 - Key considerations for future HGV fleet

In this study we considered the potential viable alternatives for decarbonising the road freight sector in a two-fold approach: rigid HGV (up to 25 tonnes) and articulated HGVs (over 25 tonnes).[2]

Heavy duty long haul rigid HGVs are likely to follow similar approach to artics[3] due to the high-power requirements of heavy loads which battery electric vehicles are not yet able to cope with. It is expected that batteries will reduce in size and gross weight, due to greater energy density, which would mean that vehicles will not need to cater so much space and weight, and would allow for more cargo to be carried, which is the core business of freight. [9] Currently there are only incentives for up to 3 axles rigids (26 tonnes) and no incentives for articulated vehicles.

[2] For more information on the different articulated and rigid HGVs consult [120]
[3] articulated HGVs commonly called 'artics'

At present, and likely to be the case within the next decade, the zero-carbon freight market faces a technological limitation of 27 tonnes maximum capacity and ~190 mile maximum range. This means there is not a commercially viable zero emission solution for articulated vehicles that carry containerised cargo over long-distances travelled. Biomethane appears as a mid-term solution to mitigate the gap for heavy duty vehicles with a nearly carbon neutral solution (between 70 to 94% carbon emissions savings when compared to a Euro VI diesel equivalent).

We summarise the technology roadmap for rigid and artics over the next decade in Figure 2-3 and Figure 2-4, respectively.

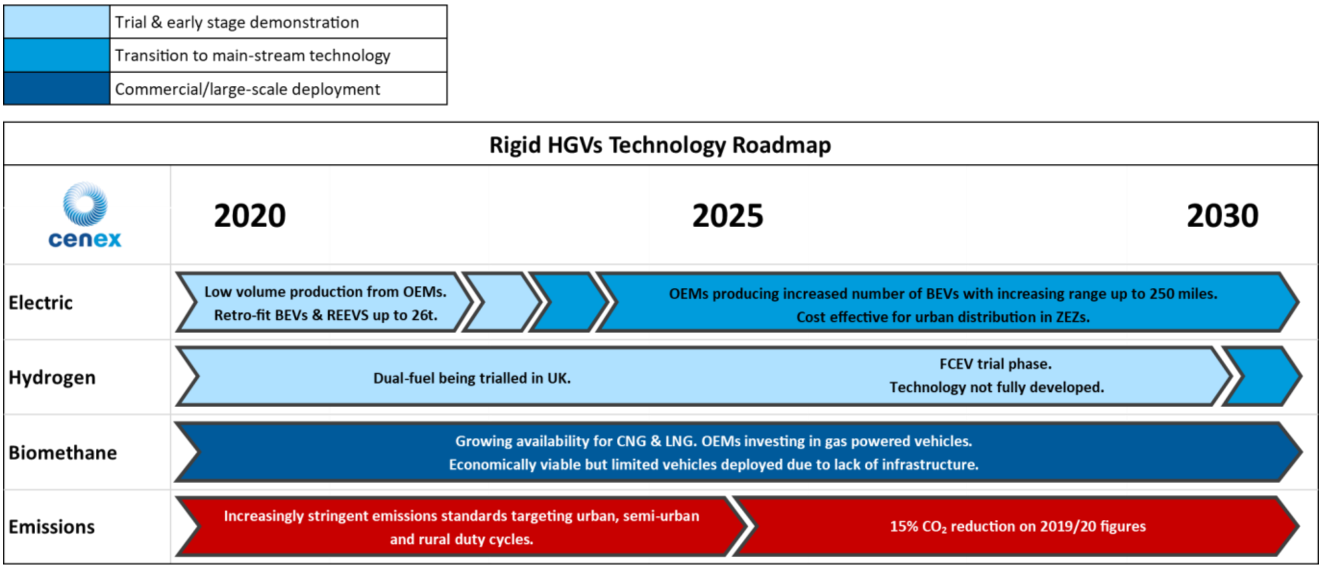


Figure 2-3 - Rigid HGVs technology roadmap (source: Cenex)

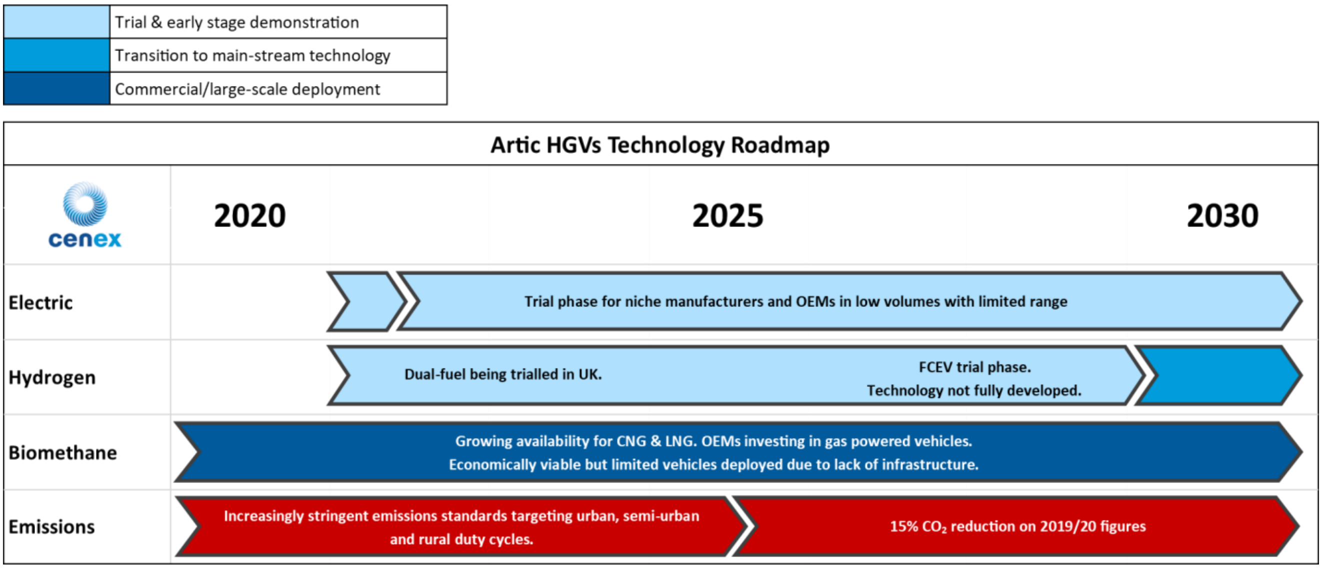


Figure 2-4 - Articulated HGVs technology roadmap (source: Cenex)

Volvo, the HGV vehicle manufacturer, recently presented a sketch of their roadmap in the different duties (urban, regional and long-distance), which showed the industry position on the path to decarbonising the freight sector. In the map below (Figure 2-5) in blue and green Volvo present their carbon free solutions readily available and in red and grey the HGVs duties lacking a readily available alternative electric and hydrogen zero emissions solution.

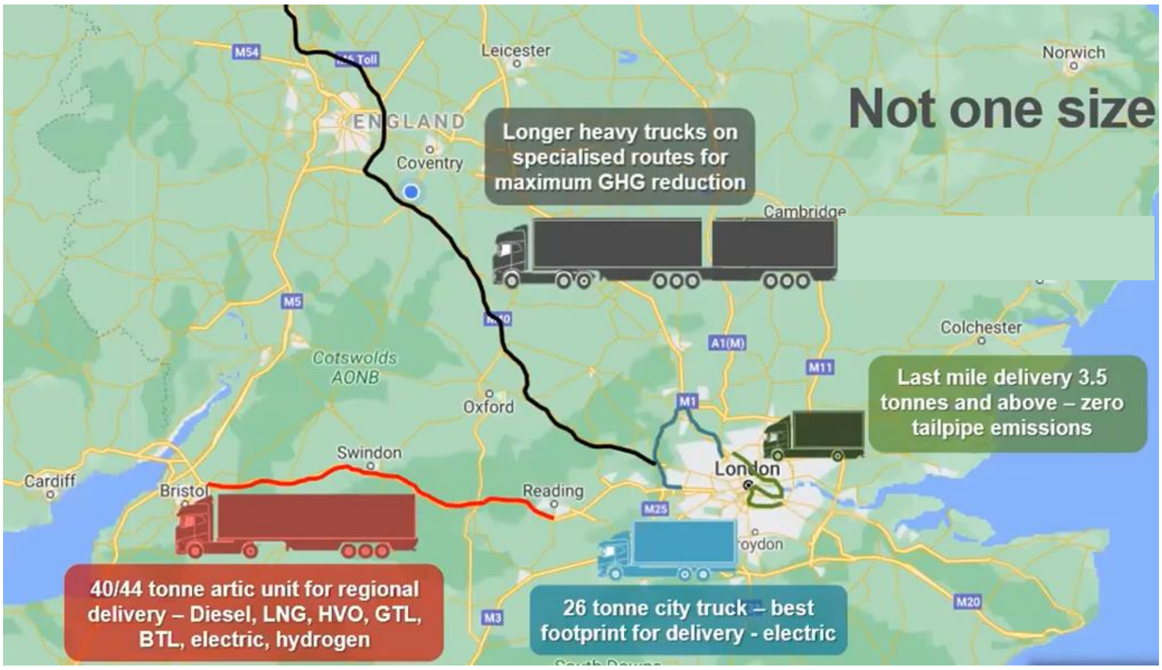


Figure 2-5 - Volvo vehicle roadmap (source: Volvo "The future of sustainable HGV fuels" webinar [10])

For HGVs we explored the technology options that offer the greatest potential to contribute to the sector's carbon abatement: Battery electric vehicles (BEV), Battery Electric Road System (ERS), Hydrogen (various forms) and Biomethane (various forms).

Below we distinguished zero emissions solutions and low emissions solutions achieved by the use of biomethane and detailed options that best serve each HGV category, artic and rigids, and service duty, medium to heavy duty with short to long distance.

Zero emission solutions

BEV for Rigid HGVs

For rigid HGVs the most likely scenario to be adopted to reduce GHG (greenhouse gases) in light-medium duty HGV is battery electric vehicles (BEVs) charged from ultra-rapid chargers - BEVs store energy in a battery (usually lithium-ion) and deliver power to the wheels through an electric motor. Braking energy is captured by the electric motor and stored as electrical energy in the battery. Battery electric HGVs are still in relatively low volume in the UK and tend to be on a trial basis only.

The medium and heavy-duty battery electric HGV market in Europe is still in the very early phase and amounted to 124 units in 2019 (44 medium-duty trucks and 80 heavy-duty trucks), on a universe of over 200 thousand medium and heavy-duty vehicles. The upfront cost ranging between 40% to 70% higher than a diesel equivalent and limited funding schemes to support offsetting the initial investment are the most likely reasons for a slow uptake from the logistics industry, which is well-known for its limited profit margins.

Battery ERS for Artic HGVs

A Battery ERS (electric road system) is powered from pantographs and charged off motorways / A roads by ultra-rapid chargers (**Figure 2-6**) – this system consists of charging a BEV through an overhead catenary system. It has been identified as a potential solution for articulated HGV operations with high proportions of trips on motorways but is not viable for urban freight deliveries.

Figure 2-6 - Battery ERS HGV driving on an Electric Road System 'eHighway' (source: Siemens [11])

Hydrogen Articulated HGVs

For articulated HGVs the most likely zero emission technologies to be adopted are:

- Hydrogen fuel celled vehicles (FCEV) refuelled from Hydrogen refuelling stations (HRS);
- Hydrogen range extender with on-board battery and hydrogen tank refuelled from HRS (H2-REX) commonly named RE-FCEV; and
- Hydrogen Electric road system (H2 ERS) powered by overhead catenaries and refuelled off motorways/A roads by HRS.

The European market for hydrogen fuel cell medium and heavy-duty trucks is still negligible.

As detailed in section **2.3.2**, hydrogen can be sourced as Green Hydrogen (electrolysis) or Blue Hydrogen (from methane reforming with 'Carbon Capture and Storage').

From the vehicle perspective, it is highly unlikely that hydrogen powered vehicles of any sort (FCEVs, H2 ERS, H2-REX) will play a significant role in the decarbonisation of light duty vehicles until 2040; similarly, green hydrogen is unlikely to meet the required demand levels during this timescale.

From an infrastructure perspective, the hydrogen infrastructure cost represents the least cost investment option for a transition to zero emission HGVs, 6 times cheaper than an ERS system.

However, the high power requirements of articulated and large rigid HGVs will largely depend on the progress of hydrogen technology, and for the time being, intermediate solutions of employment biomethane and overhead catenaries may be developed and take up a proportion of the diesel artics in the next decade. Overall maintenance costs of hydrogen vehicles are much cheaper, as they are for electric HGVs, because there are fewer moving parts. Brake wear is lower because stopping power is boosted by the energy storage system, similar to the principles of F1 cars. [12]

As with electric HGVs, hydrogen powered HGVs are also only available in relatively low volume in the UK and tend to be on a trial basis only, not commercialised at scale.

Under the H2Accelerate initiative launched at the end of 2020, vehicle manufacturers including Daimler Truck AG, IVECO, OMV, Shell and the Volvo Group have committed to work *together to help create the conditions for the mass-market roll-out of hydrogen trucks in Europe*. [13] The participants will work together to seek funding for early trial / pre-commercial projects to activate the market during the first phase of the roll-out (**Figure 2-7). In** parallel, the participants will hold discussions and communicate with policy makers and regulators to encourage a policy landscape that can help the subsequent scale up into mass-production for hydrogen HGVs and the complementary and fundamental Europe-wide refuelling network for green hydrogen.

PHASE 1	PHASE 2
ROLLOUT OF FIRST STATIONS AND TRUCKS	EUROPE-WIDE COVERAGE
▪ 100s of trucks ▪ >20 high capacity stations ▪ Proving high capacity station concepts ▪ Selective locations/clusters	▪ Second half of 2020s: Achieve volume manufacture '000's per year ▪ Rapidly reaching > 10,000 trucks ▪ Europe wide coverage of major corridors ▪ High capacity/reliability stations

Figure 2-7 - H2Accelerate phase plan (source: H2Accelerate [13])

The annualised costs for any alternative fuelled technology are lower than the current fossil fuel equivalent. This shows that although the zero-carbon options have high up-front costs, their annualised costs are 5% to 43% lower from a societal cost perspective than the fossil fuel comparator. This is driven by higher efficiencies (particularly for BEV & ERS scenarios) and lower unit costs of zero carbon fuels.

Low emission solutions

Biomethane for Heavy Duty Rigids and Articulated HGVs

Switching more HGVs from conventional diesel onto gas will provide greenhouse gas (GHG) and local air quality benefits as well as the potential for lower fuel costs for operators. HGVs using biomethane are estimated to achieve GHG savings on average between 70%, according to DfT [14] and up to 94% according to LowCVP [15]. It is possible to produce biomethane from organic waste materials via a process called anaerobic digestion; biomethane can be dispensed as compressed biomethane (bio-CNG/CBM) or liquid biomethane (bio-LNG/LBM).

Biomethane has been relatively wide spread in Central European countries over the past decades but has been limited in the UK logistics sector, with 400 biomethane heavy duty vehicles currently operating in the UK including the fleets of companies such as John Lewis Partnership, Asda, DHL, and local authorities such as Cornwall Council, London Borough of Islington. Both CBG and LBM vehicles are available as rigid and artic HGVs up to 44t and can cost an average 25% more than conventional diesel equivalent. In terms of running costs, biomethane is more economical to run than equivalent diesel due to the differential in the gas fuel duty, which the government has committed to maintain at 50% of diesel fuel duty until 2032.

Biomethane HGVs have been acclaimed to be extremely reliable and can run interchangeably on biomethane or the fossil-fuelled alternative natural gas without impacting the performance of the vehicle.

Currently, biomethane has an advantage over hydrogen for deployment in road transport because vehicles are available on the market and the refuelling network is better developed. However, significant investment in hydrogen, or a clear policy steer to use biomethane for heating, could change this picture relatively quickly. Since the Element Energy work was undertaken in 2014-15 there has been more discussion about using hydrogen, rather than biomethane, for decarbonising road freight.

Funding sources

The Office for Low Emission Vehicles (OLEV) plug-in vehicle grant scheme ('the PIVG scheme') introduced in 2021 is now extended to heavy vehicles. The OLEV grant will pay for 20% of the purchase price for freight vehicles with CO_2 emissions of less than 50% than equivalent conventional Euro VI and can travel at least 96km, up to a maximum of £16,000 for 10 vehicles purchased per customer [16].

In London, to help clean up the heavy vehicle fleet, the van scrappage and retrofit scheme already in place has been extended to small businesses operating heavy vehicles in late 2020. Due to unprecedented demand TfL has suspended before spring 2021 the heavy vehicle scheme which consisted of a grant of around £15,000 for each polluting heavy vehicle, up to a maximum of three vehicles. [17]

Examples / case studies / Best practice

Hydrogen Fleet - Aberdeen

Aberdeen has pioneered the deployment of hydrogen for light and heavy duty vehicles with the following vehicles and infrastructure deployed in the city: Europe’s largest hydrogen bus fleet, two hydrogen refuelling stations at Kittybrewster and ACHES, Co-wheels have Toyota Mirai available as car club vehicles, and there is a wide range of council owned fuel cell vehicles including cars, 16t street sweepers, and 26t refuse collection vehicles.

LEFT (Low Emission Freight & Logistics Trials) programme – UK

Over £32 million of public and private investment were delivered by the LEFT programme which supported industry-led trials and laboratory-based tests to develop low and zero emission technologies for UK commercial vehicle operators. A number of projects were funded to test the alternative fuels technologies’ performance.

2.1.2. Taxis

The key background trend of taxis is that it follows general electrification of private car fleet; in most cases taxis share both the vehicle specifications and the charging infrastructure with private cars and are expected to follow the same charging patterns, which are heavily dependent on home-based charging with frequent top-ups in public recharging infrastructure.

The future taxi fleet has initially been backed by the uptake of hybrid vehicles, with mixed fossil fuel and electric battery. In several cities across Europe, such as Berlin, London, Oslo, Paris and Rotterdam, the implementation of zero-emission and ultra-low emission zones, restricting the access for most polluting vehicles to city centres and in some cases such as Rotterdam, banning vehicles that emit carbon, has pushed the uptake of electric taxis fleets and ride-hailing fleets [18].

Cenex has undertaken a high-level assessment of the Ultra Low Emission Vehicle (ULEV) options to highlight technologies that have the potential to deliver emissions savings across entire Taxi segment at an equivalent, or lower, total cost of ownership based on current UK availability and supplier maturity. The taxis segment is by far the most prepared vehicle type to make a steady change from fossil fuel to zero emissions given the technology is commercialised at scale (for most of the vehicles in this segment) and at competitive prices, as illustrated by the technology roadmap below (Figure 2-8).

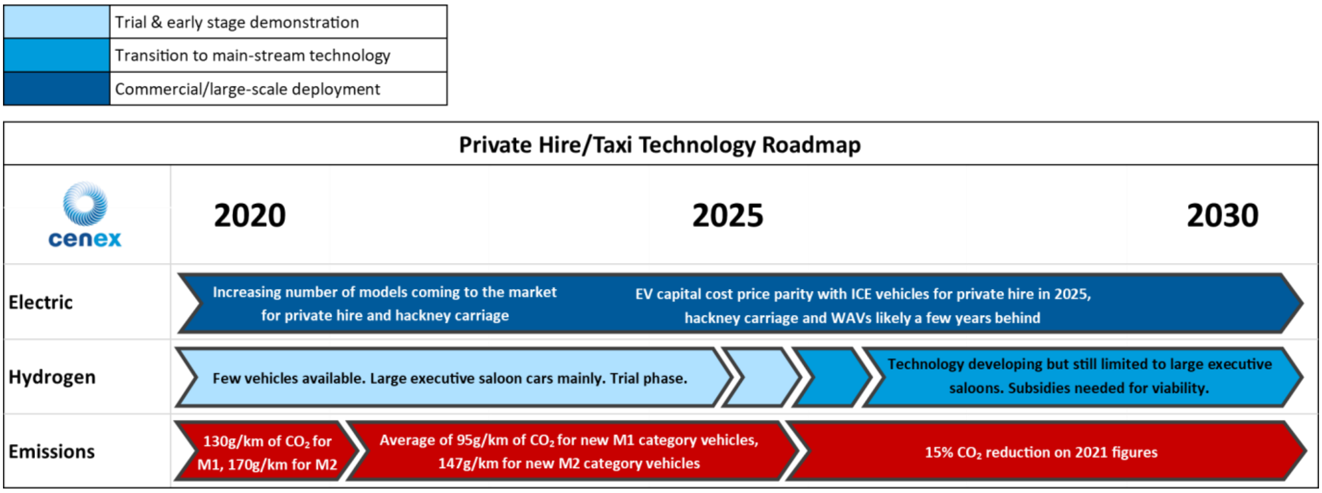


Figure 2-8 - Private hire/ taxi technology roadmap (source: Cenex)

Zero emission solutions

BEVs are available in all segments although in the Medium Passenger Van (MPV) and Medium Van (WAV) segments there is currently only one model available. Range Extender Electric Vehicles (REEVs) are available in the medium van segment only and Plug-in Hybrid Electric Vehicle (PHEVs) are available as potential replacements in the medium, large and executive car segments.

Hydrogen Fuel Cell Electric Vehicles (FCEVs) are available from Hyundai and Toyota in the medium and large car segments. FCEVs are currently uneconomical (due to the cost of vehicles and hydrogen fuel), additionally there is also a lack of viable hydrogen refuelling stations. To date, most deployments of FCEVs and hydrogen refuelling stations have been undertaken as part of publicly funded research and development projects.

As an example, as part of the Fuel Cells and Hydrogen Joint Undertaking funded Zero Emission Fleet Vehicles for European Rollout project (or ZEFER), Green Tomato Cars has deployed 50 Toyota Mirai FCEVs as private hire vehicles in London.

Cenex estimates that there are currently at least 50 ULEV models available to purchase in the UK that could potentially be used as taxi vehicles. This excludes variants of the same model with different battery capacities. Except for the large and executive car segments, there is an approximately equal split between BEVs and PHEVs.

Table 2-1 and Table 2-2 below show ULEV technology Red-Amber-Green (RAG) screening criteria and associated results.

Table 2-1 - Taxi ULEV technology RAG screening criteria (source: Cenex)

Green	High market maturity.
Amber	Low market maturity – known to be uneconomical, inadequate infrastructure.
Red	Not demonstrated or not available in the UK.

Table 2-2 - Taxi ULEV technology RAG assessment (source: Cenex)

Vehicle Type	Vehicle Segment (Rank of WTW CO_2e Emissions Contribution)	PHEV	REEV	BEV	FCEV
Cars	Medium (1)				Hyundai Nexo
	Large (2)				Toyota Mirai
	Executive (5)			SUVs only	
	MPV (3)	*		Nissan only	
Van Derived Vehicles (4)	Medium Passenger Van		Ford only		
	WAV		LEVC only	Dynamo only**	

* The only PHEVs available are the BMW 225xe and Mercedes-Benz B250e, both of which are premium models with a maximum of five seats. They are therefore unlikely to be suitable replacements for current vehicle models.

** Although there are numerous battery electric small and medium vans available (from Peugeot /Citroen/Vauxhall, Nissan, and Renault) there are few examples of type approved wheelchair conversions for these vehicles (see Brotherwood and Vic Young).

Table 2-3 below shows example vehicle specifications for relevant models, including indicative costs of currently available ULEVs. Prices include VAT and the plug-in grant where applicable (£3,000 for BEVs and £7,500 for purpose-built hackney carriage vehicles).

This information was gathered as part of the guidance prepared by Cenex in 2020 to provide advice to local authorities on the technological and commercial maturity of the ULEV taxi segment [19].

Table 2-3 - Taxi ULEV technology specifications and indictive costs (source: Cenex)

Vehicle Segment	ULEV Type	Licensed vehicles in the UK	Example Model (battery/engine capacity)	Price	Electric Only Range (miles)	Standard Charge Time (7 kW)	Rapid Charge Time (max)
Medium Car	BEV	42,000	Nissan Leaf (40 kWh)	£26,345	168	7h 30m	1h 00m
			Hyundai Kona (64 kWh)	£32,845	279	9h 35m	1h 15m
	PHEV	16,000	Toyota Prius PHEV (1.8L petrol, 8.8 kWh)	£31,695	23	2h 00m	NA
Large Car	BEV	16,000	Tesla Model 3 Standard (55 kWh)	£38,900	258	8h 00m	30m
	PHEV	24,000	Volkswagen Passat GTE (1.4L petrol, 13 kWh)	~£36,000	~34	~2h 00m	NA
Executive Car	BEV	16,000	Jaguar I-Pace (90kWh)	£60,995	292	13h 00m	1h 30m
	PHEV	17,000	Mercedes-Benz E-Class (2L petrol/diesel, 13.5 kWh)	£47,700	31	1h 15m	NA
Medium MPV	BEV	500	Nissan eNV200 (40 kWh)	£29,255	124	7h 30m	45m
	PHEV	5,000	BMW 225xe (1.5L petrol, 7.6 kWh)	£35,125	22	2h 00m	NA
Medium Van (8-seater)	BEV	-	Peugeot e-Traveller (50kWh)	~£46,000	143	~7h 30m	30m
	REEV	10	Ford Tourneo Custom PHEV (1.0L petrol, 13.6 kWh)	£48,500	33	2h 00m	NA
Hackney Carriage Vehicle	BEV	-	Dynamo Nissan eNV200 (40 kWh)	£45,500	124	7h 30m	45m
	REEV	4,000	LEVC TX (1.5L petrol, 31 kWh)	£55,599	62	3h 45m	30m

Funding sources

The OLEV grant will pay for 20% of the purchase price for electrical-powered hackney carriage taxis that can travel at least 112km (70 miles) without any emissions at all, up to a maximum of £7,500. For non-hackney carriage vehicles, the maximum grant is £3,000 for BEVs.

Examples / case studies / Best practice

Dundee - Charging hubs and ULEV Taxis

Dundee is one of the UK Government-supported Go Ultra Low Cities and has introduced three rapid charging hubs with priority access granted to taxis. In some cases, hubs are supported by solar canopies and battery storage to help mitigate peak power demand. Over 18% of the taxi and private hire fleet are already electric, equal to over 100 vehicles, and the fleet are able to access a low-cost charging fee specifically for taxis at £0.15 per kWh.

Cambridge - ULEV Taxis

Cambridge has some of the strongest policies surrounding low emission taxis in the UK, introduced in April 2018. All saloon vehicles must be ultra-low emission vehicles (ULEVs) or zero emission vehicles (ZEVs) from the 1st of April 2020. By 2028 all licensed saloon vehicles and wheelchair accessible vehicles (WAVs) must be ULEV or ZEV. In 2029 only ULEV or ZEV licensed vehicles will be able to enter the city centre.

2.1.3. Buses

Bus services have a dual role in the decarbonisation of transport. As well as changing to zero emission fleets, removing direct carbon from their operations, more attractive bus services also offer the chance to encourage modal shift from the private car, thereby reducing car trips on the network and hence emissions. As part of wider sustainable and active travel messaging, bus companies are using this wider decarbonisation as positive benefits for transferring even a small number of trips to bus.

For the more direct fleet aspects, key considerations for future fleet are:

- Route length
- Duty type (local bus, inter-urban, schools)
- Vehicle type (bus, Goldline coach etc)
- Fuelling infrastructure constraints at depots

Two technologies are being followed for the decarbonisation of global bus fleets:

- Battery electric
- Hydrogen

The nature of road-based public transport operations means that different types of service place differing demands on their vehicles, with the result that two technologies satisfy the requirements of distinct markets.

For the most part, urban and semi-urban scheduled bus services are able to use battery electric vehicles. Overnight charging in the depot provides sufficient power for approximately 220-280km dependent primarily on weather conditions. Scheduled local services and urban operations provide better opportunity for regenerative braking to feed power back into the batteries, extending range.

For longer-distance express services, hydrogen may be better suited, although this may change as battery technology develops. Two electric coaches are on trial in Scotland, on an express service between Dundee and Edinburgh with only a handful of intermediate stops. Rapid chargers are provided at Dundee to recharge the vehicles between trips.

Zero emission solutions

Battery electric

Battery electric costs are lower than hydrogen (the typical cost for a 10m bus with 350kWh battery is £340,000 compared to £160,000 for a diesel or ~£400,000 for hydrogen). Double deck bus comparisons are 380kWh battery £450,000, compared to £250,000 diesel or £500,000+ for hydrogen.

Most electric buses in service in the UK or on order make use of overnight charging in the depot. A limited number of opportunity-charged vehicles are now in service, principally in Harrogate, North Yorkshire, for local services around the town and at Birmingham Airport on car park shuttle duties.

Hydrogen

The number of hydrogen buses in Europe is estimated to be 1000 by 2024, in line with a progressive decrease in the vehicle costs but also with the expectation of a reduction of hydrogen fuel costs as a result of the predicted greater uptake of this fuel for transport in the next decade. Currently the costs of hydrogen vary between 8 and 10 pounds per kg and it is expected during the next 5 to 7 years to reduce to as low as 6 pounds per kg. The costs of the fuel are highly related to the complexity of hydrogen production facilities which at the moment are still developed on a bespoke basis as there is not a “model” to install and procure a hydrogen facility.

The EU’s CoacHyfied project is currently investigating hydrogen fuel cell electric power for coaches, including exploring ways to increase hydrogen fuel efficiency, including novel ways of harnessing waste heat from the fuel cell to power saloon air-conditioning. The CoacHyfied project is examining options for both new-build hydrogen coaches, as well as developing retro-fit options for existing vehicles, with the aim of extending the life of vehicles and so reducing scrappage and residual value issues for mid-life fleets.

The greatest advantage of Hydrogen vehicles is the storage potential which is greater than electric batteries. At present, hydrogen refuels in a few minutes vs 5-8 h for electric buses. It is expected that in the next decades (10-20 years) this barrier will disappear, and recharging batteries will be achieved in a matter of minutes. On buses in particular Hydrogen technology is currently filling the gap where electricity cannot provide the range and power required for longer distance and premium services.

In terms of maintenance costs of zero emissions buses, these are around 40% lower for electric than diesel. Hydrogen maintenance costs are still comparable to diesel costs, but it is expected that in the next decade these costs will reduce considerably with the volume growth in hydrogen buses and technology progress.

Several bus operators across the UK have already made commitments to end the purchase of diesel buses in 2021 (National Express) and become 100% zero emissions by 2035 (Stagecoach and First).

Funding sources

In 2017 a £23 million programme was launched by the Office for Zero Emission Vehicles, which is looking at funding vehicles and refuelling stations, which complements the ultra-low emission bus scheme for hydrogen buses, along with the Prime Minister’s commitment for 4,000 new zero-emission buses [20]

In March 2018, the UK Government launched the £48 million Ultra-Low Emission Bus Scheme which provided funding to 19 local authorities and bus operators to support the purchase of 263 zero emission buses. [21]

A series of Clean Bus Technology Fund and Clean Air Funds have awarded significant funding to local authorities to retrofit buses to Euro VI standard to help meet local air quality targets across the UK. [21]

Examples / case studies / Best practices

Scottish Ultra Low Emission Bus Scheme

The Scottish Ultra Low Emission Bus Scheme is a challenge fund open to bus operators, local authorities and regional transport partnerships. It provides grants for up to 80% of the price differential of a new zero-carbon bus compared to a diesel equivalent. The scheme is providing over £50 million of funding, resulting in over 270 zero-carbon emission buses joining the Scottish fleet at a cost to the exchequer of approximately £180,000 per bus. [22]

Scottish Green Bus Fund

The Scottish Green Bus Fund is a challenge fund open to bus operators, local authorities and regional transport partnerships. It provides grants for up to 80% of the price differential of a new low-carbon bus compared to a diesel equivalent. The scheme has provided over £16 million of funding, resulting in over 360 low-carbon emission buses joining the Scottish fleet at a cost to the exchequer of approximately £40,000 per bus. [23]

Nottingham Workplace Parking Levy

This is a levy scheme where all employers who provide 11 or more workplace parking spaces contribute with an annual charge of £415. In 2015/16 the Nottingham Workplace Parking Levy raised £9.3 million which has been invested in a major set of improvements to public transport, including the second phase of the city's tram network and subsidy of the electrification of some shuttle bus services. The operational cost of running the scheme is minimal and corresponds to no more than 5% of the revenue generated. [24]

2.1.4. Rail

General case for decarbonising the railway

Rail, as a mass transport solution, already has relatively low carbon emissions per passenger km, and one of the lowest in transportation [25]. This situation is further improved where the network is electrified. The image below (Figure 2-9) shows how much of Britain's railway is already electrified. [26]

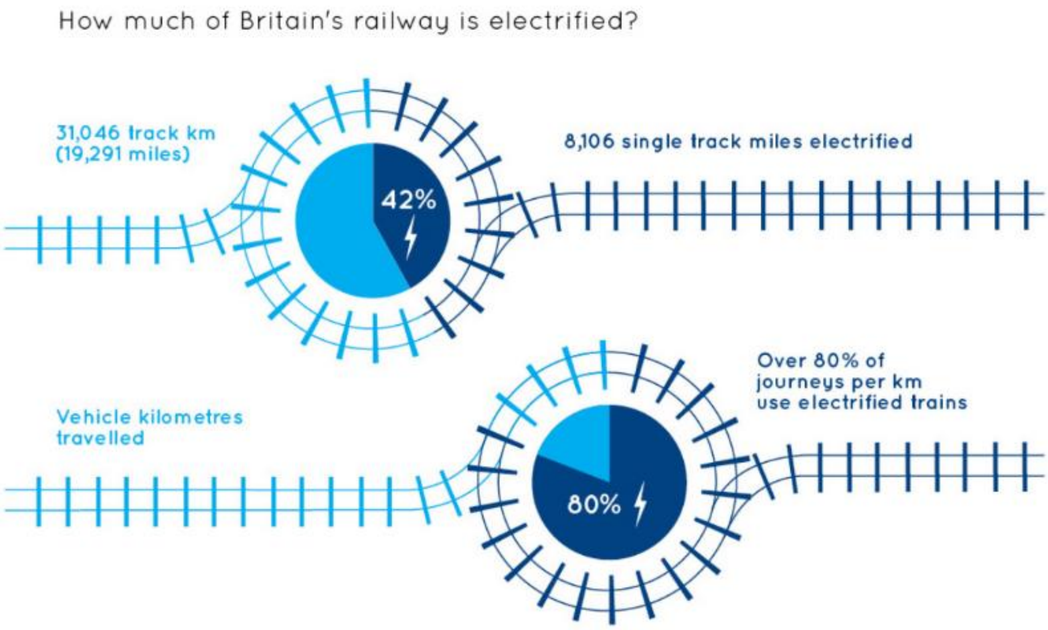


Figure 2-9 - Britain's railway electrification proportion (source: [26])

Nevertheless, the UK Government has set out an ambition to achieve "all diesel only trains off the track by 2040", and the Scottish Government has set out a commitment to "decarbonise Scotland's passenger rail services by 2035".

> Given that rail already has a low carbon impact, it has a key role to play in decarbonising the wider transport system, as mode shift of passenger or freight journeys where appropriate from road to rail will result in lower emissions within the transport sector. To maximise the opportunity for mode shift, a review of the rail network and timetable may identify options for improvement.

Technology options

Traction forms around two-thirds of greenhouse gas emissions on the UK railway [27]. Options for decarbonising rail traction are:

- Electric traction
- Battery-powered traction
- Hydrogen-powered traction
- Traction combinations (bi-mode)

It is generally recognised that the preference is to electrify where possible, largely due to the energy efficient nature of electrification over other options [28] [29]. Furthermore, electrification has the additional benefit of enabling higher performing traction than the existing diesel rolling stock, with the potential for journey time improvements and additional capacity as a result. However, despite some drawbacks, battery and hydrogen trains are feasible options, particularly where passenger and freight demand are low and therefore the business case for electrification may be challenging, or where a transition towards longer-term electrification is required.

A "top down, bottom up" approach has been identified by RSSB's Decarbonisation Taskforce and followed by Network Rail in the Traction Decarbonisation Network Strategy (TDNS), presented in Figure 2-10. This works "top down" for obvious electrification candidates, and bottom-up for obvious alternative traction, and aims to squeeze the sub-optimal options.

Figure 2-10 - Top down, bottom up approach to rail electrification and traction mode by RSSB's Decarbonisation Taskforce and Network Rail (source: [26])

The infrastructure required for electrification involves overhead line equipment (OLE) installation, which can present particular challenges at structures. Cost efficiencies can be achieved when delivering a rolling programme of electrification at scale and pace, with intentions in the UK to reduce the cost per single track kilometre (STK) from ~£2.5m/STK to ~£1m/STK [30].

Battery-electric trains operate within range constraints before re-charge. It can be feasible to re-charge at a station or depot, or while running "under the wires" in the case of discontinuous electrification. The infrastructure for battery-electric trains is less substantial than electric traction, however the range constraints, and the space required on train for the battery and the increased weight of the train lead to operational considerations and reduced top speed. Market conditions in 2019 suggested a range of 60-80km on battery power and a realistic top speed of 75-100mph, however manufacturers are working to improve these characteristics.

Hydrogen trains also have space, weight and speed considerations. Market conditions in 2019 suggested a range of around 1000km and a top speed of 90-100mph, however the storage facilities required on the train are in the region of 8 times that for diesel. Refuelling would be required roughly every 24 hours at a specific location.

Both battery and hydrogen characteristics are particularly challenging for freight and it is considered that bi-mode options would be necessary. Furthermore, electrification is likely to be the most appropriate option for lines that run at 100mph or faster, with heavy passenger demand or freight requirements.

Examples / case studies / Best practices

Network Rail (England, Scotland, Wales)

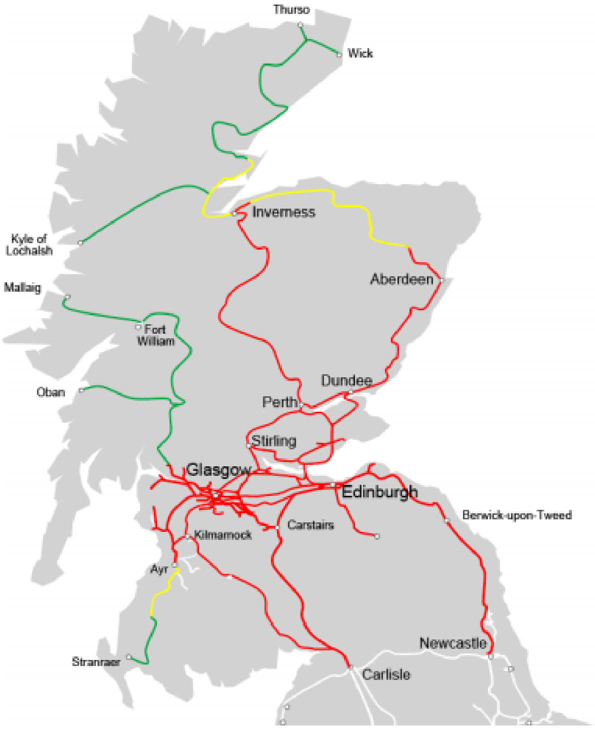
Network Rail's Traction Decarbonisation Network Strategy (TDNS) summarises that of the 15,400 single track kilometres (STKs) that are currently unelectrified, 13,000 STKs should be electrified, 1,300 STKs should have hydrogen train deployment, 800 STKs should have battery train deployment and 300 STKs are undefined as yet.

Scotland's Railway

More specifically, we can consider Scotland as a relevant case study in terms of policy, strategy and implementation. Scotland's 2019 Programme for Government [31] set out the goal to decarbonise the passenger railway in Scotland by 2035. A wide suite of recent government policy documents align with the overall aim; including the Climate Change Plan Update 2020, the Infrastructure Investment Plan 2020, and the National Transport Strategy 2 2020, and decarbonising the railway is referred to wherever appropriate throughout these documents [32] [33] [34]

The Rail Services Decarbonisation Action Plan [35] sets out the anticipated routes for electrification, battery trains and alternative traction by 2035 as shown in the image below (Figure 2-11).

The plan: our decarbonised rail network in Scotland, 2035



Map of decarbonised rail network in Scotland, 2035

The maps in this document show the rail network in Scotland; as there are no rail lines on the islands they are not shown.

- Electrified network (some 1,616 kilometres (single track kilometres) to be electrified, sections of route could potentially include discontinuous electrification) and the electrification of some freight only lines may be subject to review
- Alternative traction - transition solution (e.g. partial electrification and/or the use of alternative technology prior to electrification)
- Alternative traction - permanent solution (i.e. the use of battery or alternative traction)

Figure 2-11 - Scotland rail network decarbonisation plan (source: [35])

While there are some lines which are clearly marked as “alternative traction”, either as a transition or as permanent solution, the majority of the network is anticipated to be electrified by 2035. Development work on the strategy towards delivering that outcome is ongoing, and necessarily considers the interdependencies both within the rail network and with the energy sector.

A number of specific government policies and commitments are in place surrounding the net-zero target, most notably:

- A “hydrogen demonstrator” train is currently being converted to understand the required specification and operational aspects in relation to the Scottish rail network, and to build knowledge and experience of the requirements within Scotland’s industry. This is a collaboration between Transport Scotland (with Atkins as technical advisor), Scottish Enterprise and St Andrews University.

- An international rail cluster has been set up to unlock supply chain opportunities.

- £7m funding commitment for zero emission mobility innovation, focusing on rail and HGVs.

- 20% reduction in passenger car kilometres by 2030 (while not stated explicitly, mode shift from road to rail would be one part of achieving that reduction, alongside reducing the need to travel).

Existing funding for rail enhancements is now reported with decarbonisation as an element stated clearly, and the recent Strategic Transport Projects Review 2 Phase 1 stipulates the immediate priorities while setting out the way forward over the longer timeframe.

The combination of the policy directives and action plan has led to a fully engaged railway industry in Scotland, which is actively planning and innovating collaboratively to ensure the best possible chance of achieving a net-zero outcome.

While the approach is not yet finalised, the industry is collaborating on possible scenarios, drawing information from the train operating company, the network owner and maintainer, and the National Grid as appropriate.

2.2. Distribution Infrastructure for Alternative Fuels

2.2.1. Electricity

The UK and other countries have adopted Nationally Determined Contributions (NDC) under the Paris 2015 Agreement to the United Nations Framework Convention on Climate Change. The NDC commits the UK to reducing economy-wide greenhouse gas emissions by at least 68% by 2030 and 78% by 2035, compared to 1990 levels [36]. As part of this, the UK government aims to generate emission-free electricity by 2050, with a trajectory that will see overwhelmingly decarbonised power in the 2030s.

In the UK electricity is distributed via the National Grid infrastructure. Electricity at high voltages (400kV) is transmitted from generators to distribution companies. The electricity is then distributed to most customers at lower voltages (minimum of 11kV). Electricity interconnectors also exist, which provide the physical links to enable electricity to be transferred across borders.

Alongside the direct use of electricity for the rollout of electric vehicles (EV), electricity is also used indirectly for hydrogen production via electrolysis. These technologies will increase the demand for electricity on the grid. In the UK, it is estimated that the peak demand of around 100GW today will increase to 150GW by 2050 [37]. **See Section 2.3.1** for policy on increase in electricity production.

The UK aims to increase interconnector capacity from 4GW [2] to 18GW [3] by 2030 to enhance the flexibility of the UK's energy system. In addition, England's Strategic Road Network will invest £950m to future-proof grid capacity at motorway and major A-road service areas [3].

Electricity demand can also be managed by 'smart charging' where EVs can be charged at times of low demand and low electricity prices. 'Vehicle to Grid' concepts could allow EVs batteries to offer grid flexibility and demand shifting services.

Within the European Union, the 'Recharge and Refuel' project under the £580bn Recovery and Resilience Facility (RRF) aims to build 1m charging points by 2025 (of the 3m needed by 2030 [38]). The UK Government has committed investment of £1.9bn in its November 2020 spending review for charging infrastructure and consumer incentives across the UK [39].

2.2.1.1. EV charging infrastructure

The EV infrastructure required is highly dependent on vehicle duty and specific to the vehicle type that needs to be charged. Below, we present a set of solutions suitable for each vehicle type and a compilation of relevant case studies of EV charging alternatives deployed in the UK.

Rail: electrification

The two voltage options for electrification are 25kV AC and 1500V DC, where 25kV AC is generally seen as the standard OLE power type and 1500V DC is more commonly used for tram/train type operations. Electrification infrastructure are Overhead Line Equipment (OLE) or Third Rail. However, on mainland Britain there is a presumption against new build Third Rail [40] due to safety concerns that would need to be resolved, and therefore we assumed that new electrification in Northern Ireland would most likely involve OLE. Electric traction vehicles would therefore draw power directly from the wires, whereas battery-electric bi-mode traction would draw power from the wires where available and be self-powered where not.

Buses: EV rapid charging at depot; pantograph charging at bus stops

Average cost of infrastructure:

For depot charging typical costs for a 50kW rapid charge point are between £25,000 and £35,000 including capital cost and civils. This does not include any possible upgrades to the substations that may be required if the capacity to the site is insufficient to serve these charge points. It is likely, if multiple charge points are installed at a depot, that upgrades will be required.

Pantograph charging can incur significant costs with capital costs ranging from £175,000 to £300,000 depending on the speed of charging (upwards from 150kW). This does not include ground works or civil costs and upgrades to substations will most likely be required to serve these charge points.

Taxis: rapid charging; home charging; Dynamic wireless electric charging[4]

For taxis, the main characteristics of the duty cycle are that they are partially spent on standby/waiting mode. This allows for the opportunity of using static wireless electric charging while waiting in queue at the taxi rank. Without having a physical connection to the grid, this charging option allows for a taxi to partially recharge its battery while moving along the taxi rank, before picking up the next customer. On the other hand, most of the taxi drivers operate on an own-drive model and return with the vehicle to their home, where they can recharge their vehicle in between shifts. Since 2017 several rounds of the Ultra-Low Emission Taxi Infrastructure Scheme competition funding have been completed to fund local authorities in obtaining low emission taxis charge points [41]. Through the Electric Vehicle Home charge Scheme taxi owners can also get up to £350 (including VAT) off the cost of installing a charger at home.

Average cost of infrastructure:

For a 50kW rapid charge point that will typically be used for taxis the average capital cost, including cost of ground works and civils, is around £25,000. This does not include any possible upgrades to the substations that may be required if the capacity to the site is insufficient to serve these charge points. This cost has been taken from costs acquired from three separate suppliers and averaged.

HGVs: EV ultra-rapid chargers and ERS.

The estimated number of public ultra-rapid chargers needed to serve electric powered HGVs is assumed to be relatively low in the next decade due to the battery sizes for heavy duties vehicles still being an area in early research and the current range capacity limited to fulfil the duty cycle of rigid HGVs.

ERS infrastructure is an alternative to be considered for long-distance/ HGV corridors, but installation is likely to be more disruptive due to the need for road closures and there will be a need for increased planning time compared with ultra-rapid chargers. However, operational capability has been extensively proven for ERS in geographies such as Germany and Sweden since 2017 [42]. Therefore, the build rate capability is thought to be above the 274km/year peak that was estimated as necessary in the ERS scenario.

[4] Dynamic wireless electric charging examples: Dynacov (Coventry); WiCET (Nottingham) presented later in this section

The catenary cables, powered by the national electricity grid, would link to lorries driving in the inside lanes on 4,300 miles (7,000km) of UK roads through an extendable rig known as a pantograph – similar to those on the top of electric trains. The electricity would power the lorry's electric motor, as well as recharging an onboard electric battery that would power them to their destinations beyond the electrified roads. [43]

Average cost of infrastructure:

The Centre for Sustainable Road Freight (CSRF) proposes a challenging investment plan to build a 'UK Electric Motorway System' in a 3-phase rollout, each lasting 2 – 3 years. According to the specialists' estimates, this could be entirely self-sustaining and could pay back in 15 years using the profit margin on electricity sales to vehicles. The total cost to deploy the final ERS infrastructure network is estimated to be £19.3 billion and covers approximately 65% of all the HGV-kms in the UK. (**Figure 2-12).**

The ERS infrastructure investment can also be partially shared with other investments such as motorway service and charging stations for other vehicles, the 5G network and the intelligent transport system (ITS) infrastructure needed to support connected and autonomous vehicles (CAVs) of the future. [42].

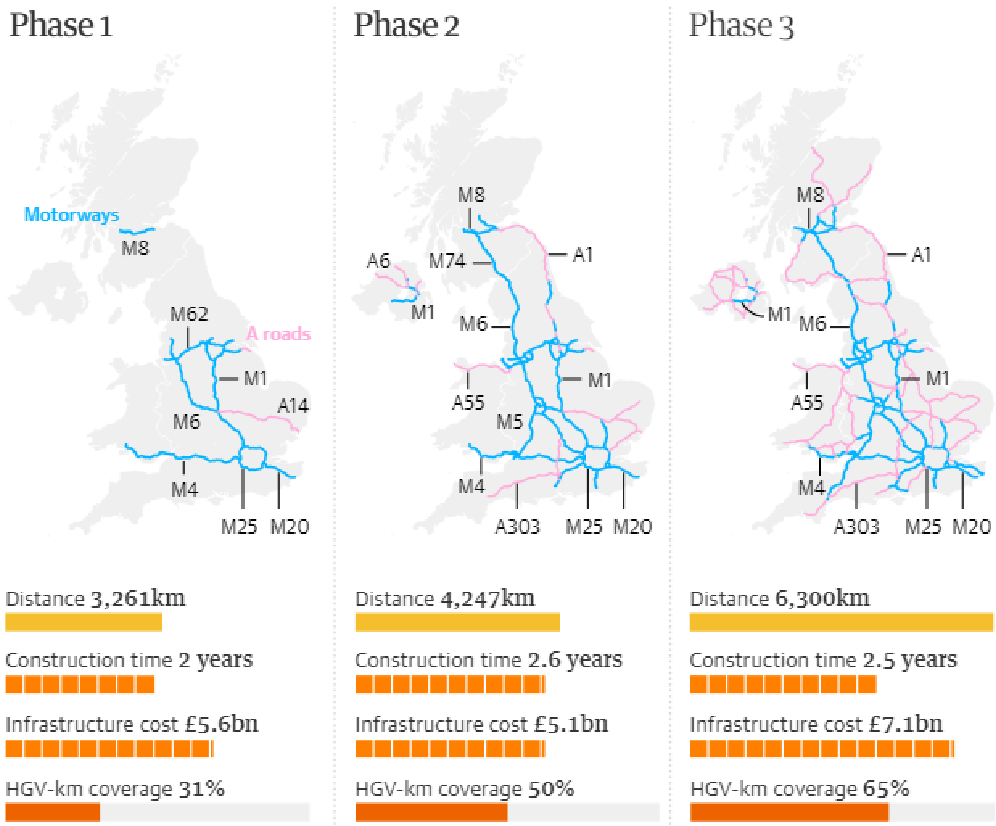


Figure 2-12 - Illustrative example of the a three-phased proposed rollout of the 'UK Electric Motorway System' [42]. Graphic source: The Guardian

Examples / Case studies / Best practice

Dynamic Wireless Charging - Coventry

DynaCoV is a research and development project based in Coventry, funded by Western Power Distribution through their Network Innovation Allowance (NIA) budget. DynaCoV is led by Coventry City Council, alongside key delivery partners Cenex and Coventry University. The project will deliver a feasibility study looking at dynamic wireless charging. This technology uses equipment installed underneath road surfaces to enable electric vehicles to recharge as they drive. [44]

Static Wireless Charging - Nottingham

Nottingham and Cenex are involved in the WiCET project, assessing the potential for deploying wireless charging infrastructure for electric taxis. The project will develop charging infrastructure, integrate wireless chargers with vehicle and road infrastructure, deliver future policy recommendations and safety observations, and engage with stakeholders to assess the financial viability of the technology. [45]

Charging hubs and ULEV Taxis - Dundee

Dundee is one of the UK Government-supported Go Ultra Low Cities and has introduced three rapid charging hubs with priority access granted to taxis. In some cases, hubs are supported by solar canopies and battery storage to help mitigate peak power demand. Over 18% of the taxi and private hire fleet are already electric, equal to over 100 vehicles, and the fleet are able to access a low-cost charging fee specifically for taxis at £0.15 per kWh.

2.2.2. Hydrogen

Hydrogen can be blended into the national gas distribution grid (up to 20% by volume is possible without major modifications, e.g. Keele University HyDeploy project [46]. The UK Government intends to have completed testing to allow the 20% by volume blend in the gas distribution grid by 2023 [47]. However, gas mixtures are unsuitable for use in the transportation sector due to the high purity of hydrogen required. Hydrogen can also be used as a 100% clean gas grid, in ‘island’ or closed network mode, for example the Keele University demonstrator [46], or H21 projects [48].

High quality hydrogen gas has been transported by pipeline since 1938. IGEM (Institute of Gas Engineers and Managers) is producing guidelines for local distribution of hydrogen by pipeline [25]. Today, Germany, France, Belgium and the Netherlands each have several hundred kilometres of hydrogen pipelines. The U.S.A. has over 2,600 km of hydrogen pipelines [25].

Hydrogen can be stored and transported in tube trailers, compressed as a gas to high pressures. It can also be transported by tank cars as a liquid (stored at -252 Celsius degrees). In the U.S.A., liquid hydrogen is also moved in bulk by rail in tanks [25].

Localised production of hydrogen at transportation hubs mitigates the need for distribution networks. This reduces losses through leakage and avoids the need for additional compression / pressure let-down which uses more energy and reduces the energy efficiency lifecycle of the process.

Taking Germany as a reference, the current operational network consists of 91 Hydrogen Refuelling Stations (HRS), most of which are partially suitable for trucks. The Fraunhofer Institute for Systems and Innovation estimates that an HRS truck dedicated network should reach 140 stations by 2050. [49]

2.2.2.1. Hydrogen refuelling infrastructure

The hydrogen refuelling infrastructure sector is still in its infancy; there are currently 12 publicly available HRS in the UK. At present there is a small-scale facility to produce hydrogen by electrolysis at one of Energia’s wind farms in North Antrim. A recent announcement has been made on the deployment of a large Hydrogen refuelling station in Belfast to serve Translink public transport operator amongst others.

The first HRSs in the UK tended to be stand-alone stations deployed in locations tied to specific funded projects. The future pathway to mass-market deployment means that increasingly HRSs may be either: integrated with conventional refuelling stations or alternative fuel refuelling hubs in the UK, such as the HRS recently installed by ITM Power in Shell refuelling stations at Cobham and Gatwick; or associated with large-scale fleet deployment and renewable energy projects such as the Tyseley Energy Park.

As the delivery of HRS is still in its relative infancy, timescales for completing this infrastructure can vary significantly. A large HRS (750 kg/day+) can take 6 to 18 months, depending on whether the site generates its own hydrogen or is provided with an external supply (on-site generation will take longer to implement).

Hydrogen refuelling points will be shared by all road vehicle modes.

Average cost of infrastructure:

HRS costs are currently high, as each station is essentially a bespoke design. However, costs are falling as more stations are deployed and as manufacturers begin to produce components at larger scale.

As an indication, an 800 kg/day capacity hydrogen station would cost approximately £3.7 million to construct, with an annual operating cost of £750,000. Over a 10-year period, assuming an average utilisation of 37% (based off Cenex's previous R&D projects), an average annual income of £1,100,000 can be expected. As the average utilisation of the station scales with time, i.e., utilisation rates are expected to increase in the future, the payback period of this station would be 12 years.

The payback period is highly sensitive to the station utilisation meaning that, if there is a lack of demand from fleet operators, it is possible that the station will never recover the capital cost invested.

Examples / Case studies / Best practice

Hydrogen and Gas Refuelling - Tyseley

Tyseley Energy Park (TEP) is home to the UK's first multi fuel, open access, low and zero carbon fuel refuelling station and is open for business.

The refuelling station at TEP is the result of a 5-year collaboration between the private and public sector and see TEP able to refuel hydrogen, compressed natural gas, biodiesel, and electric vehicles, both commercial and private. The refuelling station is commissioned and ready to receive commercial fleet, public transport fleet and private vehicles. The unmanned facility is available 24/7 for refuelling with integrated pay at pump options that accept credit, debit, and fuel card payments. [50]

2.2.3. Biomethane

Biomethane is a renewable form of natural gas, which is distributed via gas transmission and distribution networks across the UK and Europe. Biomethane is chemically indistinguishable from fossil fuel-based natural gas and can be injected into the gas distribution network alongside conventional natural gas. To provide certainty that the natural gas is renewably sourced, 'Guarantee of Origin' schemes operate across Europe. In the UK, the Green Gas Certification Scheme (GGCS) issuing Renewable Guarantees of Origin (RGGO) and the Biomethane Certificate Scheme (BMCS) issuing Biomethane Certificates (BMC) operate. These schemes track the contractual rather than physical flows of biomethane. When consumers buy biomethane, the certificates guarantee that the gas is renewable and has not been sold to anyone else.

In contrast to fossil fuel-based natural gas, biomethane can be considered close to carbon-neutral as it releases the same amount of carbon dioxide that the organic matter used to produce it absorbed while it grew. However, fugitive emissions can increase the carbon footprint.

Biomethane can be used as a vehicle fuel upon conversion to compress biomethane (bio-CNG) or liquefied biomethane (bio-LNG). The industry designation of bio-CNG effectively corresponds to Compressed Biomethane Gas (CBG); similarly, bio-LNG corresponds to Liquid Biomethane (LBM)[5]. In order to obtain Bio-CNG / LNG, the biomethane used has to be 100% sourced from food or agricultural waste, or another non-fossil-based source, and approved by the Department for Transport's Renewable Transport Fuel Obligation (RTFO). [15].

CNG distribution infrastructure costs are low as the existing gas distribution network infrastructure across the UK and Europe is used to transport the gas to suitable refuelling stations, where biomethane is compressed to CNG.

[5] The nomenclature bio-LNG and LBM, and bio-CNG and CBM can be used interchangeably as they both identify respectively, Liquified Biomethane and Compressed Biomethane

LNG production capacity is limited in Europe and does not exist in the UK. LNG demand is met by import services at coastal LNG terminals. LNG is delivered to refilling stations via tanker, which typically require large cryogenic storage and incur installation costs of £100k-£500k [51] depending on the capacity of the station. Lack of biomethane availability may present the greatest challenge to distribution (as articulated in **Section 2.3.3.)**

2.2.3.1. Biomethane refuelling infrastructure

Biomethane refuelling stations can be categorised into three types, depending on the product(s) they provide. [15]:

- Bio-CNG stations can be grid connected or have gas delivered by a gas cylinder tanker.
- Bio-LNG stations consist of a cryogenic tank and a fuel dispenser.
- Liquefied to Compressed Biogas (LCBG) stations supply both bio-CNG and bio-LNG. Bio-LNG is vaporised and compressed into storage tanks to add compressed gas functionality to the station. A sophisticated Liquefied to compressed Biogas (LCBG) station may also utilise any 'boil off' from the bio-LNG tank to compress into bio-CNG.

Biomethane is mainly suitable for large duty vehicles, namely HGVs and potentially Buses. HGV fleet operators can install refuelling infrastructure at their depot, as is the case of the company Kuehne+Nagel which has installed an LBM refuelling station at its depot. The capital costs of depot refuelling stations can be recovered through lower fuel operating costs. Alternatively, fleet operations can refuel at a public access refuelling stations, as is the case of John Lewis Partnership, which refuelled its vehicles at CNG Fuels station in Leyland and Northamptonshire, alongside other logistics providers such as Argos, and Hermes. Refuelling with biomethane is straightforward and takes approximately the same time as filling up a diesel vehicle tank.

Average cost of infrastructure

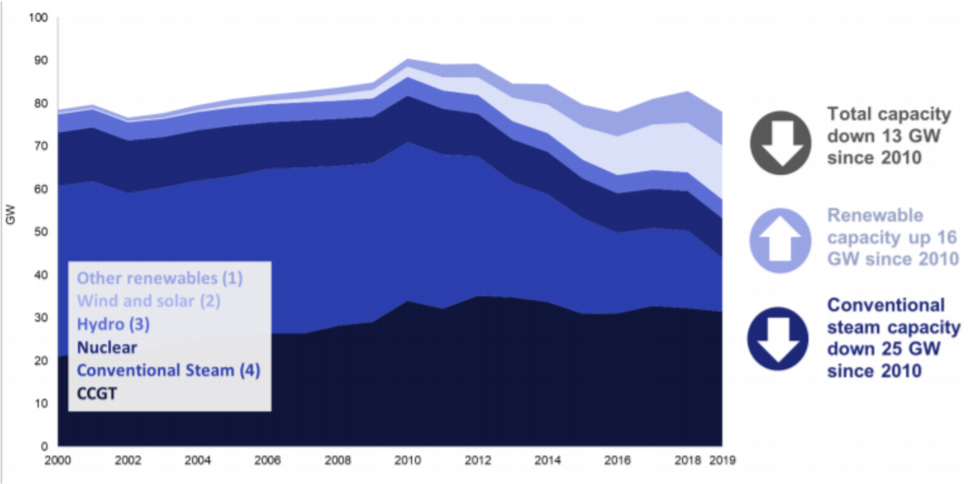
CNG refilling stations can range from £200k-£1.4m [52] [53] depending on the capacity of the station.

LNG is delivered to refilling stations via tanker, which typically require large cryogenic storage and incur installation costs of £100k-£500k.

2.3. Production and Storage of Alternative Fuels

2.3.1. Electricity

The UK government targets require the electricity system to grow and double in size by 2050 to meet the demand for low-carbon electricity. The UK Government plans to quadruple offshore wind capacity to provide renewable electricity into the National Grid (circa 40GW of electricity) by 2030. The UK Government believes this target will encourage £20bn of private investment into the UK and will invest £160m into ports and manufacturing for offshore wind turbines. Additionally, the UK is investing in the nuclear industry with a 3.2GW nuclear power station due to open in 2026 [47]. The government intends to invest up to £385m in an Advanced Nuclear Fund and hopes to attract £300 million of private sector funding [47]. Half of GB power is now generated from low carbon sources, accounting for 66% of the UK emissions reduction.



1. *'Other renewables' includes bioenergy.*
2. *Wind included from 2007*
3. *'Hydro' includes natural flow and pumped storage.*
4. *'Conventional steam' includes a small proportion of non-CCGT plants, gas turbines and plants that can be fuelled by a combination of gas, coal and oil.*

Figure 2-13 - Change in UK Energy Supply driven by carbon price [54]

The European Union aims to be Net-Zero in terms of greenhouse gas emissions by 2050, as part of the Paris Agreement. Conventional power generation produces much of the electricity produced today but is also the source of a large proportion of greenhouse gas emissions, therefore countries in the EU are switching to renewable energy sources and nuclear power. Not all countries allow nuclear power and renewable sources of electricity do not provide a constant supply, requiring energy storage. There are various options for energy storage including batteries and pumped-storage hydropower. The International Energy Association estimates that the world needs 266 GW of energy storage, growing over the next decade [55].

2.3.2. Hydrogen

The UK Government has not yet published its Hydrogen Strategy but has a 10-point plan for a Green Industrial Revolution, which aims for 1 GW of hydrogen production capacity by 2025 and 5 GW of hydrogen production capacity by 2030 [47].

The Scottish government has published a Hydrogen Policy Statement to set out the role of hydrogen in Scotland's route to Net Zero. This is supported by three hydrogen and decarbonisation studies commissioned by the Scottish Government [56].

Hydrogen is produced by two main routes to meet the Net Zero ambition, 'green' hydrogen from electrolysis and 'blue' hydrogen from methane reforming with 'Carbon Capture and Storage' (CCS). Blue H_2 is typically produced at scale at industrial sites or at an offshore terminal where the CO_2 can be readily transported subsea to safe long-term storage. Green hydrogen is currently being piloted across many sectors using containerised electrolyser units. These are modular by design and typically small scale (<1MW) when used to fuel a transport fleet or supply a small scale 'closed network'. Both types of hydrogen production have individual strengths per application. Blue hydrogen is typically needed for 'at scale' production in the short term (e.g. Project Acorn [57] or Hynet [58]), offering lower cost per kg. Green hydrogen has strong demonstration applications in cities for refuelling or island grids e.g. Aberdeen bus project, Orkney Surf and Turf project and in Northern Ireland the GennComm project.

The European Union has set a strategic objective to install at least 6 GW of renewable hydrogen electrolysers producing up to 1m tonnes of green H_2 in the EU by 2024 and 40 GW producing 10m tonnes by 2030 [59].

The European Commission (EC) estimates that investment in electrolysers could range between €24 and €42 billion by 2030. In addition, €220-340bn would be required to connect renewable sources to electrolysers to provide the electricity and €65bn for hydrogen transport, distribution and storage, and hydrogen refuelling stations [59].

A move to a UK 'hydrogen economy' to meet Net Zero targets will require significant hydrogen storage. This can be done in several forms, dependent on application: line-pack, salt cavern storage, pressure vessels, chemical hydrogen carriers. In the UK, significant early feasibility work has been done on the available salt cavern storage assets at East Yorkshire, Cheshire, Teesside, and Islandmagee (NI). These offer large scale safe storage of hydrogen, and modelling has been completed to better understand the effect of cycling hydrogen; see ETI storage project results [60]).

Examples / Case studies / Best practice

Manchester - Carbon Capture and Storage (CCS)

The HyNet North West project is based in Manchester and is based on the production of hydrogen from natural gas. It includes the development of a new hydrogen pipeline; and the creation of the UK's first carbon capture and storage (CCS) infrastructure. CCS is a vital technology to achieve the widespread emissions savings needed to meet the 2050 carbon reduction targets [58].

Sheffield - Hydrogen Gigafactory

Sheffield is home to the ITM Power hydrogen Gigafactory. The factory is the largest electrolyser factory in the world with an annual capacity of 1,000 megawatts (1 gigawatt) with a workforce over 300 people.

Keele - Hydrogen in the Gas Grid

HyDeploy is a pioneering energy demonstration project at Keele to establish the potential for blending hydrogen, up to 20%, into the mains gas supply so that carbon dioxide (CO_2) emissions can be reduced. A 16-month live demonstration of blended gas on part of the Keele gas network finished in March 2021. HyDeploy will help to determine the volume of hydrogen which can be used by customers safely and with no changes to their domestic appliances [46].

2.3.3. Biomethane

Biomethane is typically produced from biogas via an anaerobic digestion (AD) processes which has been refined to remove carbon dioxide, water vapour and trace gases. Once upgraded to meet national gas industry standards, the biomethane can be injected into the gas distribution network alongside conventional natural gas. Biomethane can also be produced through biomass gasification. This process involves the burning of carbonaceous biomass materials, converting them into gas.

As of June 2020, 18 counties were producing biomethane in Europe. Germany has the most biomethane plants (232), followed by France (131) [61]. There are approximately 80 biomethane plants in Scotland, England, and Wales [61]. General support measures in the EU and UK include feed-in tariffs, tax reduction / exemption, purchase subsidies, dedicated refuelling infrastructure targets, and promotion of production and plant construction.

Biomethane storage will play an important role in ensuring that fluctuations in production and demand will not affect guarantee of supply. In the UK and Europe, underground storage (e.g. salt caverns) is used for natural gas. If the biomethane producer or the consumer is not connected to the grid, tube trailers/tankers may be used to transport and store the biomethane [62].

Costs for AD plants vary widely depending on the production capacity of the process. However, biomethane is generally more expensive to produce than fossil fuel based natural gas, with one source quoting a minimum premium of 19% over conventional natural gas [63].

3. Benchmarking Northern Ireland

Building on the findings of the literature review, we examined key publications relating to investment in and use of alternative fuels technology and infrastructure in Northern Ireland and Republic of Ireland.

We examined the existing policies that exert influence in NI from the UK (DfT, BEIS), NI (DfI, DfE), and other relevant industry institutions such as CCC.

In the following chapters we also provide an overview of the transport system as well an appreciation of the energy system in operation in Northern Ireland.

3.1. Northern Ireland – Transport and Distribution Infrastructure

The Climate Change Committee suggested a reduction of at least 82% in emissions by 2050 given Northern Ireland's economic reliance on agriculture [64].

Possible targets in Northern Ireland climate change legislation

	All greenhouse gases	CO_2 only	All GHGs excluding agricultural methane emissions	All GHGs excluding agricultural, land use and waste methane emissions
2030	48% reduction	56% reduction	53% reduction	52% reduction
Sixth Carbon Budget period (2033-2037)	60% reduction	70% reduction	67% reduction	67% reduction
2040	69% reduction	83% reduction	78% reduction	79% reduction
2050	82% reduction	Net zero	93% reduction	96% reduction

Source: Climate Change Commission.

Figure 3-1 - CCC suggested targets for Northern Ireland [23]

The NI Executive Climate Change Bill is being considered. This Bill led by the Department for Agriculture, Environment and Rural Affairs sets targets in line with CCC recommendations [64]

In parallel, on 22nd March 2021 the non-Executive/ Private Members brought a second Climate Change Bill [65] to establish the legally binding climate objective of having a net-zero carbon, climate resilient and environmentally sustainable economy by the year 2045. This includes achieving a net-zero transport sector by the same date. At the time of writing this report the Private Member's Bill has passed the second stage of consultation.

Northern Ireland does not currently have any official climate change targets, but since GHG from Northern Ireland contribute to the UK total under the 2008 Act, it has a key role to play in at least meeting the UK's obligations under the Paris Agreement. The new legislation, as mentioned above, once introduced will set NI specific goals.

With respect to specific measures to put in place to decarbonise the transport sector current UK government policy will have a significant impact in driving the decarbonisation of the transport market in Northern Ireland. In particular DfT's The Road to Zero [14] is a UK-wide strategy and includes measures that will apply to the whole of the UK.

3.1.1.1. HGVs

In order to provide an overview of the policies for decarbonising road and rail transport in Northern Ireland, the NI Assembly Infrastructure Committee has commissioned the paper "Decarbonising Transport in Northern Ireland"

[66] that covers UK policy framework, presents high-level policies to promote ultra-low emission vehicles and measures to incentivise the model shift. We explored the most relevant policy references highlighted by the research paper: DfT's "Road to Zero" [14] and Committee on Climate Change's "Reducing Emissions in Northern Ireland" [23].

The DfT's Road to Zero introduced in 2018 a voluntary industry-supported commitment to reduce HGV greenhouse gas (GHG) emissions by 15% by 2025, from 2015 levels. The government mission is for all new cars and vans to be effectively zero emission by 2040 and by 2050 nearly every light vehicle to be zero emission, allowing HGVs for some room to follow since the technology is not in the same commercially accessible point as for light vehicles. To achieve the government aspirations for low or zero emission road freight, the Road to Zero strategy sets out the following policy objectives:

- Launching a joint research project with HE to identify and assess zero emission technologies suitable for **HGV traffic** on the UK road network.
- Introducing a new voluntary industry-supported commitment to reduce **HGV** GHG emissions by 15% by 2025, from 2015 levels.
- Working with industry to develop an ultra-low emission standard for trucks.
- Supporting industry-led R&D projects, trialling of a range of low-emission technologies for freight, which are less developed than for cars and **vans**.
- Taking steps to accelerate the adoption of fuel-efficient motoring by company car drivers, **businesses operating fleets**, and private motorists.
- Continuing to offer grants for plug-in cars**, vans**, taxis and motorcycles until at least 2020. The plug-in car and van grants will be maintained at the current rates until at least October 2018. Consumer incentives in some form will continue to play a role beyond 2020.
- Ensuring that independent and robust information is available to **HGV operators** to enable them to identify relevant measures and technologies for improving their fuel efficiency and reducing emissions.
- Undertaking further emissions testing of the latest natural gas **HGVs** to gather evidence that will inform decisions on future government policy and support for natural gas as a potential near-term, lower emission fuel for **HGVs**.
- Extending the Clean Vehicle Retrofit Accreditation Scheme (CVRAS) beyond buses, coaches and **HGVs** to include **vans** and black cabs.
- Consulting on reforming Vehicle Excise Duty to incentivise **van drivers** to make the cleanest choices when purchasing a new **van**.
- Supporting investment in UK infrastructure for the type of low carbon fuel required to help the uptake of Zero Emission Vehicles (ZEV).
- Providing grants to encourage the use of rail or water instead of road
- Conducting an operational trial of longer semi-trailers, which is authorising longer articulated goods vehicles to run on UK roads
- Working to understand the potential for demonstrator projects to overcome some of the hurdles associated with the implementation of novel freight decarbonisation technologies with partners including the Connected Places Catapult.

In 2020, DfT progressed the first step towards developing policy proposals and a coordinated plan for decarbonising transport with the publication of "Decarbonising Transport: Setting the Challenge" [21]. The policies set out to support delivering HGV emissions targets are aligned with those proposed in the Road to Zero; LGVs end of sale new petrol and diesel vehicles date has been brought forward to 2035 (from what was set out in the Road to Zero), or earlier if a faster transition appears feasible, as well as including hybrids for the first time. The UK leaving the EU means that the future approach will be at least as ambitious as the current arrangements for vehicles emissions regulations.[6]

However, as recommended by Committee on Climate Change [23] the Northern Irish government has a significant role to play through devolved policy matters and actions that further encourage the uptake of ULEVs:

- Operating and promoting specific schemes that have secured funding from the UK government, such as the ecarni scheme.
- Identifying and pursuing opportunities to secure funding from UK-wide funds for ULEV infrastructure in Northern Ireland.
- Providing leadership by decarbonising the public sector and bus fleets.
- Use of the infrastructure budget on electric vehicle charging infrastructure.
- Setting targets for ULEV sales that go beyond those laid out in the Road to Zero Strategy.
- Taking steps to address non-financial barriers for electric vehicles, including local measures such as parking, use of priority lanes, and public awareness campaigns.

3.1.1.2. Taxis

As outlined in Section 2.1.2, many taxis utilise readily-available cars or van conversions, with a limited number of bespoke vehicles (generally only wheelchair-accessible taxis). The different categories of taxi licence and service further segments the market, with vehicle type matched to the service required and fares charged (hence covering operating costs).

Beyond the national government targets for decarbonising the car fleet, no specific targets have been set for taxis. Encouraging the use of zero or ultra-low emission vehicles can be incorporated as part of licensing conditions, if specific targets or aspirations are set by the licensing authority.

A key consideration will be maintaining the availability of wheelchair accessible vehicles across the whole of the country, particularly where these may be niche products and so more expensive to buy.

Charging infrastructure will also be a consideration. Some drivers may prefer to charge at home overnight, with electricity at domestic tariff rates, whereas others may not be able to do so (for example due to living in terraced housing with no private drive) and so may seek access to taxi-specific charging facilities costing closer to domestic electricity rates.

As outlined above, key actions will be to follow the recommendations of the Committee on Climate Change, particularly with regard to accelerating the take-up of electric cars.

3.1.1.3. Buses

Although there are no official UK government targets set for buses, the Confederation for Passenger Transport (the trade body for bus and coach operators) set a target in their recently published bus strategy for all buses to be ultra-low or zero emission by 2025 (2023 in some urban areas) [21]. The aims prioritised by UK government are that conventional buses will be replaced with zero emission buses and infrastructure over a period of time, and UK government will support measures to increase bus patronage in the country.

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[6] At the time of writing this report the UK Transport Decarbonisation plan had not been published;
Decarbonising transport: a better, greener Britain was published on 14th July 2021 and can be consulted online: [Transport decarbonisation plan - GOV.UK (www.gov.uk)]

Translink has set an ambitious target for decarbonising the bus sector and aims to achieve a zero-emission bus fleet by 2040, with a mixture of electric and hydrogen buses. [67]

At the end of the 2020, Minister Mallon announced a £66million programme for 145 zero and low emission buses that will enter the Translink fleet in an effort to deliver Green Recovery, which will comprise of 100 zero emission buses (80 Battery Electric Vehicles and 20 Hydrogen Fuel Cell Electric Vehicles) to be deployed in urban services and 45 low emission buses for Ulsterbus services across Northern Ireland. The bus fleet will include the buses produced by Wrightbus, one of the largest UK bus manufacturers currently producing zero-emission buses, based in Ballymena in Northern Ireland. The first vehicles of this order have been delivered with hydrogen buses being commissioned for Metro services in Belfast; more specifically three Hydrogen Buses have been trialling in service since December 2020 supported by a refuelling station in Belfast. Similar hydrogen double-deck buses are entering service in Aberdeen, London and the West Midlands, providing additional operating experience and data gathering.

There are no publicly announced plans to introduce hydrogen or EV in long distance buses/coaches in Northern Ireland, namely the Goldline service, although the equivalent parts in GB have recently made commitments to end diesel buses acquisition in 2020 (National Express West Midlands) and to become 100% zero emissions by 2035 (Stagecoach and First). There have been no mentions of NI private bus/coach sector plans to decarbonise their fleet made publicly available at the time of writing this report.

Trials have commenced in Scotland by Ember of two electric coaches operating on an express route between Dundee and Edinburgh, with rapid charging facilities provided in Dundee to recharge the batteries between journeys. Recognising the different demands placed on batteries by coaches, as opposed to urban buses (air conditioning, limited-stop running), this demonstration project will be useful in determining the practicalities of electric coaches on Goldline services.

3.1.1.4. Rail

The European Rail Research Advisory Council (ERRAC) vision for rail transport in Europe Rail 2050 Vision [68], includes a society with carbon-free train operation and zero-emissions through alternative technologies such as fuel cells and optimised on-board and lineside energy storage; with the starting point being widespread electrification where feasible and cost effective. To support this, there is an EU target to reduce specific average CO_2 emissions from train operation by 50% from 1990 levels [69].

In the UK, a statement released by Jo Johnson MP, then Minister for Rail in 2018, posed a challenge to the rail industry to take a closer look at alternative fuels to diesel for trains capable of running on non-electrified sections of the network. The industry was challenged to take “all diesel-only trains off the track by 2040”, open the door for other technologies such as battery and hydrogen and provide a vision on how it will decarbonise. The ‘Rail Industry Decarbonisation Taskforce’ was set up to respond to this challenge.

Northern Ireland Executive has included climate change as one of its priorities in the Draft Programme for Government Outcomes, with consultation responses currently being considered.

Translink is targeting a zero-emission fleet by 2040, through migration towards propulsion systems supplied by energy generated from sustainable energy sources (e.g. electric vehicles), which aligns with the wider UK and EU targets stated above.

Work is underway to explore decarbonisation options on the railway network through the Network Utilisation Strategy (NUS) [70], to encourage rail demand and modal shift. This work takes account of the uncertainty in rail demand post-Covid-19 pandemic, with likely impacts on both short-term demand and longer-term behavioural change with increased working from home and potential reductions in business travel.

Opportunities include the following and there is an opportunity to combine these with zero emission traction to support some of the aims:

- Transforming medium and long-distance journey times, to become more competitive with other modes of transport. This could be achieved through line speed improvements, higher performing traction and local services being provided separately.

- Higher frequency of services within the Belfast area.
- More integrated transport offering.

At present there is no rail freight activity in Northern Ireland, having ceased completely in Northern Ireland in 2003 [71].The diagram below Figure 3-2 shows the comparative corridors against the existing rail network for reference [72].

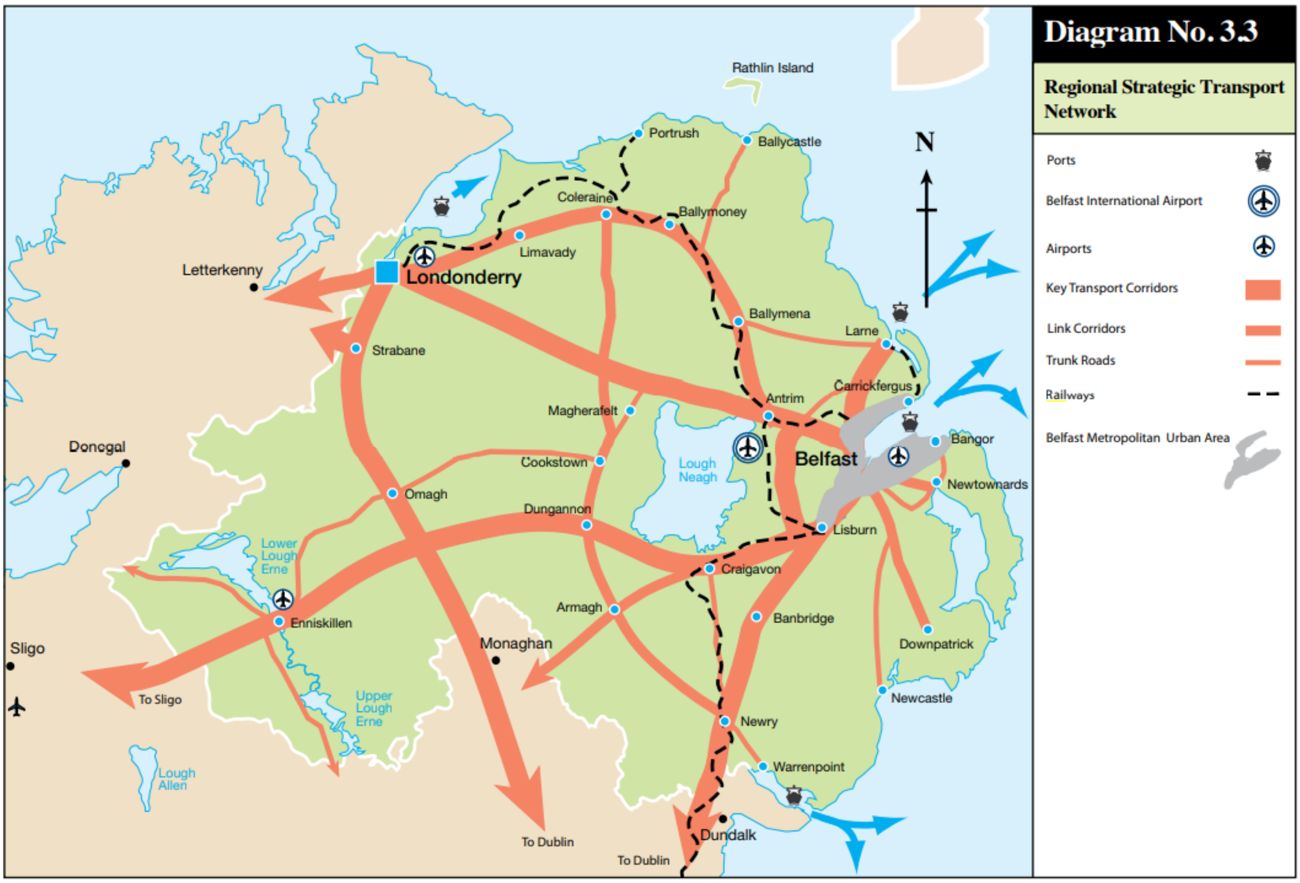


Figure 3-2 - Northern Ireland strategic transport network [72].

3.2. Northern Ireland – Energy Production and Storage

In section 3.2 we provide a broad overview of the policies and strategies related to the supply and storage of alternative fuels in Northern Ireland.

We also identify possible plans for the future supply (production and storage) of electricity, hydrogen, bio-CNG/bio-LNG and governmental plans to progressively move away from fossil fuels for transport.

3.2.1. Electricity Policies

Northern Ireland Electricity (NIE) owns the electricity transmission and distribution network and operates the electricity distribution network within Northern Ireland, with responsibility for maintenance and construction. Since 2010, NIE has been owned by ESB, and the electricity sectors across Ireland are integrated, acting under the single electricity market (SEM), since 2007. This means that Ireland generation or import is treated as a whole. SEMO is the Single Electricity Market Operator for the island of Ireland.

SONI, as part of EirGrid Group (state owned company), is the transmission system operator (TSO) in Northern Ireland; responsible for balancing power supply / demand.

Climate change legislation, such as the EU's Renewable Energy Directive, the subsequent Clean Energy Package and the UK government's 'Net-Zero by 2050' legislation is driving the decarbonisation of the energy sector. The NIE Networks for Net Zero sets out a roadmap to achieving a Net Zero energy system [73]. Under this directive, NI aims to go from 49.2% renewables in 2020 to (a minimum of) 70% by 2030 (and Net Zero by 2050). This would move the carbon intensity from around 339 gCO2e/kWh in 2018 [74] to 81gCO2e/kWh by 2030 (data provided by BEIS for UK grid average).

Now closed to new schemes, the Northern Ireland Renewable Obligation (NIRO) scheme has previously obliged electricity suppliers to generate specific quantities of electricity from renewable sources. This operates alongside the Renewables Obligations in Great Britain (GB).

The Ireland single electricity market trades with the UK market via two main interconnectors, the Moyle and East-West interconnector. Interconnectors offer the transport of electricity between two transmission systems, improving access to generating power capacity in the Republic of Ireland and Great Britain.

- 500MW Moyle interconnector HVDC to GB [75], commissioned 2001.
- 500MW East West interconnector HVDC to GB, commissioned 2012.
- ~200MW HVAC connection with ROI [75], existing.

See Section 2.4.2 for details of interconnection expansion and development.

In the immediate term, developing an ultra-rapid charging hub infrastructure across Northern Ireland would have a significant impact in terms of economic stimulus, due to the high upfront investment costs and promotion of the electric vehicle sector. NIE Networks has offered to kick start this infrastructure delivery if there is no viable market alternative [73].

3.2.2. Hydrogen Policies

The UK Department for Business, Energy & industrial Strategy (BEIS) is expected to create a £240m fund to support low-carbon hydrogen production which will be open to Northern Ireland [76]. Northern Ireland is also represented on the UK Hydrogen Advisory Council which will develop hydrogen policy across the UK [76].

The DfE has also provided Northern Ireland Water with £5m in funding to trial new electrolyser technology, with the aim that this will provide valuable insights into the technology [76]. The 1MW electrolyser will be located at a major Wastewater Treatment Works.

Northern Ireland is one of the windier parts of the UK, with the windiest areas being over the highest ground and along the coasts of Counties Antrim and Down [77]. Wind remains the dominant source of renewable electricity generation (40% achieved in 2018) in Northern Ireland accounting for 84.5% of total renewable generation volumes in 2019.

It is generally believed that 'green' hydrogen production (via electrolysis) could offer a form of energy storage to ensure that the current curtailment of wind electricity generation at night is avoided. Currently, low demand at night results in wind energy unharnessed. This is known as dispatch-down and represented 7.7% of the total available wind energy in 2019 [78]. This renewable energy could be employed to produce 'green' hydrogen via electrolysis at these times of low electricity demand. 'Blue' hydrogen could be used to scale up hydrogen production capacity until 'green' hydrogen is at sufficient scale and comparative low market cost.

The DfE [76] has identified that an area northeast of Belfast will be an ideal location for a centralised large-scale hydrogen production due to:

- Access to large volumes of electricity due to the high voltage electricity grid and nearby interconnection with Scotland.
- Proximity to demand including transport from the M1, the natural gas grid and nearby power stations.
- Suitability of Belfast Port for offshore wind generation and export of hydrogen.

The natural gas distribution system, operated by Phoenix Natural Gas (PNG), Firmus Energy, and SGC Natural Gas, will play an important role in the distribution of hydrogen. Northern Ireland's gas distribution network is relatively modern and constructed using polyethylene plastic material which is suitable for Hydrogen [79].

3.2.3. Biomethane Policies

Northern Ireland's agricultural sector has a large share of livestock-based agriculture, with the potential for a large supply of manure available to enable significant biomethane production. It is estimated that there are currently 76 Anaerobic Digestion (AD) plants operating in Northern Ireland [76], however the vast majority of these biogas producers use the gas for renewable electricity generation and not for conversion to CNG fuel. In 2020, 5.4% of renewable electricity consumed in Northern Ireland was produced from biogas equating to 197GWh [80]. However, injecting biomethane into the gas grid is more energy efficient than using the gas to generate electricity [79].

A sustainable model is required to incentivise biomethane injection into the gas grid leading to increased demand for the gas as a transport fuel. Currently no biomethane is injected into the grid due to a lack of support mechanism and lack of regulatory framework [79]. Phoenix Natural Gas have reported that Northern Ireland urgently needs a regulatory framework to facilitate injection into the grid and that this will provide the direction and momentum required for biomethane uptake. They also report that energy policy in Northern Ireland must consider the inclusion of a supporting incentivization scheme for biomethane producers [79].

No significant policies or incentives are open to new biogas/biomethane producers in Northern Ireland. Previously, the Northern Ireland Renewable Obligation (NIRO) scheme provided incentives for biomethane/biogas production via anaerobic digestion until its closure to new projects in 2017.

Northern Ireland will benefit from Great Britain's decarbonisation of the gas network due to its connection via the Scotland to Northern Ireland Pipeline (SNIP). The incentives and policies that the Scottish and UK governments are introducing to promote biomethane injection to the grid such as feed-in tariffs and the renewables obligation will therefore benefit users in Northern Ireland.

3.3. Northern Ireland Baseline

According to the Committee on Climate Change report on Northern Ireland emissions published in 2019, which rely on data collected in 2018, emissions from transport increased in 2016 to 4.5 $MtCO_2$/year, corresponding to 22% of all emissions. Despite a third consecutive increase in annual emissions, overall there has been a total decrease of 5% between 2008 and 2016, but still 29% higher than 1990 levels. The greatest contributor to this trend is the increase in car ownership rates, attributed to a fairly distributed population in the territory, which relies on private vehicles rather than public transport.

In the following chapters we provide an overview of the transport baseline as well an appreciation of the energy system in operation in Northern Ireland.

3.3.1. Transport

In the following sub-chapters, we present an overview of the current fleet composition for HGVs, Taxis, Buses and Rail. This chapters provide valuable local context of the key transport features that will influence the future uptake of alternative fuels. The information was gathered from publicly available NI sources but also through stakeholder engagement with Translink.

3.3.1.1. HGVs

Road freight has historically had the most important share of the island freight movements. According to the goods vehicle operator license stock published by DfI, licensed heavy goods vehicles shows there were 21,974 registered HGVs in NI at the end of the third quarter of 2020/21[7]. There is no publicly available data on the proportion of alternative fuelled HGVs but according to market knowledge the makeup of alternative fuelled vehicles follows the general trend in the UK, with a negligible percentage of CNG and LNG fuelled trucks travelling on the road network in NI.

Within the Irish island Dublin is the largest container port in Ireland but Belfast also handles a large volume of containerised traffic. On the other hand, Northern Ireland historically has been the region in the island where most of the roll-on roll-off activity takes place, which is effectively a maritime extension of the road haulage industry, as it involves an accompanied truck, trailer or container being transport on a ferry.

A total of 867,698 road goods vehicles passed through Northern Ireland ports in 2019, carrying 27.4 million tonnes [81], which indicates that on average each vehicle carried 32 tonnes, or approximately a full 40 feet container, which reveals the heavy duty nature of the HGV vehicle park in NI. This average is confirmed in the data published by DfI on road freight statistics, which shows that in 2019 over 91% of the cargo moved within NI was transported in vehicles with over 25 tonne gross capacity and 3 in 5 of those trips were made by an articulated HGV.[8]

According to the latest DfT road freight statistics 67 million tonnes of goods were moved within NI, between NI and GB and between NI and RoI. When comparing to the 27.4 million tonnes that passed through NI ports, it is apparent that the majority of the cargo (approximately 60%) arrives in RoI and then travels via road to NI.

Another relevant characteristic of the freight movement in NI is that half of the trips (~54%) by NI registered vehicles in 2019 corresponded to short and medium-haul distance (less than 150 km)[9], which indicates that the duty cycle of the heavy goods vehicles is not particularly lengthy but heavily loaded, confirmed by the data above that 91% of the trips corresponded to vehicles with 25 tonne gross capacity or above.

It is also fundamental to appreciate the type of infrastructure where the HGVs circulate as it influences duty cycle and refuelling/recharging opportunities. The topography of the island can be a unique natural feature, but it poses challenges to drivers in mountainous and coastal areas particularly vulnerable to extreme weather events.

[7] At the time of conducting this research, the latest available data corresponded to Q3 of financial year 2020/21; more recent data may have been published at the time of publishing this report.
[8] Table 1: Road Freight Statistics 2019, Data for Northern Ireland and Republic of Ireland, Department for Infrastructure, consulted in May 2021; not published.
[9] Tables 11a and 12: Road Freight Statistics 2019, Data for Northern Ireland and Republic of Ireland, Department for Infrastructure, consulted in 2021; not published.

The primary and secondary road network in Northern Ireland encompasses 25,000 km of public roads and is made up of strategic or trunk roads, including 115km length of motorway, dual carriageways, single lane roads which link major urban areas, which in total make up 1,300 km of the road network. The remaining 23,700 km of the road network consist of local roads [82] [83].

This makeup of the road infrastructure limits the applicability of ERS is in Northern Ireland given the limited scale of the motorway infrastructure. On the other hand, the topography of NI poses challenges to duty cycle performance which is particularly relevant to heavy duty vehicles.

3.3.1.2. Taxis

Changes in travel habits are impacting taxi operator finances and hence the desire and ability to upgrade vehicles to full electric. Further segmentation of the taxi market due to the four categories of license, including ride-hailing companies (like Uber), means that external policies are likely to be required in order to encourage investment.

New official figures show that, at the end of December 2020, there were 9,163 licensed taxi vehicles [84] , which is lower than previously. The average distance travelled per person per year is 57km, and 14 trips, which reveals that the typical journey length is less than 5km, [85] again indicating that shorter journeys are impacting on revenue taken and hence profits for reinvestment.

Most taxis are driven by their owners, even if operating under an umbrella company, so access to overnight vehicle charging facilities will be a key consideration for individuals when determining their circumstances to invest in electric vehicles. Certainty (or less variability) in potential revenue will assist with financial calculations, therefore consideration might be given to regularly reviewing the number of licenses available to minimise over-provision of services and hence reduction in revenue for each driver (but not wanting to distort the market nor restrict legitimate competition).

3.3.1.3. Buses

The bus network and fleet falls into four broad categories, namely:

- Urban/semi-urban bus services – Metro, Urby
- Shorter National services – Ulsterbus, some Goldline
- Longer distance / International coach services (NI, RoI, and England) – Goldline
- Rural/ School buses

Of the Translink fleet, approximately 400 vehicles are on urban operations, the rest semi-urban and rural. Fleet replacement cycles are 7 years for coaches (used on Goldline and interurban routes), 15 years for city buses with some of these then retained for a further 5 years to cover more rural operations.

The semi-urban and rural fleets operate a mixed service pattern, including schools services, during a typical day, maximising vehicle utilisation but requiring multi-purpose vehicles which may not be fully suited to all needs for each type of service operated.

As a high-level study, it is beyond this scope to undertake a detailed analysis of current duty lengths and demands, so broad principles are being used for strategic analysis but amended to better reflect NI situation as appropriate

Translink has 23 main depots, of which four are in Belfast and 1 is in Scotland (for their coach services across the Irish Sea to Scotland, London and Birmingham). A review will be needed of the depot estate, to work out whether it is sensible to have mixed depots, or shuffle routes to have depots with only one technology type. This also extends to heavy maintenance, training depot staff to deal with electric or hydrogen buses will be expensive, so may be better focussed on a smaller number of specialist locations. This review should be undertaken as part of

Translink's continual investment in its infrastructure, supporting closer bus/rail integration and providing high quality bus stations wherever possible.[10]

3.3.1.4. Rail

The rail network in Northern Ireland is approximately 330km in length, centred around Belfast, with passenger numbers in the region of 15 million per year. NI Railways, a subsidiary of Translink, has responsibility for all aspects of the network including running trains, maintaining rolling stock and infrastructure, and pricing. Open access operations are permitted by other operators.

The Northern Ireland passenger fleet is comprised of Class 3000 and Class 4000 diesel multiple units, with the Belfast-Dublin line operating with a standalone fleet of diesel locomotives and coaching stock which is jointly owned with Irish Rail. The existing fleet is currently being supplemented with new 6-car-units. The Class 3000's were built in 2004/05 and the Class 4000's were built in 2011/12.

The rail routes Northern Ireland's rail network are radial from Belfast [86]. The network in and around Belfast is urban in nature with stations in close proximity, while the rest of the network is relatively rural. There are some current paths that cross Belfast, however a Belfast Hub interchange is being constructed and due for completion in 2024/25; this will include a rebuilt station at Great Victoria Street and will lead to no cross-city paths. Additionally, services on the Belfast – Dublin route may be increased to 1tph. Track typologies consist of single track for the majority of the rail network (approximately 200 km) and only 129km of double track.

There are three train formation yards and maintenance facilities: York Road Engineering Depot, Adelaide Maintenance Depot and Fortwilliam Traincare Facility, which also serve as refuelling points for diesel: York Road can store 2 x 90,000 litre tanks, Adelaide can store 3 x 35,000 litre tanks, and Fortwilliam can store 2 x 70,000 litre tanks.

3.3.2. Energy system in Northern Ireland

Similarly to the previous section 3.3.1 focused on transport, we carried out a broad overview of the energy system in Northern Ireland, identifying the key characteristics that will influence the future developments in the production and storage of electricity, hydrogen and biomethane in NI.

3.3.2.1. Electricity

With increased electric vehicle uptake (and hydrogen production for hydrogen vehicles), an increase in electricity demand will occur and the production and distribution infrastructure will have to be robust enough to cope with this increase.

There are currently more than 4,000 electric vehicles (including hybrid and plug in hybrid) in Northern Ireland [87]. Although the quantity of electricity consumed by these vehicles is not readily available, in 2020 7,416 GWh of total electricity was consumed in Northern Ireland. Over this same period, 3,651 GWh was generated in Northern Ireland from renewable sources [80].

SONI (System Operator for Northern Ireland) is expected to spend £37.3m over 2022-2029 on transmission development projects, as detailed in the Transmission Development Plan for Northern Ireland [88]. NIE Networks, the Transmission Asset Owner, are expected to incur costs of £497.2m associated with these projects [88]. These projects include both network development and asset replacement projects.

A planned North South Interconnector (400kV), due for completion in 2025 will facilitate 900MW of renewable generation from ROI [89], and is critical to achieving the 70% renewable generation interim 2030 target.

Alternative energy storage options are also being explored in Northern Ireland. Two 50MW battery storage assets in Northern Ireland are in the final stages of construction and testing [90].

[10] Private bus/coach sector was not covered by the present project commission.

Currently there is a network of charging points across NI which consists of 320[11] 22kW and 17 rapid charge points [91], which offers limited opportunity to charge heavy duty and passenger vehicles, which required ultra-rapid charges.

3.3.2.2. Hydrogen

Although hydrogen production is generally viewed as suitable within NI, minimal H_2 production capacity currently exists. No public refuelling infrastructure currently exists for H_2 in NI [92].[12]

The first 'green' H_2 project in the whole of Ireland began operating in late 2020. This project involves producing hydrogen via electrolysis at a wind farm in North Antrim to fuel the first H_2 powered double decker buses in NI [93].

Firmus Energy and B9 Energy are currently investigating the potential for trials to inject hydrogen into the natural gas network at an old Michelin site in Ballymena. They are also working with DNV-GL to develop a hydrogen roadmap.

The salt cavern gas storage project at Islandmagee has been granted planning permission for natural gas storage. However, this site could also be suitable for hydrogen storage which would particularly benefit the storage of 'blue' or grid blended H_2.

3.3.2.3. Biomethane

No public refuelling infrastructure currently exists for CNG/LNG in Northern Ireland [92].

Northern Ireland and the Republic of Ireland currently have no LNG import terminals, although a terminal has been proposed on the Shannon Estuary in County Kerry.

A first of a kind facility for the production of liquid biomethane has been successfully operating at the Greenville Energy site in Northern Ireland. Although this currently offers small scale production, it has proven that bio-LNG can be produced from the agricultural waste.

[11] Information updated by the client team; information publicly available reported in [91] showed 150 22kW.
[12] Logan Energy has recently been commissioned to design and supply one of Europe's largest hydrogen refuelling stations, as announced on 2nd July.

3.4. All Island Appreciation – Republic of Ireland

This section focuses on the evidence for the Republic of Ireland, in order to complement the analysis with a high level appreciation of an all island perspective both on the policies and developments of the transport and distribution infrastructure but also on how the energy system operates in the Republic of Ireland, reiterating the message presented in previous NI focused chapters.

3.4.1. Transport and Distribution Infrastructure

In this section we present the literature review of existing policies in the Republic of Ireland related to the uptake of alternative fuelled transport (HGV, rail, buses and taxis) and provide an appreciation of how the transport system works within the island: common goals, protocols between NI and RoI cooperation between the two organisations and shared infrastructure.

3.4.1.1. HGVs

The package of solutions to be adopted for HGVs in Northern Ireland have a relevance beyond the island of Ireland, as freight activity relies on links between the island of Ireland and Great Britain and the island of Ireland and Europe. Hence it is fundamental to understand how the government of RoI is progressing the alternative fuels agenda. As a result, we consulted the most recent RoI Climate Action Plan Interim 2021, which is aimed at progressing the 2019 Climate Action Plan to reach further 7% reductions in emissions per annum.

In this interim programme the government of RoI has set out a list of actions for Transport that ranged from Mitigation, Public Sector Leading By Example to Adaptation. One of the most structural mitigation actions has already been progressed by the Department of Transport of the Republic of Ireland, which has recently published its Ten-year Strategy for the Haulage Sector in April 2021 and will be under consultation this Summer 2021 [94]. In this strategy the challenges of decarbonising the sector are discussed and the government recommends that the heavy-duty sector will need to adopt a range of different alternative fuel technologies.

To assist the decarbonisation process, the Irish Government is currently supporting the uptake of EV technologies and the continuous rollout of refuelling infrastructure for alternative fuels and technologies, with specific actions to include:

- maintaining a low excise rate for natural gas and biogas for a period of eight years to facilitate the uptake of CNG and natural gas technologies and the acceleration of indigenous renewable biogas production; and
- an accelerated capital allowance scheme for gas-propelled vehicles and related equipment.

The Department of Transport of RoI has already put in place support for the transition to low-emission freight industry by:

- implementing a new reduced tolling incentive regime for alternatively fuelled Heavy-Duty Vehicles, which was rolled out in 2020 - Low Emissions Vehicle Toll Incentive (LEVTI) [95]; and
- a new Alternatively-Fuelled Heavy-Duty Vehicle (AFHDV) purchase grant scheme launched in March 2021 to help haulage operators to bridge the differences in price between conventional and alternatively-fuelled technologies (administered by Transport Infrastructure Ireland (TII) on behalf of the Department) [96].

From this consultation and present research work, it is recommended that NI and RoI take the action to align the island approach to the licensing of freight vehicles by adopting common alternative fuelled vehicle targets. Furthermore, the alignment between Irish and British regulations and policies would be encouraged given the significant movement of vehicles operating across the islands.

To note, an example where different regulations between the jurisdictions have an impact in freight operations is the introduction of Brexit regulations, which have influenced the route chosen between NI and Europe. Since Brexit regulations came into force, freight with origins in Northern Ireland is in some cases being shipped directly to Europe avoiding the intermediate stop in England and consequent delays associated with the required paperwork.

3.4.1.2. Taxis

Parallel to initiatives in the UK, grants are being offered to support the take-up of electric vehicles for taxi operations. The Sustainable Energy Authority of Ireland is offering grants of up to €5,000 for battery electric vehicles or plug-in hybrid electric vehicles, with these grants also covering vehicles used as taxis [97] .

Models suitable for use, particularly wheelchair accessible vehicles, are the same as those for Northern Ireland.

3.4.1.3. Buses

With vehicle purchase coordinated by Coras Iompair Eireann (CIE, the Irish national transport corporation) for its Dublin Bus and Bus Eireann operating subsidiaries, investment in ultra-low and zero emission buses is being considered. As outlined above, the first fleet of Electric Range double deck buses are about to enter service in Dublin, able to operate in full electric mode in areas with poor air quality or sensitive receptors. CIE has yet to trial any zero emissions buses, but is understood to be watching UK fleet trials with interest and is gaining knowledge through its informal partnership with Transport for London.

A key consideration for Dublin is the depot estate, which may require significant investment to be able to accommodate an all zero-emission fleet. This is likely to be undertaken as part of the BusConnects network changes, to accommodate increased fleet size from service expansion as well as the extra space required for each electric bus (due to charging equipment etc).

It is understood that a preliminary assessment of current Dublin Bus schedules indicated that with only a small improvement in battery electric bus range, approximately 75% of the existing operation could be directly swapped to electric buses. The remaining 25% of duties will either need recasting, to reduce kilometrage to be within range, or the use of hydrogen buses.

Bus decarbonisation is also a mentioned as a key area of decarbonisation in the Interim Climate Action Plan on the Republic of Ireland 2021, and specific actions proposed include [98]:

- Enter into service 250 diesel-electric double deck buses with 2 to 3 kms continuous zero-emissions running capability.
- Award framework contract and place first order for: full electric single deck bus fleet; and full electric double deck bus fleet as part of transition of urban bus services to zero emissions.
- Deliver first implementation phase of the new bus network of BusConnects Dublin.
- Submit planning applications to An Bord Pleanala for Core Bus Corridor projects under BusConnects Dublin; the Cross City Link in Galway; the MetroLink Project; and the DART+ West Project

3.4.1.4. Rail

Transport accounts for 20% of the Republic of Ireland's overall emissions (and 27% of non-ETS emissions), with 4% of overall transport emissions coming from public transport.

The Republic of Ireland's National Energy & Climate Plan (NECP) 2021-2030 [99] was published in 2020 and incorporated all policies and measures up to that time which collectively sought to deliver a 30% reduction by 2030 in non-ETS greenhouse gas emissions (from 2005 levels). More recently, the RoI's Programme for Government, Our Shared Future committed to achieving a more ambitious 7% annual average reduction in greenhouse gas emissions between 2021 and 2030. The policies and measures are being reviewed in light of the new trajectory and a revision to the NECP is anticipated.

The NECP is founded on the 10 National Strategic Outcomes which are introduced in the National Planning Framework [100] and referred to in the National Development Plan 2018-2027 [101]:

- National Strategic Outcome 4 is "Sustainable Mobility" and states a clear need for a "decisive shift away from polluting and carbon-intensive propulsion systems to new technologies such as electric vehicles and introduction of electric and other alternatively fuelled systems for public transport fleets". Investment plans include "Continued investment in bus and train fleets, as well as infrastructure, to maintain safety and service levels including further expansion where required" but no further specific actions relevant to this study.

- National Strategic Objective 8 is "Transition to a Low-Carbon and Climate-Resilient Society". While there are strategic investment priorities stated, the one relevant to rail is "Comprehensive integrated public transport network for Ireland's cities connecting more people to more places (see NSO 4)" which is more focused on cities than inter-city. Investment in renewable energy is identified as a way of increasing capacity to electrify transport. General actions stated to secure early transition to zero/low emission vehicles in the private and public fleet are relevant, but do not specifically refer to commitments to decarbonise the rail fleet.

The National Development Plan specifically identifies the need for high-speed rail and journey time opportunities to be examined between Belfast, Dublin and Cork. The existing Enterprise service connects Belfast and Dublin, and it is understood that both line speed and electrification would be considered in this review.

The North South Ministerial Council launched an all-island Strategic Rail Review in April 2021, which will be overseen by transport authorities from both jurisdictions [102]. The review is expected to conclude with a strategy for the development of the railway sector on the island of Ireland over the period to 2040, and specifically includes reference to achieving climate change objectives, sustainable connectivity between the major cities (including Belfast-Dublin), regional accessibility and development, and considering potential to increase rail freight.

It is also understood from the North South Ministerial Council that officials from both jurisdictions are liaising on policy development in relation to Sustainable Transport and Travel, which would be expected to include decarbonisation of existing transport systems, as well as active travel.

Irish Rail operates a number of distinct fleets; the commuter fleet, freight fleet and intercity fleet are all diesel, while the Dublin Area Rapid Transit (DART) fleet is electric. The DART is the only electrified area in Ireland and operates at 1500v DC. The DART Expansion Programme is a key priority; it includes the investment in new train fleet, new infrastructure and electrification of existing lines. Subsequently, this programme will encourage travel on a sustainable mode of transport.

It is understood that new diesel electric trains are expected to be delivered to Irish Rail in 2022 [103]. As of 2019, here is an Expression of Interest to the market to supply 600 new electric or battery trains, and there is a feasibility study underway for replacing the Enterprise fleet [104].

Rail gauge is consistent across Ireland (Irish Gauge) but is different to gauges in Great Britain. [105]

3.4.2. Energy System

Unlike other countries within the UK, Northern Ireland has devolved responsibility for energy policy, excluding nuclear energy and carbon capture and storage (CCS) which are covered at a national level. Since November 2007, the electricity industry has been operating in the Single Electricity Market (SEM) – a single wholesale market across the Island of Ireland. Northern Ireland is a joint member of the all-island Integrated Single Electricity Market (I-SEM) shared with the ROI [77]. The primary aims of the market are to:

- Integrate the all-island market with the European Internal Energy Market;

- Increase opportunities to trade in different time frames;

- To increase the efficiency of cross-border interconnectors.

The nature of the 'all-island' market means that any energy policies in NI that affect the supply-side of energy must be compatible with ROI policy, and vice-versa, in order to avoid market distortions that incentivise inefficient generation.

The interconnection with the Irish transmission system (and planned second connection) enables the power system to be operated on an all-island basis. In the context of the SEM, it is important to note the existing and planned interconnections between GB, Ireland & France.

- The existing East-West interconnector between Ireland and GB;
- The planned Greenlink interconnector between Ireland and GB;
- The planned Celtic interconnector between Ireland and France (due to energise in 2026).

For NI customers to benefit from the increasing levels of interconnection into Ireland, it is essential that the second North South Interconnector is constructed and commissioned [89].

For H_2 as an alternate fuel the electricity market and trading agreements are of key importance. This is particularly noted, when green H_2 is preferred as a H_2 production route. The gas network in NI is not nearly as extensive as in GB, and around three-quarters of homes in NI are heated by oil or electric sources. The energy transition to clean fuels may therefore place additional constraints on the electrical network. It may also limit the growth cases for H_2 and Biomethane.

4. Barriers and Opportunities

We conducted an internal workshop with all experts involved in the project delivery, combining a wide range of expertise in different stages of alternative fuel adoptions. This ranged from production, storage and distribution of alternative fuels, to vehicle technology and operations to identify the key issues and opportunities that result from the adoption of alternative fuels in HGV and passenger transport in the NI context.

Drawing on the evidence from the previous tasks, we undertook a detailed SWOT (Strengths / Weaknesses / Opportunities / Threats) analysis of the alternative fuelled vehicle solutions for HGVs, Rail, Buses and Taxis in the context of Northern Ireland and the respective implications to the energy system in terms of distribution, production and storage infrastructure. We also identified the benefits and barriers to deploying several production and storage solutions.

The workshop allowed us to build common understanding and consensus on the most suitable solutions and the most appropriate transport forecast scenarios to be adopted in NI. Through this analysis we identified specific challenges that could be faced in the different geographies of NI – urban and rural, well connected and more peripheral.

We continued the SWOT exercise looking into the alternative energy required (electricity, H_2 and biomethane) to feed the forecast fleet of alternative fuelled vehicles. In this exercise we based our assumption on the worst-case scenario of energy consumption, with the highest energy requirements for electricity, H_2 and biomethane.

The summary of the key analysis of the SWOT workshop and the emerging key findings for each vehicle mode and energy type are compiled in the following sub sections.

4.1. SWOT Analysis – HGV

Although the timescales of this report focus on 2035 delivery, for HGV, we are also looking at an interim target in 2030. The literature review shows that there is no consensus on the general preference for hydrogen and electric over biomethane in the short-term. However, the transition to zero emissions HGVs (hydrogen and electric) in Northern Ireland will not be possible by 2035 simply because the technology for heavy duty vehicles is still in very early stages of development. Biomethane is therefore presented as close to carbon neutral (not zero carbon) which can fill in the gap in the medium term and contribute to a carbon reduction in the short-term, whilst taking advantage of an unexploited gas (methane) that is originated as a result of the activities in other sectors (namely agriculture and landfill).

A diagram representing the relative uptake of the two combinations of alternative fuels under each HGV forecast scenario is presented on Figure 4-1. These alternative scenarios have been considered in the SWOT analysis which is summarised on Table 4-1.

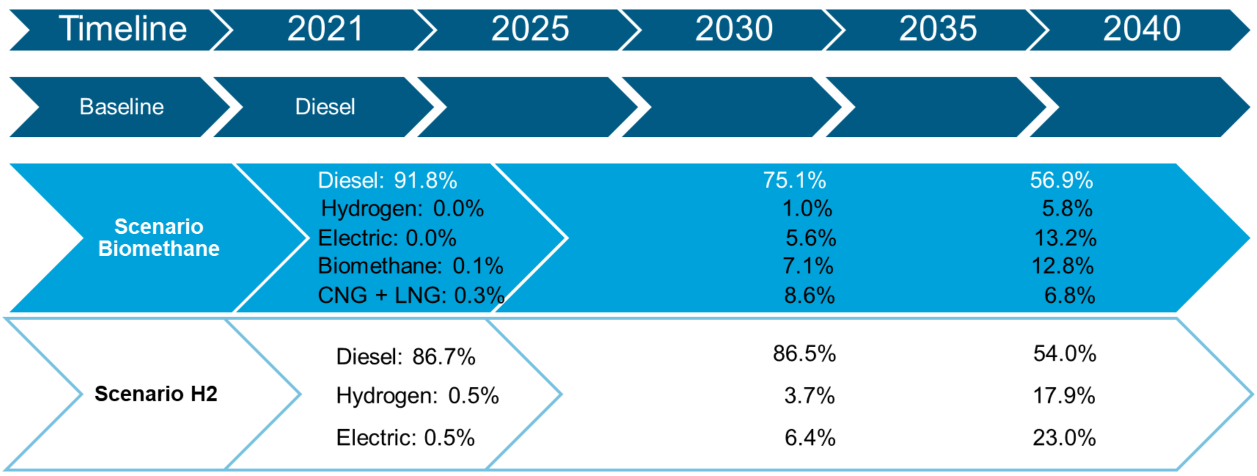


Figure 4-1 - Relative uptake of alternative fuels under each HGV forecast scenario

Table 4-1 - SWOT analysis - HGVs

	HGVs	
	Scenario 1 – Hydrogen dominates	**Scenario 2 – Biomethane/gas dominates**
S	Long term win with further carbon abatement achieved. Distribution infrastructure partially reliant on depot-based charging.	Quick win in the next decade for articulated vehicles – acts now. Circular effect of using a harmful gas that is emitted to the atmosphere for energy generation.
W	Technological maturity not achieved yet for articulated vehicles. Distribution likely to partially rely on public infrastructure for hydrogen.	Relies on uptake of biomethane which is not 100% carbon free; infrastructure becomes obsolete for transportation in 15 years. Distribution likely to rely on public infrastructure for biomethane.
O	Full decarbonisation will be achieved in the long-term.	Articulated vehicles have a readily available solution for the mid-term.
T	Hydrogen solution for articulated only available from 2035 onwards; infrastructure requirements are high with hydrogen being the foreseeable solution for articulated vehicles.	Introducing another variable to the strategy: biomethane production.
	Outcome: Scenario H_2 is the scenario that offers the highest potential benefits in the medium-long term by achieving greater carbon abatement. The opportunity should not be disregarded to implement biomethane as an interim solution for the next decade to accelerate carbon reduction, having in mind that solution is not carbon free but only 72-82% carbon neutral. [15]	

4.2. SWOT Analysis – Taxis

The discussion on the taxis forecast scenario focused on providing context to the private vehicle constraints in terms of models available and the level of progress/uptake registered in other authorities in the UK. A summary of the key findings that resulted from the zero emission taxis uptake SWOT discussion is listed on Table 4-2.

Table 4-2 - SWOT analysis - Taxis

	Taxis Scenario 1 – EV by 2035
S	Available and commercially viable technology.
W	Vehicle capital costs are still high; limited choice of vehicle types, for instance wheelchair vehicles only have available/limited options. Intensive vehicle usage and charging cycles may require more frequent battery replacement.
O	Charging at home allows taxi drivers to take advantage of domestic electricity rates.
T	Policy not in place yet in Northern Ireland; incentives required.

4.3. SWOT Analysis – Buses

The discussion on buses forecast scenario focused on providing context to why the Northern Ireland hydrogen and EV split differs to the UK-wide technology split. A summary of the key findings that resulted from the SWOT discussion on zero emission bus uptake is listed on Table 4-3.

Table 4-3 - SWOT analysis - Buses

	Buses Scenario 1 – 50% EV / 50% hydrogen
S	Flexible scenario that fits the Northern Ireland context with a mix of urban and inter-city/coach service. Readily available solution and commercially viable for EV Buses which can support a quick decarbonisation in the urban operations. Charging of EV and Hydrogen can be done at depot overnight (90-95%); rapid charging during the day between service duties to top-up EV battery if required.
W	Premium coach services / Goldline do not have a readily available technological solution. Age profile of Education vehicles requires either significant investment to more quickly move to zero emission, or extended deadline for the full elimination of diesel buses from Northern Ireland.

	Buses
	Scenario 1 – 50% EV / 50% hydrogen
O	Electric vehicles will become suitable for intercity/ coach services in the future with the development of batteries (higher energy density of batteries will allow more power in less space/weight). Electric buses whole-life costs will be lower than diesel in the near future. It is expected that there will be hydrogen-electricity parity in the medium term on the whole life cost of vehicles. Vehicle to grid opportunity by using electric buses after service duty is finished (serving as battery farms after 5pm).
T	Hydrogen prices are high at the moment; electric range of EV buses is currently limited to urban and peri-urban services. To be reviewed every 2 years based on practices & experiences UK & Europe.

4.4. SWOT Analysis – Rail

Whilst the timescales of this report focus on 2035 delivery, for rail we are looking towards 2040 for decarbonisation but with an interim target in 2035. The literature review validates the general preference for rail electrification, however, it is unlikely that Northern Ireland's entire rail network would be electrified by 2035; therefore, three alternative scenarios have been considered with the assumption that Belfast-Dublin will be electrified by 2030 given this route is already under consideration, presented in Figure 4-2.

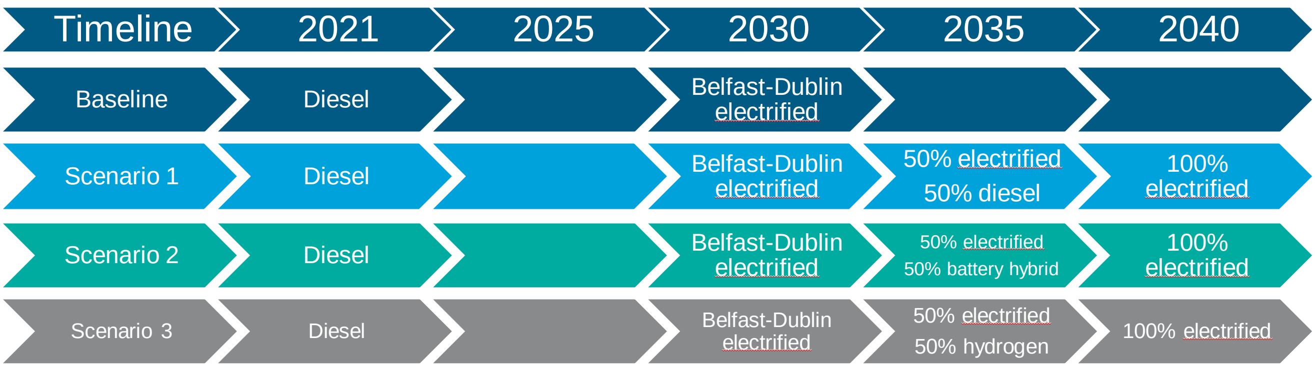


Figure 4-2 - Rail electrification timeline (source: Atkins)

The various strengths, weaknesses, opportunities, and threats of each of these three scenarios are highlighted and summarized in the table below**.** Scenario 2 and 3 are combined as they are relatively similar.

A summary of the key findings that resulted from the SWOT discussion on rail decarbonisation is listed in Table 4-4.

From the discussions held during the SWOT workshop, we concluded that the recommended option for decarbonising Northern Ireland's rail network would be Scenario 2: 50% electrification and 50% battery trains. A priority must be to decarbonise the rail network as quickly as possible, meaning that Scenario 2 and 3 are the most appropriate. When comparing battery and hydrogen technologies, battery is more proven than hydrogen; battery trains could be implemented on the network now, whereas there are currently no hydrogen trains running on the UK network at present. Therefore, alongside all other supporting evidence we suggest Scenario 2 is considered for the purposes of this study.

Table 4-4 - SWOT analysis - Rail

<table>
<tr><th></th><th>Consistent across all 3 scenarios</th><th>Scenario 1 – 50% electrification & 50% diesel</th><th>Scenario 2 – 50% electrification & 50% battery hybrid</th><th>Scenario 3 – 50% electrification & 50% hydrogen</th></tr>
<tr><td>Strengths</td><td>Electrification is a proven technology.</td><td>Consistent use of technology.

Rolling programme of delivering electrification without distraction from other forms of traction.</td><td colspan="2">Using battery or hydrogen technology would enable the rail network to be fully decarbonised by 2035 in an affordable/deliverable way.

Less infrastructure is required with battery and hydrogen technology meaning there are cost savings and reduced embodied carbon.

Hydrogen trains would only need daily refuelling.</td></tr>
<tr><td>Weaknesses</td><td>High capital cost and significant infrastructure.

A decision is needed around 25kV AC v 1500v DC.</td><td>With 50% of the rail network running on diesel, it means the network is not fully decarbonised.

Expensive infrastructure (OLE and feeder stations) in rural areas.</td><td colspan="2">Hydrogen and battery train characteristics are more limiting when compared to electric trains – there is reduced range, seating capacity and limits to operation.

It is unlikely battery and hydrogen trains would be able to transport freight.

There are uncertainties surrounding the costs of these traction technologies.

Battery and hydrogen technologies are less efficient than electrification.</td></tr>
<tr><td>Opportunities</td><td>Prioritise the 50% electrification on busiest lines.

Reduced journey times, improved operations.</td><td>Possibility of moving road freight to rail if there is a fully electrified network.</td><td colspan="2">Provides operational flexibility e.g. could run under wires if necessary.

Battery trains would make good use of the partially electrified network e.g. recharging during the journey.</td></tr>
<tr><td>Threats</td><td>Deliverability of OLE, including grid connections on time.</td><td>A strong business case could be challenging due to cost of electrification versus benefits on some certain less busy routes.</td><td colspan="2">The technology is less proven than electrification.

Rapid charging infrastructure for battery trains is more expensive.

Once the rail network is decarbonised through these traction types, full electrified may not be followed through.</td></tr>
</table>

4.5. SWOT Analysis – Electricity

The Energy Workshop session split the discussion into the need for increased production of clean electricity and secondly the requirement for new electrical storage assets. Both requirements considered the demand cases presented in 5.1.3.2 for the NI energy demand from the transport system. The recorded outputs, for each scenario, are presented below in Table 4-5 and Table 4-6.

Table 4-5 - SWOT analysis - Electrical energy production

	Electrical Energy production			
	Scenario 1 – Increased renewables (e.g. wind, solar)	**Scenario 2 – Interconnector**	**Scenario 4 – Balance of 1 and 2**	**Scenario 3 – Fossil fuels e.g., CCGT + CCS**
S	Futureproof, initial higher capex than conventional (per kwh), but lower OPEX and long-term investment.	New connector with RoI planned by 2025, Existing connector with Scotland provides energy reliance, as importing from different weather region.	Offers higher availability, security of supply.	Commercially ready, deliverable. Carbon neutral Could be sized to requirements.
W	Geographic / planning constrained, infrastructure / transmission upgrade challenges & timescales.	Dependent on commercial negotiations (political influence); prices fluctuate, less stable.	Less independent than scenario 1.	Reliant on gas from fossil sources (supports a non-net zero industry)
O	Carbon abatement (true 'net zero pathway'). Invest in jobs / skills.	Ability to also export generated energy.		Novel technology, combination with renewables (clean gas).
T	Lacks storage to support instability, lower availability, environmental impact, tourism impact. Potentially low NI employment as imported technology.	Reliance on another nation (out-with UK) for energy supply.		Environmental risk of CO_2 leak
	Outcome: Increased renewables and an additional (new) interconnector capacity will provide a balance of sufficient clean low carbon generation with security of supply where there is low renewable generation locally to NI.			

Table 4-6 - SWOT analysis - Electrical energy storage

	Electrical energy storage		
	Scenario 1 - Battery farm	**Scenario 2 – Hydroelectricity or pumped storage**	**Scenario 3- Other / novel technologies (including compressed air)**
S	Lower CAPEX investment for storage asset, as can be sized to match. Economics understood.	High CAPEX, engineering investment and infrastructure required. Longer duration storage, long life assets	Several demonstrators funded through BEIS.
W	Shorter duration of storage; cycle life may impact life of asset	Topography; identifying new opportunities in NI will be difficult.	Low Technology Readiness Level (TRL).
O	Commercial opportunities in offering additional grid services, when coupled with renewables can increase yields.	Pump storage (reverse storage)	May be suited to some of NI natural assets, e.g. salt caverns near Belfast where Gaelectric project advanced through FEED then stalled.
T	Environmental impact of resources used.	Timescales for delivery of storage could be 5+yrs	Risk of not meeting net zero timeline.
Outcome: Increased battery farm (scenario 1) would provide bankable electrical storage. This should also be supported by larger scale renewable storage projects like Hydro which may require feasibility assessment(s) to explore possible undeveloped hydro storage assets in NI. Additional, feasibility work should look at opportunities from other natural assets like salt cavern stores, e.g. Islandmagee salt caverns previously planned for compressed air storage.			

4.6. SWOT Analysis – Hydrogen

For the hydrogen energy discussion, the debate focused on predominant production and storage options, that have been explored as part of wider UK decarbonisation plans. It was noted that the green H_2 pathway would imply increased electrical capacity to be provided, unless this demand is met through local ‘off-grid’ projects. The recorded outputs, for hydrogen production and storage are presented below in Table 4-7 and Table 4-8, respectively.

Table 4-7 - SWOT analysis - Hydrogen production

	Hydrogen Production		
	Scenario 1 – Green route (electrolysis)	**Scenario 2 - Blue hydrogen from methane reforming**	**Scenario 3 – Importing hydrogen through carriers**
S	Feasible to cover NI requirements up to 2030; best suited to transport / fuel cells where high purity is required.	Provides lowest cost option until mid-2030; provides economy of scale, hydrogen volumes to kick start hydrogen economy.	Can be done readily via ammonia by ship, at low cost. Carrier ships have been developed capable of carrying liquified hydrogen as a commodity (but not yet utilised for this).
W	Costly route to hydrogen requiring significant investment.	Cost neutral to green hydrogen likely in mid 2030s; carbon neutral but not carbon free (up to 95% capture rates).	Lifecycle efficiencies poor; diluted, transport via shipping heavily pollutant. Potential boil-off of liquid hydrogen during transportation. Infrastructure to transport within the NI.
O	Can be scaled up as modules, organic growth model. Independence from grid for transport projects.	Less carbon impact is achieved by using existing infrastructure.	Ammonia (liquid form) or other forms of hydrogen carrier could be imported/exported.
T	Supply chain constrained, technology lacks scaling to larger module sizes, may miss net zero timescales.	Risk of greenwashing and supporting O&G industry.	True carbon accounting may be distorted or not justifiable.
Outcome: Scenario 1 (given relatively low hydrogen requirement for transport in NI and already strong balance of renewables in grid (~50%). It also provides a Net Zero pathway without a required switch in the future (e.g. Scenario 2 would be phased out in mid-2030's).			

Table 4-8 - SWOT analysis - Hydrogen storage

	Hydrogen Storage		
	Scenario 1 - Salt caverns	**Scenario 2 – Line pack pipeline**	**Scenario 3 – Local tanks / pressure vessels**
S	Huge relative storage volumes. Safe long-term storage.	Simple solution.	Commercially ready, easy to deploy to demand cases.
W	Length of time to leach new caverns and planning may miss Net Zero timescales. Repurposing is possible but not without technical challenges.	Due to low hydrogen density, high volumetric rates are needed to match Nat Gas energy content. This means line packing can only offer modest energy store or buffer to gas grid.	Small relative volume of storage takes up large footprint. Planning consent.
O	Security of supply, provides flexibility, possibly commercial opportunity in arbitrage.	UK 'Iron mains' upgrade project makes pipeline suitable for 100% hydrogen.	Can size to demand, and scale accordingly, can be relocated or removed (as required)
T	Not done yet at high pressures in UK.	The NI network is relatively small (compared to UK), so smaller relative storage.	Large hydrogen storage presents major accident hazard.
Outcome: Scenario 1 with 3 as required for local / off grid projects or as a buffer			

4.7. SWOT Analysis – Biomethane

Although Biomethane has not been selected as the preferred alternative fuel for any vehicle type, it is understood that there is a role for biomethane as the technology is readily available and makes use of circular economy gains; by converting waste (from agriculture, animal farming and landfill) into a source of energy, which provides 82-92% of the raw biomethane energy content. [15]

Rather than dissipating the greenhouse gases to the atmosphere as the waste breaks down, it is recommended that biomethane sources are fully mapped, quantified and developed into project opportunities.

More national investigation is needed to understand what the biomethane production and storage opportunities could look like in Northern Ireland. The biomethane could be applied and used in many different sectors, shipping being one of the sectors, which is likely to be one of the hardest areas of transport to be otherwise decarbonised.

A summary of the key findings that resulted from the SWOT discussion on biomethane production and storage is listed in Table 4-9 below.

Table 4-9 - SWOT analysis - Biomethane production and storage

	Biomethane Production and storage
	Scenario – Biomethane increase
S	Inexpensive; multi-use case (can be used for other purposes) to be combined with other fuels for other modes – down chain biochemical products (bio-polymers); avoidance costs.
W	Obsolete for transport; timely / technical limitations to on–demand applications; requires back-up storage.
O	Re-direct to other uses; off-sets carbon imports of natural gas / LNG and decarbonising shipping activity inherent.
T	Requires 10 times more capacity (at a minimum).
Outcome: The biomethane scenario discussed is to increase biomethane production and redistribute biomethane uses where it maximises decarbonisation in 'whole system', or hard to reach areas, e.g. from direct power generation to fuelling HGVs.	

5. Alternative Fuels Potential Achievable Take-up

5.1. Transport Demand and Distribution Infrastructure

For each vehicle under analysis in this study - HGVs, taxis, buses and rail - we proposed what the future fleet could look like in the timeline 2021-2035.

To define the baseline vehicle fleet composition, we consulted publicly accessible data sets and were informed by the previous chapter 'Northern Ireland Baseline'. We established the vehicle forecast scenarios based on published studies on the future uptake of alternative fuels from important institutions in the UK (Committee on Climate Change, Ricardo Energy, Translink, Low Carbon Vehicle Partnership[13]) and based on expert assumptions on what the most likely scenarios will be, given the current understanding of the technologies' maturity and the context of Northern Ireland. We also consulted our pool of experts in several engagement activities throughout the present study to advise.

We established the forecast scenarios taking into account the context of different parts of NI, considering the inferences of a mixed territory with urban areas such as Belfast metropolitan area and Londonderry, but also including cross-border linkages such as Newry , and more rural areas of NI.

In the following sections we present the approach developed for each mode to define the baseline and the future transport demand. We also present the methodologies developed to estimate the indicative energy requirements and the suggested distribution infrastructure of public charge-points and gas/hydrogen refuelling stations required to support the alternative fuelled fleet along the timeframe 2020-2035.

The combined energy demand estimates for HGVs, taxis and buses informed the production and storage capacity required in Northern Ireland along the timeframe 2020-2035 which is presented in section 5.2. The energy demand required for rail has not been considered as part of the present research work.

Figure 5-1 summarises the complexity of the task described above and makes evident the number of iterations explored to gather the energy demand for the four transport modes. This figure also highlights the three applications of the energy demand data: including the estimation of distribution infrastructure and production and respective storage required to support the level of demand. It should be noted that the refuelling and recharging infrastructure requirements vary across transport mode, due to varying geographic distribution, distinct duty cycles and service needs.

[13] now named Zemo Partnership

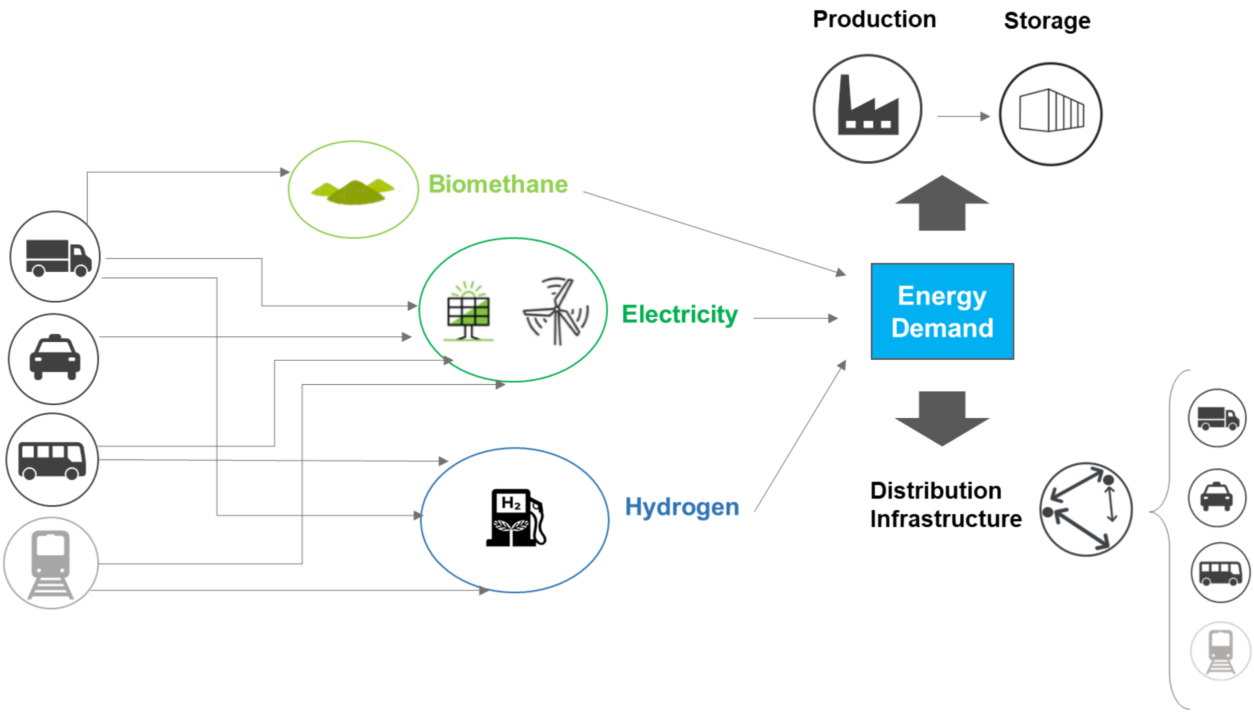


Figure 5-1 - Methodology to estimate energy demand required by future alternative fuelled fleet and its application (source: Atkins)

5.1.1. HGVs

5.1.1.1. Baseline and Forecast Scenario

The vehicle baseline and overall structure of the vehicle parc[14] for HGVs has been developed using the following data sets:

- VEH0105 – Vehicle parc registrations UK.
- DfI Driver vehicle operator and enforcement statistics: Section 6 road transport licensing – HGV registrations in NI.
- VEH0506 – Rigid and Artic relative split by Gross Vehicle Weight within each vehicle type.
- Road Traffic Estimates (calendar year 2019) [106] – Annual average mileages.
- Using a third party forecast [7] for the total number of HGVs (all fuel types) expected to be registered in the UK from now to 2035. Apply these factors pro rata to Northern Ireland to forecast the total future HGV vehicle numbers.
- The split of Rigid vs Artic vehicles has been taken as 43:57 as per the 2014 figures shown in the DfI statistics.

For HGVs (rigids and articulated vehicles) two forecast scenarios have been developed:

- Scenario 1 – Hydrogen dominates: Higher uptake of hydrogen fuel cell vehicles based on data in the 6th Carbon Budget by the Committee on Climate Change (CCC) released in December 2020 [107]. The "hydrogen dominates" scenario represented in Figure 5-2 follows the figures stated below:

[14] Vehicle parc refers to the number of vehicles in a region

- Zero-emission vehicles (ZEVs) to make up 96% of new sales of HGVs by 2035 (42% battery electric, 54% hydrogen fuel-cell) and almost 100% by 2040.
- There to be around 170,000 zero-emission HGVs and coaches (approximately 33% of the fleet) in operation by 2035, rising to 67% of the fleet by 2040.
- Biodiesel to meet 10% of HGV/bus diesel demand by 2040.

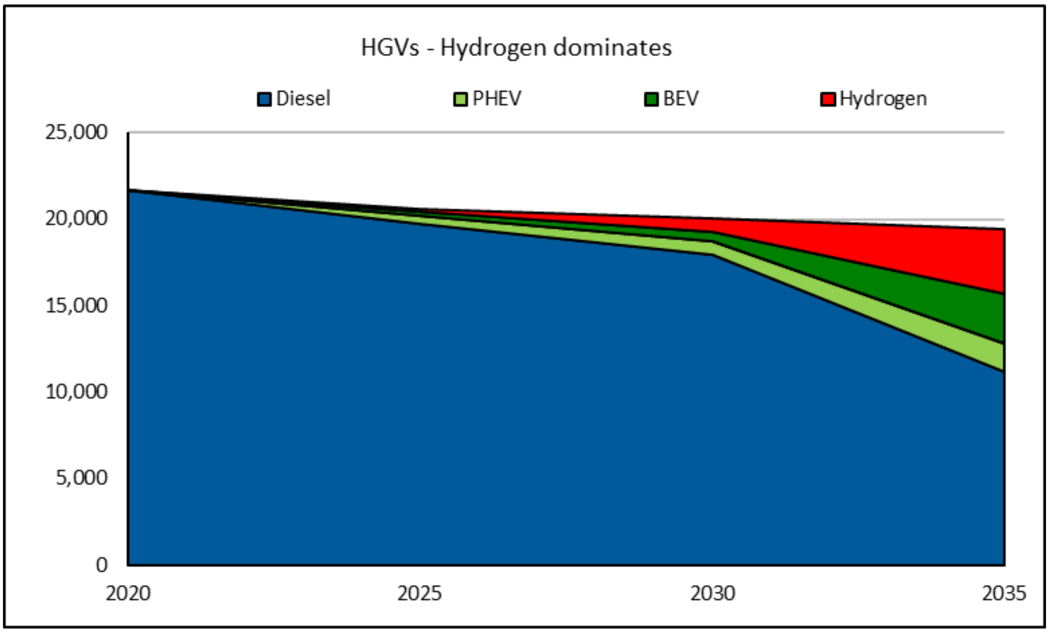


Figure 5-2 - HGVs forecast scenario 1: hydrogen dominates (source: Cenex)[15]

- Scenario 2 – Biomethane/Gas dominates: Higher uptake of gas-powered vehicles using forecasts developed by Element Energy for the Low Carbon Vehicle Partnership now Zemo Partnership - The “gas dominates” scenario predicts a diverse mix of fuels to displace diesel with biomethane having the largest market share. Key figures are stated below and are represented in Figure 5-3:
  - Gas (primarily biomethane) to meet 25% of HGV demand by 2040
  - Hydrogen to meet 10% of HGV demand by 2040
  - Electric to meet 20% of demand by 2040
  - Biodiesel to meet 6% of demand by 2040

[15] PHEV stands for Plug-in Hybrid Electric Vehicle and BEV for Battery Electric Vehicle. A full list of acronyms can be found in the **Glossary of Terms** on **page v**

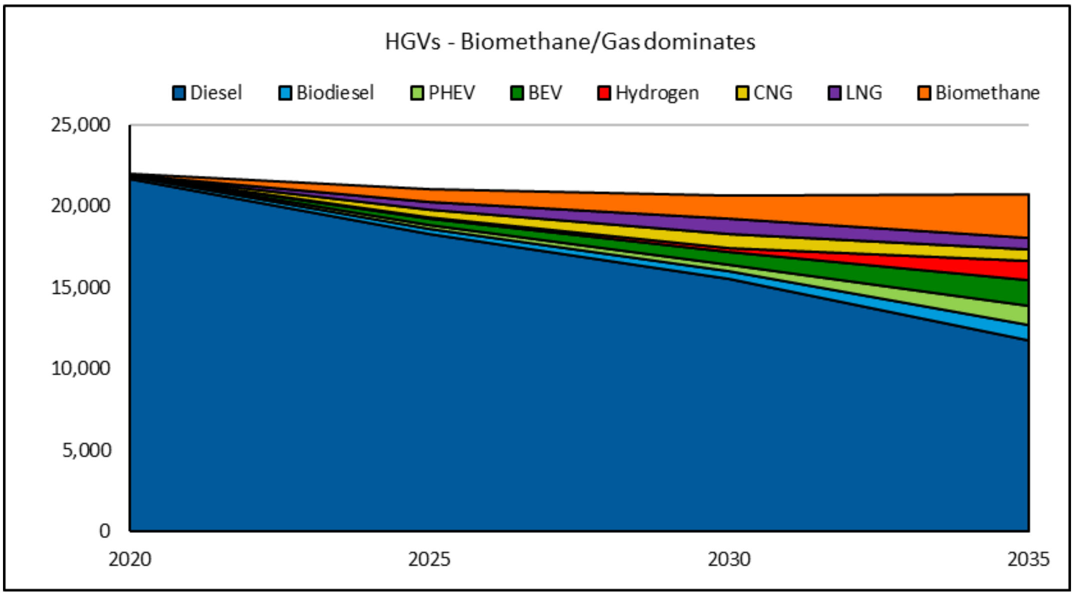


Figure 5-3 - HGVs forecast scenario 2: biomethane/gas dominates (source: Cenex)

Figure 5-4 summarises of the relative uptake of each alternative fuel under each forecast scenario, which shows that even in 2030, the share of alternative fuelled vehicles is relatively low, with diesel still making up the greatest proportion of the vehicle parc.

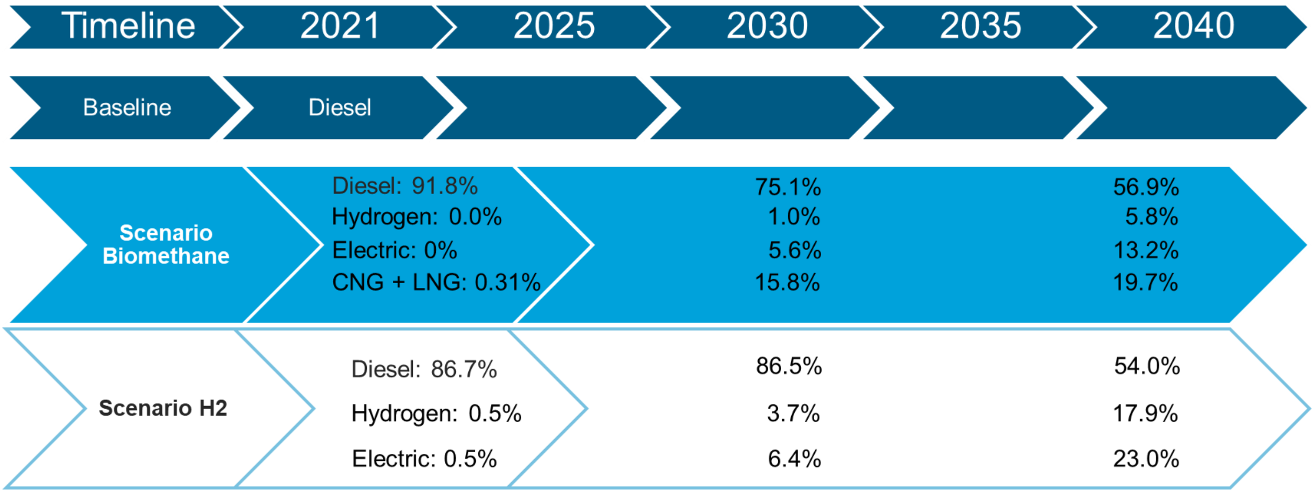


Figure 5-4 - Relative uptake of alternative fuels under each HGV forecast scenario (source: Atkins)

For each scenario, Scenario 1 - Hydrogen dominates and Scenario 2 – Biomethane dominates, the number of vehicles of each fuel type, required energy demand, and required public infrastructure were worked through to 2035.

5.1.1.2. Energy Demand Calculation

The total demand has been estimated for alternatively fuelled HGVs in 2035 for both scenarios (Hydrogen and Biomethane dominate scenarios) and a high-level indicative estimate for the number of charge-points and gas/hydrogen refuelling stations needed to service this demand.

To calculate the energy demanded for the future HGV park the following steps were completed:

1. Convert total vehicle mileage for all HGVs, as modelled in the baselining, into litres of diesel equivalent using fuel economy figures provided from UK Government datasets Table TSGB0304 (ENV0104) [108].

2. Convert litres of diesel equivalent into energy demand (MJ) using Defra's fuel energy density figures [109].

3. Convert energy demand (MJ) to volume of alternative fuels using Defra's fuel energy density figures and vehicle energy consumption from Cenex's proprietary Fleet Advice Tool.

The energy demand calculations inform both the alternative fuels distribution infrastructure (section 5.1.1.3) and the energy demand (section 5.2) section.

5.1.1.3. Distribution Infrastructure

To estimate the infrastructure requirements for HGVs several assumptions were made for each fuel type, as presented below.

Biomethane / Gas Infrastructure

The following assumptions have been made:

- It is estimated that 60% of refuelling will be done at depot and 40% at public stations. This is as per the current estimated split of depot vs public diesel refuelling researched during the Midlands Connect Strategy research work carried out by Cenex and Atkins in 2019.

- Gas demand will be split equally between CNG and LNG (which can be sourced from biomethane).

- Gas station capacity will be 25,000 kg per day. This is the upper end of capacity for stations available now, but we predict this would become standard if more gas vehicles were on the road.

- Daily gas station utilisation will be 50% of total capacity as estimated by CNG Fuels.

Using the forecasts for energy consumption and the above assumptions, the model estimates the number of gas stations required to meet demand.

Hydrogen Infrastructure

The following assumptions have been made:

- It is estimated that 30% of refuelling will be done at depot and 70% at public stations. This is half the rate of depot refuelling as for diesel or gas, reflecting the fact that hydrogen is a lower maturity technology and so the roll-out of depot infrastructure is likely to be slower.

- Hydrogen station capacity will be 5,000 kg per day [107]. This is towards the upper end of capacity for stations available now but is likely to become standard if more hydrogen vehicles were on the road.

- Daily station utilisation will be 50% of total capacity, as per the gas station utilisation forecast.

Using the forecasts for energy consumption and the above assumptions, the model estimates the number of hydrogen stations required to meet demand.

EV / Charge point Infrastructure

The following assumptions have been made:

- It is estimated that 97.5% of recharging will be done at depot and 2.5% at public sites. This is adapted from Ricardo's (2019) forecast that 100% of HGV charging will be at depot. We expect some public charging to take place.
- HGVs will use an even split of 50kW and 150kW charge points.
- Each charge point will provide an average of 12 charging events per day, each of 60 minutes duration. There is a lack of data available showing likely charge point utilisation rates; an assumption was made based on Cenex's experience in analysing the future network usage patterns.

Using the forecasts for energy consumption and the above assumptions, the model estimates the number of 50kW and 150kW charge points required to meet demand.

The alternative fuel distribution infrastructure for all HGVs (artics and rigids) in 2030 and 2035 is presented below for each scenario in the table below.

Table 5-1 - HGVs infrastructure requirement in 2030-2035 for scenario 1 (hydrogen dominates) and scenario 2 (biomethane/ gas dominates)

	HGVs refuelling/ recharging Infrastructure				
Year	**50 kW**	**150 kW**	**Hydrogen**	**Bio-CNG**	**Bio-LNG**
Scenario 1 - Hydrogen dominates					
2030	29	11	6	-	-
2035	122	41	23	-	-
Scenario 2 – Biomethane/ Gas dominates					
2030	29	11	2	6	6
2035	58	20	8	8	8

Unlike for other modes, the uptake of alternative fuelled HGVs will take longer to have a meaningful impact, hence the required infrastructure will only be required at scale from 2030 onwards.

5.1.2. Taxis

5.1.2.1. Baseline and forecast scenario

The vehicle baseline and overall structure of the vehicle parc for HGVs has been developed using the following data sets:

- VEH0105 – Vehicle parc registrations UK.
- DFI Driver vehicle operator and enforcement statistics: Section 6 road transport licensing.
- Road Traffic Estimates (calendar year 2019) – Annual average mileages.

An assumed target date for the taxi fleet being zero emission has been taken as 2035. This is an ambitious date, though plenty achievable, with local authorities such as Cambridge stating a target date of 2028 for a fully zero emission and ULEV fleet and Nottingham stating 2030. These cities already have policy and legislation in place for low and zero emission taxis and so 2035 is considered a sensible target date for NI, given there is no policy in place to incentivise the uptake of alternative fuelled taxis in NI.

Only one scenario is proposed for Taxis, with the assumption that all vehicles will be convert to electric by 2035. Given the market, and favourable costs of EVs vs hydrogen vehicles, it is highly unlikely that any hydrogen taxis will exist in NI.

A standard s-curve has been drawn between 2021 and 2035 to indicate a possible uptake rate for EV taxis, as shown in Figure 5-5, though this will be heavily driven by policy and the shape of the curve will change dependant on how strict this policy is.

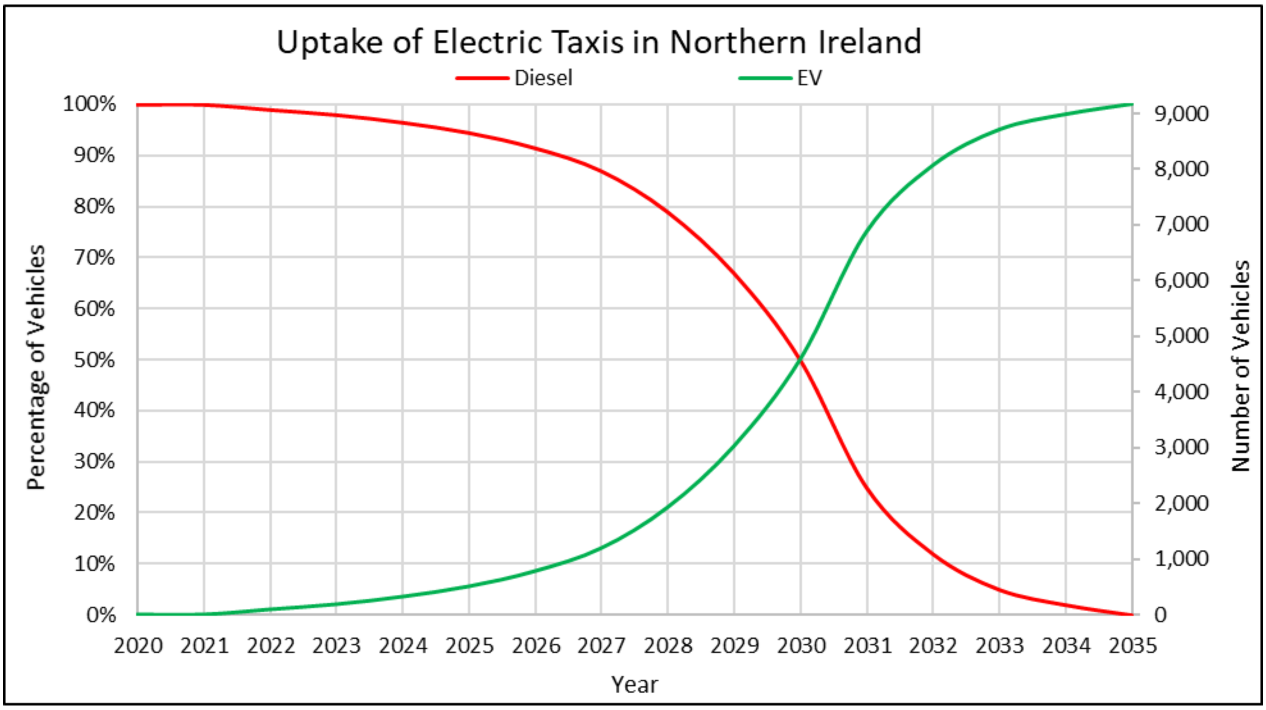


Figure 5-5 - Taxis forecast scenario: uptake of electric vehicles (source: Cenex)

For the EV taxis uptake scenario, the number of vehicles, required energy demand, and required public infrastructure were worked through to 2035.

5.1.2.2. Energy Demand Calculation

In order to calculate the energy demanded for the future Taxi parc the following steps were completed:

1. The average annual mileage for taxis has been taken from the Taxi Strategy for the South East Wales [110]. This strategy states an average annual mileage of 25,000 miles per vehicle. Cenex conducted many surveys across the Wales region, which is thought to be similar to the NI region.
2. Convert the mileage of the vehicles for diesel and electricity into fuel required and energy demand using Cenex's own proprietary fleet advice tool for equivalent miles per fuel unit

5.1.2.3. Distribution Infrastructure

In order to inform the distribution infrastructure requirements we assumed that 70% of all charging is done at home by the taxi owners [111][16]. The remaining 30% of charging will be done at public charge points where we assumed 50 kW chargers will be required for fast charging of the vehicles and are utilised for 8 hours per day. This follows the approach of the taxi strategy for Dundee City Council, which is considered the leader in the UK for zero-emission taxi deployment.

Table 5-2 - Distribution infrastructure for forecasted taxi fleet

Year	Number of Taxis		Public Charge points required*
	Diesel	EV	
2020	9,164	0	0
2025	8,660	504	8
2030	4,582	4,582	71
2035	0	9,164	141

* assumes 70% of all charging is done at home and public charge points are 50kW utilised for 8 hours per day

5.1.3. Buses

5.1.3.1. Baseline and forecast demand

The vehicle baseline and overall structure of the vehicle parc for HGVs has been developed using the following data sets:

- VEH0105 – Vehicle parc registrations UK.
- DFI Driver vehicle operator and enforcement statistics: Section 6 road transport licensing.
- NI Transport Statistics 2019-2020 [85] – Annual average mileages.
- School transport has been excluded from this analysis.

Due to the high-level nature of this study, it was proposed that rather than providing a modelled scenario (based on detailed analysis of current duty lengths and demands), we defined the proposed zero emission bus scenario based on broad principles of current industry trends and commitments made by major operators and tailored to the local context to better reflect the NI situation as appropriate.

[16] National Travel Survey, Table NTS0908

Shifting buses to Zero Emissions (ZE) will depend a lot on technology, and how this continues to develop over the next 10-15 years.

An assumed target date for the bus fleet being zero emission has been taken as 2035. This is an ambitious date, though plenty achievable, with cities such as Coventry and the Cardiff capital region stating earlier target dates of 2026 and 2028, respectively. These cities already have policy and legislation in place for low and zero emission buses and so 2035 is considered a sensible target date for NI.

Only one scenario is proposed for the ZE bus uptake with an equal split between EV and hydrogen buses by 2035.

The split of EV to hydrogen vehicles proposed of 50:50 for NI meets the specific localised context of NI, considerably different to GB which is more likely to follow a 95 electric: 5 hydrogen split due to a more urban bias. This increase in hydrogen uptake in NI takes into account that of the 1,400 buses in NI, 1,000 of these cover semi-urban and rural routes, requiring higher daily ranges that would likely move to hydrogen. Further justification for the proposed split is stated below:

- Hydrogen refuelling infrastructure is expensive and has considerable safety requirements (more onerous than diesel), and so may not be possible at every depot. There are also implications on the depot infrastructure itself – the maintenance buildings may need modification or even demolition and reconstruction to incorporate the necessary safety features to look after hydrogen fleets.

- Electric bus battery range is rapidly improving, and so future electric buses may be suitable where they might not be today.

- It might be that neither battery nor hydrogen technology affordably gets to the current position with diesel, and therefore there will be a need for Translink to review their operations to determine what changes need to be made (e.g. swapping vehicles out to recharge during the day; provision of opportunity charging, perhaps at schools, so the buses can top-up charge whilst waiting for the children; some routes might need to be amended to better suit one type of vehicle; different patterns of interworking services may be better to align combined packages of routes to different vehicle/fuel types).

- Reviews should also extend to Translink's depot estate – working out whether it is sensible to have mixed depots, or shuffle routes around to have depots with only one vehicle type. This also extends to heavy maintenance – training depot staff to deal with electric or hydrogen buses will be expensive, so may be better focussed on a smaller number of specialist locations.

- We suggest maintaining a watching brief as to what is happening in Wales and Scotland, and perhaps rural areas of north and south-west England, to provide benchmarking for Translink's more rural operations and where trends are heading, particularly given geography and topography of these locations and similarities with NI.

A standard s-curve has been drawn between 2021 and 2035 to indicate a possible uptake rate for zero emission buses, though this will be heavily driven by policy and the shape of the curve will change dependent on how strict this policy is. It is known from conversations with Translink that in 2022 there will be 80 electric buses and 20 hydrogen buses in service and so this has been accounted for in Figure 5-6 below.

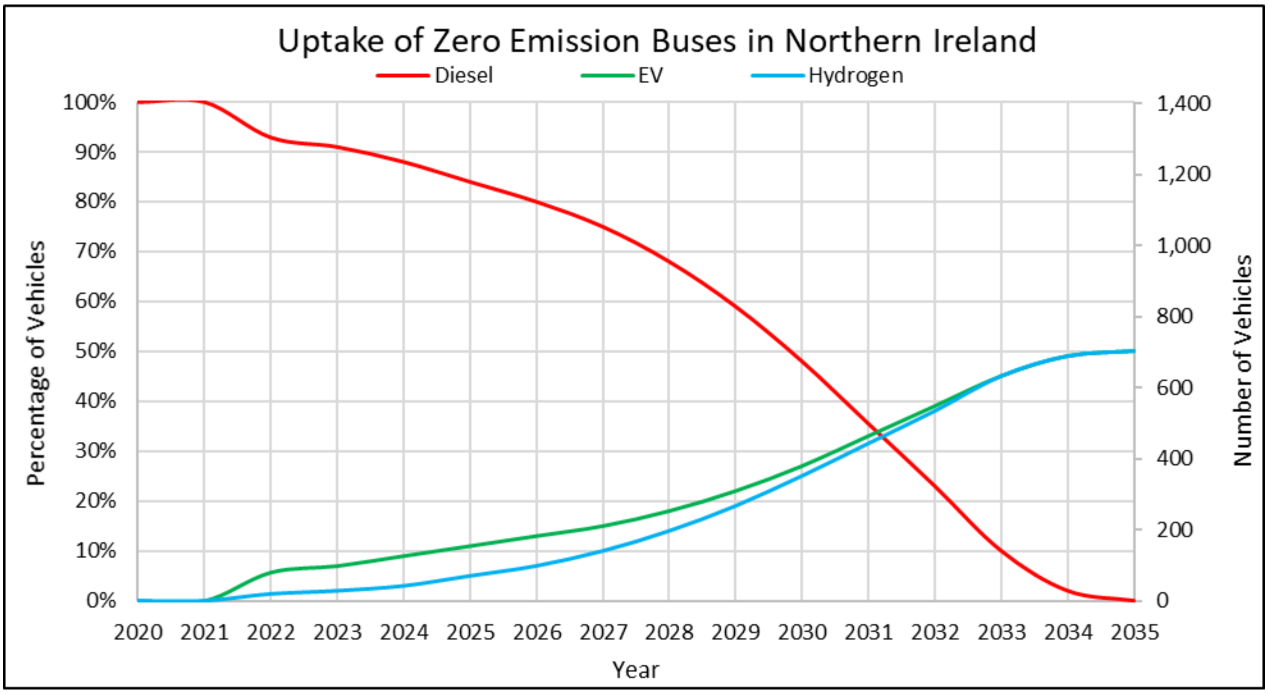


Figure 5-6 - Buses forecast scenario: uptake of zero emission buses (source: Cenex)

For the EV -Hydrogen split uptake scenario, the number of vehicles by fuel type, required energy demand, and required public infrastructure were worked through to 2035.

5.1.3.2. Energy Calculation

In order to calculate the energy demanded for the future zero emissions Bus fleet the following steps were completed:

1. The total bus mileage of 42,400,000 miles has been taken from the DfI transport statistic tables [85] and the average annual mileage calculated given the number of registered vehicles. This gives an average annual mileage of 30,178 miles per bus.
2. Converting the mileage of the vehicles for diesel, electricity, and hydrogen into fuel required and energy demand using the Zemo low emission bus certificates for equivalent energy demand per mile [112].

5.1.3.3. Distribution Infrastructure

We established the distribution infrastructure requirements founded on the assumption of a 1:1 ratio for EV buses and charge points, and the assumption of 2,000 kg daily capacity for hydrogen refuelling stations. The charge points will likely be required to provide a minimum charging speed of 50 kW.

Table 5-3 summarises the required distribution infrastructure for buses in the timeline 2020-2035. All refuelling will likely be done at bus depots; it is likely that the depot locations may require to be re-assessed in line with the high electricity requirements of EV and hydrogen refuelling infrastructure.

Table 5-3 - Distribution infrastructure required for forecast bus fleet

Year	Number of Buses			Charge points required at depot	HRS stations required at depot*
	Diesel	EV	Hydrogen		
2020	1,405	0	0	0	0
2025	1,180	155	70	155	1
2030	675	379	351	379	4
2035	0	703	702	703	8

*Dependant on spread over depots of hydrogen vehicles, assumed 1,000 kg daily use (on Hydrogen refuelling Stations with 2,000 kg daily capacity.

5.1.4. Rail

Whilst the timescales of this report focus on 2035 delivery, for rail we are looking towards 2040 but with an interim target in 2035. The literature review validates the general preference for rail electrification, hence all three scenarios include electrification. However, due to the infrastructure requirements and rolling stock procurement necessary, it is unlikely that Northern Ireland's entire rail network would be electrified by 2035, therefore, three alternative scenarios have been considered with the end goal for electrification being 2040 (Figure 5-7):

- Scenario 1 – electrify 50% of the network by 2035, and the remaining 50% by 2040. The 50% of the network that was not electrified by 2035 would still use diesel trains.
- Scenario 2 – electrify 50% of the network by 2035 and the remaining 50% of the network will use battery-electric hybrid. Full electrification of the remaining network will take place by 2040.
- Scenario 3 – electrify 50% of the network by 2035 and the remaining 50% of the network will use hydrogen technology.

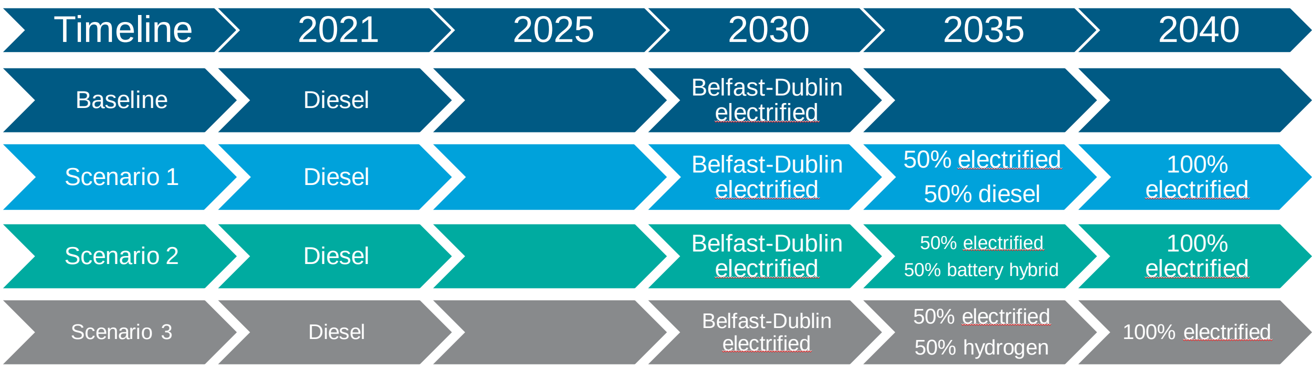


Figure 5-7 - Rail forecast scenarios (source: Atkins)

There is an assumption that Belfast-Dublin will be electrified by 2030 given this route is already under consideration.

5.1.4.1. Baseline and forecast demand

Forecasting rail energy demand is an extremely complex task and in order to provide an estimated quantitative figure, further work outside the scope of this study is required to understand the energy demand for each scenario, including rated peak performance and charging requirements. However, we can affirm with certainty that increased capacity would be needed at strategic points of the rail network to accommodate the electricity requirements from a zero-emission electric train fleet.

5.1.4.2. Energy Demand Calculation

Instead, a high-level view of the likely scale of energy demand for the railway has been estimated, with the intention of providing an order of magnitude only rather than detailed information:

i. Annual vehicle miles for NIR and annual train miles for Enterprise, for 2018/19
ii. Conversion to estimated total annual diesel consumption in base case, using average diesel consumption rates supplied by Translink for a Class 3000 / 4000 diesel multiple unit (for NIR) and a Class 201 locomotive (for Enterprise)
iii. Conversion to a range of potential annual electricity consumption (kWh), based upon data from a range of electric multiple units. This assumes that diesel multiple units and Enterprise loco-hauled sets will be replaced by electric multiple units of an equivalent length.

It should be noted that electricity consumption varies depending upon speeds, gradients and other operating characteristics, as well as the variance for battery versus electric traction. This is being considered as part of a separate 12-month commission for DfT.

For the purposes of this study a range has been presented on Table 5-4 to indicate order of magnitude relating to electric traction of the forecast scenario where the Northern Ireland rail network (and the cross-border route to Dublin) is fully electrified. To note that this estimate does not account for any future increase in train mileage on the network, e.g. doubling the frequency of the Enterprise service.

Table 5-4 - Indicative scale of annual rail energy demand, based on 2018/2019 annual mileage

	Annual (approximate figures)
Vehicle mileage (baseline NIR)	10.2m miles
Train mileage (baseline Enterprise)	0.6m miles
Vehicle mileage (forecast NIR + Enterprise)	15.3m miles
Diesel consumption (baseline)	c.17m litres
Electricity consumption (forecast)	c.55-80m kWh

5.1.4.3. Distribution Infrastructure

For full electrification, Overhead Line Equipment provides power directly to the electric trains, whereas battery-electric bi-mode traction would draw power from the wires where available and be self-powered by battery where not. A series of feeder stations would be required, however the locations of these would be dependent on many factors which are not part of this study.

5.2. Alternative Fuel Production and Storage

In the previous section 5.1 we presented the methodology developed to estimate the alternative fuels requirement by transport mode (HGVs, taxis, buses and rail). The alternative fuels estimates were then combined as the total fuel use for each alternative fuel.

The methodology developed by Cenex for road transport (HGVs, taxis and buses) was as follows:

- Estimated total miles, in millions per year.
- Conversion of 'total miles' to million litres diesel equivalent; using BEIS conversion of 0.5162 equivalent Litres diesel per mile.
- Conversion to Energy content (MJ); using DEFRA fuel energy density figures.
- Converted to fuel demand in equivalent units for each alternate fuel considered (kg, L , kWh).

This approach was used to estimate the total fuel demand case for HGVs, taxi and buses at key milestones in the timeline, as shown in Table 5-5.

The energy demand required for rail has not been considered as part of the present research work. However, based on high level estimation it is likely that rail energy demand will approximately require between 10-15% increase to the total energy demand required in 2035 presented in Table 5-5, according to the figures presented in Table 5-4 in the previous section.

Rail electrification was excluded from the transport demand assessment, due to availability of data and the complexity of this topic, which is being investigated through separate commissions. As described in section 5.1.4.1 the nature of rail charging infrastructure may be misrepresented by looking at kWh or energy consumed alone, as the importance of fast charging means a requirement for high voltage/current charging infrastructure, grid reinforcement and network reinforcement local to the train stations. This would require a detailed assessment to establish an accurate energy demand required. An order of magnitude estimation was made for the NI electrification network, which provides an initial high-level estimate only.

Table 5-5 provides an indication of the level of new production that would be needed to meet the transport demand cases (see section 4). These are for comparison only, and further assessment of optimal technology selection, siting and integration to existing infrastructure would be recommended.

Table 5-5 - Total alternative fuel demand cases 2020 to 2035

		2020	2025		2030		2035	
Fuel	**Units**	**Baseline**	**Low**	**High**	**Low**	**High**	**Low**	**High**
Diesel	litres	664,521,228	589,897,081	642,037,300	504,691,265	592,671,885	-	382,846,666
Biodiesel	litres	6,846,051	12,012,954	13,729,091	17,314,919	20,777,903	30,563,410	42,961,995
Electricity	kWh	1,954,834	69,633,786	73,263,630	172,313,873	175,521,296	346,814,703	632,650,064
Hydrogen	kg	-	718,982	1,436,266	2,808,837	7,104,702	12,009,999	31,523,737
CNG	kg	1,083,885	543,407	17,555,319	-	34,328,262	-	29,677,546
LNG	kg	1,083,885	543,407	17,555,319	-	34,328,262	-	29,677,546
Bio-methane	kg	660,654	331,219	27,119,306	-	54,055,561	-	105,779,923

Figure 5-8 presents the summary total for each alternative fuel. For clarity, the assumptions used are as follows:

- **Biomethane** combined includes CNG and LNG. Although these sources may not use biofuel sources, if they can be offset with biomethane in the form of Bio-CNG and Bio-LNG, there is the direct carbon saving, and additionally the indirect benefit of not requiring LNG imports (e.g. shipping).

- **Hydrogen** fuel assumptions are based on pure H_2, or 120MJ/kg. It is noted that several production sources deliver lower calorific fuel (low LHV) than natural gas (of approx. 47MJ/kg), where higher volumetric quantities are therefore needed to match the thermal demand. The quantities presented (kg) could therefore be higher if a less than 'very high purity' hydrogen is not available.

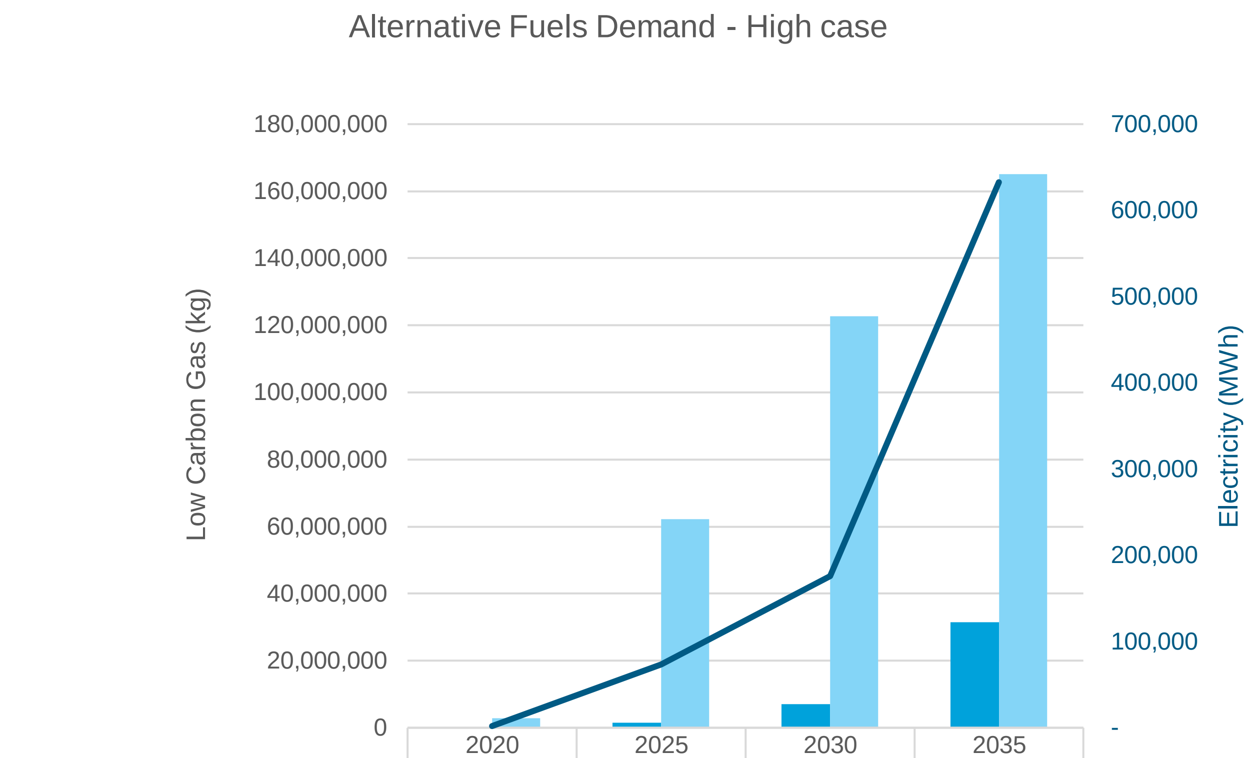
- The **hydrogen** for propulsion of vehicles is assumed via fuel cell electric drive train only, and H_2 combustion or hybrid options were excluded from the study scope. It should be noted that the combustion method provides a market ready solution for diesel HGV fleet, but will only be an intermediate or short term solution.

- **Electricity** is presented as an annual energy requirement in kWh, but it is noted that the electrical requirement will require greater investigation into the demand profile, peak power requirement (kW) and suitable grid reinforcements needed.

- It is noted that if **hydrogen** is produced through Green H_2 route, this would impose additional electrical demand on the grid. This has not been assessed as part of the demand cases in Table 5-5.

Hydrogen Technical characteristics: It should be noted that the energy content of H_2 streams is commonly misunderstood. H_2 has a very high energy density by mass, yet has a very low molecular size, so when the hydrogen is less than very high purity levels, the energy content by volume decreases rapidly. For instance, a 90vol% H_2 'Blue' stream through methane reforming, may sound like 90% clean, but the LHV value could be less than Natural gas, therefore requiring 3x the 'throughput' or production to match a Natural gas application, which may be difficult to achieve.

For each alternative fuel, the highest demand case was taken for each fuel (see Table 5-5) which gives the following summary annual demand cases presented in Figure 5-4. The energy scenarios were assessed as part of a SWOT analysis workshop and key outcomes from the SWOT discussion were used to inform the energy demand scenarios.



	2020	2025	2030	2035
Hydrogen	0	1,436,266	7,104,702	31,523,737
Biomethane sources combined	2,828,425	62,229,944	122,712,085	165,135,015
Electricity	1,954	73,264	175,521	632,650

Figure 5-8 - Summary of the total alternative fuels demand – high case (source: Atkins)

To meet these demand cases, we considered typical examples of production and storage options for each alternative fuel type. It is noted that the storage requirement is less than the annual demand case, but storage would be needed in each case for several reasons, including security of supply to arbitrage fuel cost, as a buffer from transmission/distribution.

In the following subchapters we examined the indicative production and storage solutions required to meet the demand for the energy types analysed in this study – electricity, hydrogen and biomethane. Due to the variety of energy production and storage options available a Red-Amber-Green assessment (RAG assessment) was conducted; and each option was classified according to the classification presented on Table 5-6.

Table 5-6 - Key energy RAG assessment

	Option can meet demand criteria for milestones (in Figure 5-8). The production or storage estimate (kWh) meets the demand case, or can meet it with multiple(s) of option.
	Option partially meets demand criteria for milestones (in Figure 5-8). The option is constrained by min. construction timescales or challenges to scale the technology.
	Option unlikely to meet demand criteria for milestones (in Figure 5-8). Option provides insufficient production capacity or depth/duration of storage.

5.2.1. Electricity

The examples shown in Table 5-7 indicate the scale of new electrical generation needed to meet the transport demand. The examples given in the options are typical electrical generation options and give an indication of the size in rated power (MW) of the renewables needed. These are based on existing or new generation as given in the comparative examples. It is noted that Galway Wind Farm by comparison is approx. 169MW and is the largest onshore in ROI. For major infrastructure projects like this, the construction timescales with planning would be 5 years as a minimum. This is recognised by the Amber scoring for some options. However, where the option is based on an existing project, the timescales to commissioning may be accelerated.

Table 5-8 shows the indicative scale of new energy storage solutions to guarantee security of supply to meet the transport demand.

Table 5-7 - RAG assessment of alternative fuels - electricity production

Electricity Production options				RAG assessment			
Option	**Indicative production**	**Typical annual generation**	**Comparative example equivalent to:**	2020	2025	2030	2035
Production #1	50MW wind farm (assumes 30% availability)	131,400 MWh	Slieve Rushen Wind Farm, NI (54MW)	Challenge to build in timescale	2x option needed	4x option needed	4x +++ option needed
Production #2	200MW interconnector (assumes 50% availability)	876,000 MWh	Planned HVDC connection to NI, 200MW	Challenge to build in timescale			
Production #3	CCGT + CCS, 400MW (assumes 40% availability)	700,000 MWh	Coolkeeragh power station, 408MW CCGT	Challenge to build in timescale			

Table 5-8 - RAG assessment of alternative fuels - electricity storage

Electricity storage options				RAG assessment			
Option	**Indicative storage**	**Typical annual storage**	**Comparative example equivalent to:**	2020	2025	2030	2035
Storage #1	50MW battery storage farm (supporting renewables)	~200MWh	Gore st battery storage, NI (50MW)	Partially			
Storage #2	Hydro power increase capacity, 360MW	720,000 to 1,600,000MWh	Silvermines Hydro project[17]				
Storage #3	Novel ES tech. Like LAES, CAES, Flow battery or other, 200MW	1,200 MWh	Based on Highview power demonstrator, GB		challenge to scale	challenge to scale	challenge to scale

5.2.2. Hydrogen

For the hydrogen scenarios the two main H_2 production sources were considered, and typical electrolyser datasheets were considered by leading UK manufacturers. For the blue H_2 production, a comparative methane reformer unit was assumed from the UK HyNet or Acorn leading industrial cluster projects. It is very likely a combination of all three storage options would be needed, but the unique geology, near Belfast, lends a specific opportunity for H_2 storage at scale in salt caverns. However, the construction process for salt caverns is lengthy

[17] Based on the proposed 'Silvermines' 360MW project in early planning [117]

and would need to be started as early as possible. In addition, further investigation is needed on the capacity and suitability for hydrogen storage at this site.

Table 5-9 and Table 5-10 show the indicative scale of new hydrogen production and storage solutions required to guarantee the safety of supply to meet the transport demand.

Table 5-9 - RAG assessment of alternative fuels - hydrogen production

Hydrogen production options				RAG assessment			
Option	**Indicative production**	**Typical annual generation**	**Comparative example equivalent to:**	2020	2025	2030	2035
Production #1	green H_2 focus, on local container solutions	~150,000kg	Estimate from electrolyser OEM datasheets for 1MW	Challenge to build in timescale			Challenge to scale
Production #2	blue H_2 via SMR or ATR	78,840,000kg per module	thermal reformer technology to HyNet & Acorn projects	Challenge to build in timescale			
Production #3	Import via gas pipeline	Not limited	SNIP pipeline to GB				

Table 5-10 - RAG assessment of alternative fuels - hydrogen storage

Hydrogen storage options				RAG assessment			
Option	**Indicative storage**	**Typical annual Storage**	**Comparative Example:**	2020	2025	2030	2035
Storage #1	Islandmagee salt cavern storage	120,000MWh possible per cavern	Planned salt cavern construction ongoing at Islandmagee	Challenge to build in timescale		Multiple caverns may be needed	Multiple caverns may be needed
Storage #2	Linepack in gas grid	Limited by pipe network length	NI gas grid				
Storage #3	Local (pressure vessel) tanked option.	Can be scaled accordingly to medium scale.	Examples at all major industrial clusters.				

5.2.3. Biomethane

The biomethane scenarios are based on scalars of the existing Anaerobic Digestion production. It is shown that a 10-fold increase, from 78 plants to 780 plants, would be difficult to achieve the 2035 demand. This increase in production could be achieved by fewer larger plants, but feedstock sourcing may still be a significant challenge. It is therefore likely that biomethane production would need supplemented with other biofuel sources/feedstocks. For biomethane storage, when biomethane is blended in the gas grid the gas supply can use existing storage options, however NI urgently needs a regulatory framework that facilitates the injection of biomethane into the natural gas network.

Table 5-11 and Table 5-12 show the indicative scale of new biomethane production and storage solutions required to guarantee the safety of supply to meet the transport demand.

Table 5-11 - RAG assessment of alternative fuels - biomethane production options

Biomethane production options				RAG assessment			
Option	**Indicative production**	**Typical annual generation**	**Comparative Example**	2020	2025	2030	2035
Production #1	redirect all AD plants to biogas for fuel	281,000 MWh	Existing AD plants in NI		challenge to scale		
Production #2	increase AD plants 10 fold.	2,810,000 MWh	Theoretical 10fold increase				
Production #3	increase AD plants 10fold, plus explore other fuel sources	3,372,000 MWh	Theoretical 10fold increase + other fuel stocks				

Table 5-12 - RAG assessment of alternative fuels - biomethane storage options

Biomethane storage options				RAG assessment			
Option	**Indicative storage**	**Typical annual Storage**	**Comparative Example**	2020	2025	2030	2035
Storage #1	Use National grid storage infrastructure (e.g. caverns, linepack) through Grid injection	Limited by pipe network length	NI gas grid				
Storage #2	Local tanked option + Supply/demand balancing	Limited by safety case and site footprint	Examples at all major industrial clusters.		challenge to scale	challenge to scale	

6. Action Plan and Assessment Framework

Structure of the Action Plan

From undertaking this research study and through extensive engagement between the subject matter experts in the transport and energy sector we proposed an Action plan setting the critical path in the 2021-2035 timeline for the adoption of alternative fuels for HGVs and passenger vehicles in Northern Ireland.

We developed short, medium- and longer-term practical measures for transport, general but also specific to each mode to achieve the adoption, use and distribution of alternative fuels by 2035. Equally we proposed short to long-term measures for the energy sector, aligned with the transport objective of progressing the decarbonisation agenda in the 2021-2035 timeline.

These short to long-term measures are classified in a three-scale colour code (as per Table 6-1) against the 2021-2035 timeline in 5-year intervals according to level of action required in each the period, reflecting the urgency but also technology readiness of the solution.

Table 6-1 - Timeline key

Timeline	Action required	Some level of input/action is required	Minimal action required in this period

We grouped the transport related measures in six key areas of action:

- T0 - Climate change target for NI
- T1 - Improve knowledge sharing and decision making
- T2 - Data collection, monitoring and evaluation
- T3 - Technology choice, demand management and behavioural change
- T4 - Incentivise transport operators to move towards a zero emissions fleet
- T5 - Improve distribution infrastructure

Each Transport measure has been assigned to one or more transport modes, according to the relevance of the proposed action to the specific mode.

Energy specific actions have been organised according to the energy type. One key action stands out which aims at setting clear climate change targets for NI energy system. The key energy actions are as follows:

- E0 - Climate change target for NI
- E1 - Electricity
- E2 - Hydrogen
- E3 - Biomethane

The Action Plan was developed to support the adoption of the proposed vehicle forecast scenarios whilst accounting for uncertainties about future market demand for alternative fuelled vehicles, future technology developments and planning of infrastructure delivery. For instance, many of the proposed actions/measures are flexible in the extent, stakeholders involved and even in the timeframe they are recommended to be implemented.

Assessment Framework

We complemented the Action plan with a high-level assessment of the proposed measures with the objective of distinguishing some of the key characteristics of each measure relevant to DfI.

We classified each measure against affordability, public versus private delivery responsibility, technical feasibility, market acceptability, political acceptability and contribution to carbon abatement.

For the technical feasibility, market acceptability, political acceptability and contribution to carbon abatement we adopted a Red-Amber-Green (RAG) classification as detailed on Table 6-4.

We set out below the criteria that form the assessment framework, providing the respective scales used in classification of each criterion.

Affordability: this criterion provides an indicative scale of costs of each action, varying from low investment (up to 100 thousand pounds) to high investment required (over 100 million pounds) (Table 6-2).

Public vs Private: this criterion shows the share of public and private responsibility towards the implementation of an action. It varies from solely public responsibility, which relies on public authorities and government to lead the implementation of the action to private sector driven actions, where the industry and providers will be key implementors (Table 6-3).

Technical feasibility: provides an indication of the degree of technical complexity, or how difficult it is to implement the action from the technical point of view. This varies from an action relying on existing proven technology or in methodology ready to be implemented to no identifiable technology or method available (Table 6-4).

Market acceptability: this criterion offers our expert view of the market[18] perception based on the likelihood of gathering market support and interest in seeing an action being implemented. (Table 6-4).

Political acceptability: this criterion provides an indicative scale of the likely political buy in for each action, varying from no political support to fully aligned with the political agenda. Some actions may be aligned with the overall desired outcome of the political agenda – climate change action – but might not be the preferred measures to achieve this outcome. (Table 6-4).

Contribution to carbon abatement: direct contribution of the action to reducing carbon emissions compared to the business as usual scenario, ranging from negative to high impact. For all the actions that act as enablers the classification attributed is "neutral" as they do not generate a difference by themselves but rather by acting as facilitators for other measures that effectively deliver less carbon emissions than the current scenario. (Table 6-4).

Table 6-2 - Key to affordability criterion

Criterion	Key				
Affordability	££££££	££££	£££	££	£
	High investment required		Medium range investment		Low investment required

[18] Market encompasses transport and energy sector businesses, operators, distributors as well as transport and energy users.

Table 6-3 - Key to Public vs Private criterion

Criterion	Key				
Public vs Private	● Public	◕	◑ Shared Public-Private	◔	○ Private

Table 6-4 - Key to color-coded criteria: technical feasibility, market acceptability, political acceptability and contribution to carbon abatement

Criteria	Key				
	(red)	(orange)	(yellow)	(olive)	(green)
Technical feasibility	no identifiable technology/ method		potential technological option/ method trials still awaiting		existing proven technology/ methodology
Market acceptability	minimum market perception		neutral		high acceptability
Political acceptability	no political support		limited political support		fully aligned with political agenda
Contribution to carbon abatement	negative impact		neutral		high impact

Indicative Infrastructure Requirements

Throughout this Action Plan we complemented the policy actions with the indicative infrastructure that needs to be put in place until 2035 both in terms of distribution infrastructure as electric charge points, hydrogen refuelling and biomethane refuelling stations (Figure 6-1) but also energy (electricity, hydrogen and biomethane) production and storage required (Figure 6-2) which was informed by chapter 4. Although we are only providing the indicative figures until 2035, these are in line with the ultimate goal to achieve Northern Ireland Net Zero transport sector by 2050.

The indicative infrastructure requirements can also be found in the full version of the Action Plan and Assessment framework for Energy and Transport, presented in the following sections 6.1 and 6.2.

Figure 6-1 - Transport Actions - Improve distribution infrastructure measures mapped against 2021-2035 timeline

	Key Areas of Action	Measures/ Actions	HGVs	Buses	Taxis	Rail	Timeline 2021-2025	Timeline 2025-2030	Timeline 2030-2035
Transport	T5 - Improve distribution infrastructure	Biomethane Distribution infrastruture for HGVs: public infrastructure required (CNG and LNG combined)	x					12	16
		Continuous improvement of electrification for rail				x			50% of NI network electrified
		EV Distribution infrastruture for HGVs: public infrastructure required (50 kW and 150 kW)	x				-	50 kW: 29 150 kW: 11	51 kW: 112 150 kW: 41
		EV Distribution infrastruture for Buses: infrastrcuture required at Bus depots (50 kW)		x			155	379	703
		EV Distribution infrastruture for Taxis: public rapid chargers (50 kW)			x		8	71	141
		Hydrogen Distribution infrastruture for HGVs: public infrastructure required (Hydrogen refuelling stations, HRS)	x				-	6 HRS	8 HRS
		Hydrogen Distribution infrastruture for Buses: infrastrcuture required at Bus depots		x			1 HRS	4 HRS	8 HRS

Figure 6-2 - Energy Actions - Production and storage mapped against 2021-2035 timeline

			Timeline		
	Key Areas of Action	**Measures/ Actions**	**2021-2025**	**2025-2030**	**2030-2035**
Energy	**E1** - Electricity	**Production:** new clean energy production required by the end of each 5 year interval (e.g. wind farm)		100MW+	200MW+
		Storage: new clean energy storage required by the end of each 5 year interval (e.g. battery farm)		>5 medium projects	>10 medium projects
	E2 - Hydrogen	**Production:** H2 production needed at the end of each 5 year interval (e.g. electrolyser unit)		1MW production unit	multiple 1MW production units
		Storage: H2 storage required at the end of each 5 year interval (e.g. salt cavern storage)		1x cavern (small or med)	multiple caverns (small/med size)
	E3 - Biomethane	**Production:** Biomethane production needed at the end of each 5 year interval (e.g. Anaerobic Digestion unit)		10x increase in AD units	10x increase + other biofuels sources
		Storage: Biomethane storage required at the end of each 5 year interval (e.g. using gas grid infrastructure storage)	existing storage (linepack, caverns, tanks)	multiple tank farms	careful management of supply and demand in addition to prior measures

6.1. Action Plan and Assessment Framework for Transport

The compiled Action Plan and Assessment framework for Transport can be found in the following page on Table 6-5. The Action plan and assessment framework for transport comprises 30 actions/measures organised in 6 key areas of intervention.

It was observed throughout the development of the action plan that there is a lot of commonality across the modes in terms of actions required to plan and deploy alternative fuels uptake in NI. We combined all transport modes – HGVs, buses, taxis and rail - in a single action plan, and identified common as well as specific actions suggested for each mode as well as the indicative public distribution infrastructure required to be in place by the end of each 5-year period along the 2021-2035 timeline.

Table 6-5 - Action plan and assessment framework for transport

	Key Areas of Action	Measures/ Actions	HGVs	Buses	Taxis	Rail	Timeline 2021-2025	Timeline 2025-2030	Timeline 2030-2035	Assessment criteria: Affordability	Public vs Private	Technical feasibility	Market acceptability	Political acceptability	Contribution to carbon abatement
Transport	**T0 -** Climate change target for NI	Setting clear NI government commitments to decarbonise the transport sector and establishing target metrics for timeline 2021-2035	x	x	x	x				£					
		Map the key actors in alternative fuels market in Northern Ireland and Republic of Ireland and to develop and implement an engagement programme	x	x	x	x				£					
	T1 - Improve knowledge sharing and decision making	Public communication and consultation on Northern Ireland Net Zero strategy and the implications to the transport sector	x	x	x	x				£					
		Stakeholders engage, cooperate and form partnerships to support and promote alternative fuels uptake: public sector, academia, businesses (infrastructure & vehicle providers, fleet operators, fuel providers).	x	x	x	x				£					
		Disseminate best practices, technology maps and funding opportunities on alternative fuels options available, cost and GHG emmission performance to support fleet operators and local authorities	x	x	x	x				£					
		Develop training programmes for drivers and fleet managers to improve skillset in alternative fuels operation, safety and vehicle maintenance to desmystify the alternative fuelled vehicles' operation	x	x	x	x				££					
	T2 - Data collection, monitoring and evaluation	Create a road transport model for Northern Ireland to understand the forecast road traffic volumes, to include all freight vehicles (HGVs and LGVs), all bus classes and service types (coach, urban bus, school bus, mini-bus, etc) and taxi classes.	x	x	x					££					
		Integrate Road and Rail demand models to explore opportunities for modal shift in both passenger and freight trips	x	x	x	x				££					
		Collection and publication of transport data both in Northern Ireland and across the island of Ireland to better understand the transport patterns and support the transport demand model	x	x	x	x				££					
		Digital twin of infrastructure (cross-cutting Energy, Transport, Manufacturing)	x	x	x	x				£££					
	T3 - Technology choice, demand management and behavioural change	Create joint public-private funding programmes to support vehicle technology trials (Hydrogen freight vehicles expected in the first half of the next decade)	x	x		x				££					
		Research opportunities for reducing the negative impact of road freight trips (consolidation, last-mile green initiatives, modal shift, joint procurement)	x							£££					
		Transport demand management through policy / legislation/ regulation to incentivise optimisation of resources (redefining bus/rail/freight routes, public transport priority measures, introduction of larger vehicles to provide additional capacity, redistributing fleet across the country)	x	x	x	x				££					
		Improve driving efficiency: driver training to improve fuel efficiency	x	x	x	x				£					
		Introduce legislation to ban the sale of fossil fuel vehicles once technology is proven and starts commercialisation at scale	x	x	x	x				£					
	T4 - Incentivise transport operators to move towards a zero emissions fleet	Introduce funding for vehicle and mode shift based upon carbon abatement potential	x	x		x				££					
		Grant schemes and fiscal incentives to incentivise companies to invest in zero carbon vehicles and charging /refuelling infrastructure	x	x	x	x				£££					
		Introduction of an emissions-based vehicle tax to be phased-in according to the technology maturity	x	x	x	x				£					
		Vehicle scrappage scheme to promote the purchase of alternative fuelled vehicles	x	x	x					£££					
		Review depots/ logistics centres location in light of sub-station capacity required to recharge EV vehicles	x	x		x				£					
	T5 - Improve refuelling infrastructure	Develop and publish a charging and refuelling infrastructure strategy for alternative fuels which stays ahead of demand and assists in enabling the transition to zero emission vehicles	x	x	x	x				£££					
		Create joint public-private partnerships to support refuelling technology trials	x	x	x	x				££					
		DfI to provide guidance for local authorities to adapt planning policies to include recharging and refuelling infrastructure, including the use of Section 106 agreements to increase private sector investment in refueling infrastructure	x	x	x					£					
		Biomethane Distribution infrastruture for HGVs: public infrastructure required (CNG and LNG combined)	x					12	16	££	◔				
		Continuous improvement of electrification for rail				x			50% of NI network electrified	££££	○				
		EV Distribution infrastruture for HGVs: public infrastructure required (50 kW and 150 kW)	x				-	50 kW: 29 150 kW: 11	51 kW: 112 150 kW: 41	£££	◔				
		EV Distribution infrastruture for Buses: infrastrcuture required at Bus depots (50 kW)		x			155	379	703	£££	○				
		EV Distribution infrastruture for Taxis: public rapid chargers (50 kW)			x		8	71	141	£££	◔				
		Hydrogen Distribution infrastruture for HGVs: public infrastructure required (Hydrogen refuelling stations, HRS)	x				-	6 HRS	8 HRS	££££	◔				
		Hydrogen Distribution infrastruture for Buses: infrastrcuture required at Bus depots		x			1 HRS	4 HRS	8 HRS	££££	○				

6.2. Action Plan and Assessment Framework for Energy

The compiled Action Plan and Assessment framework for Energy can be found in the next page on Table 6-6. The Action plan and assessment framework for energy comprises 16 actions/measures organised in 4 key areas of intervention. As with transport, we have combined all energy types – electricity, hydrogen and biomethane – in a single action plan and identified the production and storage requirements in terms of solutions required to support the increased demand for each fuel type along the timeline 2021-2035.

Table 6-6 - Action plan and assessment framework for energy

	Key Areas of Action	Measures/ Actions	Timeline: 2021-2025	Timeline: 2025-2030	Timeline: 2030-2035	Assessment criteria: Affordability	Assessment criteria: Public vs Private	Assessment criteria: Technical feasibility	Assessment criteria: Market acceptability	Assessment criteria: Political acceptability	Assessment criteria: Contribution to carbon abatement
Energy	**E0-** Climate change target for NI	Setting clear government commitments to decarbonise the energy system (in Northern Ireland) and establishing target metrics for the production and storage of each identified alternative fuel type in the timeline 2021-2035				£	●				
		Map the key actors in alternative fuels market in Northern Ireland and Republic of Ireland and to develop and implement an engagement programme				£	●				
	E1 - Electricity	Ensure the stakeholders responsible for delivering the second interconnector to ROI meet the 2026 deadline and communicate throughout project with transport stakeholders to mitigate risk.				£££	●				
		Detailed assessment/modelling is needed of the level of energy storage needed in the NI system for transport demand (to consider as a minimum: storage technology type, location, security of supply)				££	●				
		Assess NI electrical infrastructure for required network upgrades (flexiblity and capacity) to meet future demand cases for Transport				££	●				
		Production: new clean energy production required by the end of each 5 year interval (e.g. wind farm)		100MW+	200MW+	£££££	◔				
		Storage: new clean energy storage required by the end of each 5 year interval (e.g. battery farm)		>5 medium projects	>10 medium projects	££££	◔				
	E2 - Hydrogen	Feasibility assessment and decision needed on the use of Hydrogen storage at scale at the islandmagee salt cavern site near Belfast.				££	●				
		Detailed assessment/modelling is needed of the level of energy storage needed in the NI system for transport demand (to consider as a minimum: storage technology type, location, security of supply)				£	◕				
		Assess suitability of the NI and ROI gas network for blended, pure (100%) and linepack/storage potential (for Hydrogen and Biomethane) and asssess against future energy scenarios.				££	◔				
		Production: H2 production needed at the end of each 5 year interval (e.g. electrolyser unit)		1MW production unit	multiple 1MW production units	£££££	◔				
		Storage: H2 storage required at the end of each 5 year interval (e.g. salt cavern storage)		1x cavern (small or med)	multiple caverns (small/med size)	££££	◔				
	E3 - Biomethane	Develop a regulatory framework that facilitates the injection of biomethane into the natural gas network				££	◑				
		Introduce incentivisation scheme for biomethane producers to maximse NI opportunity to utilise biomethane energy				££	◑				
		Production: Biomethane production needed at the end of each 5 year interval (e.g. Anaerobic Digestion unit)		10x increase in AD units	10x increase + other biofuels sources	££££	◔				
		Storage: Biomethane storage required at the end of each 5 year interval (e.g. using gas grid infrastructure storage)	existing storage (linepack, caverns, tanks)	multiple tank farms	careful management of supply and demand in addition to prior measures	£££	◔				

7. Recommendations

Certainty and direction in Government policy is key for a successful transition. This project aims to set the direction of travel towards a more sustainable transport sector; with the objective of mitigating greenhouse gases emissions and achieving the 2050 net zero target for all CO_2 emissions in Northern Ireland.

This research study is the first step in developing recommendations for an 'all-island' approach to planning an infrastructure network for the production, storage and distribution of alternative fuels for the transport sector. The proposed Action Plan identified further work that will be required to refine the initial estimates of demand and infrastructure requirements.

The key takeaway from the Action Plan and Framework Assessment is the need to define **clear Northern Ireland government commitments to decarbonise transport and the energy system, while establishing target metrics for the timeline 2021-2035 and beyond**. It is essential that the Northern Ireland government sets ambitious objectives aligned with the United Kingdom, and that these are widely communicated to industry, businesses and the general public. In parallel, the Northern Ireland government should communicate the net zero strategy with detail on what policies and measures will be implemented that will affect the transport, energy sector and wider society.

It is recommended that the next step is to **map the key stakeholders in the alternative fuels market in Northern Ireland and Republic of Ireland** and to develop and implement an engagement programme with relevant institutions to the decarbonisation agenda. This list could include fleet operators and industry stakeholders, relevant public institutions, logistics operators, alternative fuels infrastructure providers (distribution and production/storage suppliers) as well as vehicle manufacturers.

By rolling out these engagement activities the Northern Ireland government will be equipped with a better understanding of the roles of different organisations allowing to **identify in which areas Department for Infrastructure (DfI) can exercise its influence**. For those areas identified outside of its sphere of influence, **DfI should make sure its requirements and expectations for decarbonising transport are effectively communicated.**

On the public sector side, **DfI has the opportunity to promote a 'whole systems' approach by regularly communicating with the relevant bodies that can influence the uptake of alternative fuels in Northern Ireland.** Namely the Department for the Economy (DfE) which is developing the Energy Strategy for Northern Ireland, and the Department of Agriculture, Environment and Rural Affairs (DAERA). It is also equally important to establish a clear communication channel with UK central government, particularly the Department for Transport (DfT) and the Department for Business, Energy& Industrial Strategy (BEIS) as well as with the responsible bodies across the geography in Republic of Ireland, specifically the Department of Transport (DoT) and the Department of the Environment, Climate and Communication (DECC). DfI can take the initiative by organising roundtable events and workshops to promote the work carried out, including the findings of this study.

To make an informed decision on the way forward, it is crucial that DfI invests in the collection and publication of statistical data in Northern Ireland to better understand the transport patterns in its geography. **It is recommended to commission the development of an up to date road transport model for Northern Ireland** to understand the forecasted traffic volumes in particular ensuring adequate granularity of private, public transport and freight vehicles. It is recommended that this model is then integrated with the Republic of Ireland transport model for an 'all island' appreciation of transport movements, which is fundamental to ensure consistency and better planning for infrastructure such as alternative fuels refuelling points. Another opportunity that the public sector should seek is in the **integration of road and rail demand models** to explore opportunities for modal shift in both passenger and freight trips, which will support the reduction of road traffic and contribute to further carbon abatement.

The public sector has an important role as well in **influencing the upskilling and promoting education in alternative fuels**. This can be done by promoting training programmes in association with educational institutions targeted at improving skills in the operation of alternative fuelled vehicles, including maintenance, safety and energy efficiency.

DfI can be influential in defining the optimum locations for deploying the alternative fuels infrastructure, through the publication of a charging and refuelling infrastructure strategy for alternative fuels, which stays ahead of demand and assists the key stakeholders in enabling the transition to zero emission vehicles[19]. This strategy should be informed by feasibility studies of the most suitable locations for installing distribution infrastructure, with engagement from industry stakeholders. Although some of the actions fall under the duty of the private sector as an investor, promoter and deliverer of the technology and infrastructure, collaboration between the public and private sectors is necessary to enable cost-effective implementation of alternative fuels from production to storage and fuelling locations in Northern Ireland. The public sector has a key role as the regulatory and advisory body, and the capacity to influence how the deployment of infrastructure should be prioritised to better serve industry needs.

In parallel, **DfI has the opportunity to shape the roll-out of the production and storage of alternative fuels**, by taking the lead in the modelling work, to be developed in collaboration with the DfE. Key activities would be to refine the level of energy production and storage needed in the Northern Ireland system for future transport demand. DfI can also support the DfE on other commissions related to the assessment of the existing energy infrastructure and in developing an energy regulatory framework that facilitates the uptake of alternative fuel vehicles.

DfI alongside other public sector bodies can also play an important role by enabling funding and financial support and creating incentives to attract the transport operators to increase their uptake in zero emissions fleets. **It is recommended that DfI helps to shape these supporting mechanisms** by communicating and contributing to discussions with relevant authorities, HMRC (Her Majesty's Revenue & Customs) and BEIS. DfI could support providing advice on how to shape these mechanisms which could be in the form of incentives but also disincentive acting measures ranging from grant schemes and fiscal incentives that support the uptake of alternative fuelled fleet, to introducing legislation that discourages the use of carbon intensive transport, such as emission-based vehicle tax or ban of fossil fuel vehicles for those modes where the technology is commercialised at scale.

This project is the first assessment on how Northern Ireland could drive the alternative fuels agenda forward. The high-level nature of this pre-feasibility study relies on broad estimates based on a series of assumptions. It is therefore recommended as part of future work that this research is further refined with more detailed and granular data, informed by stakeholder engagement activities and complemented by sector or mode specific studies.

Some of the components of this study are already being considered in separate assessments, namely the NI rail electrification feasibility study. We recommend that when available DfI reviews the present research study with the findings from parallel work such as the rail feasibility study for DfT to complement the analysis carried out in this study. It is also advised to carry out sensitivity tests of the transport forecast scenarios that were developed as part of this study to address the uncertainties around the technology choice.

The study was based on a top-down approach to analysing Northern Ireland transport system and it is recommended that, as part of the next steps, a bottom-up approach with greater geographic granularity of data is carried out to understand in detail the transport patterns and better inform the distribution of energy required to supply the transport system.

Further to undertaking detailed analysis of the demand and supply side and gathering stakeholders to understand various dependencies between options, it is recommended that the policy interventions suggested in the action plan are further examined to explore the practical and financial implications of their implementation.

In the following bullets we present the summary of recommendations from this study:

- **Setting clear and ambitious goals for decarbonising the transport and energy sector in Northern Ireland.**
- **2035 target should be ambitious in order for the 2050 target to be achievable**. Action needs to be prioritised in short term to guarantee that there are systems in place to support a net zero society by 2050.
- **Establishing communication pathways with key stakeholders** to share knowledge and collect information that will support the transition of the transport sector to alternative clean fuels.

[19] Following the example of other transport bodies such as Midlands Connect that have recently published a summary of the alternative fuels strategy [118]

- **Electricity production and storage capacity needs to increase substantially** not only to serve the future electrified fleet, but also to support the wider alternative fuels infrastructure roll-out.

- **Change of behaviour towards transport** can heavily support the transition through a more rational use of resources. Following the "avoid shift improve" framework can help to minimise the unnecessary journeys, shift to a more sustainable mode or combine multiple trip purposes in one single journey.

- **Actions implemented according to an 'order of merit' of carbon abatement** is essential to ensuring that the highest potential carbon saving is achieved; consideration should be made to the most difficult sectors/areas to decarbonise when defining the strategy for adoption. For instance, larger vehicles that do not have a zero-emissions solution yet may rely on a carbon-reduced solution, but that should not be the case for lighter vehicles where there are several zero-emissions options commercialised at scale.

- A **balanced management approach of the energy system**, taking into consideration transport and other sectors such as domestic heating, is fundamental to optimising the usage of each fuel and the potential carbon abatement. This is the whole systems approach.

- It is recommended that DfI implements the pathway of **30 actions proposed for passenger vehicles and HGVs in the Action Plan for Transport** and the **16 actions that constitute the Action Plan for Energy for the production and storage of electricity, hydrogen and biomethane** along the 2021-2035 timeframe (presented in chapters 6.1 and 6.2, respectively)

- Finally, it is recommended that DfI initiates the implementation of the two action plans by prioritising the measures with greater chronological pressure to be completed by 2025 followed by those that generate the greatest carbon abatement.

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