



Reducing the Environmental Impact of Freight

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National Infrastructure Commission

Final Report

FUTURE OF FREIGHT

Evidence Base

This report by Cambridge Economic Policy Associates (CEPA) and Frazer-Nash Consultancy (Frazer-Nash) was commissioned as part of the evidence base for the National Infrastructure Commission's study on the future of freight.

As with all supporting evidence commissioned by the National Infrastructure Commission, the views expressed and recommendations set out in this report are the authors' own and do not necessarily reflect the position of the Commission.

**NATIONAL
INFRASTRUCTURE
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EXECUTIVE SUMMARY

The UK has committed to a reduction in its greenhouse gas (GHG) emissions of 80% on 1990 levels by 2050. Domestic transport (passenger and freight) represents over a quarter of UK GHG emissions.¹ The sector overall is starting to make progress towards lower-emission fuels, as take-up of electric cars and vans grows. However, an increase in transport demand meant that by 2017 the sector had only achieved a 1% reduction in emissions² since 1990. Transport is one of the sectors that will be required to reach greater than 80% reduction for the UK to meet the target, as some sectors will struggle to reach 80%, and with the UK Government setting ambitious targets for decarbonisation of surface transport,³ the NIC are considering if and how zero emissions might be possible by 2050. Reducing GHG emissions from freight transport is important – HGVs alone account for 4% of UK emissions.⁴

The NIC asked CEPA and Frazer-Nash to illustrate zero emissions in road and rail freight could be achieved by 2050, acknowledging that this is a significant challenge which largely rests on the uncertain ability of manufacturers and industry to accomplish major advances in low emission technology on a much accelerated timeframe. This report therefore aims to understand which zero-emission technologies could individually make a significant contribution to decarbonisation, how these technologies could together ensure the UK meets the 2050 zero emission target and the role that Government will need to play in incentivising change.

Reducing GHG emissions from heavy freight transport is a particular challenge, when compared to cars and small vans, because alternatives to large mainly diesel road vehicles do not yet exist. We understand that one manufacturer has developed an HGV that is currently undergoing testing for approval for the plug-in grant – there are not enough public details at this stage to understand whether it will get approval and whether its range is enough for long-distance.

We found that other countries are generally making slow progress towards the use of low-emission fuels and technologies for freight transport. Governments of other European countries have intervened to support lower-emission vehicles, including electric vehicle grants, lower taxes on low-emission fuels, and clean air zones with charges or penalties for entering (similar to London's Ultra-Low Emission Zone). Where support schemes have clear and consistent commitment from government, higher take-up is achieved – stability is important. The main challenge to date is the lack of sufficient technological advances (e.g. electric HGVs with sufficient range and fast charging). Although trials are underway, no technology is sufficiently developed that it can be considered the main focus for the transition to zero emissions in freight transport.

Recognising the early stage of development of decarbonising technologies, we reviewed alternative fuels and technologies to understand which might make a meaningful contribution to the UK reaching zero-emissions in the transport sector by 2050. While none are ready for mass take-up in the immediate future, our assessment has identified options in development that might make big contributions to decarbonising freight by 2050. These are summarised in Table 1.

¹ CCC (Jun 2018) "Reducing UK emissions. 2018 progress report to parliament" available [online](#) p.150

² BEIS (Mar 2018) "2017 UK Provisional Greenhouse Gas Emissions" available [online](#)

³ HM Government (Jul 2018) "Road to Zero" available [online](#)

⁴ CO₂e: CCC (Jun 2018) "Reducing UK emissions. 2018 progress report to parliament" available [online](#) p.150

Table 1: Summary of key options for decarbonising road and rail freight.

Option	Discussion
Electrification of the rail network	With 42% of the GB rail network already electrified, and 5% of rail freight running on electricity, this is currently the only proven technology that represents an opportunity for freight decarbonisation. It currently seems that growth in this area will be difficult as the cost for further electrification is high and Government is not supportive of additional electrification schemes. We anticipate that the cost of electrified roads (E-highways) will be a barrier to their adoption if other options (e.g. battery HGV and hydrogen) develop well.
Battery-powered HGVs and trains	<p>Battery-powered HGVs are being trialled, with R&D ongoing to improve their viability e.g. in relation to range and charging speed to enable long-distance journeys. Technological advancements in these areas are expected to encourage higher take-up, if the associated charging infrastructure is also in place.</p> <p>Battery-powered freight trains are also a possibility, but a freight train is much heavier than an HGV or passenger train, which presents a bigger challenge for balancing the weight/size and range of the battery. If further rail freight electrification is pursued, trains may need to have a secondary source of power for any non-electrified areas, with batteries a potential option.</p>
Hydrogen	<p>Hydrogen can be produced through steam methane reformation (SMR, which requires carbon capture and storage to be considered emissions free) or electrolysis. The hydrogen is then stored cryogenically at high pressure (700bar), and then released through a fuel cell to generate electricity to drive one or more electric motors. It is currently used small scale in the UK e.g. TfL has a small fleet of hydrogen powered buses.</p> <p>The main challenge here is the large scale production and distribution systems that would need to be set up to facilitate use at scale. This is likely to be both time consuming and costly. Hydrogen's viability in freight may only increase if other sectors also adopt it e.g. domestic heating, which would support the production and distribution infrastructure required to use it at scale.</p>
Advanced biofuels	<p>Advanced biofuels use waste rather than crops, can be used in place of diesel, and provide reductions in CO₂ emissions. There is a limited supply of waste and there are competing uses, limiting the available advanced biofuels for use in transport to potentially 9% of the market.⁵</p> <p>We consider that biofuels they can make a helpful contribution to reductions in CO₂ emissions while other technologies are developing.</p>

We set out two timeline scenarios that demonstrate the scale of the challenge and need for Government support. Our baseline scenario is based on current trajectories in the development of the most promising low-emission technologies identified in our comparative assessment. It suggests that without ambitious Government action to facilitate implementation, there will be slow progress. Our analysis suggests that less than 50% of the road freight fleet, and 15% of the rail freight fleet, will be decarbonised by 2050 – using biofuel and battery HGVs alongside existing electrified rail freight.

Our ambitious scenario sets out the progress required to reach near-zero emissions by 2050, with the Government playing an important role. This includes helping the technology and infrastructure to be in place to allow take-up of low-carbon road freight technologies to accelerate sharply from the late 2030s onwards if the 2050 target is to be achieved. In this scenario battery HGVs represent the majority of the road fleet (~75%), with electrified locomotives representing the majority of the rail fleet (~75%). It would be very ambitious to expect these two technologies to achieve 100% penetration in their

⁵ Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

respective markets by 2050, so biofuel and hydrogen are also included. Biofuel is included as a low emission (but not zero emission) interim fuel in both rail and road freight (9%),⁶ and hydrogen is assumed to be developed for use in rail and road freight (~16%).

In our view, unless the Government adopts an ambitious strategy, the UK will fail to meet the 2050 target for zero emissions from freight. We recommend that:

- **The government's immediate focus should be on addressing current technological uncertainty** related to the potential application of new low emission fuels in the freight system and trying to accelerate technological maturity. This requires supporting the key options through R&D in the earlier years, then updating and re-focusing the funding on the options that emerge as more viable as new information and technological advancements arise.
- **Government coordinates its efforts with the countries with which the UK has the most RoRo trade,**⁷ on technology development and standards as new vehicles and infrastructure are rolled out. Our country case studies demonstrate a lack of coordination at present, with countries pursuing different approaches to reducing emissions. With high levels of cross-border trade, it is important that countries' approaches to decarbonising freight are harmonised to the extent that RoRo freight is still capable of operating efficiently (e.g. without spending additional time changing modes or seeking refuelling/charging stations).
- **Government makes funding available for infrastructure to facilitate adoption of electric vehicles as the technology becomes available.** This includes an expanded network of refuelling stations and/or charging points, particularly during the early stages of market growth. Without this support, small and medium fleet operators are likely to find the transition more challenging, as developing their own dedicated refuelling stations will rarely be viable.
- **Government begins to plan for a scenario in which it supports long term investment in the network infrastructure should the need arise.** This may be particularly necessary if electrification or hydrogen prove to be priorities, to provide industry and other stakeholders with sufficient confidence to invest in new technologies when planning their future fleet requirements. This could include a study into freight route electrification for rail, to understand which freight routes (and parts of routes) would be considered a priority, recognising that in some lower-traffic areas of the network an alternative (e.g. hydrogen or battery) may be more cost-effective, potentially requiring hybrid vehicles.

Based on the available evidence on the application of these low-emission fuel technologies in the freight sector, expected rates of technological progress and the progress achieved by the other countries in our study, the UK needs to adopt a well-targeted and ambitious strategy to facilitate delivering a zero-emissions freight system by 2050.

⁶ Biofuel is expected to contribute up to 9% given the limited supply of input (waste) and the competing uses for it. It does emit some CO₂. Source: Transport and Environment (Jun 2017) "Roadmap to climate-friendly land freight and buses in Europe", available [online](#)

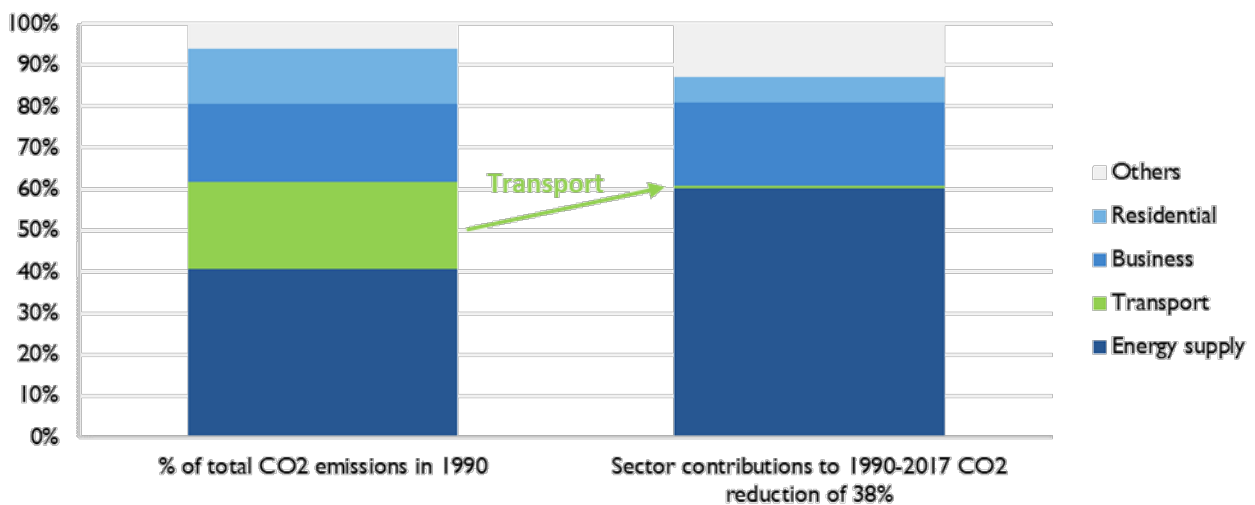
⁷ RoRo freight is that which is carried in the same vehicle both on the roads of the UK and abroad. RoRo markets can be distinguished in several ways, e.g. country of origin or destination, country of registration, or port of embarkation. The UK's main RoRo markets, by destination, are France, the Netherlands, Ireland, Belgium, Denmark and Germany.

I. INTRODUCTION

I.1. THE TRANSPORT SECTOR'S DECARBONISATION CHALLENGE

The UK has committed to reducing greenhouse gas (GHG) emissions by 80% on 1990 levels by 2050, with CO₂ accounting for 75% of 1990 UK GHG emissions. To date the UK has achieved a 43% reduction in GHG emissions, and a 38% reduction in CO₂ emissions. Figure I.1 shows the level of CO₂ emissions from the main UK sectors in 1990, and how these sectors contributed to the 38% reduction. Transport has to date made no contribution to CO₂ reductions, with energy supply accounting for the majority of the overall reduction. Reductions in emissions from the energy supply is an important input to the other sectors, for example zero-emission electricity can run zero-emission electric vehicles.

Figure I.1: Reduction in CO₂ emissions by different sectors, 1990-2017



Source: CEPA analysis of BEIS (Mar 2018) "Table 1: UK greenhouse gas emissions by source sector, headline results, UK, 1990-2017" available [online](#)⁸

Although established technologies exist for tackling emissions in cars and to an extent small freight vehicles (vans), reducing GHG emissions from freight transport is a particular challenge because alternatives to large mainly diesel road vehicles do not yet exist. The Committee on Climate Change (CCC) have stated that decarbonisation will require improvements in vehicle technology alongside improvements in logistics/management. Technological options for reducing emissions significantly are in development, with several potential options that might contribute to reaching the 2050 target being trialled but no zero-emission options, other than electrification of rail freight, are market ready (biofuel is market ready but is not zero-carbon, and does emit other pollutants at the point of use).

⁸ A breakdown of transport GHGs emissions CCC (Jun 2018) "Reducing UK emissions. 2018 progress report to parliament" available [online](#) p.150

1.2. SCOPE OF THIS REPORT

In November 2017, the UK government asked the National Infrastructure Commission (NIC) to undertake a study on the future of freight⁹ that considers, among other key issues, the actions needed to improve the sector's environmental impacts. The NIC's study will conclude in Spring 2019.

To support its overall future of freight study, the NIC commissioned Cambridge Economic Policy Associates (CEPA) and Frazer-Nash Consultancy (Frazer-Nash) to jointly undertake a concise and evidence-based piece of research examining how the UK can move towards a zero-emissions¹⁰ freight transport system in 2050. While the UK's overall target is an 80% reduction in GHG emissions, the NIC wish to understand what would be necessary to reach 100%, particularly in light of the Government's recent commitment that by 2050 "almost every car and van [will] be zero emission".¹¹ We understand that the 80% target will not be met uniformly by all sectors, with some (including power supply and transport) expected to exceed 80% while others have lower targets (including agriculture).¹²

Specifically, the NIC asked us to undertake:

- a review of international examples of how other countries have begun a transition to lower carbon and better air quality through the transport system, particularly in the UK's key roll-on, roll-off (RoRo) freight markets – in this case we chose France, Germany, Ireland, the Netherlands and Sweden;¹³
- a comparative review of the potential of alternative fuels for road freight, their technological and market maturity, effectiveness for different parts of the freight transportation system, and the barriers and opportunities towards delivery of new fuel types at scale;
- an assessment of how the environmental impacts and emissions of rail freight can be reduced by 2050, including the relative potential and feasibility of alternative fuels for locomotives, and an assessment of the infrastructure that could be required to enable the transition;
- development of a potential timeline to transition to the use of alternative fuel, acknowledging technological uncertainties, and outlining the barriers to take up and the actions that may be required to overcome them; and
- an assessment of potential financial support/incentive schemes to encourage and enable freight operators to transition to lower-emission vehicles.

We researched the potential application of low emission fuel in the freight transport system through a high-level desk-based review of information available in the public domain. The scope of our study did not include:

⁹ HM Treasury (Nov 2017) "New National Infrastructure Commission study" available [online](#)

¹⁰ The focus of this study is on decarbonisation, given the 2050 targets. We also consider, where relevant, reductions in PM_x, NO_x, and SO_x, which are at the centre of air quality concerns

¹¹ HM Government (Jul 2018) "Road to Zero" available [online](#) p.2

¹² This is demonstrated at an EU level in: European Climate (Sep 2018) "Net Zero by 2050" available [online](#), p.22

¹³ RoRo freight is that which is carried in the same vehicle both on the roads of the UK and abroad. RoRo markets can be distinguished in several ways, e.g.: country of origin or destination, country of registration, or port of embarkation.

- detailed discussion and analysis of the existing literature on freight decarbonisation;
- primary research or data collection;
- consideration of the wider decarbonisation context beyond freight transport; or
- detailed quantification of the potential impact of the alternative fuels on emissions, or the social value of making progress towards zero emissions.

This report is structured as set out in Table I.1.

Table I.1: Report structure

Section	Contents
Section 2	Summary of the five international case studies that we developed to assist the NIC in understanding how other countries are transitioning to lower emissions from freight and the key findings observed from their experience.
Section 3	Consideration of a range of alternative fuels and technologies and whether they might make a meaningful contribution to the transition towards a zero-emission freight system.
Section 4	Development of illustrative timelines for the transition to a zero-emission road and rail freight system by 2050.
Section 5	Assessment of the potential financial support and incentive schemes that might support the transition towards reduced emissions from the freight system.
Annexes A, B and C	Detailed information on our international case studies and the comparative assessment of alternative fuels.

2. INTERNATIONAL REVIEW

We developed five international case studies to assist the NIC in understanding how other countries have begun their transition to lower freight carbon and pollutant emissions, to inform the UK's approach.

Our case studies demonstrate that the countries studied are making slow progress towards the use of low-emission energy sources for transport. None of the countries studied has however developed a model or even a strategy that the UK could adopt on the basis that doing so would meet the emissions challenges that we face. Although options such as electrified highways are being explored, and in some cases alternative fuels used, these countries highlight the same challenges that the UK faces i.e. that decarbonising freight is particularly challenging because vehicles are heavy and travel long distances, and because the supporting infrastructure requirements can be extensive and costly.

While no single country provides a clear leading example, the case studies present several themes that provide lessons learned. These are summarised in the table below.

Table 2.1: Themes arising from the international case studies

Theme	Discussion
National context	It is important to recognise that there are contextual differences between other countries and the UK that means that the solutions adopted by other countries may not work (as effectively) in the UK. For example, it seems unlikely that it would be economic or viable to transport as much freight by rail or inland waterways (as a % share of total freight) in the UK as some European comparators. This is due to the shorter distances (which favours the relative flexibility of road transport) involved and the limited capacity of the canal network in the UK.
Wider policy environment	Sweden's progress and, to a lesser extent the renewed commitment demonstrated by the French government, is associated with a wider policy environment that is supportive of carbon reduction and air quality improvement measures. Both of these countries have targeted 'carbon neutrality' by 2050. Such actions are likely to have played some role in encouraging earlier efforts to decarbonise and reduce emissions from freight transport.
Range of supportive interventions	Most of our focus countries, particularly France, have adopted a package of interventions to encourage take-up of low emission vehicles. Financial incentives, whether in the form of purchasing subsidies (or penalties), reduced taxes on renewable fuels, or clean air zones (such as London's Ultra Low Emissions Zone), are not sufficient on their own. Investment in associated infrastructure is also required (e.g. filling stations and recharging points). Although as yet there is no evidence of an availability threshold over which the network is sufficient to encourage change. Stronger incentives may also be needed, such as local restrictions on the use of vehicles that do not meet certain emissions standards. It is important that local restrictions are harmonised to ensure that they do not simply encourage HGVs to make a small diversion that results in higher overall emissions.
Scale of interventions	While some of the countries we studied had introduced financial incentive schemes, the scale of support on offer is far less than that made available to support the generation of low-carbon electricity. Energy supply accounted for twice the CO ₂ emissions in 1990, and has made the most progress in decarbonising to date (60% of UK reductions by 2017 came from the energy supply sector). ¹⁴

¹⁴ BEIS (Mar 2018) "UK greenhouse gas emissions by source sector, headline results, UK, 1990-2017" available [online](#)

Theme	Discussion
	This early progress by the energy supply sector has been supported by high levels of funding (e.g. £10bn on low carbon levies in 2018-19). ¹⁵ There is currently lower levels of funding for supporting electric vehicles (£1.5bn 2015-21). ¹⁶ At a European-wide level, greater financial support that is coordinated between countries could stimulate a step-change in investment in low emission freight vehicles.
Stability of funding for support schemes	It is important that the government maintains consistent messages and commitments with respect to support schemes. This is demonstrated through the studies of the schemes in France and Sweden, where the schemes had strong and consistent messaging that supported high take-up.
Interim solutions, contributing to medium term achievement (e.g. 2030 targets)	<p>None of the countries we studied have overcome the limited battery range of electric freight vehicles, which is the main barrier to their adoption in the near future). There are some early highway electrification trials in Sweden or Germany. It is too early to evaluate these or determine how widely such infrastructure heavy solutions might be rolled-out.</p> <p>The countries we studied demonstrated support for a range of alternative fuels, including biofuels, natural gas and hydrogen, to meet shorter term commitments (such as the 10% target in the EU's Renewable Energy Directive).</p> <p>In the longer term, to and beyond 2050, support for the medium term/interim solutions could be reduced as new technologies become "market ready".</p>
Variety of approaches	<p>Countries across Europe appear to be developing a variety of approaches to a transition to low carbon. The Netherlands, Sweden, and Ireland are focusing on developing alternative fuels (including LNG and biofuel), Germany is supporting growth in rail freight, and France is focusing on electric vehicles and hydrogen fuel with restrictions or financial penalties on the most polluting vehicles.</p> <p>There appears to be a lack of coordination and consistency in the countries' approaches to reducing emissions in freight, which may lead to issues with RoRo freight vehicles being able to efficiently operate in both origin and destination countries.</p>

Our first step was to identify a long list of EU countries that might make a useful case study to contribute to our understanding of potential approaches to decarbonising transport, particularly freight transport. This long list included Germany, the Netherlands, France, Belgium, Ireland, Italy, Spain, Poland, Sweden, and the Czech Republic.

The NIC requested that the countries chosen include those with a high level of RoRo traffic to and from the UK and/or a high value of goods traded with the UK. This enables an effective comparison with the UK context and also highlights the importance that the UK's approach to decarbonisation is harmonised with the countries with which we have the most RoRo trade – to ensure trucks etc can operate efficiently in both countries. This led to the inclusion of France, Germany, Ireland, and the Netherlands.

We also include Sweden, one of the European leaders in adopting low-emission fuels in transport. In addition, the usefulness of a case study on any country depends on the availability of sufficiently detailed relevant information so our selection criteria considered data availability.

¹⁵ Office for Budget Responsibility (March 2018) "Economic and Fiscal Outlook – supplementary fiscal tables: receipts and other – table 2.7" available [online](#)

¹⁶ HM Treasury (July 2018) "Charging Infrastructure Investment Fund: Request for Proposals" available [online](#)

In Table 2.2 overleaf, we summarise the key points taken from each of the case studies. The detailed findings for each of the case studies can be found in Annex A, including all references for key facts and figures.

Table 2.2: Summary of case study findings (references and sources are set out in Annex A)

Country	Freight market	Progress towards reducing emissions	Alternative fuels and enabling policies
<p>France - the main country of disembarkation for RoRo traffic travelling from the UK to Europe (i.e. the UK's main RoRo market).</p>	<ul style="list-style-type: none"> • Around 60% of RoRo vehicles travelling from the UK disembark in France. • Freight transport has been declining since 2008 but France is still a significant European market. • Rail freight has steadily lost modal share due to a lack of competitiveness. 	<ul style="list-style-type: none"> • Estimated 11% reduction in CO₂ per capita relating to the transport sector between 2004-14.¹⁷ • France missed its goal to cut greenhouse gas emissions in 2016, and will revise its target to align with their pledges in the Paris Climate Agreement. • Overall SO_x and NO_x emissions have fallen since 1980 by 72% and 14% respectively. 	<ul style="list-style-type: none"> • Relatively close to achieving EU target of using 10% of renewable fuel energy for transport (currently 8.9%). • Growing number of electric vehicles in the passenger market (1.7% market share) enabled by financial incentives and expanding charging network. • Introduced CRIT'Air scheme in 2018 to restrict most polluting vehicles from urban centres. • Pledged to stop the sale of petrol and diesel-powered vehicles by 2040.
<p>Germany - one of the UK's largest trading partners and the fifth largest RoRo destination.</p>	<ul style="list-style-type: none"> • More freight is transported in Germany than any other European country – over 500 billion tonne-kilometres in 2016. • Strong growth expected to continue. • Around 23% of freight is carried by rail. 	<ul style="list-style-type: none"> • Estimated 6% reduction in CO₂ per capita relating to the transport sector between 2004-14. • Germany is unlikely to meet its Energiewende 2020 carbon reduction targets. • Air quality is improving but major cities report PM₁₀ and NO₂ levels in excess of EU limits 	<ul style="list-style-type: none"> • Around 7% of the energy for transport comes from renewable sources – mostly biofuels. • Responded to growing demand with a new rail freight strategy, including use of public funding to introduce temporary infrastructure access subsidies (see Federal Ministry of Transport and Digital Infrastructure (2017)). • Trials of electrified highways are planned for 2019 and 2020, aimed at reducing emissions from long-haul HGVs. • Some financial support for passenger electric vehicles, but relatively little financial support for other low-emission fuels generally in either passenger or freight markets.

¹⁷ In the same period the UK made a reduction of 10%, having increased CO₂ emissions every year between 1991 and 2007, and reduced them every year between 2008 and 2013. Source: BEIS (Mar 2018) "Table 1: UK greenhouse gas emissions by source sector, headline results, UK, 1990-2017" available [online](#)

Country	Freight market	Progress towards reducing emissions	Alternative fuels and enabling policies
<p>Ireland - the third largest RoRo destination for goods vehicles travelling from the UK.</p>	<ul style="list-style-type: none"> • Around 13% of RoRo vehicles travelling from the UK disembark in Ireland. • 99% of freight is transported by road. 	<ul style="list-style-type: none"> • Estimated 22% reduction in CO₂ per capita relating to transport sector between 2004-14 • Ireland is likely to miss 2020 carbon reduction target • Air pollution is considered to be getting worse as traffic volumes grow 	<ul style="list-style-type: none"> • Around 5% energy for transport comes from renewable sources – significantly short of the 10% EU target. • National policy focuses on developing natural gas and biofuels as alternative fuels in the freight sector. • Government recently announced National Clean Air Strategy to reduce pollution and harmful emissions, particularly from transport.
<p>Netherlands – the second largest RoRo destination for goods vehicles travelling from the UK.</p>	<ul style="list-style-type: none"> • Around 18% of RoRo vehicles travelling from the UK disembark in Netherlands. • Only around 35% of freight is carried by road – freight is mostly transported along inland waterways. 	<ul style="list-style-type: none"> • Estimated 13% reduction in CO₂ per capita relating to transport sector between 2004-14. • The Netherlands complies with almost all EU emission limits for air quality. 	<ul style="list-style-type: none"> • Less than 5% of the energy for transport comes from renewable sources. • Government is considering introducing new emissions standards for lorries. By 2020 it will be mandatory for fuel providers to blend biofuels with petrol or diesel. • Policy does not focus on any single technology and it is expected that there will be a role for a mix of alternative, low carbon fuels.
<p>Sweden - One of the leading European adopters of renewable fuels for transport.</p>	<ul style="list-style-type: none"> • Important freight and logistics hub for Northern Europe. • Around 35% of freight transported by rail. • Less than 2% of RoRo vehicles travelling from the UK disembark in Sweden. 	<ul style="list-style-type: none"> • Estimated 7% reduction in CO₂ per capita relating to transport sector between 2004-14. • Relatively low levels of air pollution with the lowest rate of deaths related to air quality amongst EU countries. 	<ul style="list-style-type: none"> • Highest share of transport fuels from renewable sources compared to other EU countries – over 30%. • Biofuels are the most prevalent form of low carbon fuel, supported by lower tax rates. • Supportive policy environment – carbon tax in place since 1995 and financial incentives to purchase electric passenger vehicles. • Two highway electrification schemes (E-highways) are being trialled near Stockholm.

Source: CEPA and Frazer-Nash analysis

3. COMPARATIVE REVIEW OF ALTERNATIVE FUELS AND TECHNOLOGIES

The case studies demonstrate some use of alternative fuels e.g. biofuels and hydrogen, to meet short term targets whilst other power sources – such as suitable batteries for heavy vehicles – remain in development. The comparative review in this Section considers whether and how a range of alternative fuels and technologies including battery might make a meaningful contribution to reaching zero emissions of CO₂,¹⁸ in the transport of freight by road and rail. While minor variations on diesel technologies will make some contribution to decarbonisation, more substantial change is required to reach zero emissions by 2050. Therefore, we focus on substantively different fuels or technologies to those in use today, rather than minor variations on diesel technologies

We undertook this review in two parts:

- **A high-level assessment of long list of alternative technologies and fuels, informing selection of a short list.** We first considered a long list of fuels and technologies that may be suitable for each of road and rail freight, taking into account the high-level feasibility, scalability, current maturity, and likely development cycles.
- **A detailed assessment of the short-listed options.** Here we undertook a more detailed review of the short-listed options (four for each of road and rail). We focused on a range of criteria including technology maturity, emissions and environmental impact, safety, cost, infrastructure, and technical aspects (e.g. fuel energy density, refuelling speed, propulsion power density).

As a result of our assessment, we identified key technologies for inclusion in the transition timelines in Section 4, as set out in Table 3.1.

Table 3.1: Summary of technologies and fuels identified for inclusion in the timelines.

Option	Discussion
Electrification of the rail network	With 42% of the GB rail network already electrified, and 5% of rail freight running on electricity, this is currently the only proven technology that represents an opportunity for freight decarbonisation. It currently seems that growth in this area will be difficult as the cost for further electrification is high and Government is not supportive of additional electrification schemes. We anticipate that the cost of electrified roads (E-highways) will be a barrier to their adoption if other options (e.g. battery HGV and hydrogen) develop well.
Battery-powered HGVs and trains	Battery-powered HGVs are being trialled, with R&D ongoing to improve their viability e.g. in relation to range and charging speed to enable long-distance journeys. Technological advancements in these areas are expected to encourage higher take-up, if the associated charging infrastructure is also in place. Battery-powered freight trains are also a possibility, but a freight train is much heavier than an HGV or passenger train, which presents a bigger challenge for balancing the weight/size and range of the battery. If further rail freight electrification is pursued, trains may need to have a secondary source of power for any non-electrified areas, with batteries a potential option.
Hydrogen	Hydrogen can be produced through steam methane reformation (SMR, which requires carbon capture and storage to be considered emissions free) or electrolysis. The hydrogen is stored cryogenically at high pressure (700bar), and then released through a fuel cell to generate electricity

¹⁸ The focus of this study is on decarbonisation, given the 2050 targets. We also consider, where relevant, reductions in PM_x, NO_x, and SO_x, which are at the centre of air quality concerns.

	<p>to drive one or more electric motors. It is currently used small scale in the UK e.g. TfL has a small fleet of hydrogen powered buses.</p> <p>The main challenge here is large scale production and distribution systems that would need to be set up to facilitate use at scale. This is likely to be both time consuming and costly. Hydrogen's viability in freight may only increase if other sectors also adopt it e.g. domestic heating, which would support the production and distribution infrastructure required to use it at scale.</p>
Advanced biofuels	<p>Advanced biofuels use waste rather than crops, can be used in place of diesel, and provide reductions in CO₂ emissions. There is a limited supply of waste and there are competing uses, limiting the available advanced biofuels for use in transport to potentially 9% of the market.¹⁹</p> <p>We consider that biofuels they can make a helpful contribution to reductions in CO₂ emissions while other technologies are developing.</p>

Sections 3.1 and 3.2 provide high-level summaries of these assessments, with the full assessments in Annex B and Annex C.

3.1. LONG LIST ASSESSMENT

We selected a long list of seven fuels and technologies for each of road and rail freight:

- Biofuels
- Synthetic fuel
- Hydrogen
- E-highway/ Rail electrification
- Liquid Petroleum Gas (LPG)
- Natural Gas
- Electric battery

These fuels and technologies were intentionally selected to provide a wide range of options. We assessed them against three high-level criteria, as set out in Figure 3.1.

Figure 3.1: Summary of approach to scoring the fuels and technologies in the short list assessment

<p>Maturity risk level</p> <p>We consider the maturity of each fuel or technology using the Technology Readiness Level (TRL) scale. There are nine levels, where 1 is very early-stage and 9 represents a very mature fuel or technology.</p>	<p>Potential benefits and potential issues</p> <p>We assess benefits and issues separately, identifying whether the fuel or technology provides benefits or barriers that are important to the transport mode, and whether the fuel or technology possesses key desirable characteristics such as low emissions and high refuel speed. We also consider whether the fuels and technologies could have a negative impact on the performance of the transport mode.</p>
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Table 3.2 below sets out the long list assessment, and gives justification for selection of the short list. The technologies were short-listed based on an initial desk-based review of technologies and Subject Matter Expert Judgement. It was not pre-determined that the short list would have the same technologies for road and rail. As the assessment sets out in Annex B, we assess the fuels and technologies for each of road and rail separately but reach the same conclusion for each mode.

¹⁹ Transport and Environment (Jun 2017) "Roadmap to climate-friendly land freight and buses in Europe", available [online](#).

Table 3.2: Assessment of the long list fuels and technologies, and selecting those for the short list and detailed assessment. Full definitions and assessments are in Annex B.

Fuel or technology	Justification
Long list options taken through to the short list	
Electric battery: electricity is delivered to an electric motor from an on-board battery.	As the government recognises, ²⁰ technologies to enable electric HGVs are less developed than for cars and vans. While there are 38 electric cars eligible for the plug-in grant, and 9 small vans, there are no HGVs currently eligible. ²¹ Electric battery HGVs and trains are being trialled and may be most suitable for short range vehicles/trains with lighter loads. There are some technological issues to overcome, with R&D underway and manufacturers hopeful of being able to improve the range/weight ratio of batteries, and the charging speed.
E-highway/rail electrification: electricity is delivered to an electric motor from outside of the vehicle.	Powering road and rail vehicles is one of the most efficient uses of low-carbon electricity, E-highways and rail electrification have a low fuel cost. Rail electrification is commonplace, with 42% of the GB network electrified. Trials of E-highways are underway. There is a high cost of installing and maintaining electrification infrastructure, and so it may not be cost-efficient to electrify the entire road and rail freight networks, requiring that vehicles are hybrid for when off the electrified route (this may be a battery).
Synthetic fuel: generated from chemical reactions, a direct substitute for diesel.	Synthetic fuel can be used with current engine technology, and is currently being trialled on road vehicles, with low levels of production. Carbon capture methods can be used for the generation of synthetic fuel, by extracting CO ₂ from the atmosphere to combine with hydrogen generated through electrolysis of water. This can then be blended with fossil fuels.
Hydrogen: stored on-board the vehicle, processed through a fuel cell to power an electric motor.	Hydrogen trucks are being trialled, hydrogen trams have been used since 2016, and hydrogen trains will be used from 2020. Producing hydrogen requires a significant amount of electricity as it is only 30% efficient when compared to direct electric motors. Large scale use would require the development of hydrogen distribution infrastructure.
Long list options not taken through to the short list	
Liquefied Natural Gas (LNG): a lower-emission fossil fuel	LNG and LPG are capable of providing a reduction in CO ₂ emissions, but do not make it to the short list because other fuels (as included in our short list) provide far greater savings, on both road and rail. Compressed Natural Gas (CNG) is rated similarly. There are also concerns that LNG is an imported fuel, which may present security of supply issues if it becomes a key fuel for transport. These fuels have slightly lower NO _x emissions than diesel, but this difference is narrowing as emission standards improve. PM _x emissions are very low, and SO ₂ emissions are low, yet directly proportional to the amount of sulphur in the fuel. ²²
Liquid Petroleum Gas (LPG): a lower-emission fossil fuel	

²⁰ HM Government (Jul 2018) “Road to Zero” available [online p.9](#)

²¹ OLEV (Oct 2016, accessed Aug 2018) “Guidance: plug-in van grant: extension to larger vans” available [online](#)

²² United States Environmental Protection Agency (July 2008) ‘AP-42 Compilation of Air Emissions Factors: Section 1.5’ available [online](#)

Fuel or technology	Justification
<p>Biofuels: harvesting biological matter to create a direct substitute for diesel</p>	<p>Standard (1st generation) biofuels, grown from food or crop land, can only make a limited contribution to decarbonising freight:</p> <ul style="list-style-type: none"> • They have a minimal impact on CO₂ emissions, and in some cases the GHG emissions are worse than fossil diesel.²³ • Adoption of 1st generation biofuels to contribute towards the 2020 targets is limited due to concerns regarding the land required and competing uses for that land.²⁴ The Government has also indicated its intention to limit 1st generation biofuels to focus on advanced biofuels.²⁵ <p>Advanced (2nd, 3rd, 4th generation) biofuels, those using waste, can provide more significant reductions in CO₂ emissions. NO₂ emissions increase when biofuels are burnt compared with diesel, due to high levels of oxygen present, though particulate matter and sulphur dioxide generally decrease.</p> <p>There is a limited supply of waste and there are competing uses – it has been suggested that a limit of 9% might apply for transport.²⁶ As their contribution is limited we do not include these in the short list analysis but do include them as part of our timeline scenarios as they may be a good contributor while other technologies mature.</p>

3.2. SHORT LIST ASSESSMENT

Having selected the short list as summarised in Table 3.2, we undertook more detailed assessments of the short-listed fuels and technologies.

²³ Transport and Environment (Apr 2016) “Globiom: the basis for biofuel policy post-2020” available [online](#)

²⁴ European Commission (Accessed Sep 2018) “Land use change” available [online](#)

²⁵ Department for Transport (Aug 2018) “Biofuel statistics” available [online](#); HM Government (Jul 2018) “Road to Zero” available [online](#)

²⁶ Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)



Figure 3.2 sets out the assessment of the short-listed technologies and fuels.

Detailed assessments, including the sources and references for the assessment, are in Annex C.

Figure 3.2: Summary of assessment of short-listed technologies, with full assessment (with sources and references) in Annex C

Battery HGV or trains

Batteries are stored in an on-board battery (likely to be lithium-ion) and charged while stationary. While available for cars and lighter vans, freight is more difficult – its higher weight requires a higher capacity battery, which then takes up more space that could otherwise be used for freight. R&D is therefore ongoing in road and rail freight.

Key benefits:

- Zero emissions at point of use, (whole-system emissions depends on electricity generation).

Potential issues

- Batteries use more space (and add weight) to provide the same mileage as diesel, reducing the available space/weight for carrying freight.
- Slow refuelling at present – it needs to be fast enough that refuelling time does not exceed breaks. Under 1 hour may be possible by 2050 but take-up will be affected until this can be achieved.
- Range concerns – significant technological advancement needed to reach range of several hundred miles, as can be driven in a single HGV driver's shift. Drivers worry about being stranded if the range is insufficient, and also risk missing just-in-time delivery targets.
- Requires investment in charging infrastructure, electricity grid reinforcement, and higher electricity generation.
- Expected to be initially very expensive, but technological advancements (and fuel savings) may be able to make it more viable by 2030.

Synthetic fuel

- Electricity is used to produce a synthetic substitute for diesel that can be used in standard diesel engines.
- Small amounts are in production, but this option has not yet reached a full trial.

Key benefits

- Can be refuelled as quickly as diesel.
- Comparable safety and power as diesel.
- Lower emissions of pollutants such as SO_x and PM_x than diesel.

Potential issues

- Requires investment in low-emission electricity generation and distribution of electricity, and fuel production and distribution.
- Higher cost for purchasing the fuel than diesel.
- Carbon emissions at point of use are comparable to diesel, so relies on there being savings of carbon in the production process to be an improvement on diesel.
- NO_x emissions may be reduced at the tailpipe, though this is dependent on the specific synthetic fuel and the engine it's being used in; some may not be compatible for NO_x reduction.

Rail electrification

- Already in use, accounting for 5% of rail freight tonne-km, with 42% of the network electrified at present.

Key benefits:

- Only technology that is currently established in use.
- Zero emissions at point of use, but whole-system relies on low-emission electricity generation.

Potential issues

- Requires investment in rail electrification, and another fuel for non-electrified sections.
- High cost of vehicle and infrastructure in a sector which is currently declining.

E-highways

- Electricity is delivered from an external source: overhead power line, power line in road, or wireless charging. A pilot is underway in Sweden, and planned for Germany in 2019 and 2020.

Key benefits

- Zero emissions at point of use but relies on low-emission electricity generation.

Potential issues

- Requires significant investment in vehicles and infrastructure, likely needing batteries too for non-electrified sections.
- Safety concerns present in any approach.
- In early development, thus an uncertain future.

Hydrogen

- Hydrogen is stored at high pressure and released through a fuel cell to generate electricity to drive an electric motor. Have begun feasibility trials on trucks, and rail demonstrations.

Key benefits

- Can be refuelled as quickly as diesel.
- Zero emissions at point of use if production uses electricity (relies on low-emission generation) and uses it less efficiently than an electric engine.

Potential issues

- Hydrogen fuel cost expected to be around twice the cost of diesel by 2050 (excluding tax).
- Lighter than diesel but takes up more space, that would otherwise be used to carry freight.
- Requires a hydrogen production and distribution network – and depending on the production method, requires either electricity grid reinforcement or carbon capture and storage.

3.3. KEY FINDINGS FROM THE COMPARATIVE REVIEW

The comparative review of the long list and short list of alternative fuels has highlighted several technological issues that must be overcome before any of the technologies will be ready for freight operators to adopt *en masse*:

- **Advanced biofuels.** Biofuels offer an improvement over diesel that can contribute to reducing carbon emissions while other technologies develop and are adopted. Thus they are considered a key part of the transition timeline (Section 4) despite having some emission and scalability issues as identified in the long list assessment (Annex B).
- **Requirement for a mix by 2050.** We consider it unlikely that there will be a "one-size fits all" technology, given differences in technology viability. There would therefore need to be a mix of technologies in use to reach the 2050 target, although if such a target didn't exist it might be possible to wait for technological advancements to present a 'clear winner'.
- **Electrification of the highway and rail networks** would involve very significant upfront capital investment that would in our view be likely to pass a cost benefit analysis only on routes with heavy traffic flows (i.e. not all of the network would be electrified). Therefore, freight vehicles would additionally require a battery (or other hybrid power source) to operate on any non-electrified section of the network.
- **Battery road vehicles benefit from being in use already, and from having zero tailpipe emissions.** There need to be technological advances to overcome the limitations (in capacity/range per unit of mass/volume, and charging speeds), otherwise it may be possible for other technologies to overtake battery HGVs as a key contributor to decarbonisation. Batteries, electrification and hydrogen have remained promising after the detailed short list assessment.
- **Electricity demand.** All four short-listed options for road and for rail would likely result in an increase in the UK's total demand for electricity.²⁷ In the case of electric vehicles, the grid would need to be reinforced to enable high-speed charging at key locations (e.g. depots and service stations), and there may also need to be incentives in place to encourage off-peak charging. The requirements that hydrogen and synthetic fuel place on the grid would depend on the chosen methods and models of production, but may require localised grid reinforcement.
- **Synthetic fuels currently give worse whole-life emissions than standard diesel.** Upon looking into synthetic fuels in more detail, the production of the fuel is the least efficient use of electricity of all the technologies identified. With the current level of electricity grid CO₂ production, the overall CO₂ emissions from synthetic fuels are currently slightly worse than using diesel. This will improve as the grid is decarbonised. SO_x and PM_x emissions are generally considered to be reduced, however there is ambiguity over NO_x emissions. Reductions are dependent on the specific synthetic fuel used, and relies on the replacement of parts such as

²⁷ The NIA estimates that energy demand, including from more electric vehicles, could increase 9-26% by 2030. NIC (Jul 2018) "National Infrastructure Assessment" available [online](#), p.41

gaskets and tubes within the engine.²⁸ Currently this is not considered to be an economically or environmentally viable option, however these fuels may become more environmentally viable should low-carbon electricity sources be used for production of a variety of fuels which reduce NO_x emissions, but this will likely always be the least efficient fuel technology.

The government will need to work in the coming years to ensure that these barriers are addressed as early as possible, to facilitate a transition to zero emissions in surface transport by 2050.

²⁸ DW (Accessed Aug 2018) “Can clean synthetic diesel fuels succeed?” available [online](#)

4. TRANSITION TIMELINE

Based on our assessment of the potential usage of alternative low emission fuels for freight transport, the NIC asked us to develop an illustrative timeline for the transition to a zero-emission freight system by 2050. This was to identify the main barriers to take up and the potential actions that may be required to overcome them.

4.1. KEY TRANSITION MILESTONES

Our approach has been to utilise ‘key maturity milestones’ in the development and deployment of the shortlisted low emission fuel technologies (and associated infrastructure) up to the point at which they are ‘likely’²⁹ to be available for mass take up by freight and logistics operators. The key milestones are the points at which the technology has achieved:

- demonstration in a lab or test environment;
- demonstration in a live environment (i.e. on the network) at a small scale;
- development to allow production and operation at a practical scale and cost;
- adequate roll out of associated infrastructure to enable take up and market growth; and
- mass market adoption.

As we indicate in the introductory section of the report freight decarbonisation is different from decarbonising cars. There remains very significant uncertainty around the possible speed of progress on technology and infrastructure to support freight decarbonisation, which makes it difficult to identify a clear transition pathway. For example:

- There is significant uncertainty around the pace of technological advancements. For example, despite the emergence of smaller electric van models,³⁰ and the production of a small number of gas-powered heavy freight vehicles,³¹ we cannot predict with any confidence the rate of technological change or the ultimate end point in terms of the future fuel mix, given the present level of maturity of the short-listed technologies assessed in Section 0. We note that OLEV and Highways England are together pursuing a research project to “identify and assess zero emission HGV technologies and their suitability to the UK road network and freight operations” that will help to address this uncertainty³² but findings are not yet available.
- There is also unknown potential for improvement in technology quality between now and 2050. Changes in quality might include, for example, improvements in the battery range: size ratio, or improvements in the efficiency of fuel production.

²⁹ ‘Likely’ - by reference to the time taken by other technologies to mature.

³⁰ SMMT (February 2017) “Nissan tops electric van charts” available [online](#)

³¹ For example, see FreightWaves (2018) “Natural gas-powered trucks are well ahead of electrification” available [online](#); NGT News (2017) “Volvo Introduces New Heavy-Duty LNG Trucks” available [online](#).

³² HM Government (Jul 2018) “Road to Zero” available [online](#) p.15

- There are substantial challenges in relation to the affordability and delivery of associated infrastructure required to support freight decarbonisation. For example, concurrent electrification of the UK road and rail networks would be expensive and would potentially reduce the funds available for the government to invest in other transport projects.

Based on the issues identified during our comparative assessment of the shortlisted technologies, the length of time it typically takes for energy technologies to mature, and the complexities of freight transportation (particularly possible impacts on the incentives to develop innovative technologies and national infrastructure), we estimated approximately how long it might take (in years) for each fuel technology to reach these milestones. Our estimates are shown in Table 4.1 and Table 4.2 below. They are presented as a wide range to reflect the underlying uncertainties described above, and should be considered as illustrative of the challenge ahead rather than a modelled prediction.

In terms of adoption, sources³³ show that from 2010 to 2018 the number of electric vehicles registered in the UK went from 10 to 178,000. Although a significant increase this represents only ~0.6% of the overall number of such vehicles in the UK.³⁴ This growth is an example of stage iv, however it is in the context of individual consumers not commercial businesses. We know from OLEV that take up of electric commercial vehicles i.e. the small vans that are currently available, is much slower than has been the case for cars.

³³ SMMT (Jan 2012) “December 2011 – EV and AFV registrations” available [online](#)

NextGreenCar (Accessed Oct 2018) “Electric car market statistics” available [online](#)

³⁴ RAC foundation (Accessed Oct 2018) “How many vehicles are there in Great Britain?” available [online](#)

Table 4.1: Summary of trajectory to 100% adoption (in fleet) of alternative fuels and technologies – road freight.

Stage of a typical development cycle	Status once complete stage	Battery HGVs	E-highways	Synthetic fuel	Hydrogen
<p>Maturation stages: The key factors driving the "maturation" stages are the amount of effort required to:</p> <ul style="list-style-type: none"> • Develop and approve business cases for investment. HGVs and freight trains are large and expensive pieces of equipment, therefore significant justification will be required. • Demonstrate safety cases for a) the development of the technology, and b) the development/use of infrastructure. • Understand the technology, how to model and design it, how it will be used, how it interfaces with infrastructure, producing evidence/modelling of cost, operation and safety. • Overcome unforeseen technical difficulties/barriers that can arise as research continues. 					
i: Design and develop technology in a laboratory/test facility such that it could be used in a demonstration.	TRL: 6 Adoption: 0%	2-5 years to develop technology.	0 years if import; 2-5 years to develop technology in UK.	3-4 years to wait for imported fuel to become available and for initial quality and safety tests.	0 years if import vehicles; 3-6 years if develop technology in UK.
ii: Demonstrate on an individual truck with test section of infrastructure, e.g. field test.	TRL: 7 Adoption: 0%	1-3 years of safety testing and data collection.	2-5 years to install test infrastructure and do safety tests in the UK.	5-9 years to install a pilot fuel generation plant, including 1-2 years of testing.	3-6 years to install or modify fuel infra and simultaneously test vehicle (1-2 years).
iii: Prototype demonstrated on a series of trucks using a small section of actual infrastructure.	TRL: 8 Adoption: 0%	2-5 years to develop demonstrator model and introduce infra (battery swapping or charging).	4-6 years to install demonstrator model and infrastructure.		4-6 years to develop demonstrator model and install infrastructure.
iv: Small take-up by some users, with appropriate infrastructure in place, although some limitations on infrastructure as not widely distributed.	TRL: 9 Adoption: 0-10%	5-10 years for initial take-up, relying on infra and improved costs over diesel. Requires mass vehicle manufacture.	10-15 years for initial take-up, relying on infra and improved costs over diesel. Requires mass vehicle manufacture.	10-15 years for initial take-up, needing lots of electricity and fuel production, and improved cost over diesel.	10-15 years for initial take-up, requiring installation of refuelling infrastructure and improved costs over diesel.

Stage of a typical development cycle	Status once complete stage	Battery HGVs	E-highways	Synthetic fuel	Hydrogen
<p>Adoption stages: The key drivers affecting "adoption" are:</p> <ul style="list-style-type: none"> • Confidence in the market to adopt the technology. For relatively large investments like vehicles this is likely to take longer than for smaller, low cost assets. • The amount of time for large infrastructure projects to be granted funding. • The amount of time taken for large infrastructure project to be understood, designed and commissioned. 					
v: Medium penetration of the market, nearly full infrastructure installed.	TRL: 9 Adoption: 30-50%	5-10 years of improving infra and take-up.	8-12 years of improving infra and take-up.	10-15 years of improving production capacity and take-up.	8-12 years of improving infra and take-up.
vi: Technology becomes widespread, covering almost all of the market, and all infrastructure that will be built has been built.	TRL: 9 Adoption: 70-100%	5-10 years of more improving infra and take-up.	8-12 years of improving infra and take-up.	10-15 years of improving production capacity and take-up.	8-12 years of improving infra and take-up.
<p>Overall range: bringing together the ranges for the six stages, the overall range is wide and key factors include the level of (and success of) R&D, strength of incentives, and policy.</p>		18-47 years	32-60 years	38-63 years	33-57 years

Table 4.2: Summary of trajectory to 100% adoption (in fleet) of alternative fuels and technologies – rail freight.

Stage of a typical development cycle	Status once complete stage	Battery trains	Electrification	Synthetic fuel	Hydrogen
<p>Maturation stages: The key factors driving the "maturation" stages are the amount of effort required to:</p> <ul style="list-style-type: none"> • Develop and approve business cases for investment. HGVs and freight trains are large and expensive pieces of equipment, therefore significant justification will be required. • Demonstrate safety cases for a) the development of the technology, and b) the development/use of infrastructure. • Understand the technology, how to model and design it, how it will be used, how it interfaces with infrastructure, producing evidence/modelling of cost, operation and safety. • Overcome unforeseen technical difficulties/barriers that can arise as research continues. 					
i: Design and develop technology in a laboratory/test facility such that it could be used in a demonstration.	TRL: 6 Adoption: 0%	6-9 years to develop technology in UK.	0 years - Trains already operating.	3-4 years to wait for imported fuel to become available and for initial quality and safety tests.	6-9 years to develop and trial technology.
ii: Demonstrate on an individual locomotive with test infrastructure, e.g. a field test.	TRL: 7 Adoption: 0%	1-2 years of safety testing and data collection.	0 years – Some trains already operating.	5-9 years to install a pilot fuel generation plant, including 1-2 years of testing.	3-6 years to install fuel infra and simultaneously test vehicle (1-2 years).
iii: Prototype demonstrated on a series of locomotives using a small section of actual infrastructure.	TRL: 8 Adoption: 0%	2-5 years to develop demonstrator model and introduce infra (battery swapping or charging).	0 years – Some trains already operating.		4-6 years to develop demonstrator model and install infrastructure.
iv: Small take-up by some users, with appropriate infrastructure. Limitations on infrastructure as not widely distributed.	TRL: 9 Adoption: 0-10%	4-10 years for initial take-up, relying on infra and improved costs over diesel. Requires mass vehicle manufacture.	8-12 years for initial take-up, relying on infrastructure development and improved take-up.	10-15 years for initial take-up, needing lots of fuel production, and improved cost over diesel.	9-13 years for initial take-up, requiring infrastructure and improved costs versus diesel.

Stage of a typical development cycle	Status once complete stage	Battery trains	Electrification	Synthetic fuel	Hydrogen
<p>Adoption stages: The key drivers affecting "adoption" are:</p> <ul style="list-style-type: none"> • Confidence in the market to adopt the technology. For relatively large investments like vehicles this is likely to take longer than for smaller, low cost assets. • The amount of time for large infrastructure projects to be granted funding. • The amount of time taken for large infrastructure project to be understood, designed and commissioned. 					
v: Medium penetration of the market, nearly full infrastructure installed.	TRL: 9 Adoption: 30-50%	5-10 years of improving infra and take-up.	8-12 years of improving infra and take-up.	10-15 years of improving production capacity and take-up.	9-13 years of improving infra and take-up.
vi: Technology becomes widespread, covering almost all of the market, and all infrastructure that will be built has been built.	TRL: 9 Adoption: 70-100%	5-10 years of more improving infra and take-up.	8-12 years of improving infra and take-up.	10-15 years of improving production capacity and take-up.	9-13 years of improving infra and take-up.
<p>Overall range: bringing together the ranges for the six stages, the overall range is wide and key factors include the level of (and success of) R&D, strength of incentives, and policy.</p>		23-51 years	29-41 years	38-63 years	42-65 years

4.2. TECHNOLOGY ADOPTION

Section 4.1 set out our estimated maturity trajectories for each short-listed fuel technology. Before these can be translated into a timeline for the transition to a zero emission freight system, we also need to consider how some of the technological, economic and other practical issues identified in the comparative assessment might impact the development curve and actual take-up of new technologies. These issues are explained in Table 4.3 below.

Table 4.3: Technological, economic and other practical issues affecting development and adoption

Fuel	Technological issues affecting adoption
Battery powered heavy duty freight vehicles	<ul style="list-style-type: none"> • Pace and scope for improvements in battery range and reductions in battery size/weight is uncertain. Current battery size displaces freight. Charging time may also be a limiting factor. • Further research and development (R&D) and trialling of battery technology required to prove viability.
e-Highways and rail electrification	<ul style="list-style-type: none"> • Electrification of road and rail networks would require several billion pounds of upfront government investment. Unlikely to pass a cost-benefit test except on busiest routes where other issues such as bridge density may impact feasibility. Consequently, we do not expect e-Highways to drive (additional) uptake of electrical freight vehicles without significant government intervention. • Likely that gaps will remain in the electrified network, particularly the “last mile”, and that freight vehicles will need batteries or other hybrid power source to travel on non-electrified sections. • Electrification of the rail network is proven, but only a few small schemes trialling highway electrification are in operation in Europe (i.e. technology is not mature) and none of the UK’s key RoRo trading partners have adopted e-Highways as the preferred pathway to zero emissions. • Further R&D and lab environment trials required in the UK to test feasibility.
Synthetic diesel fuels	<ul style="list-style-type: none"> • Cost of fuel production projected to remain significantly above other sources, in part because the production process is an inefficient use of energy relative to other fuels. • Currently there are no production plants in the UK. Developing fuel production facilities, and investment in associated electricity generation and grid infrastructure, would require substantial investment.
Hydrogen	<ul style="list-style-type: none"> • Hydrogen is not produced at sufficient scale in the UK to accommodate mass market take-up, and production costs are expected to remain high for the foreseeable future. • Substantial investment would also be required in associated transmission and distribution network. • Hydrogen requires larger tanks and more robust engineering to store it, leading to cost/safety implications. • Total costs are unlikely to permit mass market adoption unless investment can be spread across other decarbonising sectors (e.g. domestic heating and appliances). • Overall take-up expected to be low by 2050 without government establishing a clear policy to develop hydrogen as a transport fuel and facilitating the associated network investment.

Taking these issues and the illustrative trajectories described in Section 4.1 into account, the following sections build a baseline scenario based on current technology trajectories, and a more ambitious scenario illustrates how the UK might have to accelerate the transition towards a zero emission freight system by 2050.

4.3. BASELINE SCENARIO: CURRENT TECHNOLOGY TRAJECTORIES

The baseline scenario represents the current trajectories in the development of the shortlisted low carbon technologies considered in our comparative assessment, but also including biofuel which is also considered to be a viable technology for progress in the short-term rather than as part of the long-term strategy. The baseline scenario is also based on the assumption that government policy towards these alternative fuel technologies remains unchanged from its current status.

Across all technologies, our baseline scenario assumes that the R&D activities required to bring low carbon fuels to the freight market will be led by industry. While the government currently provides a degree of financial assistance for such activities, we assume that the level of support remains broadly unchanged. Completing these stages could take 10 to 15 years (as shown in Tables 4.2 and 4.3 above) depending on the technology, and we stress that this is an illustrative range which depends to a large extent on uncertain advancements in technology.

To simplify our timeline, we also assume that sufficient investment is delivered to expand the UK's capacity to generate low-carbon energy and reinforce the electricity networks (noting that this will likely require a significant increase in government support and customer energy bills) and that this investment is delivered over the next 10 to 15 years, to accommodate the much wider shift to electric vehicles.

4.3.1. Road freight

In the baseline scenario for road freight, we have made the following assumptions about how the current technology trajectories interact with the issues described in Table 4.3 above, to affect the adoption of low emission fuels:

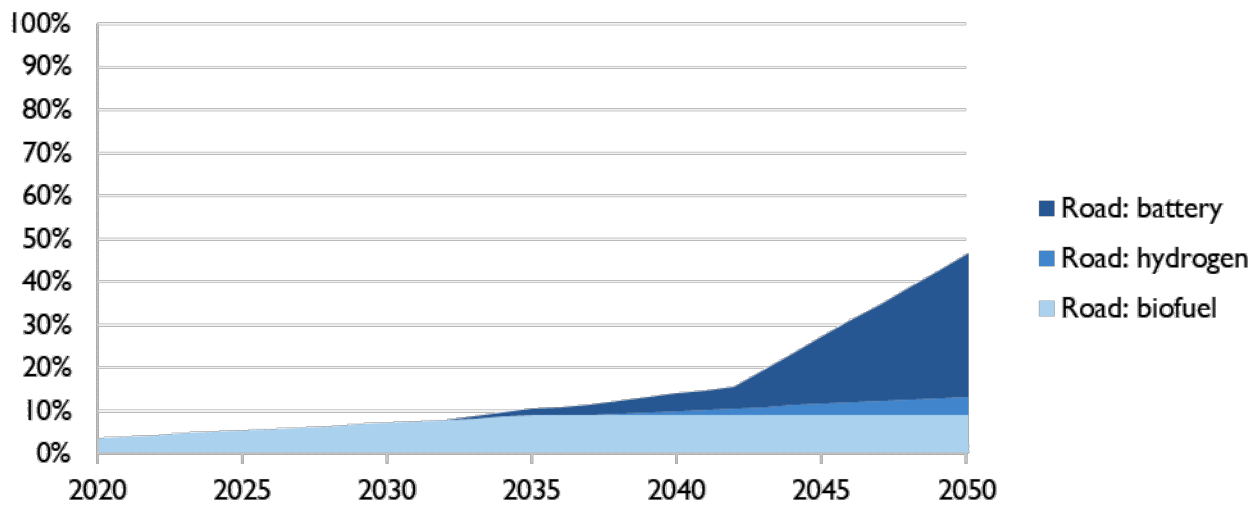
- **Advanced biofuel.** Biofuel is currently used in transport but the volumes produced are limited by available inputs and other competing uses. We assume that the utilisation of advanced biofuel in the road freight system will grow to the maximum level possible – around 10% – by the mid-2030s with no further growth after that. This relies on the assumption that there is no further growth in other competing uses of biofuel which would otherwise reduce the amount available for freight. We must also note that biofuel has only minimal impact on CO₂ emissions.
- **Battery electric vehicles.** We assume that battery technology will develop such that concerns about range and charging are sufficiently eased to encourage the emergence and take up of battery-powered vans and light commercial vehicles, primarily operating in local and urban markets for last-mile deliveries, from the mid-2030s. Battery electric vehicle market share grows throughout the 2040s as new vehicle costs fall (relative to diesel technology) and older vehicles are replaced. But it is uncertain how much longer it takes to develop battery technology capable of powering heavy goods vehicles. We consider it is unlikely that manufacturers are successful in bringing battery HGVs to the market before the 2040s. Battery electric vehicles are therefore limited to around 40% of the market by 2050. We assume that some additional government support is provided for electric vehicle charging infrastructure as current support is insufficient, we assume there would be enough to kick-start roll out until it is commercially proven.
- **Hydrogen.** A fleet of hydrogen powered lorries is assumed to develop during the 2040s because of the limited supply of other low emission fuels, although the growth of the hydrogen fleet is itself limited by the constrained supply of hydrogen fuel and related infrastructure. We consider that the fleet will amount to around 5% of the total freight vehicle fleet by 2050. We also assume that the

government does not coordinate the roll-out of a hydrogen infrastructure network, but if a decision is taken to convert the gas network to hydrogen, this may speed up adoption by providing a distribution network.

- **e-Highways.** None of the highway network is electrified as this would require a Government decision to undertake a very significant programme of public investment.
- **Financial incentives.** Early models of new low emission vehicles are likely to be more expensive than their diesel comparators as manufacturers will need to recoup development costs. Additionally, the upfront cost of purchasing a new vehicle may present a barrier to operators, who will be better off by maintaining and operating their existing fleet. Therefore, the adoption of low emission fuels for road freight in the late 2030s is assumed to be supported by a package of financial incentives which is broadly similar (in real terms) to those currently available on new electric cars and vans through the Office for Low Emission Vehicles (most notably grants to reduce the upfront cost by 20% of the purchase price, up to a maximum of £8,000). This is assumed to be an extension of current government policy, although the cap on any financial support may need to be increased (above £8,000) in order to have the desired incentive effect on large, expensive HGVs (noting that a higher cap would also increase the cost the scheme). If successful, this would help to support a replacement rate of between up to 5% of vehicles per annum through the 2040s – if HGVs have a useful life of 10-15 years, although 7-10% may be possible once user confidence is high.

Figure 4.1 illustrates how these assumptions translate into the adoption of low emission fuels over time.

Figure 4.1: Penetration (by number of vehicles) of alternative low emission fuels in the road freight transport market under the baseline scenario



Overall, only around 50% of the road freight fleet would be powered by low emission fuels in the baseline scenario by 2050.

The low penetration of alternative fuels during the first two decades of the baseline scenario is a result of the time required to develop and test the feasibility of new technologies, and then to run a series of trials on small parts of the live network. Biofuel is the main driver of growth before the mid-2030s but market penetration is limited by that availability of fuel and other competing sectors.

Once the associated infrastructure networks (i.e. electric freight vehicle charging network, and the production and distribution of hydrogen fuel) are expanded to accommodate freight traffic, which we

estimate may occur sometime in the next 15 to 20 years, battery, and to a lesser extent hydrogen, vehicles will play an important role in the transition.

4.3.2. Rail freight

In the baseline scenario for rail freight, we have made the following assumptions:

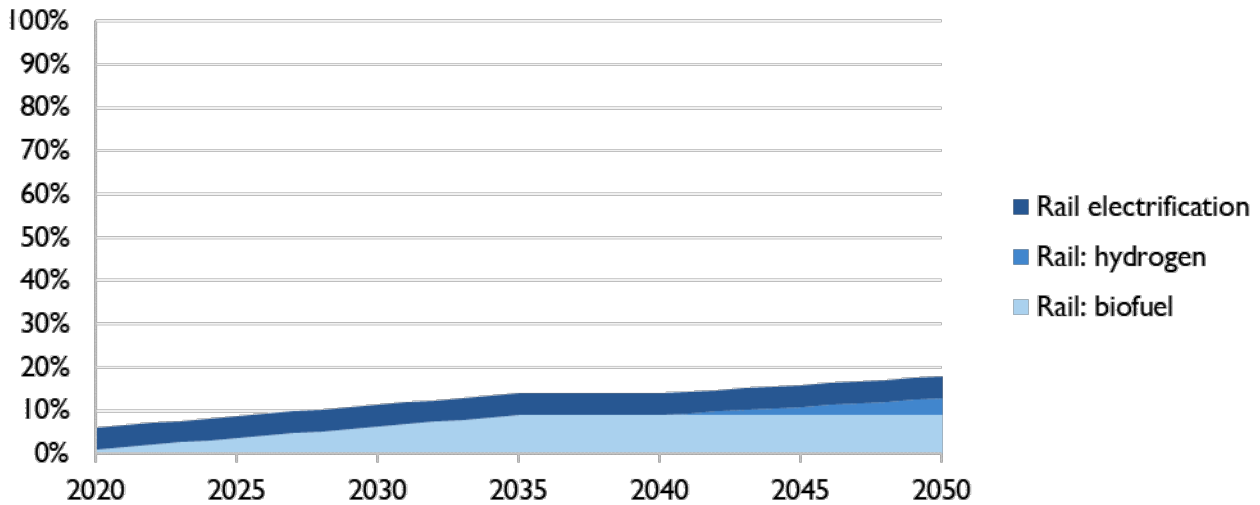
- **Advanced biofuel.** Biofuel is not currently used in rail transport because the volumes produced are limited by available inputs and other competing uses. We assume that the utilisation of advanced biofuel in the rail freight system could grow to around 9% by the mid-2030s, with no further growth after that. This relies on the assumption that there is no further growth in other competing uses of biofuel which would otherwise reduce the amount available for freight. We must also note that biofuel has only minimal impact on CO₂ emissions.
- **Hydrogen.** A small fleet of hydrogen powered freight trains may become viable by 2040 because of the limitations of other low emission technologies and the government’s current policy stance on electrification, although the growth of the hydrogen fleet is limited by the constrained supply of fuel. We also assume that the government does not coordinate the roll-out of a hydrogen transmission and distribution network.
- **Battery-powered trains.** Due to the uncertain potential of battery technology for use in hauling rail freight (especially in relation to range because of the low probability that key freight routes will be fully electrified in this timeframe), we assume that any improvements in battery technology are insufficient to lead to the introduction of battery-powered freight trains before 2050.
- **Electrification (and electric freight trains).** According to the latest data, around 5% of freight (tonne-km) is currently moved by electric freight trains.³⁵ However, the government has recently cancelled electrification schemes on cost grounds and there are no plans to resume the electrification programme. As such, we assume in this scenario that electrification will not support an increase in electric rail freight by 2050.
- **Financial incentives and the residual value of diesel rolling stock.** The upfront cost of purchasing new rolling stock may be an unattractive option for rail freight operators, who will be better off by maintaining and operating their existing fleet. The asset life of freight rolling stock can be in excess of 20 years and the residual value of the current fleet is likely to be significant.³⁶ Based on existing government policy, we do not assume that specific support measures for rail freight (e.g. purchasing subsidies for fleet operators) are introduced, or that the government mandates the use of low emission rolling stock (e.g. through a mandated direction to procure electric rather than diesel vehicles).

Figure 4.2 illustrates how these assumptions translate into the adoption of low emission fuels over time.

³⁵ Department for Transport (Sep 2016) “Rail Freight Strategy. Moving Britain Ahead” available [online](#). The consumption of electricity in transporting freight has increased in recent years and so its proportion of the total may have increased. See ORR (Oct 2018) “Rail infrastructure, assets and environmental. 2017-18 annual statistical release” available [online](#)

³⁶ There is no public data on the age of UK rolling stock, however the average age of all freight cars in the United States was 24.5 years in 2010. See Statista (accessed October 2018) “Average age of freight rail cars in the United States from 2005 to 2011 (in years)” available [online](#)

Figure 4.2: Penetration of alternative low emission fuels in the rail freight transport market under the baseline scenario



Source: CEPA and Frazer-Nash analysis

Overall, only around 20% of the rail freight fleet would be powered by low emission fuels in the baseline scenario by 2050. The economics of replacing older diesel rolling stock also results in a much slower transition than for road freight.

Biofuels are the main driver of growth before 2040 because none of the other technologies are assumed to be sufficiently mature to be deployed on the live network. Post 2040 there would be some additional growth as hydrogen-powered rolling stock becomes viable, but the rate of adoption is limited by the available fuel and the limited roll out of associated infrastructure networks. Importantly, there is no increase in electrification as a means of powering rail freight, despite being the only option which could (based on current technological maturities) reduce the emissions of the majority of the fleet.

4.4. AMBITIOUS SCENARIO: ACCELERATED TIMELINE TOWARDS DECARBONISATION BY 2050

The baseline scenario demonstrates that without substantial new intervention by government, the UK will fail to reduce emissions from the freight transport sector to zero by 2050.³⁷

Acknowledging that the goal to reduce freight transport emissions to zero is a significant challenge which largely rests on the uncertain ability of manufacturers and industry to accomplish major advances in low emission technology on a much accelerated timeframe, the NIC asked us to illustrate how this could be achieved by 2050.

This more ‘ambitious’ scenario demonstrates, illustratively, the take-up of low emission technologies if government and industry is able to overcome technological and economic barriers. By working backwards from 2050 we determine approximately the required maturity of each technology by key milestone date such that zero emissions are achieved by 2050.

In order to accelerate the pathway to zero emissions in both the road and rail freight systems by 2050, the ambitious scenario assumes that the government coordinates the development of a core infrastructure network (comprising rail electrification, electric vehicle charging infrastructure and hydrogen refuelling

³⁷ The Government’s target is for all new cars and vans to be effectively zero emission by 2040. See HM Government (July 2018) “The Road to Zero” available [online](#), page 2. The CCC has advised that this level of decarbonisation of the transport sector is required to support the UK meeting its overall targets as set out in the Climate Change Act.

facilities) by 2035, in order to facilitate adoption by the ‘mass market’ of freight operators. In our view, it is currently highly uncertain whether such a milestone is achievable, but it is necessary if the UK is to reach a zero emission freight system by 2050.

Assuming these milestones can be met, the ambitious scenario also assumes that almost the entire fleet of freight vehicles is replaced by new, low emission units over approximately 15 years. Although there will be an underlying rate of replacement as older vehicles expire, commercial vehicles can be long lived assets. The average age of an HGV in the UK is estimated at 7.5 years and rising. 14% of the HGV fleet is over 13 years old.³⁸ The average age of rolling stock (including passenger stock) in the UK is currently over 20 years old.³⁹ Rail freight stock tends to be much older, and we understand that despite its aging profile the fleet is considered reliable. Therefore, fleet replacement will need to be accelerated by government through the use of financial incentives which encourage operators to dispense with their existing diesel vehicles in favour of purchasing (or leasing) new low emission stock. Given the lack of progress in encouraging the take-up of low emission vans in the UK, a ‘step change’ may be required in terms of the scale of incentives available.

We also assume that the technologies pursued in the UK are broadly aligned with those adopted across Europe, particularly those countries which are the UK’s main RoRo markets (i.e. France, Netherlands, Ireland and Germany). This would facilitate faster adoption of low emission fuels by international freight operators based on the nature and availability of the associated infrastructure installed in the UK. This is a challenging assumption given that there appear to be a variety of approaches emerging across the case studies we examined, although we note that over a longer timeframe international operators would gradually adapt to the new environment in any case.

4.4.1. Road freight

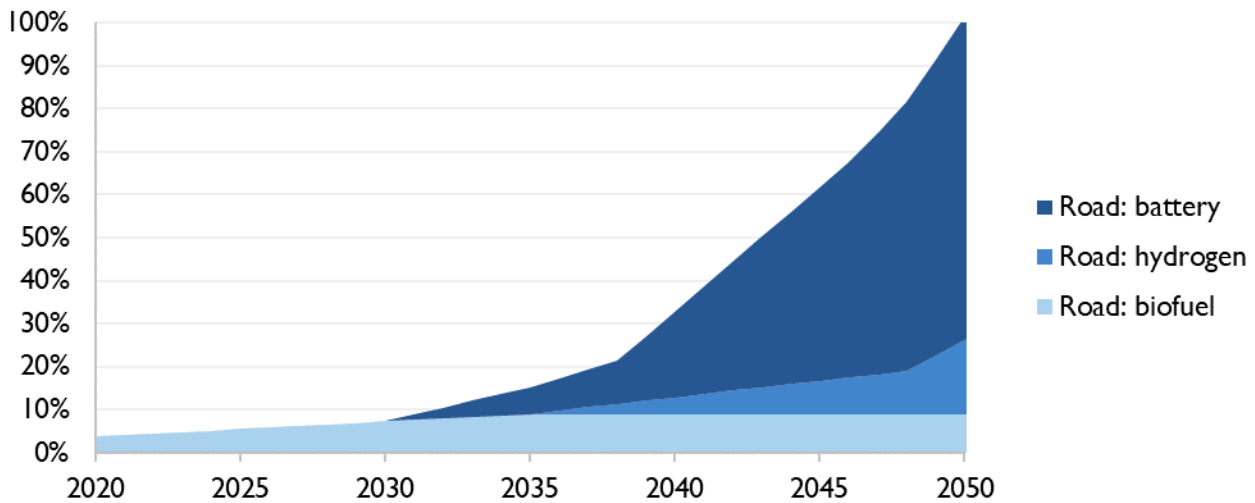
In the ambitious scenario for road freight, we have made the following assumptions about the trajectories of the main low emission technologies:

- **Advanced biofuel.** Our biofuel assumption is the same as in the baseline scenario due to the limitations on the inputs needed to produce the fuel and other competing uses. Therefore, we assume that the utilisation of advanced biofuel in the road freight system will grow to the maximum level possible – around 9% – by the mid-2030s with no further growth after that.
- **Hydrogen.** The increased production of hydrogen allows it to become a viable fuel for heavy goods vehicles, particularly in the 2040s, but the size of the fleet is still constrained by the production process and the need to develop a distribution and refuelling infrastructure network.
- **Battery electric vehicles.** We assume that with significant support from government and wider industry, manufacturers are able to develop batteries which are viable for powering both light and most heavy commercial goods vehicles (i.e. they are sufficiently small, light, and offer long range capability).

³⁸ Motor Transport (February 2016) “Texaco Report 2016: overview of the UK commercial vehicle industry” available [online](#)

³⁹ Office of Rail and Road (October 2017) “Rail infrastructure, assets and environmental: 2016-17 Annual Statistical Release” available [online](#)

Figure 4.3: Penetration of alternative low emission fuels in the road freight system under the ambitious scenario



Source: CEPA and Frazer-Nash analysis

Figure 4.3 shows that in order to achieve 100% penetration of low emission fuels by 2050, any new technologies need to be sufficiently mature by the end of the next decade (i.e. 2030). This suggests an important role for government by helping the technology and infrastructure to be in place to allow take-up of low-carbon road freight technologies to accelerate sharply from the late 2030s onwards. In this scenario battery HGVs represent the majority of the road fleet (~75%). It would be very ambitious to expect that the entire road freight fleet would be battery-powered by 2050, so biofuel and hydrogen will also contribute. Biofuel is an interim fuel which accounts for around 9% by 2050,⁴⁰ and hydrogen develops to around 16%.

4.4.2. Rail freight

In the ambitious scenario for rail freight we have made the following assumptions about the technologies:

- **Advanced biofuel.** As per the baseline scenario, we assume that the utilisation of advanced biofuel in the road freight system will grow to the maximum level possible – around 9% – by the mid-2030s with no further growth after that.
- **Hydrogen.** The increased production of hydrogen allows it to become a viable fuel for freight trains, particularly in the 2040s, but the size of the fleet is still constrained by the production process and the need to develop a distribution and refuelling infrastructure network.
- **Electrification of track.** To achieve zero emissions from the rail freight sector, government and industry will need to focus on the proven technology and restart a rolling programme of electrification that includes key freight routes. We assume that concerns over the affordability and value for money of electrification schemes can be overcome in the next 5 to 10 years, and that Network Rail is funded (and has the capacity) to deliver the programme. It will be necessary to

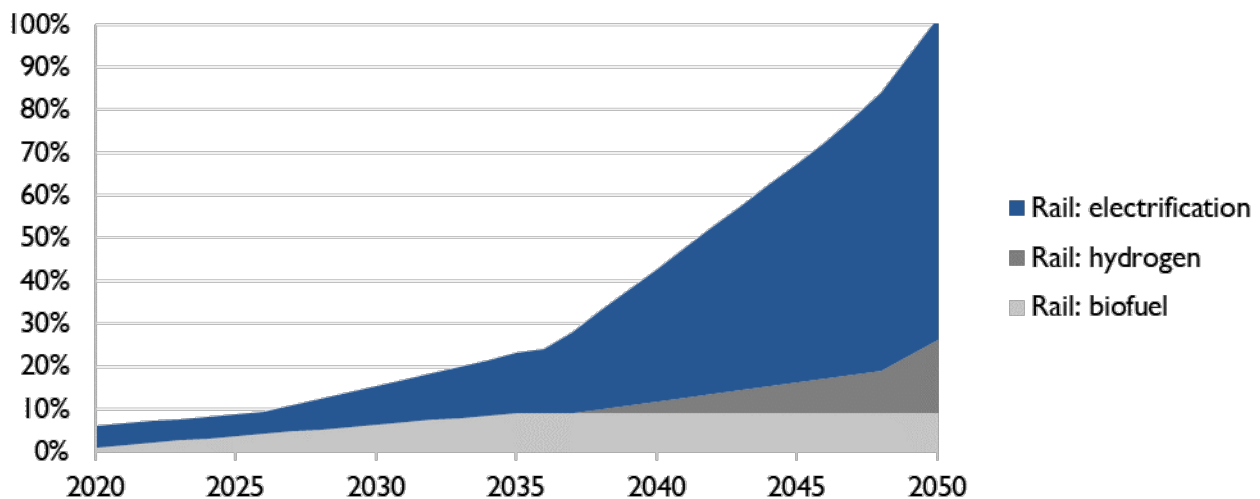
⁴⁰ Biofuel is expected to contribute up to 9% given the limited supply of input (waste) and the competing uses for it. It does emit some CO₂. Source: Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

undertake an assessment of the rail freight network to understand if it is cost-effective to electrify the entire network in the coming decades, or whether lower-traffic areas should be served by alternatives (e.g. with hydrogen or batteries). Some industry commentators have speculated that a “modest” programme of route electrification could encourage a significant increase in the amount of electrically hauled freight in the UK.⁴¹

- **Adoption of new rolling stock.** Based on current replacement cycles, we assume that rolling stock has an asset life of around 33 years, resulting in an average replacement rate of existing stock of 3% per annum. This may require that industry is incentivised (or compelled) to purchase new electric rolling stock rather than continuing to replace retired stock with diesel locomotives. The initial growth could be accelerated with investments in the regions with the densest traffic, and by ensuring that additional rolling stock (to address any traffic growth) is electric as early as is practicable.⁴²

Figure 4.4 illustrates how these assumptions into the adoption of low emission fuels over time.

Figure 4.4: Penetration of alternative low emission fuels in the rail freight system under the ambitious scenario



Source: CEPA and Frazer-Nash analysis

About 75% of rail freight could be electrified by 2050 in our ambitious scenario, but given the need to electrify the rail network first, freight operators will take up new electric rolling stock at an accelerated rate from the late 2030s.

We think it is unrealistic that 100% of rail freight could be electrified, especially where traffic flows are low, so the remaining 25% of rail freight operating on sections of the network where electrification is uneconomic could be powered by a small fleet of biofuel and hydrogen-powered trains. Rail freight currently accounts for less than 9% of all inland freight in the UK, so attaining zero emissions from the last economic of rail freight routes is likely to achieve marginal environmental benefits at a relatively high cost.

⁴¹ Julian Worth (Apr 2018) “Charting an electric freight future” in Modern Railways

⁴² Julian Worth (Apr 2018) “Charting an electric freight future” in Modern Railways

4.5. KEY FINDINGS FROM THE TIMELINES

The UK has yet to demonstrate that it could deliver a zero-emissions freight system by 2050. There is little evidence on the application and progress of low emission fuel technologies in the freight sector, and our case studies demonstrate slow progress achieved by the other countries. In our view, unless the government adopts a deliberate and ambitious strategy, the UK will fall well short, as illustrated by the baseline scenario.

To accelerate the timeline, the government's immediate focus should be on addressing some of the current uncertainty about the potential application of new low emission fuels in the freight system and trying to accelerate technological maturity. This stage is critical in determining which fuels might become commercially viable on a mass scale and will enable the government to focus its limited financial resources on those technologies that are most likely to gain market share. It will also provide a useful signal to investors in fuel production and associated infrastructure networks, for whom stability of government policy and support is a relevant factor in investment decisions.

It is currently thought unlikely that there will be a "one-size fits all" technology, given differences in technology viability. There would therefore need to be a mix of technologies in use to reach the 2050 target, although if such a target didn't exist it might be more possible to wait for technological advancements to present a 'clear winner'.

If government and industry can collectively focus on developing key technologies and delivering the supporting infrastructure more significant progress is likely. The costs of addressing these barriers are likely to be very large and there remains substantial uncertainty around the viability of low emission fuel technologies in the freight system. It will also be important that the decision-makers consider whether actions taken in one area affect those in another – if the best option for decarbonising passenger road travel is different to the best option for decarbonising freight road travel, it would be worth considering which option is better overall. This should not be restricted within road or rail, or even transport – actions in the energy sector, for example, could have an impact on the viability of EV or hydrogen as a fuel.

Countries will have to work together on technology development and standards as new vehicles and infrastructure are rolled out. With high levels of cross-border trade, it is important that countries are harmonised to the extent that RoRo freight is still capable of operating efficiently.

Overcoming this central uncertainty may require the government to revisit current policy positions, particularly with regards to electrification of the rail network. Although alternative technologies are advancing and applications may be found for passenger services, rail freight presents a different set of challenges. Electrification is presently the only feasible option which delivers a significant reduction in rail freight emissions by 2050.

Finally, kick-starting the market for low emission freight vehicles will likely require substantial incentives that go far beyond anything yet available in the transport sector, to ensure that new technologies are attractive to freight operators. The form of these incentives and other options for financial support are explored in Section 5.

5. FINANCIAL INCENTIVES

Substantial acceleration of the current trajectory of decarbonisation in transport is required to achieve full decarbonisation by 2050, and there remains significant uncertainty about whether the required technology and supporting infrastructure can be developed and then scaled up to meet this timetable.

Industry has in recent years begun thinking about this transition and the technologies that might be commercially viable in a lower emissions environment. Our transition timelines discussion (Section 4) demonstrates that the baseline scenario involves little development and adoption of lower emission fuels and technologies. Widespread adoption of new, zero carbon vehicles at the pace needed to meet the 2050 deadline will likely require the UK government to pursue a highly ambitious policy agenda coupled with significantly increased investment in the associated infrastructure which is essential to decarbonising transport.

This section attempts to answer the question: “**what financial incentives or support could the UK government provide to encourage and enable freight operators to make the transition?**”. In doing so, we examine the potential financial support and incentive schemes that might support a zero-emissions transport system, drawing on examples from the UK and other case study countries, as well as the decarbonisation of other sectors. This section assesses the key strengths and weakness of each approach and draws out some of the key findings in the context of reducing emissions from freight transport in the UK.

For the foreseeable future, the traditional incentive-based approach, where subsidies and/or tax incentives are offered on the purchase of lower emission vehicles, is unlikely to facilitate the scale of transformation desired without other forms of support.

The full package of financial support will need to cover four areas:

- **Support for R&D activity and technology trials (Section 5.1)**
 - The government’s immediate focus should be on funding research and testing of alternative, low carbon fuels and technologies, to address some of the current uncertainty about technological frontiers and speed up advances in performance. This stage is critical in determining which fuels might become commercially viable on a mass scale, and will enable the government to focus its limited financial resources on those technologies that are most likely to gain market share.
 - Examples include: Ofgem Network Innovation Competition, Highways England Innovation Designated Fund, and Innovate UK / OLEV Low Emission Freight and Logistics Trial.
- **Investment in new infrastructure (Section 5.2)**
 - The rate of adoption of low carbon fuels is likely to be limited by the availability of the necessary infrastructure to produce the fuel (without generating higher carbon emissions in the process), distribute it around the country (or at least to key locations) and allow for refuelling (or provide traction power in the case of electrification). Once some of the key uncertainties around technological performance have been resolved, the government should support (in some cases by directly funding) new investment in order to accelerate mass adoption. Government could undertake direct investment and grants, and could also underwrite investment by the private sector (e.g. using existing regulatory frameworks that allow companies to recover efficiently-incurred investment costs).

- Examples include: Charging Infrastructure Investment Fund, London Hydrogen Bus Interchange, and OLEV Charging Infrastructure Fund.
- **Subsidies and tax exemptions related to vehicle purchase (Section 5.3)**
 - Over the longer term, the government should introduce incentives which encourage freight operators to replace their current diesel fleet with lower emission vehicles, by reducing the relative cost of purchasing/leasing and operating new lower emission vehicles (or conversely by increasing the relative cost of diesel). This is typically achieved by subsidising the upfront cost of purchasing the vehicle and/or offering preferential tax rates on low carbon fuels.
 - Examples include: OLEV Electric Van grants, and ‘Bonus / malus’ incentives (France and Sweden).
- **Exemptions from charges levied on usage of the road network (Section 5.4)**
 - Over the longer term, the government should introduce incentives which encourage freight operators to replace their current diesel fleet with lower emission vehicles, by reducing the relative cost of purchasing/leasing and operating new lower emission vehicles (or conversely by increasing the relative cost of diesel). This is typically achieved by subsidising the upfront cost of purchasing the vehicle and/or offering preferential tax rates on low carbon fuels.
 - Examples include: London Ultra Low Emission Zone, road tax exemptions for electric vehicles, reduced fuel duty.

These options are discussed in the following subsections of this report.

There are additional policies that the government might introduce to provide industry with incentives to develop new technology and accelerate the pace of transition, or to encourage greater efficiency in freight movements, thereby reducing the decarbonisation challenge. Detailed assessment of such options was outside of the scope of our report however they might include:

- **Expanding the 2040 end to the sale of diesel vehicles to include HGVs, or restricting their use.** In July 2017, the government announced that it would end the sale of all new conventional petrol and diesel cars and vans by 2040 in a bid to tackle air pollution and carbon emissions. The restriction could be extended to include HGVs, effectively signalling to manufacturers that there will be a growing market for new, low emission HGVs as the 2040 deadline approaches. The extension would need to be credible, as consumer perceptions about the readiness of the technology may impede take-up (for example, the take-up of smart meters may have been reduced by negative perceptions about data security and the risk of issues with billing or switching suppliers⁴³).
- Other options might include designated low emission zones (such as the Ultra-Low Emission Zone in London and the Crit’Air scheme in France) which place charges on the most polluting vehicles to encourage vehicle users to switch to lower-emission vehicles.

⁴³ Utility Week (Aug 2018) “Energy UK and BEIS issue defence of smart meters” available [online](#)

- **Road pricing.** The Government could place a levy on freight operators' use of the road network. This would increase the relative cost of each trip and encourage operators to increase the payload associated with each journey, requiring fewer vehicles (and therefore emissions) to transport the same volume of freight. A levy could also improve the relative competitiveness of rail freight and encourage freight to shift from road to rail, further reducing the overall scale of the decarbonisation challenge. Levy receipts could be used to fund some of the new infrastructure requirements (although we recognise that the UK government does not generally hypothecate revenue streams to particular purposes).

5.1. SUPPORT FOR R&D ACTIVITY AND TECHNOLOGY TRIALS

As discussed in Section 4, there is no consensus as yet on which of the low emissions fuels and technologies will be commercially viable and available to the mass market in time to make a significant contribution to decarbonisation by 2050. While the government may be able to dictate the direction of travel, it is uncertain to what extent it can influence the speed of the technological changes which lie ahead, some of which push the boundaries of current scientific knowledge.

Our view is that the government's immediate focus should therefore be on funding research and testing alternative, low carbon fuels and technologies, in order to address some of the technological barriers in the hope that this will accelerate the development of commercially viable options. Without the government providing financial support for R&D-style activities, the market may struggle to overcome the technological barriers which impede decarbonisation. There are several key factors, including:

- **New technological innovations are non-rival, non-excludable goods.** Private firms face reduced incentives to invest in new, greener technologies because they will not be able to capture the full financial benefits of their innovation if rivals are able to copy their innovation without incurring any of the initial R&D costs. Other mechanisms, e.g. patents, might present an alternative approach to addressing the market failure but could bring other issues that prevent the wider deployment of the fuel or technology.
- **The relative cost of coordinating the research activities of private firms is high,** resulting in inefficient duplication and fewer technological spill overs (i.e. it takes longer to achieve advances in new technologies and major breakthroughs are harder to achieve).
- **There are information asymmetries** between innovative manufacturers and financial markets, which increases financing costs while these firms develop new vehicles powered by greener technologies.

Table 5.1 below sets out some of the approaches which have been used by the UK government and regulators to stimulate innovation and support the development of low emission technology to the point of commercialisation.

Table 5.1: Schemes used to support research, development and demonstration of low emission technology in the UK

Scheme	Funds available	Description
RIIO-EDI Network Innovation Competition (Ofgem)	£70m per annum 2015 – 2023	<ul style="list-style-type: none"> The Network Innovation Competition is an annual opportunity for electricity network companies to compete for funding for the development and demonstration of new technologies, operating and commercial arrangements. Funding will be provided for the best innovation projects that help all network operators understand what they need to do to provide environmental benefits, reduce costs, and maintain security. Funding is provided for those innovation projects that meet a range of evaluation criteria, including: the need to accelerate the development of a low carbon energy sector, providing value for money for energy customers, generating knowledge that can be shared amongst all network companies, and going beyond business as normal.⁴⁴
Innovation Designated Fund (Highways England)	£150m over the period 2015 – 2021	<ul style="list-style-type: none"> Designed to sustain beneficial partnerships and foster new relationships between Highways England and industry. Grants are available to innovative technology projects that support improved environmental outcomes. Projects must meet some strict criteria, including the need to “add value to the Strategic Road Network”.
Innovate UK / OLEV Low Emission Freight and Logistics Trial	£20m awarded in January 2017	<ul style="list-style-type: none"> Funding provided by DfT and delivered by Innovate UK and OLEV to support electric vans and hydrogen dual-fuel lorries. Funding was allocated competitively to 20 firms who set out plans for innovative ways to deploy low and zero emission vehicles. Projects include the trial of a fleet of 80 gas-powered HGVs. By the end of 2018 all trial projects will have deployed their low emission fleets, totalling over 300 low emission vehicles across the UK. The project is due to complete in Spring 2020.

Although there are other mechanisms that can be used to ‘incentivise’ R&D activities (such as patents or venture capital funding) grant funding is often preferred due to several key advantages:

- It allows government to retain a degree of control over the ultimate objective that the innovation is trying to achieve.
- Disbursement of the grant can be linked to the completion of specific outcomes.
- The commercial value of any successful outputs may be highly uncertain.
- It facilitates collaboration between industry partners without introducing potentially conflicting commercial objectives.

5.2. INFRASTRUCTURE INVESTMENT

A significant factor that will affect the take-up of low emission fuels is the provision of infrastructure that will accommodate their growth. Electric vehicles, for example, will create extra demand that may have

⁴⁴ Ofgem (June 2017) “Electricity Network Innovation Competition Governance Document version 3.0” available [online](#)

implications for the generation of low-carbon energy and the capacity of the electricity networks to deliver energy to users. Some of the other technologies that we considered in our assessment, such as hydrogen and synthetic diesel, are not currently produced at the required scale in the UK and would require investment in new infrastructure to produce the fuel and then to distribute it around the country.

We do not have sufficient information on the potential total investment requirement to facilitate the transition, as it will depend in large part on the eventual technologies that become commercially viable. Below, we describe some of the factors that the UK government will have to consider for the main infrastructure categories. Further explanation of how the infrastructure requirements might differ by technology can be found in Annex C.

5.2.1. Low-carbon energy generation

Whatever technology is adopted, the first hurdle to overcome would be generating enough low carbon electricity. National Grid's *Future Energy Scenarios* estimates that the increase in electricity demand from electrically-powered light and heavy goods vehicles on the road could (under the scenarios in which the UK's 2050 carbon reduction target is met) reach around 26TWh per year, based on an increase of over 8.5 million such electric freight vehicles.⁴⁵ We note that National Grid consider a range of scenarios, and in those scenarios where the carbon reduction target is not met, heavy goods vehicles will still be mostly powered by diesel or petrol fuel in 2050.

National Grid's estimates are based on a set of assumptions that we cannot test based on published information. To provide a point of comparison, we carried out our own indicative analysis of the impact of replacing the entire road freight fleet with electric vehicles on annual electricity demand. Our analysis suggests that the road fleet's annual electricity demand would equate to roughly 80TWh⁴⁶ (by comparison National Grid estimate that the total energy demand (across all fuels) from freight transport will equate to around 75TWh by 2050⁴⁷). This equates to about 25% of present UK electricity demand, requiring additional low carbon generation equivalent to, for example, almost double the present wind power portfolio.⁴⁸ Hydrogen-powered motors, which are currently much less efficient than direct electric motors,

⁴⁵ CEPA calculations based on National Grid (July 2018) "Future Energy Scenarios – Data Workbook v2" available [online](#)

⁴⁶ The 80TWh estimate is reached using a range of sources: Recent consumption of the road-freight vehicle parc of 14.3 mTOE (source: BEIS Energy Consumption in the UK, table 2.02); energetic efficiency of electric vehicles (source generation to wheel) of 73%, (see Transport and Environment (Jun 2017) "Roadmap to climate-friendly land freight and buses in Europe", p.28, available [online](#)); and, in the absence of any definitive data, an estimate that the energetic efficiency of the present internal combustion freight vehicle parc is roughly 35-40%. This calculation makes no adjustment for any losses or savings resulting from a heavier (battery) or lighter (overhead electrification) power train in comparison to internal combustion engine.

⁴⁷ CEPA calculations based on National Grid forecasts for annual demand for light and heavy goods vehicles under the 'Community Renewables' and 'Two Degrees' scenarios. See National Grid (July 2018) "Future Energy Scenarios – Data Workbook v2" available [online](#)

⁴⁸ Wind power in the UK produces about twice as much electricity in winter as summer, presenting a major seasonal smoothing issue given that road transport has a more even demand over the course of the year, although construction traffic has a summer peak. There is also a week to week smoothing issue with wind power.

would require around 3.3 times more electrical energy⁴⁹ compared to an electric-powered fleet (roughly 270TWh per year). Synthetic diesel would require roughly 450TWh per year.

Delivering the required investment in low-carbon electricity generation means that additional support will be required in the form of Contracts for Difference (CfDs) or other similar tariff schemes, the costs of which are ultimately shared across energy consumers. Some of this investment, and the wider network investment required to connect new generation to the grid and distribute it to consumers, could potentially be avoided if smart charging can be implemented, whereby vehicles can be charged when electricity demand (and thus prices) are lower.

5.2.2. Transport infrastructure

Although energy infrastructure is funded by users, under the current model transport infrastructure is generally grant funded by the taxpayer. Electrification of key rail freight routes (including the ‘last mile’ of infrastructure) may cost billions of pounds and take decades to complete. For example, cost estimates for the full Great Western electrification project reached £2.8 billion (in 2012-13 prices) and the Midland Main Line £3.2 billion (also 2012-13 prices) before the Secretary of State’s decision to cancel three electrification projects in July 2017.⁵⁰

Although there are no completed e-Highway trials on which we could base a reliable cost estimate, we assume that the upfront investment required to electrify the Strategic Road Network would be many times larger than the cost of electrifying the rail network. If the government is unwilling or unable to fund this investment, it will have to rely on the more limited capacity of private investors. However, in a small number of short ‘last mile’ locations, there may exist a commercial case for freight operators to co-invest alongside government.

5.2.3. Refuelling infrastructure

Another important component of the infrastructure environment relates to refuelling (or recharging in the case of electric vehicles). There will need to be sufficient density of refuelling stations in locations that are important to freight operators to permit efficient recharging and encourage take-up. ‘Range anxiety’ – a concern about the range that can be travelled before a vehicle will need to be refuelled – will also dictate that refuelling locations will be required at regular intervals along key freight routes.

Here there is a role for the private sector to play, as the provision of refuelling infrastructure could be a lucrative commercial opportunity over the longer term once there is a sufficiently large market for each station. However, in the early growth phase of low emission vehicles, or in more remote locations where the size of the local market is limited, there may be a role for government support in the form of grants to ensure that new stations are financially viable. This will be particularly important for small freight operators who lack the resources to develop their own refuelling facilities. Operators with larger fleets (or smaller fleets being aggregated by a third party) may develop their own facilities without government support and, unless there is a wider benefit for other operators, there will be a reduced role for government support.

⁴⁹ See Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, p.28, available [online](#).

⁵⁰ National Audit Office (March 2018) “Investigation into the Department for Transport’s decision to cancel three rail electrification projects” available [online](#)

Table 5.2 below provides some examples of financial support schemes that are available to support refuelling and charging infrastructure.

Table 5.2: Charging infrastructure support schemes available in the UK

Scheme	Description
Charging Infrastructure Investment Fund	<ul style="list-style-type: none"> In 2017 the government announced it would invest, alongside the private sector, in a new £400m fund for electric vehicle charging infrastructure. Government will invest up to £200m. The aim of the fund is to catalyse the rollout of electric vehicle charging infrastructure by providing greater access to finance on a commercial basis – i.e. to generate a return. The fund manager will be able to invest in a range of products in the capital spectrum, and in both projects and companies, but most focus on greenfield infrastructure. The government is in the process of appointing a fund manager and hopes the fund will begin investing in 2019.
OLEV Charging Infrastructure Schemes ⁵¹	<p>OLEV manages the following charging infrastructure schemes on behalf of the UK government:</p> <ul style="list-style-type: none"> The Electric Vehicle Homecharge Scheme provides grant funding of up to 75% towards the cost of installing electric vehicle charging points at domestic properties. The Workplace Charging Scheme is a voucher-based scheme that provides £500 support towards the up-front costs of electric vehicle charge-points for eligible businesses, charities and public sector organisations. The On-street Residential Chargepoint Scheme provides £6m of grant funding for local authorities towards the cost of installing on-street residential charging points, available on a first come, first serve basis. The scheme covers 75% of the upfront costs up to £7,500 per charge point. A £20m fund for ultra low emission taxi charging point infrastructure that local authorities can compete for.
London's Hydrogen Bus Fleet	<ul style="list-style-type: none"> Transport for London (TfL) has run a small fleet of hydrogen powered fuel cell electric buses on the RV1 (Tower Gateway to Covent Garden) route since 2003. The fleet was expanded to eight buses in 2010, at a cost of £15m. The buses have a range of around 400-450km, enough for a full day. They are refueled overnight at the Lea Interchange Depot, which was built especially for this fleet at a cost of around £2.8m. Hydrogen fuel for the fleet is generated in the Netherlands and imported by truck. The project was funded by TfL, supported by a £2.1m grant from the Department of Energy and Climate Change and a small grant from European Union via the Clean Hydrogen in Cities (CHIC) project.⁵²

5.3. SUBSIDIES AND TAX EXEMPTIONS RELATED TO VEHICLE PURCHASE

There are already examples of financial incentive schemes that focus on purchasing low emission vehicles, here in the UK and in other countries studied (e.g. France and Sweden operate a 'bonus-malus' system offering a bonus/rebate on the purchase of a low emission vehicle, or a penalty on the registration of vehicles that do not meet certain emission thresholds). These tend to focus on the passenger transport

⁵¹ OLEV (Oct 2016) "Grant schemes for electric vehicle charging infrastructure" available [online](#)

⁵² Transport for London (December 2010) "Mayor of London unveils hydrogen bus fleet for the Capital" available [online](#)

market, although light commercial vehicles are also eligible for certain schemes. For example, in the UK OLEV offers grants to subsidise the purchase of passenger electric vehicles, electric vans, and electric HGVs. OLEV’s car grant scheme has been reasonably successful, but there has been less enthusiastic take-up of van grants. Two key factors are: concerns about battery range; and a lack of availability of electric vans larger than about two tonnes.

The primary purpose of these schemes is to subsidise the purchase cost of a new vehicle, since the up-front cost may be a significant constraint that consumers find challenging to overcome. The cost difference is expected to narrow over time as economies of scale reduce production and manufacturing costs. A secondary purpose of these schemes is to encourage the socially optimal production of low emission vehicles. There are positive benefits for society (“positive externalities”) of electric vehicle take-up that are often not taken into account when a consumer is choosing which vehicle to buy/lease, and so a subsidy/grant passes some of this social benefit to the consumer.

Therefore, the design of new incentives would need to consider both the additional cost incurred by the consumer and the wider social benefits of decarbonisation and cleaner air, such that it establishes a sufficient price signal to optimise the rate of adoption. In practice, there is also a third factor that needs to be considered – the perceived inconvenience experienced during the adoption of a new technology. For example, longer refuelling times or uneven distribution of refuelling stations might make consumers hesitant to use electric vehicles, meaning that a stronger incentive (i.e. a more generous subsidy) could be required to encourage take-up while a technology’s adoption rate remains low.⁵³ These issues are discussed in Table 5.3 below.

Table 5.3: Minimum definition of cost incurred and social benefit, and additional considerations

	Minimum definition	Additional considerations
Cost required to encourage consumer to switch – often treated as cost incurred	This is the value that the targeted users would have to spend to make the change themselves – for example this may cover the difference in price between diesel and low-emission HGVs, taking into account additional factors such as fuel savings.	There may also be factors that do not have an obvious monetary value, for example the perceived inconvenience of using EV while the infrastructure is still in early development. An additional financial incentive may be required to encourage take-up.
Social benefit	This is the value to society, for example of reduced CO ₂ /PM _x /NO _x emissions from upgrading each single vehicle.	When a technology is still in the early stages of adoption, or when trying to encourage manufacturers, an additional financial incentive may be appropriate to encourage take-up and stimulate the market. The incentive value can be reduced as consumer confidence in the technology increases. The ‘social benefit’ aspect therefore may need to consider a longer time horizon.

⁵³ Additionally, any EU State Aid restrictions need to be considered – the level of grant offered by OLEV is to some extent limited by State Aid rules.

The effect of these factors can be seen in the contrasting case of two recent incentive schemes operated in the UK: the UK plug-in van grant by OLEV (Box 5.1) and the UK solar panel subsidies (Box 5.2).

Box 5.1: UK plug-in van grants⁵⁴

The UK Office for Low Emission Vehicles (OLEV) launched the Plug-in Van Grant in early 2012 to try to bring the purchase price of an electric van more in line with that of a typical diesel van. Initially the grant was worth 20% of the cost of a light electric van (<3.5 tonnes) up to a maximum of £8,000. Take-up was lower than expected – in the first four and a half years only 2,500 grants had been claimed, and by March 2018 a total of 4,000 claims had been made. OLEV are currently reviewing the grant to understand why take-up has been low. Among a range of factors, we understand a lack of electric vans in the 2.5-3.5 tonne range has had an impact

In 2016 the grant was extended to include heavier vans and trucks (>3.5 tonnes) at the same incentive level. At the time there were no eligible models on the market. OLEV introduced the grant as it recognised the need to provide an additional financial incentive to stimulate the market. The first 200 heavier electric van grant applicants are eligible to receive a 20% grant up to a higher cap of £20,000. As of mid-2018 manufacturers still had not developed an HGV that has been approved for the grant, but we understand that one manufacturer already has 10 electric HGVs on the road that are undergoing testing to seek grant approval as soon as possible.

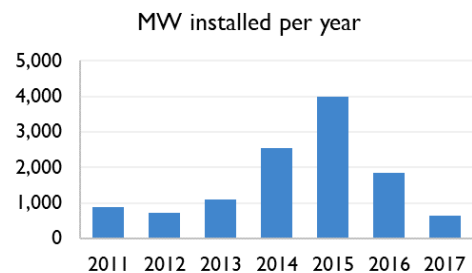
The evidence suggests that the financial incentive has not been as strong as OLEV had hoped, in part because of the lack of availability of vehicles. An additional likely factor is that the grant only covers part of the actual “cost incurred” in purchasing an electric van rather than a diesel one (partly due to state aid limits)⁵⁵. It does not directly address the perceived inconvenience associated with new technology and the charging infrastructure.

Box 5.2: UK solar subsidies

Until March 2012, the government offered subsidies of between 19.0 and 43.3p/kWh to households that installed solar panels with a capacity of up to 150kW (the subsidy varied according to the capacity of the installation) paid for through increases in consumer bills.⁵⁶ Applicants received a guaranteed subsidy for 20 years, which could be considerably longer than it took to recover the cost of installation.

From April 2012, the subsidy was reduced to between 12.9 and 21.0p/kWh and has since been gradually reduced further to between 0.12-4.17p/kWh.⁵⁷ The social benefit of the solar panels

depends upon what fuel to generate electricity is being displaced. For example, if it is displacing coal generation, the social benefit would be about 3.0 to 9.0 p/kWh of electricity generated⁵⁸ or about 1.5 to 4.5 p/kWh for displacing gas-powered generation.⁵⁹ Initially coal was substantially being displaced, but increasingly gas is being displaced by solar generation. By comparison, the present social cost of CO₂ emissions is currently assessed by government at between 3.3 and 9.9p/kg.⁶⁰



⁵⁴ OLEV (Oct 2016, accessed Aug 2018) “Guidance: plug-in van grant: extension to larger vans” available [online](#)

⁵⁵ Department for Business Innovation & Skills (Jul 2014) “State Aid” Article 36, available [online](#)

⁵⁶ DECC (Feb 2012) “Feed-in Tariffs Scheme: Government Response to Consultation on Comprehensive Review Phase I – Tariffs for solar PV” available [online](#)

⁵⁷ Ofgem (Jul 2018, accessed Aug 2018) “Feed-in Tariff (FIT) rates” available [online](#)

⁵⁸ Assuming 0.9 kgCO₂e per kWh of electricity from coal. See Carbon Footprint of Electricity Generation, Parliamentary Office of Science and Technology, POSTNote Update number 383, June 2011.

⁵⁹ At 0.45 kgCO₂e per kWh

⁶⁰ BEIS, Data tables supporting Green Book guidance on valuing energy use and greenhouse gas emissions, Table 3, December 2017, values for 2018, low and high scenarios, values in 2017 price levels. These values increase rapidly in later years, reaching about three times the present value by 2046.

Box 5.2: UK solar subsidies

The success of this scheme demonstrates that where initial subsidies can be set significantly higher than the private cost (and social benefit achieved through decarbonisation), it can help to stimulate the market and encourage take-up.

The effectiveness of incentive schemes is generally higher the closer they are to the point of sale so that operators are clear on the value of the incentive at the point of transaction, and because it helps to overcome the upfront cost difference between the new technology and diesel. Grants are also effective because they have to be applied for, thus allowing the government to retain a degree of financial control – although only if the scheme has a cap to the number or value of grants. Importantly, the subsidies can be technology neutral (as long as they focus on emission thresholds) and because they are directly linked to sales, it helps to stimulate innovation by manufacturers whilst protecting value for money.

Whilst the current incentives available in the UK are reward-only, these incentives could be strengthened through the imposition of a symmetric penalty on older, diesel, vehicles that do not meet emissions standards.

Where the technology has a number of issues to overcome, these grants provide a relatively weak incentive on manufacturers to bring new models to market, or to encourage cooperation between manufacturers and industry on new freight trials.

Another potential drawback of these schemes is the cost. For example, the UK government has spent over £0.5bn on the plug-in car grant to date,⁶¹ and in 2017 had to commit an additional £100m to enable the Plug-in Car Grant to continue to 2020.⁶² Although the take-up of low emission freight vehicles in the near future is expected to remain low, the cost differentials between established diesel models and new technologies may be large in absolute terms (see Box 5.3 below), resulting in a long term government commitment that requires very substantial expenditure.

Box 5.3: Hydrogen-powered fuel cell buses

In 2017 TfL began the process of procuring a new supplier framework for hydrogen powered buses with a potential value of over £120m. The framework is available to TfL and other UK city authorities, EU transport authorities and private bus operators. Developed as part of the 'Joint Initiative for hydrogen Vehicles across Europe', the framework will help to purchase 139 new buses across European cities (including 20 expected for London) co-funded by national grants and a €32-million grant under the EU's Horizon 2020 framework program for research and innovation. The initiative should help to standardise the procurement and deliver cost reductions, whilst demonstrating the benefits of hydrogen powered transport to public transport authorities, private operators and the public.⁶³

The new generation of hydrogen buses cost around £750k each, although it is hoped that the unit cost will fall to around €570k under the new framework. This compares to £170k for a standard single-decker diesel bus in London (£210k for a double-decker).⁶⁴

⁶¹ HM Government (Jul 2018) "Road to Zero" available [online](#)

⁶² HM Treasury (November 2017) "Autumn Budget 2017" available [online](#)

⁶³ Green Car Congress (May 2017) "TfL launches tender for bulk procurement of fuel cell buses" available [online](#)

⁶⁴ Transport for London (May 2017) "FOI request detail: Hydrogen" available [online](#)

5.4. EXEMPTIONS FROM CHARGES LEVIED ON USAGE OF THE ROAD NETWORK

Another set of incentives that could be applied to low carbon vehicles relates to the ongoing costs of vehicle operation and usage of the road network. Generally these focus on preferential tax treatment, for example, in the UK certain electric vehicles are currently exempt from road tax.⁶⁵ The UK government also applies less fuel duty to certain types of clean fuel, such as natural gas, LPG, and biomethane and zero duty charge to electricity or hydrogen.

Tax relief for certain fuels can help to make them more competitive, but they are not technology neutral, which could distort the market for low carbon vehicles and reduce the incentives for cost reduction. They might also be less valuable to freight operators when planning fleet investment, since they have less certainty that tax rates will stay low into the future.

In London, vans that produce less than 75g of CO₂ emissions benefit from a 100% discount on the London Congestion Charge, whilst in other cities and urban areas (such as Milton Keynes) free or discounted parking is available to electric vehicles. Other cities could employ low emission zones similar to the London-based Ultra Low Emission Zone, which will be introduced from April 2019. Under such schemes, all freight vehicles that do not meet Euro VI emissions standards will incur a daily charge to operate within the zoned area or may face a much higher penalty charge (e.g. £1,000). While we expect that such incentives might only have a marginal impact on demand for low emission freight vehicles, it could be particularly valuable to 'last mile' freight operators.

5.5. KEY FINDINGS

To date, incentives in the transport sector have been limited to grants that subsidise low emission vehicle purchase and some favourable tax treatments for low emission fuels relative to diesel. These are contributing to the increasing take-up of electric vehicles in the passenger market, but other factors are also likely to have played some role (e.g. lower prices of new cars, installation of new charging points).

Despite recent growth in the passenger market, sales of electric vans have not been stimulated. This is in part because the technology is not sufficiently developed and there are few suitable models on the market. Although there is potential for new grants to be awarded over the next couple of years, the evidence suggests that a subsidy on the purchase cost is not sufficient to stimulate the development of low emission models in heavier goods vehicles.

By comparison with decarbonising the energy system, reducing transport emissions is likely to prove more challenging, but the scale of available subsidies is substantially different. If the government is serious about encouraging freight operators to reach zero emissions by 2050, the amount of support will need to be more generous and much larger than anything currently available in transport.

The government's immediate priority should be to build on the available funding for research and development of low emission technologies, but ensure that funding streams are available with a particular focus on freight vehicles given the technical challenges that need to be overcome are greater. Given that there are several contenders for technological progress in freight transport, it may be sensible for the government to support research and development, or trials, in several areas in the earlier years. As well as supporting technological advancements to contribute to decarbonisation, this would provide decision-

⁶⁵ Gov.uk (Accessed October 2018) "Vehicles exempt from vehicle tax" available [online](#)

makers with an insight into the progress of research and development, which can assist planning of infrastructure development.

There will also need to be funding available to support adoption through an expanded network of refuelling stations and/or charging points, particularly during the early stages of market growth. Without this support, small and medium fleet operators are likely to find the transition more challenging, as developing their own dedicated refuelling stations will rarely be viable.

Alongside this, particular technologies (notably electrification and hydrogen) may also have substantial network infrastructure requirements, the cost of which is highly uncertain. The government should begin to plan for a scenario in which it supports long term investment in the network infrastructure should the need arise, to provide industry and other stakeholders with sufficient confidence to invest in new technologies when planning their future fleet requirements.

Annex A. CASE STUDIES

A.1. FRANCE

A.1.1. The freight system

France is the UK's main RoRo market – 60% of all goods vehicles travelling to Europe from the UK disembark in France.⁶⁶ Over the last decade inland freight movements (those by road, rail and inland waterways) have declined by 27% since peaking at just under 280 million tonne-kilometres in 2007. Road freight transport grew at an average of 2.5% per annum in the decade preceding the financial crisis, but has been in continual decline thereafter. The French rail freight sector is also in absolute (in terms of tonne-kilometres transported) and relative (as a share of total freight transport) decline – in 2016 it accounted for just 16% of freight transported⁶⁷ – a trend that is commonly attributed to network capacity constraints and the long-term decline in demand from heavy industry.⁶⁸

A.1.2. Progress towards reducing emissions

The French government has set a target for the country to become “carbon neutral” by 2050.⁶⁹ Despite this ambitious goal, recent progress has been disappointing. In 2016, CO₂ emissions rose 3.6% over the targeted 447 million tonnes meaning France failed to meet pledges it made at the Paris Climate Agreement.⁷⁰

France currently generates most of its energy from nuclear power. Although this is a relatively low carbon source, the Government hopes to become less reliant on nuclear power (it has a public target of reducing the share of nuclear to 50 percent “as soon as possible” – although the government does not expect to achieve this before 2030) and that low-carbon electricity generation will meet more of France's energy needs in the future.⁷¹ Currently around 18% of total electricity demand is met from renewable sources according to Reseau de Transport d'Electricite data.⁷² Historically, one of the main barriers that has restricted the development of low-carbon electricity production projects has been local opposition – particularly to onshore wind farms – and this is a key area that the Government hopes to address in order to accelerate low-carbon electricity projects.⁷³

⁶⁶ Department for Transport (May 2018) “International Freight Statistics: Roll-on Roll-off Goods Vehicle Survey” Table RORO0301

⁶⁷ OECD Data (Accessed August 2018) “Freight transport” available [online](#)

⁶⁸ International Railway Journal (Oct 2017) “French rail freight policy: that sinking feeling” available [online](#)

⁶⁹ Reuters (Jan 2018) “France to revise carbon emissions target after missing 2016 goal” available [online](#)

⁷⁰ Energy and Technology (Jan 2018) “France fails to meet climate goals, promises to double down on carbon reduction” available [online](#)

⁷¹ Reuters (Nov 2017) “France postpones target to drop share of nuclear energy in power mix” available [online](#)

⁷² Bloomberg (Jan 2018) “Can France Mix Nuclear and Renewable Power?” available [online](#)

⁷³ Reuters (Jan 2018) “France plans to accelerate wind power projects” available [online](#)

Air quality outcomes are also mixed. Since 1990 emissions of air pollutants have decreased in France, particularly from the agricultural and manufacturing sectors, but road transport remains a significant contributor.^{74,75}

A.1.3. Alternative fuels and enabling policies in the transport sector

Between 2004 and 2014 France saw an estimated 11% reduction⁷⁶ in CO₂ emissions per capita attributable to the transport sector,⁷⁷ due in part to a decline in freight transport movements. Nonetheless, freight transport still has a significant impact on CO₂ emissions and air quality. The European Commission has submitted final warnings to France (as well as to the UK, Germany, Spain and Italy) for continued breaches of NO₂ limit values, particularly in urban areas. In 2017 France's supreme court of appeal for administrative justice (the Conseil d'État) ruled that the French government had to produce a new plan to bring NO₂ and PM₁₀ emissions in line with EU limits.

Previous government measures aimed at reducing emissions from the transportation sector have focused on investing in new and improved infrastructure to encourage the use of the rail and waterway networks for freight transport. These delivered little progress against a background of falling demand.⁷⁸ There was also an attempt to introduce an 'Ecotax' – a tax applied to heavy goods vehicles – which aimed to rationalise short-to-medium distance journeys (i.e. transporting the same amount of freight in fewer journeys) as well as funding new infrastructure. The tax was never implemented as a result of industry protests. It was replaced by a less ambitious (in terms of expected revenue) levy on heavy goods lorries using major transport routes.⁷⁹

More recently government policy has focused on encouraging the take-up of low emission vehicles, focusing on passenger vehicles (where market share has now reached 1.7%⁸⁰). For example, the Government has introduced low emission vehicle quotas for public fleets and is subsidising the installation of electric vehicle recharging infrastructure to encourage public take-up – France reportedly installed almost 12,000 charging points in 2017.⁸¹

There are also financial incentives to encourage consumers to exchange older, polluting vehicles for electric ones. The government first introduced a 'bonus / malus' system in 2008 and the scheme has been extended and increased in recent years. As of 2017, it is possible to earn a "superbonus" of up to €10,000 (£8,400) on the purchase of a new electric vehicle (if the older, polluting vehicle is scrapped) and there is also a

⁷⁴ Paris Innovation Review (Dec 2016) "Air quality and energy transition: the French case" available [online](#)

⁷⁵ OECD (2016) "Environmental country review: France" available [online](#)

⁷⁶ In the same period the UK made a reduction of 10%, having increased CO₂ emissions every year between 1991 and 2007. Source: BEIS (Mar 2018) "Table 1: UK greenhouse gas emissions by source sector, headline results, UK, 1990-2017" available [online](#)

⁷⁷ Analysis based on World Bank data series: "CO₂ emissions (metric tons per capita)", available [online](#); and "CO₂ emissions from transport (% of total fuel combustion)", available [online](#).

⁷⁸ International Railway Journal (Oct 2017) "French rail freight policy: that sinking feeling" available [online](#)

⁷⁹ The Local (Jun 2014) "France replaces doomed ecotax with 'truck tolls'" available [online](#)

⁸⁰ International Energy Agency (accessed Oct 2018) "Electric vehicles: Tracking clean energy process" available [online](#)

⁸¹ motor1.com (Feb 2018) "France leading the charge in electric car infrastructure" available [online](#)

€10,000 “penalty” for purchasing a high emission vehicle. However, the scheme does not apply to commercial vehicles at present.

To combat poor air quality in urban centres, France introduced the CRIT’Air scheme earlier this year. Every vehicle entering low emission zones in certain French cities⁸² must display a sticker that categorises the vehicle according to its Euro emissions standard. Vehicles with certain stickers may be either permanently excluded from the city centre (for the most polluting vehicles), or temporarily excluded when pollution levels are high. Drivers caught breaking the rules face an on-the-spot fine of up to €135 (£117).⁸³

The investment in electric vehicle charging infrastructure and incentives schemes appears to be showing some early signs of success. France is reportedly the second largest market for electric vehicles in Europe after Norway – over 26,000 battery electric vehicles were sold in France in 2017 (compared to 13,500 in the UK)⁸⁴ although this remains a small percentage of new vehicle registrations.

Despite these more successful policies, the French government has remained under pressure to introduce additional measures to meet its air quality and climate goals, leading to its early 2018 announcement of plans to stop the sale of petrol and diesel-powered vehicles by 2040.⁸⁵

The Macron-led government also appears to be backing hydrogen gas as an alternative low carbon transport fuel. Last year the government pledged €100m every year towards “Plan Hydrogène” – a strategy to develop hydrogen for use in industry and transport. It aims to have 5,200 hydrogen-powered vehicles, mainly commercial and heavy goods vehicles such as buses, trains and trucks, in circulation by 2023, supported by 100 hydrogen filling stations (up from just 20 in June 2018).⁸⁶ French-based rolling stock manufacturer Alstom is also testing hydrogen trains.⁸⁷

A.1.4. Summary

France has made little progress towards reducing emissions from the freight sector (relative to the other case studies chosen). It is inhibited partly by the relative decline of the rail freight sector.

The experience of the ‘bonus-malus’ incentives scheme over the last ten years appears to demonstrate that the average CO₂ emissions of the (new) passenger fleet has fallen. This would suggest that such schemes can successfully encourage vehicle take-up and provide incentives for manufacturers to produce models that reduce emissions. The lack of incentives for commercial and freight vehicles may be limiting the growth of this market.

Financial incentives alone are unlikely to be sufficient to achieve significant decarbonisation of the freight fleet. Vehicle charging infrastructure, higher emissions standards and implementation of low-emission vehicle quotas in urban areas are also likely play an important role.

⁸² Paris, Lyon, Grenoble, Lille, Strasbourg, Toulouse, Chambéry, Marseille

⁸³ RAC (June 2018) “Crit’Air clean air stickers - need to know for driving in France” available [online](#)

⁸⁴ European Environment Agency (Jun 2018) “Electric vehicles as a proportion of the total fleet” available [online](#)

⁸⁵ Energy and Technology (Jan 2018) “France fails to meet climate goals, promises to double down on carbon reduction” available [online](#)

⁸⁶ RFI (Jun 2018) “France to invest millions in hydrogen energy production” available [online](#)

⁸⁷ Republique Francaise (Accessed July 2018) “Hydrogen Plan: “making our country a world leader in this technology””, available [online](#)

A.2. GERMANY

A.2.1. The freight system

Germany's transport network carries more freight than any other country in Europe – over 500 billion tonne-kilometres were carried in 2016 alone.⁸⁸ It is one of the UK's main trading partners and the value of goods imported from Germany (to the UK) is greater than any other country.⁸⁹ Although not as significant as France or Ireland, Germany is still a major RoRo market for the UK.⁹⁰

There is expected to be continued growth in the volume of freight moved in Germany over the next decade.⁹¹ Although around 23% of freight is currently carried by rail there are concerns that the rail freight sector will not be able to accommodate the expected growth in freight demand, which would be likely to have significant environmental implications from growing freight traffic on German roads.⁹²

A.2.2. Progress towards reducing emissions

The German government has set relatively ambitious carbon reduction targets by EU standards – it aims to reduce GHG emissions by 40% (relative to a 1990 baseline) by 2020, rising to 55% by 2030 and 95% by 2050.⁹³ It intends to meet this goal primarily through the transition from coal and nuclear power towards renewable sources of energy generation⁹⁴, although it is currently predicted to miss its 2020 target (it is only expected to achieve a reduction of around 32%).⁹⁵

Air quality also remains a concern. NO₂ levels in German cities often breach acceptable EU limits, prompting warnings from the European Commission⁹⁶, although total NO_x (-56%), SO₂ (-92%) and PM_{2.5} (-46%) emissions fell significantly between 1990 and 2012.⁹⁷

A.2.3. Alternative fuels and enabling policies in the transport sector

Despite an estimated 6% decrease in CO₂ emissions per capita attributable to the transport sector between 2004 and 2014,⁹⁸ the sector is almost entirely dependent on fossil fuels. Steady growth in traffic

⁸⁸ OECD Data (Accessed August 2018) “Freight transport” available [online](#)

⁸⁹ HM Revenue & Customs (Jun 2018) “Regional Trade Statistics” available [online](#)

⁹⁰ Department for Transport (May 2018) “International Freight Statistics: Roll-on Roll-off Goods Vehicle Survey” Table RORO0301

⁹¹ Federal Ministry of Transport and Digital Infrastructure (June 2017) “Rail Freight Masterplan” available [online](#)

⁹² Federal Ministry of Transport and Digital Infrastructure (June 2017) “Rail Freight Masterplan” available [online](#)

⁹³ Clean Energy Wire (July 2018) “Germany’s greenhouse gas emissions and climate targets” available [online](#)

⁹⁴ Clean Energy Wire (June 2018) “Climate goal failure warrants high Energiewende priority” available [online](#)

⁹⁵ Clean Energy Wire (June 2018) “Germany on track to widely miss 2020 climate target” available [online](#)

⁹⁶ Deutsche Welle (May 2018) “EU takes Germany to court over air pollution” available [online](#)

⁹⁷ European Environment Agency (2014) “Air pollution fact sheet 2014: Germany” available [online](#)

⁹⁸ Analysis based on World Bank data series: “CO₂ emissions (metric tons per capita)”, available [online](#); and “CO₂ emissions from transport (% of total fuel combustion)”, available [online](#).

volumes and wider economic conditions have resulted in slower than expected progress.^{99,100} Germany's underperformance on reducing its carbon emissions may be due, in part, to a wider policy environment that is perceived to be reluctant to address the automobile industry and its reliance on diesel fuel-powered vehicles, and has been slow to adopt meaningful penalties for polluters.

The Federal Government appears to recognise that the sector will need to adopt carbon-neutral fuels, alongside the development of new technologies and incentives, if climate commitments are to be met. Examples of government and industry-led initiatives to support decarbonisation of the freight sector include:

- **Taxation of Liquefied Natural Gas (LNG).** In 2017 the Power and Electricity Taxation Act was amended to extend a period of lower of lower taxes for LNG-powered transport until 2024. This has boosted the popularity of LNG-powered heavy goods vehicles. The development of the associated filling infrastructure is less advanced. The first LNG filling station where several tanks can be filled at once (like a conventional petrol station) was opened in April 2017 in Grünheide, Berlin. The proponents of LNG claim that it is a 'proven, secure and economically sound'¹⁰¹ technology, which reduces dependency on oil, the German Energy Agency state that the energy efficiency of LNG-powered engines and fuel provision should be improved before LNG becomes a cost-effective solution. LNG is generally seen as a medium term, interim option while alternative technologies are still at an early stage of development.¹⁰²
- **Grants for alternative transport fuels.** The Federal Ministry of Transport has established a relatively small (€10m) fund to subsidise battery and fuel cell electric trucks and those with alternative fuels such as LNG and Compressed Natural Gas (CNG).¹⁰³
- **Rail freight strategy.** In 2017 the Federal Ministry of Transport published a new strategy to support the rail freight market and facilitate investment in new network capacity and reliability. New measures included support for the industry to introduce "very long" trains, government funding for further electrification schemes and the retrofitting of rolling stock, and time-limited government subsidies to reduce freight access charges. It also proposed potential changes that would see freight operators facing reduced traction costs by reducing the burden imposed by climate levies and environmental taxes.¹⁰⁴
- **Electric trucks.** Siemens and Scania will be trialling electrically-powered trucks on three new German electrified highways (eHighways) during 2019 and 2020, with the aim of reducing carbon emissions from long-haul heavy duty freight vehicles. Different battery capacities are being tested. They are in general similar to the eHighway trials in Sweden, i.e. to be powered by pantographs fitted to the frame behind the cab of the lorry.¹⁰⁵

⁹⁹ OECD (June 2018) "OECD Economic Surveys: Germany" available [online](#)

¹⁰⁰ Clean Energy Wire (June 2018) "Germany on track to widely miss 2020 climate target" available [online](#)

¹⁰¹ New Civil Engineer (September 2017) "Germany looks to LNG to cut emissions" available [online](#)

¹⁰² German Energy Agency (September 2014) "Liquefied Natural Gas and Renewable Methane in Heavy-Duty Road Transport" available [online](#)

¹⁰³ electrive.com (June 2018) "Subsidy scheme for electric trucks in Germany" available [online](#)

¹⁰⁴ Federal Ministry of Transport and Digital Infrastructure (June 2017) "Rail Freight Masterplan" available [online](#)

¹⁰⁵ PR Newswire (May 2018) "Scania to Supply 'Trucks for German eHighways' Research Project" available [online](#)

A.2.4. Summary

Decarbonisation of the freight sector in Germany is likely to have been impeded by the absence of adequate financial incentives or mobility restrictions which encourage firms to adopt low emission vehicles.

Alternative low carbon technologies have different levels of “readiness” which may require a strategy for medium term (or interim) solutions while longer term solutions are developed.

It is too early to tell whether more recent interventions will prove effective and/or scalable.

A.3. IRELAND

A.3.1. The freight system

Road accounts for the vast majority of freight transported in Ireland, heavy rail is also used. Long-run data shows that the weight of goods carried by train decreased from 3.4 million tonnes in 1985 to 578,000 tonnes in 2014. The primary categories of goods carried in 2014 are mineral ores, petrol and oil and general freight.¹⁰⁶

The Republic of Ireland is the UK's third highest RoRo disembarkation country (13.4% in 2017), and is a major goods trading partner with the UK¹⁰⁷ While there are policies in place to decarbonise the transport sector, Ireland has struggled to reduce GHG emissions in recent years and is likely to fail to meet its 2020 targets.¹⁰⁸ This is because of the unexpectedly rapid economic recovery seen in recent years which in particular has driven faster growth in the energy sector.

A.3.2. Progress towards reducing emissions

Ireland saw an estimated 22% reduction in transport CO₂ emissions per capita between 2004 and 2014.¹⁰⁹ There was an increase in CO₂ emissions reported in 2013, 2014 and 2015 as the economy recovered from the downturn. Ireland's total GHG emissions are set to increase up to 2020 which is largely driven by strong economic growth and also fuel tourism, whereby motor fuel is purchased in the Republic of Ireland mainly due to differing tax and exchange rates between it and Northern Ireland. Growth in fuel consumption from diesel cars and freight is expected up until 2025.¹¹⁰ Ireland is increasingly likely to miss the target of 20% reduction by 2020, achieving only a 1% reduction, and may incur financial penalties as a result.

The Environmental Protection Agency (EPA) monitors air quality in Ireland. Air quality can be significantly worse during winter, mostly due to higher heating demands and cold, still weather which prevents pollution from rising and/or being carried away by winds. New standards based on EU directives introduced over the past two decades have reduced vehicle emissions, though by less than forecast. This has been offset somewhat by an increase in vehicles on the roads.^{111 112}

Air pollution is considered to be worsening with higher emissions of the five main pollutants, however SO₂ emissions have been reduced due to behavioural changes and regulatory enforcement.¹¹³ In particular, the

¹⁰⁶ Department of Transport, Tourism and Sport (April 2016) "Transport Trends" available [online](#)

¹⁰⁷ Department of Transport, Tourism and Sport (May 2018) "Road goods vehicles travelling to Europe by country of disembarkation and port group - All goods vehicles by country of disembarkation and port group" spreadsheet available [online](#)

¹⁰⁸ Irish Times (July 2018) "Ireland 'can't reach' target to cut carbon emissions by 2020" available [online](#)

¹⁰⁹ Analysis based on World Bank data series: "CO₂ emissions (metric tons per capita)", available [online](#); and "CO₂ emissions from transport (% of total fuel combustion)", available [online](#)

¹¹⁰ Irish Times (May 2018) "Ireland locked in trend of rising carbon emissions, says EPA" available [online](#)

¹¹¹ Environmental Protection Agency (accessed August 2018) "Air quality standards" available [online](#)

¹¹² Department of Communications, Climate Action & Environment (Accessed August 2018) "Air Quality Overview" available [online](#)

¹¹³ The Irish Times (March 2018) "Irish emissions of three key air pollutants getting worse – EPA" available [online](#)

use of cleaner, low sulphur content fuels in combustion and transport, in response to effective licensing and enforcement, has led to overall decrease in SO₂ emissions.

A.3.3. Alternative fuels and enabling policies in the transport sector

There have been several enabling factors in Ireland, which mostly consist of plans and strategies, as follows.

- **National Mitigation Plan (2017).** ‘The ultimate aim is to ... increase the use of alternative fuels in the freight sector.’ The EU’s Renewable Energy Directive specifies a legally binding 10% renewable energy in transport target to be achieved by all Member States by 2020.
- **National Policy Framework on Alternative Fuels Infrastructure for Ireland (2017).** This describes the long-term vision for decarbonising transport by 2050, and the ambition is that all new cars and vans sold in Ireland will be zero-emissions by 2030. The movement towards electrically-fuelled cars and commuter rail will be underway by 2030, with natural gas and biofuels developed as major alternatives in the freight and bus sectors.¹¹⁴ A strategy for HGVs is to follow once standards have been set by the EU.
- **National Policy Position on Climate Action and Low Carbon Development (2014).** Commits to a reduction in CO₂ emissions of at least 80% (compared to 1990 levels) by 2050 across the electricity generation, built environment and transport sectors.
- **National Clean Air Strategy.** This is in development, and aims to reduce levels of pollution by tackling emission sources, particularly from transport emissions in cities.¹¹⁵
- **Renewable Energy Support Scheme (2018)** The Irish government has announced approval for this scheme, which aims to ‘incentivise the introduction of sufficient renewable electricity generation to meet national and EU-wide renewable energy and decarbonisation targets out to 2030.’¹¹⁶

Advances in battery technology and lower electrical vehicle costs suggest that electrification of the car fleet will be the predominant low carbon choice.¹¹⁷

Natural gas could provide greater long-term competitiveness in the freight sector -Liquefied Natural Gas (LNG) is a viable option, however there are currently no LNG facilities in Ireland.¹¹⁸ While planning

¹¹⁴ Department of Transport, Tourism and Sport (May 2017) “National Policy Framework: Alternative Fuels Infrastructure for Ireland” available [online](#)

¹¹⁵ Department of Communications, Climate Action & Environment (Accessed August 2018) “National Clear Air Strategy” available [online](#)

¹¹⁶ CleanTechnica (August 2018) “Ireland Approves Renewable Energy Support Scheme, Aiming For 2019 Auction” available [online](#)

¹¹⁷ Department of Transport, Tourism and Sport (May 2017) “National Policy Framework: Alternative Fuels Infrastructure for Ireland” available [online](#)

¹¹⁸ LNG World Shipping (August 2017) “Shannon LNG plan ‘remains live’ despite NextDecade FSRU plan for Ireland” available [online](#)

permission has been granted for a LNG-import terminal in Shannon, this is quite a controversial project and a final investment decision has not yet been reached.¹¹⁹

While the solutions are not as clear-cut for larger vehicles, it is expected that the freight and bus sectors will also continue on a positive trajectory towards full penetration of low emissions vehicles (LEVs) by 2050.¹²⁰ This is based on the National Policy Framework on Alternative Fuels Infrastructure for Transport in Ireland, which cites a report by Bloomberg suggesting that passenger electric vehicles will be as affordable as their 'fossil fuel counterparts' by 2022. If this is the case it will contribute significantly to the rise in take-up Low Emissions Vehicles, however our research (and therefore scenarios) do not include such an optimistic view for HGVs.

A.3.4. Summary

Since 2014, Ireland has published several plans and frameworks on environmental and climate topics as it has become clear that the rapidly growing economy has reversed the annual declines in GHG emissions seen over the previous decade, increasing the likelihood of missing 2020 targets.

Ireland saw a 22.2% decrease in transport-related GHG emissions between 2004 and 2014. Due to increased economic growth and fuel tourism, these emissions have since been steadily increasing. The EPA anticipates that these will continue to increase until 2025, resulting in low confidence that the Irish government will reach their 2030 emissions targets. The National Clean Air Strategy is in development at consultation stage. It will aim to promote policies that enhance and protect the quality of air, particularly from the transport sector. LNG has been considered as an alternative fuel which could help reduce emissions, and demand for electric vehicles is likely to increase in the domestic transport industry. It is less clear for freight, particularly when compared with other EU countries such as the Netherlands and Sweden.

¹¹⁹ LNG World Shipping (August 2017) "Shannon LNG plan 'remains live' despite NextDecade FSRU plan for Ireland" available [online](#)

¹²⁰ Department of Communications, Climate Action & Environment (January 2013) "Climate Action and Low-Carbon Development: National Policy Position Ireland" available [online](#)

A.4. NETHERLANDS

A.4.1. The freight system

The Netherlands has a high value of import and export with the UK, a large number of goods vehicles on UK roads, and the second-highest volume of RoRo freight traffic with the UK (17.5% of total in 2017).¹²¹ The Dutch government also has a clear vision to reduce transport emissions, which (including freight) account for around 20% of GHG emissions.¹²²

In July 2018 a draft Climate Agreement was published which outlined aims to reduce national GHGs by 49% by 2030 to meet targets under the Paris Climate Agreement.¹²³

A.4.2. Progress towards reducing emissions

The Netherlands achieved an estimated 13% reduction in transport CO₂ emissions per capita between 2004 and 2014,¹²⁴ and a 13% overall reduction in GHGs between 1990 and 2017.¹²⁵ The government has set an ambitious target of reducing emissions by 55% in 2030, above the EU target of 50%. Lower CO₂ emissions have mainly been attributed to a change in fuels used to generate electricity, and reduced gas consumption for heating (the government is actively disconnecting 170,000 homes a year from the gas grid, to be replaced by alternative fuels and assisted by better insulation)¹²⁶. There have been fluctuations in the transport sector, with occasional sharp increases in goods transported by road and aviation.¹²⁷

The Netherlands complies with “virtually all” European emission limits for air quality.¹²⁸

A.4.3. Alternative fuels and enabling policies in the transport sector

To further reduce GHG emissions by 49% by 2030, the Dutch government has published a draft Climate Agreement. In order to meet that target, the transport sector has been committed to the following:

¹²¹ Department of Transport, Tourism and Sport (May 2018) “Road goods vehicles travelling to Europe by country of disembarkation and port group - All goods vehicles by country of disembarkation and port group” spreadsheet available [online](#)

¹²² Government of the Netherlands (Accessed August 2018) “Measures to reduce greenhouse gas emissions” available [online](#)

¹²³ Groenlinks (June 2018) “The Netherlands presents ambitious Climate Law” available [online](#)

¹²⁴ Analysis based on World Bank data series: “CO₂ emissions (metric tons per capita)”, available [online](#); and “CO₂ emissions from transport (% of total fuel combustion)”, available [online](#).

¹²⁵ The Straits Times (June 2018) “Dutch parliament to set target of 95% CO₂ reduction by 2050” available [online](#)

¹²⁶ Energy Post (June 2017) “A revolution: The Netherlands kisses gas goodbye – but will it help the climate?” available [online](#)

¹²⁷ Centraal Bureau voor de Statistiek (August 2017) “Lower CO₂ emissions in Q2 2017” available [online](#)

¹²⁸ Government of the Netherlands (Accessed August 2018) “Measures to reduce greenhouse gas emissions” available [online](#)

- Trade organisations have agreements on sustainable transport such as replacing their rolling stock with more energy efficient models.¹²⁹
- Fuel providers must blend petrol and diesel with biofuels, whereby biofuels will account for 10% of fuel by 2020.¹³⁰

In 2013 more than forty organisations, including the government, made an agreement on energy for sustainable growth - '**Energieakkoord**' marks the start of the transition to a sustainable future in the Netherlands¹³¹ The commitments include a 100 petajoule energy saving by 2020, an increase in the share of renewable energy to 14% by 2020 and 16% by 2023 and 15,000 new jobs.¹³²

The Dutch government has developed their vision on sustainable transport fuels, '**Brandstoffenvisie**'. This is a multi-track strategy which includes a general commitment to switch to electric propulsion combined with sustainable biofuels and renewable gas. It commits the rail sector to replace diesel trains with LNG and bio-LNG trains where feasible.¹³³ Electrification is seen as a major option to decarbonise the transport industry, and it is recognised that this requires increasing the carbon footprint of the energy production sector.

National Air Quality Cooperation Programme (NSL): this was designed to make sure the Netherlands meets the emission limits, in particular for PM and NO₂. Environmental 'zones' have been designated whereby the local authorities can ban the presence of the most polluting lorries away from towns or cities to prevent air pollution.¹³⁴

There does not appear to be a preferred technology for reducing road transport emissions in the Netherlands and it seems likely that in the near term they will continue with a mix of options, including battery electric vehicles, hydrogen fuel cell vehicles and more efficient internal combustion engines running on low-carbon fuels (such as biofuels and other synthetic fuels).

Electric passenger vehicles are already relatively established, with the Netherlands' small size and population making it well suited to the adoption of these vehicles. There are currently around 100,000 plug-in and all-electric vehicles in use, and about 25,000 electric vehicle charging points are publicly available.¹³⁵ There have been various fiscal incentives introduced to encourage take-up of electric vehicles –

¹²⁹ Government of the Netherlands (Accessed August 2018) "Measures to reduce greenhouse gas emissions" available [online](#)

¹³⁰ Government of the Netherlands (Accessed August 2018) "Measures to reduce greenhouse gas emissions" available [online](#)

¹³¹ TNO (Jan 2017) "Decarbonising Commercial Road Transport" available [online](#)

¹³² Social and Economic Council (accessed August 2018) "Energy agreement for sustainable growth" available [online](#)

¹³³ Social and Economic Council (Jun 2014) "A vision on sustainable fuels for transport" available [online](#)

¹³⁴ Government of the Netherlands (Accessed August 2018) "Measures to tackle air pollution" available [online](#)

¹³⁵ Statistics Netherlands (May 2017) "Number of electric cars continues to grow" available [online](#)

some have since been rolled back (e.g. an exemption from registration tax) but other subsidies and perks such as reserved parking spaces remain in place.^{136, 137}

In 2018 a five-year pilot scheme hydrogen filling station for hydrogen-powered buses was introduced by PitPoint, an international supplier and systems integrator of clean fuels¹³⁸ The PitPoint filling station will use 'green' hydrogen, which is a by-product from the production of chlorine (itself powered by wind power). For large vehicles that travel long distances, hydrogen may be a more suitable approach than battery-powered vehicles, due to the current range limits on battery-powered large vehicles.¹³⁹ Hydrogen filling stations have already been established in Antwerp, Rhoon and Helmond.¹⁴⁰

A significant LNG network has been developed, enabled by the Netherlands' flat terrain which allowed HGVs to travel across the country with early-stage LNG engines, which were less powerful and sophisticated than regular ones.¹⁴¹ However for this to make a substantial impact on emissions, technological developments must increase to enable more powerful engines to be used.

A.4.4. Summary

The Dutch government has been making clear steps towards decarbonising the transport industry, with ambitious policies and incentives. The Netherlands have achieved a 13% reduction in transport CO₂ emissions between 2004 and 2014. In recent years, the government has promoted buy-in for these policies across society, for example incentivising consumers to buy electric vehicles by providing infrastructure and prioritised parking, and encouraging stakeholders across the economy to sign up to agreements on sustainable growth and transport fuels. Efforts have been focused on encouraging hydrogen powered vehicles (currently buses), an increase in electrification of domestic vehicles, and investment in using low-carbon fuels. It is likely that a combination of these options is where the future of sustainable transport lies in the Netherlands. Transport is recognised as a key contributor to poor air quality within cities, motivating the focus on cars and buses.

¹³⁶ Inside EVs (accessed August 2018) "Netherlands Shocks With Nearly 16,000 Plug-In Electric Car Sales In December!" available [online](#)

¹³⁷ City of Amsterdam (assessed August 2018) "Charging and parking electric vehicles" available [online](#)

¹³⁸ Pitpoint (accessed August 2018) "About Pitpoint" available [online](#)

¹³⁹ PitPoint Clean Fuels (Jan 2018) "PitPoint realises new hydrogen filling station" available [online](#)

¹⁴⁰ PitPoint Clean Fuels (Apr 2017) "PitPoint acquires hydrogen refuelling station in Antwerp" available [online](#)

¹⁴¹ New Civil Engineer (Sep 2017) "Germany looks to LNG to cut emissions" available [online](#)

A.5. SWEDEN

A.5.1. The freight system

Sweden accounts for less than 2% of RoRo goods vehicles travelling from the UK to Europe,¹⁴² but it is an important freight and logistics hub for Northern Europe and the Baltic region. Freight transport is growing steadily – 39.2 billion tonne-kilometres of freight was transported by road in 2016 – although rail freight transport has remained relatively flat over the last decade. Sweden transports a relatively high share of freight by rail – around 35% of total inland freight.¹⁴³ This is partly because rail freight tends to be more competitive (relative to road) over longer distances, and due to the heavy nature of the freight being moved (e.g. iron ore, timber and industrial goods).

A.5.2. National progress towards reducing emissions

Sweden has a reputation for adopting proactive environmental and climate change measures despite accounting for less than 0.2% of global GHG emissions. The Swedish government has been able to implement a number of initiatives which have facilitated the transition to a lower carbon economy. Notable measures include:

- the introduction of the ‘Green Certificate Scheme’ in 2003,¹⁴⁴ placing a quota obligation on electricity suppliers to purchase a certain proportion of the electricity that they sell from renewable sources¹⁴⁵; and
- a tax on carbon-intensive fuels such as oil and natural gas which has been in place since 1995.¹⁴⁶

Sweden is also considered one of the most innovative countries when it comes to environment-related technology,¹⁴⁷ partly due to investments in environmental research & development (expenditure on R&D to find innovative sustainable solutions represented 3.3% of GDP in 2013 – Sweden is ranked 4th highest amongst OECD countries¹⁴⁸) in areas such as biofuels, smart grids and carbon capture and storage.¹⁴⁹

Sweden is committed under Roadmap 2050, an EU initiative, to reduce GHG emissions by 40% by the year 2020 against a 1990 baseline. It also has long term aims to move towards less carbon-intensive means of producing energy and improving energy efficiency, and to become “carbon neutral” by 2050.¹⁵⁰

¹⁴² Department for Transport (May 2018) “International Freight Statistics: Roll-on Roll-off Goods Vehicle Survey” Table RORO0301

¹⁴³ OECD Data (Accessed August 2018) “Freight transport” available [online](#)

¹⁴⁴ Swedish Institute (Accessed July 2018) “Sweden tackles climate change” available [online](#)

¹⁴⁵ Energy Regulators Regional Association (May 2012) “Renewable support schemes for electricity produced from renewable sources” available [online](#)

¹⁴⁶ Swedish Institute (Accessed July 2018) “Sweden tackles climate change” available [online](#)

¹⁴⁷ OECD (Nov 2014) “OECD Environmental Performance Reviews: Sweden” available [online](#)

¹⁴⁸ Swedish Institute (Accessed July 2018) “Sweden tackles climate change” available [online](#)

¹⁴⁹ Swedish Institute (Accessed July 2018) “Sweden tackles climate change” available [online](#)

¹⁵⁰ Swedish Institute (Accessed July 2018) “Sweden tackles climate change” available [online](#)

On air quality, Sweden is considered to be one of the cleanest nations in the EU – only 0.4 in every 100,000 deaths are related to air pollution, compared to 25.7 in the UK.¹⁵¹ In urban areas PM₁₀ pollution is 10.2 micrograms per cubic metre, compared with the OECD average of 20.1¹⁵², although there can be seasonal fluctuations in NO_x and PM_x levels due to the transport sector, particularly in urban areas.¹⁵³

A.5.3. Alternative fuels and enabling policies in the transport sector

Sweden achieved an estimated 7% reduction in CO₂ emissions per capita attributable to the transport sector between 2004 and 2014.¹⁵⁴ By 2016, it already used the highest percentage share of energy from renewable sources in transport compared to any other EU Member State.¹⁵⁵ Recent data shows that domestic travel emissions continue to decline, due in part to the increasing availability of biodiesel at filling stations, though emissions from the transport sector as a whole increased significantly in 2016 due to shipping and aviation.¹⁵⁶

Such progress has been possible because of ready access to biofuels – all filling stations which sell more than a specified amount of petrol and diesel must also supply a renewable fuel.¹⁵⁷ The government is aiming for 50% of transport fuels to be biofuels by 2030, and has applied a lower rate of tax on biofuels to encourage conversion.¹⁵⁸

A second factor is the financial incentives associated with the purchase of low emission vehicles which, combined with the faster than expected decline in the cost of batteries, means that electric vehicles increasingly compete with biofuels as the most viable option for meeting Sweden’s low carbon passenger transportation objectives.¹⁵⁹ Sweden operates a ‘bonus’ or rebate to buyers of low emission vehicles funded by the government.¹⁶⁰ Take-up of the scheme has been higher than originally anticipated, creating some uncertainty around the availability of funding and deterring more buyers. The scheme has been extended on multiple occasions to address this uncertainty and support electric vehicle growth.

Sweden’s ambition is to have a vehicle fleet that is completely rid of fossil fuels by 2030 but, like most other countries, less progress on decarbonisation of heavy-duty and road freight vehicles. This may be due, in

¹⁵¹ The Guardian (May 2017) “Air pollution kills more people in the UK than in Sweden, US and Mexico” available [online](#)

¹⁵² Swedish Institute (Accessed July 2018) “Sweden tackles climate change” available [online](#)

¹⁵³ United Nations Environment Programme (Accessed July 2018) “Sweden Air Quality Policies”

¹⁵⁴ Analysis based on World Bank data series: “CO₂ emissions (metric tons per capita)”, available [online](#); and “CO₂ emissions from transport (% of total fuel combustion)”, available [online](#)

¹⁵⁵ Eurostat (March 2018) “Share of transport fuel from renewable energy sources” available [online](#)

¹⁵⁶ Statistics Sweden (May 2017) “Greenhouse gas emissions increased during all quarters of 2016” available [online](#)

¹⁵⁷ Opus Energy (August 2017) “Superb Sweden: How they’ve achieved 52% renewable power” available [online](#)

¹⁵⁸ Government Offices of Sweden (October 2017) “The Swedish Government’s climate initiatives – three years into the electoral period” available [online](#)

¹⁵⁹ Stockholm Environment Institute (2017) “How can we decarbonize road freight transport by 2030?” available [online](#)

¹⁶⁰ The International Council on Clean Transportation (February 2017) “Lessons learned from Sweden’s electric vehicle rollercoaster” available [online](#).

part, to fewer policy interventions in the freight market. There are currently two electrification solutions being trialled:

- **eRoadArlanda, Stockholm Airport.** The Swedish Transport Association has electrified approximately 2km of highway near Stockholm Arlanda Airport. Vehicles are powered from two parallel tracks in the road which connect to a retractable, moveable arm underneath an electric truck. These are design to transfer electricity to the battery, removing the need to stop for charging. This public track was introduced in April 2018, and if successful, will be rolled out across the country's highways, where the cost is said to be recouped within three years from introduction.¹⁶¹
- **eHighway project, Stockholm.** In 2016 a stretch of highway near Stockholm was electrified by installing overhead cables as part of a 2 year trial. Lorries are connected to the overhead wires by a pantograph power collector which is mounted on the frame of the vehicle. While driving on this stretch of highway the lorries are completely powered by electricity and are emission free (apart from the emissions resulting from the generation of electricity).¹⁶²

A.5.4. Summary

Sweden is the leading EU country with regards to using renewable fuel energy in transport.

One of the main factors in Sweden's relatively successful attempts to decarbonise the transport sector to date has been the political (and public) support for a broad range of environmental and climate change measures, such as carbon taxes. It seems likely that individual measures may have been less effective if implemented in isolation.

Rebates offered on purchases of low emission (passenger) vehicles also appear to have worked well, although it appears that the stability of scheme funding is important to generating consistent take-up.

It is also likely that the availability of natural resources has been a key factor in the growth of Sweden's bioenergy sector and the decarbonisation of Sweden's transport system. This would be difficult and possibly undesirable to replicate in the UK given its land use impacts.

It is too early to evaluate the efforts made to reduce carbon emissions from the freight sector, but it seems likely that the transition to a fully decarbonised fleet by 2030 will require Government intervention.

Biofuels may continue to play an important role. Electrification is not yet a proven concept that could be scaled up, but early trials may highlight useful lessons that could be applied to other proposed schemes and in other countries. Particularly around the cost effectiveness of relatively infrastructure heavy solutions.

¹⁶¹ New Atlas (April 2018) "Sweden's new electric highway works like a scaled-up slot car track" available [online](#)

¹⁶² Daily Scandinavian (February 2017) "Electric highway in Sweden" available [online](#)

Annex B. LONG LIST OF FUELS AND TECHNOLOGIES

As discussed in Section 3, we undertook a comparative review of alternative fuels and technologies that might contribute to the UK's decarbonisation of road and rail freight, contributing to the UK's progress towards its 2050 decarbonisation targets. This annex sets out in more detail the selection of our long list of fuels and technologies, our high-level assessment of that long list, and our chosen short list.

B.1. SELECTION OF LONG LIST

We selected a long list of seven fuels and technologies for each of road and rail freight:

- **Biofuel:** Alternative fuels that are generated from harvesting biological matter that have similar properties to fossil fuels. These are a key method referenced in literature to decarbonise transport with minimal impact to engine technology. There are two types, standard biofuel (1st generation) which is made using crops, and advanced biofuel (2nd, 3rd, 4th generations), which is made using waste.
- **Synthetic fuel:** Alternative fuels that are generated from chemical reactions. Carbon capture methods can be used to extract CO₂ from the atmosphere, which is then reacted with hydrogen to produce the synthetic fuel. They have similar properties to fossil fuels. This is a key method referenced in literature to decarbonise transport with minimal impact to engine technology.
- **Electric - battery (internal power):** Electricity is stored on the mode of transport (lorry/train) to be delivered to an electric motor for propulsion. This is presented as a mechanism for carbon-free transport in literature, assuming a carbon-free source of electricity.
- **Electric - power line (externally powered):** Electricity is delivered from outside the mode of transport (lorry/train) to an electric motor for propulsion. This is presented as a mechanism for carbon-free transport in literature, assuming a carbon-free source of electricity. Electric power is already utilised on the UK rail network.
- **Hydrogen:** Hydrogen is generated through methods such as electrolysis of water and distributed as a fuel. This is then stored in a tank onboard the mode of transport. It is typically presented with a fuel cell that generates electricity to power electric motors. This is presented as a mechanism for carbon-free transport in literature, assuming a carbon-free source of electricity to create the hydrogen.
- **Liquid Petroleum Gas (LPG):** Currently used as a fuel in HGVs. It has been considered for decarbonisation of marine vessels. It has reduced emissions compared to conventional fuels.
- **Natural Gas/Liquid Natural Gas (LNG):** This has been considered for container ships for decarbonisation as it has lower emissions than fossil fuels, and so we consider its potential application for rail and road fuels.

B.2. ASSESSMENT OF LONG LIST

This range of fuels and technology was selected to provide a wide range of options. We assess them against three high-level areas, providing 'RAG' ratings as set out in Figure B.1 below.

Figure B.1: Summary of approach to scoring the fuels and technologies in the short list assessment

<p>Maturity risk level</p> <p>We consider the maturity of each fuel or technology using the Technology Readiness Level (TRL) scale. There are nine levels, where 1 is very early-stage and 9 represents a very mature fuel or technology. For this high-level assessment, we group the nine levels into three RAG ratings.</p> <p>RAG ratings: maturity levels</p> <table border="1"> <tr><td>High risk: TRL levels 1-3</td></tr> <tr><td>Medium risk: TRL levels 4-6</td></tr> <tr><td>Low risk: TRL levels 7-9</td></tr> </table>	High risk: TRL levels 1-3	Medium risk: TRL levels 4-6	Low risk: TRL levels 7-9	<p>Potential benefits and potential issues</p> <p>We assess benefits and issues separately, identifying whether the fuel or technology provides benefits or barriers that are important to the transport mode, and whether the fuel or technology possesses the following desirable characteristics:</p> <table border="1"> <tr> <td> <ul style="list-style-type: none"> • Low technology cost. • High infrastructure availability. • High fuel energy density. • High refuel speed. </td> <td> <ul style="list-style-type: none"> • High propulsion power density. • Low emissions. • High safety. </td> </tr> </table> <p>We also consider whether the fuels and technologies could have a negative impact on the performance of the transport mode.</p> <table border="1"> <tr> <td>RAG rating: potential benefits</td> <td>RAG ratings: potential issues</td> </tr> <tr> <td>Minimal or no benefit</td> <td>Critical issues/negative effects</td> </tr> <tr> <td>Minor or partial benefit</td> <td>Some performance reduction</td> </tr> <tr> <td>Provides significant benefits</td> <td>Minimal performance reduction</td> </tr> </table>	<ul style="list-style-type: none"> • Low technology cost. • High infrastructure availability. • High fuel energy density. • High refuel speed. 	<ul style="list-style-type: none"> • High propulsion power density. • Low emissions. • High safety. 	RAG rating: potential benefits	RAG ratings: potential issues	Minimal or no benefit	Critical issues/negative effects	Minor or partial benefit	Some performance reduction	Provides significant benefits	Minimal performance reduction
High risk: TRL levels 1-3														
Medium risk: TRL levels 4-6														
Low risk: TRL levels 7-9														
<ul style="list-style-type: none"> • Low technology cost. • High infrastructure availability. • High fuel energy density. • High refuel speed. 	<ul style="list-style-type: none"> • High propulsion power density. • Low emissions. • High safety. 													
RAG rating: potential benefits	RAG ratings: potential issues													
Minimal or no benefit	Critical issues/negative effects													
Minor or partial benefit	Some performance reduction													
Provides significant benefits	Minimal performance reduction													

Table B.1 overleaf sets out our assessment of the long list fuels against these three categories, for both road and rail.

Table B.1: Summary of high-level assessment of long list of fuels

Fuel or technology	Road			Rail		
	Maturity	Potential benefit	Potential issues	Maturity	Potential benefit	Potential issues
Biofuels: Biofuel is developed from biomass. Advanced biofuel is from waste and residues. These can substitute petrol and diesel in engines.	Green	Red	Green	Green	Red	Green
	<p>These fuels can generally be used with current engine technology. However, biofuels using crops are limited by legislation to have a contribution under 10% of all transport fuel¹⁶³ and have negligible effect in reducing emissions.¹⁶⁴ There is insufficient waste/residue for advanced biofuels to have a contribution above 9%,¹⁶⁵ although they do virtually remove Greenhouse Gases (GHG) where they are used. There are mixed views as to the extent of biofuel's reduction in CO₂ emissions due to the high volumes produced from manufacturing and burning the biofuel. Nitrogen dioxide emissions increase when biofuels are burnt compared with diesel due to high levels of oxygen present, though particulate matter and sulphur dioxide generally decrease.¹⁶⁶</p>					
Synthetic fuel: using electricity to produce a liquid fuel that can be used as a diesel substitute	Amber	Green	Amber	Amber	Green	Amber
	<p>These fuels can be used with current engine technology. Requires a significant level of electricity as the process is only ~18% as efficient in generation as direct electric drivetrains.¹⁶⁷ The fuel process is currently being trialled and appears that there are relatively low levels of production. Significantly worse overall emissions from producing the fuel if a carbon capture method is not used, though similar tank to tailpipe emissions of carbon. No sulphur is produced, and PM_x emissions are low. Rail engines would be comparable with HGVs, hence there is a similar maturity.</p>					

¹⁶³ Politico (Apr 2015) "EU agrees to limit biofuel use" available [online](#)

¹⁶⁴ Transport and Environment (Apr 2016) "Globiom: the basis for biofuel policy post-2020" available [online](#)

¹⁶⁵ Transport and Environment (Jun 2017) "Roadmap to climate-friendly land freight and buses in Europe", available [online](#)

¹⁶⁶ Air Quality Expert Group (prepared for Defra) (2011) "Road Transport Biofuels: Impact on Air Quality", available [online](#)

¹⁶⁷ Transport and Environment (Jun 2017) "Roadmap to climate-friendly land freight and buses in Europe", available [online](#)

	Road			Rail		
Fuel or technology	Maturity	Potential benefit	Potential issues	Maturity	Potential benefit	Potential issues
Hydrogen: released through a fuel cell to generate electricity to drive an electric motor.	Amber	Green	Amber	Amber	Green	Amber
	Hydrogen trucks are being trialled. Requires a significant level of electricity as only ~30% as efficient in generation as direct electric drivetrains. ¹⁶⁸ Good range (but added >1t per vehicle), ¹⁶⁹ good refuel capability, but high system cost including on-vehicle technology, production and infrastructure (if piped).			Small hydrogen passenger trains are being sold for use from 2020 onwards, ¹⁷⁰ while hydrogen trams have been used since 2016. Requires significant level of electricity as the process is only 30% as efficient in generation as direct electric drivetrains. Good range (but added mass per vehicle), good refuel capability, but expected to have same high relative system cost as road, including on-vehicle technology, production and infrastructure. ¹⁷¹		
Electric battery: electricity is stored in a battery on board a vehicle with an electric motor.	Amber	Green	Amber	Amber	Green	Red
	Electric Heavy Good Vehicles (HGV) are being trialled, primarily for urban journeys. Electric batteries have an energy density around 1/15th of diesel making them more challenging for HGV applications, reducing range. Charging can take many hours, which is an issue alongside range. Better suited for short-range, lower duty vehicles.			Electric battery trains have been trialled in the UK but only for lighter passenger trains. They are therefore less mature than for HGVs, however this is primarily due to the issues arising from low energy density. Electric batteries have an energy density around 1/15th of diesel making them impractical for freight train applications as it reduces range/increases weight. Charging can take many hours but can happen while on electrified sections. Better suited for short-range, lightweight trains.		

¹⁶⁸ Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

¹⁶⁹ Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

¹⁷⁰ Alstom press releases (Jul 2018) “Coradia iLint hydrogen train receives approval for commercial operation in German railway networks” available [online](#)

¹⁷¹ Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

	Road			Rail		
Fuel or technology	Maturity	Potential benefit	Potential issues	Maturity	Potential benefit	Potential issues
<p>E-highway: a powerline provides electricity to the truck.</p> <p>Electrification of rail tracks: (overhead or third rail).</p>	Amber	Green	Amber	Green	Green	Amber
	E-highway systems are being trialled in Sweden, Germany and California. This approach has a comparatively lower cost (technology and infrastructure) compared to other options. ¹⁷² Most efficient use of electricity. Would require some amount of on-vehicle storage for areas without power available or where there are system failures. Otherwise it would require deployment on all delivery routes and have redundancy in the system.			Electrification of the rail network is already a recognised activity that is ongoing. Whilst there have been cancellations of works due to cost ¹⁷³ , it seems reasonable that the overall cost trend across technologies in road freight would be broadly similar in rail, and that electrification is the cheapest approach. ¹⁷⁴ Due to the use of lesser travelled routes for freight the cost effectiveness will vary. This is one of the most efficient uses of low-emission electricity.		
<p>Natural gas (LNG): a fossil fuel burnt in an engine similar to a petrol engine.</p>	Green	Red	Amber	Green	Red	Amber
	Natural gas technology is mature and is commercially available, however using fossil fuel sources only leads to a reduction in CO ₂ of around 20%. ¹⁷⁵			Natural gas technology has been retrofitted onto some trains. However the use of fossil fuel sources leads to a relatively small reduction in emissions compared to other options. LNG trains have been suggested to be 50% more expensive ¹⁷⁶ and would require building of new infrastructure.		

¹⁷² Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

¹⁷³ The Guardian (Mar 2018) “Rail Electrification Plans Cancelled Purely for Cost Reasons”, available [online](#)

¹⁷⁴ Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

¹⁷⁵ Politico (Apr 2015) “EU agrees to limit biofuel use” available [online](#)

¹⁷⁶ GE (Nov 2014) “Training Trains to Run on Natural Gas”, available [online](#)

Fuel or technology	Road			Rail		
	Maturity	Potential benefit	Potential issues	Maturity	Potential benefit	Potential issues
Liquid petroleum gas (LPG): a fossil fuel burnt in an engine similar to a petrol engine.	Green	Red	Amber	Amber	Red	Amber
	LPG has been used in HGVs to substitute diesel use. The fuel has similar properties to diesel and is already widely available. However a 25% substitution only results in a 6% reduction in emissions, ¹⁷⁷ with other sources querying any reductions. ¹⁷⁸			There is little evidence that LPG has been considered for rail. Evidence from HGVs suggest that the emissions saved would be lower than that from other technologies.		
Hybrid: Can use hydrocarbon and electric propulsion elements in series or parallel. Can be merged with other technologies.	Amber	Amber	Amber	Green	Amber	Amber
	Hybrid HGVs are being trialled ¹⁷⁹ and early savings of 30% emissions have been shown. Hybrid systems increase the mass present due to additional components, and have the potential for similar recharge issues to electric batteries, however they provide an opportunity to get the best of multiple technologies.			Hybrid (dual-mode) electric and diesel trains are in operation. Hybrid systems increase the mass present due to additional components, and have the potential for similar recharge issues to electric batteries, however they provide an opportunity to get the best of multiple technologies.		

¹⁷⁷ Calor (accessed Jul 2018) “Duel Fuel”, available [online](#)

¹⁷⁸ Sustainable Business Toolkit (Jul 2012) “Benefits of LPG vs Petrol Vehicles” available [online](#)

¹⁷⁹ Volvo (Feb 2017) “Volvo tests a hybrid vehicle for long haul”, available [online](#)

B.3. SELECTION OF SHORT LIST

Table B.2 below summarises the assessment of the long-listed fuels and technologies, and sets out which four are short-listed for detailed assessment.

Table B.2: Selection of the short list fuels and technologies for the comparative review detailed assessment

Fuel or technology	Justification
Options taken through to the short list	
Electric battery	Electric battery HGVs and trains are being trialled and may be most suitable for short range vehicles/trains with lighter loads – low energy density compared to diesel, and charging can take several hours.
E-highway/rail electrification	E-highways are being trialled, and electrification of rail is already common but expensive/time-consuming to roll out. One of the most efficient uses of low-carbon electricity for powering road and rail vehicles, so has a comparatively lower cost than other options assessed here. May require on-board storage of energy for times when off the electrified routes.
Synthetic fuel	Synthetic fuels can be used with current engine technology, and is currently being trialled on road vehicles, with low levels of production. It requires a lot of electricity as it is only 18% efficient as direct electric motors.
Hydrogen	Hydrogen trucks are being trialled, hydrogen trams have been used since 2016, and hydrogen trains will be used from 2020. It requires a lot of electricity as it is only 30% as efficient as direct electric motors, and would require hydrogen distribution infrastructure.
Options not taken through to the short list	
Liquified Natural Gas (LNG)	LNG and LPG are capable of providing a reduction in CO ₂ emissions, but do not make it to the short list because other fuels provide far greater savings, on both road and rail. Compressed Natural Gas (CNG) is rated similarly.
Liquid Petroleum Gas (LPG)	
Biofuels	Standard biofuels have limited benefits, as they have a minimal impact on CO ₂ emissions. We therefore consider advanced biofuels instead, which use waste. Advanced biofuels can provide more significant reductions in CO ₂ emissions, but there is a limited supply – we anticipate that they may play a continuing but small role. We therefore do not include these in the short list, it does feature in the transition timelines as it can provide a useful interim contribution

Annex C. DETAILED ASSESSMENT OF SHORT-LISTED FUELS AND TECHNOLOGIES

As discussed in Section 3 and Annex B, we undertook a detailed assessment of a short list of four alternative fuels and technologies that may contribute to the decarbonisation of UK road¹⁸⁰ and rail freight by 2050. This short list is set out in Figure C.1 below.

Figure C.1: Summary of short-listed fuels and technologies

Battery

- Being trialled on road and rail.
- Currently only suitable for short range HGVs and trains with lighter loads – low energy density compared to diesel, and charging can take several hours.

Electrification/E-highways

- E-highways are being trialled. Up-front cost of electrification infrastructure would be substantial, but greater efficiency of electricity could reduce fuel costs for industry.
- Less than half of the rail network is electrified and the government has scaled back plans for future electrification due to escalating costs. Greater efficiency of electricity could reduce fuel costs for industry.
- Vehicles may need to be hybrid for non-electrified areas of the road or rail network.

Synthetic fuel

- As this uses current engine technology, the assessment is the same for road and rail.
- It is being trialled, with low levels of production.
- Requires a lot of electricity as it is only 18% efficient as direct electric motors.

Hydrogen

- This is being trialled in HGVs, and has been used in some trams since 2016, and planned for trains from 2016.
- Requires a lot of electricity as it is only 30% as efficient as direct electric motors, and would require hydrogen distribution infrastructure.

To assess this short list, we first consider the maturity of the fuel and/or technology involved. The higher the maturity of the fuel the greater the chance that it will be appropriate for use and that investment will have its intended consequences. We summarise the maturity of each short-listed fuel and technology using a TRL rating; the TRL ratings are set out in Table C.1 below. Although these are taken from a nuclear industry source, they are generic enough to be appropriate for this high level assessment.

Table C.1: Definitions of the nine Technology Readiness Levels (TRL)

TRL	Generic Definition
9	Actual technology system qualified through successful mission operations
8	Actual technology system completed and qualified through test and demonstration
7	Technology prototype demonstration in an operational environment
6	Technology system/subsystem model or prototype demonstration in a relevant environment
5	Technology component and/or basic technology subsystem validation in relevant environment
4	Technology component and/or basic technology subsystem validation in laboratory environment

¹⁸⁰ The assessment for road freight focuses on HGVs. The findings may be broadly transferred across to lighter freight vehicles, but there will be some differences. The refuel time may be faster if a vehicle has a smaller capacity, with less space available in the vehicle the battery size may be an even bigger concern, etc.

TRL	Generic Definition
3	Analytical and experimental critical function and/or characteristic proof-of concept
2	Technology concept and/or application formulated
1	Basic Principles observed and reported

Source: Nuclear Decommissioning Authority (Nov 2014) "Guide to Technology Readiness Levels for the NDA Estate and its Supply Chain" available [online](#)

We then assess each option against several criteria, which are described in Table C.2 below.

Table C.2: Summary of assessment criteria used in assessing the short-listed fuels and technologies

Criterion	Description
Technology cost	The high-level relative cost of a system, considering both the capital and operating cost for the technology on the vehicle and its supporting infrastructure. This will be influenced by the existing availability of compatible infrastructure (see below).
Infrastructure availability	A factor influencing technology cost is whether a fuel can use an existing infrastructure or whether a new network of fuel distribution is required.
Incidence of economic costs	The costs and benefits of each technology may be shared between users, taxpayers and wider society, or they may fall primarily on specific groups. This criterion is not scored as distributional assessments are outside the scope of this report.
Fuel energy density	The energy density of fuel has an impact on how much of the vehicle has to be taken up for fuel storage, or alternatively how often the vehicle has to refuel.
Refuel speed	The faster a vehicle's refuel speed the greater the amount of time it can spend performing movement of freight.
Propulsion power density	The power density of the associated drivetrain has an impact on how much of the vehicle has to be taken up by it.
Emissions	A key focus of the NIC study is decarbonising the UK freight system to minimise the environmental impact and meet international agreements. Nitrous Oxides (NO _x), Sulphurous Oxides (SO _x) and particulate emissions are also of concern.
Safety	For any technology to be adopted it has to be demonstrated that it is safe for commercial use.

In assessing these criteria, we apply ratings as set out in the table below.

Table C.3: Ratings used in applying the assessment criteria

Blue: Better than current diesel technology.	Amber: Slightly worse than current diesel technology.
Green: Comparable to current diesel technology.	Red: Significantly worse than current diesel technology.

C.1. ROADS SHORT LIST

This section sets out the detailed discussions of the short-listed fuels and technologies for road freight.

Table C.4: Summary of detailed assessment of the short-listed options for road freight

Criteria	Battery HGVs	E-highways	Synthetic fuel	Hydrogen
Maturity evaluation	TRL 7	TRL 7	TRL 6	TRL 7
Technology Cost	Amber: Slightly worse than current diesel technology	Amber: Slightly worse than current diesel technology	Red: Significantly worse than current diesel technology.	Red: Significantly worse than current diesel technology.
Infrastructure Availability	Amber: Slightly worse than current diesel technology	Red: Significantly worse than current diesel technology.	Red: Significantly worse than current diesel technology.	Red: Significantly worse than current diesel technology.
Fuel Energy Density	Red: Significantly worse than current diesel technology.	Blue: Better than current diesel technology	Green: Comparable to current diesel technology.	Amber: Slightly worse than current diesel technology
Refuel Speed	Red: Significantly worse than current diesel technology.	Blue: Better than current diesel technology	Green: Comparable to current diesel technology.	Green: Comparable to current diesel technology.
Propulsion Power Density	Blue: Better than current diesel technology	Blue: Better than current diesel technology	Green: Comparable to current diesel technology.	Green: Comparable to current diesel technology.
CO ₂ emissions and air quality	Blue: Better than current diesel technology	Blue: Better than current diesel technology	Amber: Slightly worse than current diesel technology	Blue: Better than current diesel technology
Safety	Green: Comparable to current diesel technology.	Amber: Slightly worse than current diesel technology	Green: Comparable to current diesel technology.	Amber: Slightly worse than current diesel technology

C.1.1. Battery HGV

In this mode, electricity is stored in a battery (i.e. as chemical energy) on board the vehicle that is then delivered to one or more electric motors. This assessment focuses on battery charging rather than battery swapping. The assessment around the vehicle would be much the same, but different infrastructure would be required for battery swapping – which would itself bring additional requirements such as harmonisation between makes and brands, and swapping infrastructure.

Where electricity can be produced and utilised with a higher efficiency than diesel fuel, this can lead to significant energy savings. Systems can be recharged either by plugging to a power source or by “swapping out” used batteries for new ones. Electric trains offer zero exhaust emissions and quieter operation.

Many battery chemistries are available; lithium-ion batteries dominate due to their current mass manufacture, reasonable cost and relatively high energy density as compared to other batteries.

Electric Heavy Good Vehicles (HGV) are being trialled, primarily for short urban journeys. Smith Electric Vehicles produced lorries up to 12 tonnes in weight however the company has stopped trading due to a lack of funding.¹⁸¹ In 2015 BMW deployed 40 tonne electric trucks to transport parts between facilities with a range of 62 miles.¹⁸² Other examples in 2018 include trials of 26 tonne trucks from MAN¹⁸³ and 7.5 tonne trucks from eCanter.¹⁸⁴

Table C.5: Detailed assessment of battery HGV

Criteria	Score and reasoning for battery HGV technology	
Maturity evaluation	TRL 7	Electric HGVs up to 12 tonnes have been available commercially since 2010, but not widely deployed. ¹⁸⁵ There are also trials of 40+ tonne vehicles, primarily for urban journeys, with DHL focusing on small electric trucks. ¹⁸⁶ Smaller HGVs (around 7.5tonnes) have been trialled over short distances in the UK but larger trucks travelling long routes have not been demonstrated. ¹⁸⁷
Technology Cost	Amber	Some organisations which promote electric mobility and charging infrastructure have argued that battery electric vehicles will be cheaper than diesel by 2050. ¹⁸⁸ However, we think that overall, including associated infrastructure costs, the evidence suggests

¹⁸¹ Pink H. (Feb 2017) “Smith Electric Vehicles ceases trading – or does it?”, available [online](#)

¹⁸² Temperton J, Wired (2015) “BMW’s 40 tonne electric truck hits public roads”, available [online](#)

¹⁸³ SMMT (Aug 2018) “MAN begins electric truck trials” available [online](#)

¹⁸⁴ Edie (Oct 2018) “Hovis incorporates first all-electric trucks into delivery fleet” available [online](#)

¹⁸⁵ There were about 700 of these in 2013. Business Wire (Jun 2013, accessed Sep 2018) “Smith Electric Fleet surpasses 700 vehicles and five million miles of operation” available [online](#)

¹⁸⁶ DHL already has 6,000 electric trucks in use in Germany, and aims to produce up to 20,000 small electric trucks a year. Electrek (May 2018, accessed Sep 2018) “DHL’s StreetScooter opens second factory as it emerges as an important EV manufacturer” available [online](#)

¹⁸⁷ Engineering Council (Sep 2017) “Royal mail trials electric vehicles” available [online](#)

Postal and Parcel technology international (Oct 2018) “DPD opens UK’s first all-electric parcel depot” available [online](#)

¹⁸⁸ For example, see Siemens (2015) “eHighway, Innovative Electric Road Freight Transport”, available [online](#) and Hoekstra, A. (Sep 2017) “Electric Trucks, Chapter 4: Energy Delivery”, available [online](#)

Criteria	Score and reasoning for battery HGV technology	
		<p>that the cost of battery electric vehicles will be more expensive than diesel (although this is dependent on tax policy).</p> <p>There are three main cost considerations:</p> <ul style="list-style-type: none"> • The amount of freight that is displaced by the battery. • The cost of building and managing a charging network infrastructure and electricity grid reinforcement. • The taxes applied to diesel and diesel vehicles. <p>A truck of 40 tonnes is claimed at needing half its weight in batteries if it is to have a 1,000km range.¹⁸⁹ Other estimates suggest that a 40 tonne truck would require 9 tonnes of batteries – which may present an issue for range and for the volume of space available for freight.¹⁹⁰ Electric trucks currently cost about twice as much as diesel trucks, but make that back on lower fuel and maintenance costs. A study in the Netherlands¹⁹¹ concluded that by 2025 the vehicle cost of an electric truck is likely to be lower than that of a diesel one, however there is a large amount of uncertainty around this claim.</p> <p>The cost of the additional charging infrastructure required to service the market could be significant and estimates range from £1,000-£40,000 per charging station, depending on power type.¹⁹² The government has announced a commitment to invest £400m in the network but it seems likely that more investment will be needed.</p> <p>Additional charging infrastructure (and increasing use of electric freight vehicles) will have implications for the wider energy system. It may require expensive electricity network reinforcements if demand is relatively inflexible – in practice there are likely to be a number of sites on the network where reinforcement is required. But if demand is flexible and can respond to appropriately established price signals (e.g. by charging vehicles outside peak periods), the need for reinforcement could be avoided.¹⁹³</p>
Infrastructure Availability	Amber	<p>The electrical infrastructure required for battery vehicles falls into 2 aspects, the grid to deliver the electricity and the charging capability required for HGVs. The grid is already in place and will require reinforcement for growth in other electric vehicles and electric heat, therefore the scale of reinforcement can be increased. Recharging will require high power charging stations to be added at all fuelling stations.</p>
Incidence of economic cost	N/A	<p>The costs of electrical energy would fall on users. Since these are likely to be lower than diesel, there may be a commercial case for freight companies to invest in an electric vehicle fleet (where the upfront costs are currently higher). However, previous experience suggests that taxpayer-funded grants may be required to subsidise the higher capital costs and to encourage the market to develop.</p> <p>Since there may be a commercial case for developing charging infrastructure services, these costs might also fall on users. However, the government has already established an electric vehicle charging infrastructure investment fund which shows that a significant portion of the early infrastructure costs are likely to be borne by taxpayers.</p> <p>The cost of electricity grid reinforcement would fall on users. The extent to which these costs fall on the users of vehicle charging infrastructure, as opposed to all</p>

¹⁸⁹ Siemens (2015) “eHighway, Innovative Electric Road Freight Transport”, available [online](#)

¹⁹⁰ Transport and Environment (Sep 2017) “Electric Trucks’ contribution to freight decarbonisation”, available [online](#)

¹⁹¹ Hoekstra, A. (Sep 2017) “Electric Trucks, Chapter 4: Energy Delivery”, available [online](#)

¹⁹² Energy Saving Trust (Aug 2017) “Guide to chargepoint infrastructure for business users”, available [online](#)

¹⁹³ Ofgem (July 2018) “Future Insights Paper 5 - Implications of the transition to electric vehicles” available [online](#)

Criteria	Score and reasoning for battery HGV technology	
		<p>energy consumers, depends on the evolution of the regulatory framework – under current arrangements electric vehicle users will impose considerable costs which will be borne by all consumers.¹⁹⁴</p> <p>The main impact on taxpayers would be the gradual decline in fuel duty tax revenues due to lower use of heavily-taxed diesel. This trend is already apparent, but would be accelerated if freight companies moved away from diesel.</p>
Fuel Energy Density	Red	<p>The energy density of Li-ion batteries is, at most, about 7% that of diesel (up to 2.5MJ/l¹⁹⁵ compared to diesel's 37MJ/l¹⁹⁶) Any technological improvements in this area are unlikely to be meaningful enough to allow battery HGVs to compete with diesel in this area.</p>
Refuel Speed	Red	<p>Current superfast chargers (approximately 350kW) would take two hours to charge a truck with a 250 mile range.¹⁹⁷ In theory, by 2050 charge times of less than an hour may be possible (requiring charge rates of around "1C").¹⁹⁸ A one-hour charge time is still significantly longer than current diesel technology, but might be practical depending on the length of time for loading/unloading. Battery swapping may be more practical, but does require harmonisation between makes and brands, and swapping infrastructure. For a 300l lorry tank equivalent, to provide 11.1GJ in one hour a charger of 3080kW is required, around 9 times the power of current superfast chargers.</p> <p>The selection of technology to be used in these vehicles can be affected by how they are used, in terms of how and when they are refuelled. Changes in driving behaviour, or the use of autonomous trucks, could also change the operating concept.</p>
Propulsion Power Density	Blue	<p>Electric motors have higher power-to-weight ratios than diesel engines.</p>
Emissions	Blue	<p>The tank-to-tailpipe emissions for an electric vehicle are negligible through the use of batteries on road and rail vehicles.</p> <p>The lifecycle environmental impact of producing the components required for these large batteries should also be considered. In particular there are environmental concerns associated with nickel mines, which can produce emissions of potentially toxic metals and sulphur dioxide and cause issues for disposal of potentially hazardous waste.¹⁹⁹</p> <p>There are no studies for HGVs but it appears that the 'whole life' emissions of an electric car are lower than a diesel car after only two years of operation.²⁰⁰ This assumes 2030 levels of CO₂ emission from electricity generation.</p>
Environmental	Blue	<p>Tank to tailpipe emissions of carbon and air pollutants are zero.</p>
Safety	Green	<p>While there are no studies on the safety of electric HGVs, electric cars have achieved some of the highest ratings possible from the European New Car Assessment Programme (NCAP) which provides a standardised assessment of safety. Key hazards</p>

¹⁹⁴ Ofgem (July 2018) "Future Insights Paper 5 - Implications of the transition to electric vehicles" available [online](#)

¹⁹⁵ Panasonic (accessed Aug 2018) "Specifications for NCR8650GA", available [online](#)

¹⁹⁶ Neutrium (accessed Aug 2018) "Specific energy and density of fuels", available [online](#)

¹⁹⁷ Transport and Environment (Sep 2017) "Electric Trucks' contribution to freight decarbonisation", available [online](#)

¹⁹⁸ Radio Electronics (Accessed Oct 2018) "Li-ion Lithium Ion Battery Charging" available [online](#)

¹⁹⁹ The Guardian (August 2017) 'Nickel mining: the hidden environmental cost of electric cars' available [online](#)

²⁰⁰ The Guardian (Oct 2017) "Electric cars emit 50% less GHG than diesel" [online](#)

Criteria	Score and reasoning for battery HGV technology
	<p>come from the use of high-voltages, and the potential for chemical fires arising from damage to the batteries leading to thermal runaway. It seems that the risk of puncture/fire can be mitigated through the careful distribution and packaging of the batteries (allowing better structural design/mass distribution) as well as proper maintenance, while any battery malfunctions can be managed with a battery management system.²⁰¹</p>

²⁰¹ Biello. D., Scientific American “Should Battery Fires Drive Electric Cars off the Road” available [online](#)

C.1.2. Road electrification

An Electric highway (E-highway) requires electricity delivered from an external source such as:²⁰²

- an overhead power line;
- a power line in the road; or
- inductive under the vehicle (wireless charging).

This assessment focuses on an overhead power line that would work similarly to rail. Overhead power lines (catenary wires) transmit energy to hybrid vehicles via a pantograph (roof mounted pole to make contact with wire). The pantograph allows direct power transmission to the electric motor of the adapted truck, allowing them to run fully electric. Active pantographs can connect and disconnect up to speeds of 90 km/h²⁰³. The pantograph has sensors to allow adjustment and compensation for lateral truck motion in lane. Vehicles will require another fuel to operate if disconnected from the electricity source, therefore it is likely that E-highways are dependent on the supporting technologies for electricity or hybrid vehicles.²⁰⁴ E-highway systems are being trialled in California,^{205,206} while in Sweden a 2km stretch of road has been opened for general use.²⁰⁷ Additionally, the autobahn in Germany is also being modified for E-highway.²⁰⁸

Table C.6: Detailed assessment of e-highways

Criteria	Score and reasoning for battery e-highways	
Maturity	TRL 7	Combining overhead power, pantographs and trucks requires a transfer of mature technology to new application. Pilot projects have tested the technology and there are a small number of fully open e-highways in other countries. It has not been demonstrated to meet the needs of current HGV operations in the UK.
Technology Cost	Amber	<p>Overall we consider that the cost of highways electrification is likely to be slightly more expensive than current diesel technology because:</p> <ul style="list-style-type: none"> • The upfront investment required to install electrification infrastructure across the major freight routes would be substantial • It is likely that the electricity grid would need reinforcement in some locations • Freight vehicles would still need to carry a battery which reduces the amount of freight which could be carried • These costs are only partially offset by the savings achieved via the lower cost of electricity used to power the vehicle. <p>The most significant uncertainty is the upfront cost of highways electrification. Recent experience from the UK rail industry is that rail electrification projects were</p>

²⁰² Transport and Environment (Jul 2017) “Roadmap to climate-friendly land freight and buses in Europe” available [online](#)

²⁰³ Siemens AG (2017, accessed Aug 2018) “Feature: eHighway – Solutions for electrified road freight transport” available [online](#)

²⁰⁴ Siemens (2015) “eHighway, Innovative Electric Road Freight Transport”, available [online](#)

²⁰⁵ Siemens (Jun 2016) “World’s first eHighway open in Sweden” available [online](#)

²⁰⁶ Siemens (2015) “eHighway, Innovative Electric Road Freight Transport”, available [online](#)

²⁰⁷ Siemens (Jun 2016) “World’s first eHighway open in Sweden” available [online](#)

²⁰⁸ Siemens (Aug 2017, accessed Aug 2018) “Siemens builds eHighway in Germany,” available [online](#)

Criteria	Score and reasoning for battery e-highways	
		<p>more expensive to deliver than originally anticipated and that the costs are higher in the UK than other international comparators. It is also likely that the electricity grid would require reinforcement in some locations to meet demand.</p> <p>The upfront infrastructure costs would be partly offset by the energy cost savings achieved by each vehicle using the electrified network, but it is unlikely that electrification will 'pay for itself'.</p> <p>In addition, similar factors which apply to battery HGV technology would also apply to electrified highways, as it is likely that freight vehicles would still need to travel on unelectrified sections of the network.</p>
Infrastructure Availability	Red	<p>The electrical infrastructure for E-Highways falls into two aspects, the grid to deliver the electricity and the power lines for HGVs. The grid is already in place and will require reinforcement for growth in other electric vehicles and electric heat, therefore the scale of reinforcement can be increased. The power lines do not exist and have not been demonstrated on UK roads. Roads are not expected to need alteration, although this needs to be considered with UK congestion (i.e. how much overtaking is required).</p>
Incidence of economic cost	N/A	<p>The costs of electrical energy would fall on users. Since these are likely to be lower than diesel, there may be a commercial case for freight companies to invest in an electric vehicle fleet (where the upfront costs are currently higher). However, previous experience suggests that taxpayer-funded grants may be required to subsidise the higher capital costs and to encourage the market to develop.</p> <p>The cost of highways electrification would likely fall on the taxpayer given the scale of investment required and the limited revenue streams which could be captured by a private delivery body. Under the unlikely scenario that electrification projects could be delivered under a PPP-style model, users of the network would pay a charge. But this is only feasible if the overall cost to the user was significantly lower than diesel (or if their ability to use diesel vehicles was restricted). It is likely that higher user (distribution) costs would be passed on to end consumers.</p> <p>The cost of electricity grid reinforcement would fall on users. The extent to which these costs fall on the users of vehicle charging infrastructure, as opposed to all energy consumers, depends on the evolution of the regulatory framework – under current arrangements electric vehicle users will impose considerable costs which will be borne by all consumers.²⁰⁹</p> <p>In addition to the cost of funding the electrification works and a method for users to pay for electricity use, taxpayers would also be affected by the gradual decline in fuel duty tax revenues. This trend is already apparent, but would be accelerated if freight companies moved away from diesel.</p>
Fuel Energy Density	Blue	<p>Using an E-Highway approach removes some, if not all of the need for energy storage on the vehicle. If this is hybridised with other technologies then their respective fuel energy density should be considered.</p>
Refuel Speed	Blue	<p>Power is delivered directly to the truck and can be used immediately while charging a battery for use off the power lines.</p>
Propulsion Power Density	Blue	<p>Electric motors have higher power-to weight ratios than diesel engines.</p>
Emissions	Blue	<p>This technology benefits from zero tank to tailpipe carbon and air pollutant emissions compared with diesel, due to the use of electricity to power the road and rail vehicles. The technology could also use low carbon sources such as solar panels</p>

²⁰⁹ Ofgem (July 2018) "Future Insights Paper 5 - Implications of the transition to electric vehicles" available [online](#)

Criteria	Score and reasoning for battery e-highways	
		<p>along the side of the roads to generate the required electrical power, meaning while e-highways are used, direct and indirect emissions are negligible.</p> <p>E-highways are one of the most efficient uses of electricity from the grid with an overall efficiency of 73%.²¹⁰ This is around twice as efficient as a diesel engine and can be powered from low-emission sources. As the grid is decarbonised E-fuel will emit less GHG compared to diesel.</p>
Safety	Amber	<p>There are safety issues to be addressed through the use of exposed cables or “third rails” on open roads as there are risks to be managed in terms of ensnaring or how likely a vehicle is to lift off the road in a high speed incident.</p> <p>The infrastructure requires adjustment around gantries, bridges and existing flora/fauna. A near-constant supply is required to ensure continuous vehicle speed, but brief breaks (e.g. for bridges) may be manageable through small batteries.</p>

²¹⁰ Transport and Environment (Jul 2017) “Roadmap to climate-friendly land freight and buses in Europe” available [online](#)

C.1.3. Synthetic fuels (roads)

Electricity can be used to produce a synthetic fuel, which may be methane or versions of gasoline/diesel. The most environmentally friendly process (not using fossil fuels) involved is to extract hydrogen from water via electrolysis, and extract carbon dioxide from carbon capture, that are then synthesised into a diesel substitute.²¹¹ Liquid fuel can be a diesel substitute used in current engines. If the electricity used for the production is low-emission, the fuel becomes zero emission. This assessment considers diesel substitutes.

Current road and rail vehicles can use synthetic fuels without any adjustments, so the requirement is to develop the fuel production and distribution. Fuel production is currently being trialled: Audi announced in early 2018²¹² that sufficient amounts of fuel were produced to run initial engine tests. This means that the process appears to be some way from producing sufficient diesel to perform substantial testing. Sunfire claims it has produced around three tonnes of a synthetic crude oil substitute, and that a “high-volume production plant” will open in 2020 to produce ten million litres a year.²¹³

The below assessment considers the use of synthetic fuel for both road and rail freight – given that existing vehicles can already use these fuels, the focus is on production and distribution of the fuel, which would be much the same for both rail and road freight.

Table C.7: Detailed assessment of synthetic fuels for road freight

Criteria	Score and reasoning for synthetic fuels (“E-fuels” or “E-diesel”)	
Maturity	TRL 6	Only small amounts have been produced suggesting that this fuel (E-diesel) is closer to a laboratory experiment than a trial of demonstration of production. Once the production process is matured the rest of the systems (distribution, propulsion) are already in existence.
Technology Cost	Red	Overall, the cost of E-fuels is likely to be significantly more expensive than diesel, because: <ul style="list-style-type: none"> • Production costs are more expensive due to the intensive energy requirements. The cost of production is currently around £4/litre.²¹⁴ Reducing this cost to match current fossil fuel costs would require much larger scale production, efficiency improvements in the production process and lower low-emission energy input costs. However, a 2017 study²¹⁵ suggests that E-fuels diesel will be between three and four times the cost of diesel in 2050 without taking taxes into consideration. • Significant investment in electricity grid capacity would be required to meet the demands of the E-fuel production process.

²¹¹ Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

²¹² Audi (Mar 2018, accessed Aug 2018) “Audi advances e-fuels technology” available [online](#)

²¹³ Audi (Mar 2018, accessed Aug 2018) “Audi advances e-fuels technology” available [online](#)

²¹⁴ Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

²¹⁵ Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

Criteria	Score and reasoning for synthetic fuels (“E-fuels” or “E-diesel”)	
Infrastructure Availability	Red	<p>Infrastructure covers three areas: the generation of electricity, the production of fuel and the distribution of fuel.</p> <p>A significant amount of grid capacity is required in order to deliver the amount of fuel required. This is because the through-chain efficiency of e-fuel is significantly lower than that for battery/E-highway vehicles²¹⁶ (which is 4-6 times higher than E-fuel). The amount of low carbon generation required across Europe has to increase tenfold, of which 80% of this demand would be due to E-fuels.²¹⁷</p> <p>The production of these fuels would require a significant increase in production facilities, requiring significant capital expenditure.</p> <p>Fortunately the infrastructure for distribution of fuel is already in existence.</p> <p>There is the potential for E-fuels to meet all of the required demand, but it would require a significant increase in electricity generation, and uses electricity much less efficiently than direct electric motors (about 18% of the efficiency).²¹⁸</p>
Incidence of economic cost	N/A	The costs of E-fuel production and distribution would fall on users. Since these costs are likely to be significantly greater than diesel, hydrogen, or electrification, incentives will be required to encourage the transition. The cost of enhancing the capacity of the electricity grid would also fall on users.
Fuel Energy Density	Green	E-fuel diesel has comparable energy density to diesel.
Refuel Speed	Green	E-fuel diesel can be refuelled at a comparable rate to diesel.
Propulsion Power Density	Green	E-fuel diesel can be used in existing propulsion systems. ²¹⁹
Emissions	Amber	<p>The tank-to-tailpipe CO₂ emissions for an E-fuel vehicle are the same as a current diesel vehicle.²²⁰ The well-to-tailpipe emissions of synthetic fuel are worse than diesel:</p> <ul style="list-style-type: none"> • Diesel is reported to require around 6kWh per gallon to produce,²²¹ or 5.7MJ/l, which is equivalent to 15% of the diesel energy content. • In E-fuel production, one source²²² suggests that only 44% of the input energy is converted to E-fuel, therefore the production losses are 56% of the input energy. This is equivalent to 127% of the diesel energy content (56% lost/44% embodied). This suggests that the overall emissions (well to tailpipe) are much worse for E-fuel compared to diesel, however the tank to tailpipe emissions are then recaptured in production (leaving the production emissions

²¹⁶ Transport & Environment (Nov 2017, accessed Aug 2018) “The role of electrofuel technologies in Europe’s low carbon transport future” available [online](#)

²¹⁷ Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

²¹⁸ Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

²¹⁹ Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

²²⁰ Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

²²¹ Green Transportation (Accessed Aug 2018) “The 6 kWh electricity to refine gasoline would drive an electric car the same distance as a gasser?” available [online](#)

²²² Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

Criteria	Score and reasoning for synthetic fuels (“E-fuels” or “E-diesel”)	
		themselves). At current levels of grid carbon production, E-fuel is slightly worse (production and use) than diesel.
Environmental	Amber	<p>Synthetic fuel is considered to have slightly worse well to tailpipe emissions of carbon as compared with diesel. It has lower air pollutants such as sulphur and particulates.</p> <p>The overall lifecycle process of synthetic fuel will be worse than diesel should carbon capture methods not be used at the start of the process, and if low carbon sources are not used during the electrolysing process. Therefore, this technology is highly dependent on improvements to the grid and using low carbon sources of energy, as well as upfront investment in carbon capture technologies. Using current grid carbon production and carbon capture as part of the process, CO₂ emissions are slightly worse than diesel.</p>
Safety	Green	E-fuel diesel has comparable safety to diesel.

C.1.4. Hydrogen (roads)

Hydrogen as a fuel is suitable for existing road and rail vehicles can currently be produced through reforming steam methane (SMR), although this requires carbon capture and storage.²²³ In the case of road vehicles this process provides a 10% reduction in well-to-wheel emissions when compared to diesel HGVs.²²⁴ Hydrogen can also be produced from electrolysis, and research and development are underway for producing hydrogen through electrolysis of water, although there are some electrolysis stations in the UK.²²⁵ In Road to Zero,²²⁶ it is suggested that in 2050 electrolysis would be the least polluting (carbon dioxide) mechanism for the formation of hydrogen, (having 90% lower emissions than diesel, using a low-carbon grid for HGVs) therefore it is assumed that this is the approach that would be pursued for rail. In turn this would require a growth in the electricity used to produce hydrogen. In all cases tailpipe NO_x and PM_x is negligible.

The hydrogen is then stored cryogenically at high pressure (700bar), and then released through a fuel cell to generate electricity to drive one or more electric motors. The use of hydrogen on the railways is referred to as “Hydrail”.

The existing reforming steam methane method is more likely to require the hydrogen to be produced centrally and distributed via a gas or super-cooled set of pipes, whereas the electrolysis method allows production to be more easily decentralised as electrolysis can take place on-site where it is pumped into the vehicle. If produced locally then sufficient electrical power to do so is required.

There have been no commercial vehicles launched yet, however some manufacturers have been testing the technology:

- Asko in Norway began trialling a hydrogen truck in 2018, and expect to have four types of truck in the near future.²²⁷
- Toyota has developed a fuel cell truck that is running some routes in Los Angeles as part of a feasibility study.²²⁸
- An American start-up, Nikola,²²⁹ claims that it will be selling hydrogen power trucks from 2020.

²²³ Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

²²⁴ HM Government (Jul 2018) “Road to Zero” available [online](#)

²²⁵ ITM Power (Sep 2018) “ITM Power opens seventh hydrogen refuelling station at Johnson Matthey’s Swindon site on M4 corridor” available [online](#)

²²⁶ HM Government (Jul 2018) “Road to Zero” available [online](#)

²²⁷ FuelCellsWorks (2018) “The First Hydrogen Powered Truck in Northern Europe to Create a new Norwegian Industry” available [online](#)

²²⁸ Field K. (Apr 2018) “Toyota Explores the Potential of a Hydrogen Fuel Cell Powered Class 8 Truck” available [online](#)

²²⁹ Transport and Environment (Jul 2017) “Roadmap to climate-friendly land freight and buses in Europe” available [online](#)

Table C.8: Detailed assessment of hydrogen

Criteria	Score and reasoning for hydrogen	
Maturity	TRL 7	Production of hydrogen is mature but has low adoption. Hydrogen trucks have recently started being trialled in feasibility studies.
Technology Cost	Red	<p>Overall, hydrogen is expected to be significantly more expensive than diesel. A 2017 study²³⁰ suggests that hydrogen fuel cost could be around twice the cost of diesel in 2050 without taking taxes into consideration. Factors that contribute to the much larger cost include:</p> <ul style="list-style-type: none"> • The predicted costs of hydrogen fuel tanks (c£20k per vehicle) and fuel cells (c£10-40k) mean that vehicles are likely to be more expensive than diesel or battery vehicles. • Producing the hydrogen fuel is a relatively expensive and inefficient use of electricity. • It will likely require substantial investment in new production, distribution, storage and filling infrastructure. • The UK does not have an established supply chain for hydrogen as a transport fuel. More broadly, the UK does not have an established strategy for hydrogen technology and its potential uses in transport, domestic consumption etc.
Infrastructure Availability	Red	<p>Infrastructure covers 3 areas: the generation of electricity, the production of hydrogen and the distribution of hydrogen.</p> <p>A significant amount of grid capacity is required in order to deliver the amount of fuel required. This is because the through-chain efficiency of hydrogen compared to batteries/E-highways. Hydrogen has an efficiency of 22% compared to 73% for direct charging.²³¹ A significant amount of low-emission generation would be required to support this demand.</p> <p>The production of these fuels would require a significant increase in production facilities, requiring significant capital expenditure.</p> <p>In addition, if hydrogen is to be produced centrally and distributed then there may need for a high pressure, super-cooled, distribution network. Some trial hydrogen fuel infrastructure is available in London and hydrogen is already transported for some chemical processes. An alternative is on-site electrolyzers that would require sufficient electrical power supply.</p>
Incidence of economic cost	N/A	The costs of hydrogen production and associated distribution infrastructure would likely fall on users. However, because the upfront vehicle and ongoing fuel costs are likely to be significantly greater than diesel, it is likely that financial incentives (in the form of taxpayer funded subsidies) will be required to encourage the transition. Without an established market for hydrogen powered vehicles it also seems likely that taxpayer funded support will be required to encourage the development of the wider supply chain.
Fuel Energy Density	Amber	Hydrogen contains around 130MJ/kg ²³² compared to diesel's 43MJ/kg. Diesel contains around 37MJ/l, while liquefied hydrogen (-253C) contains

²³⁰ Siegemund and Schmidt (Nov 2017) "E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU," Deutsche Energie-Agentur GmbH (dena)

²³¹ Transport and Environment (Jul 2017) "Roadmap to climate-friendly land freight and buses in Europe" available [online](#)

²³² Fung M (2005) "Energy Density of Hydrogen", 2005 available [online](#)

Criteria	Score and reasoning for hydrogen	
		<p>2.36kWh/l when liquefied or 0.75kWh/l at 40MPa (gas).²³³ Scaling to 70MPa (700bar) suggests approximately 1.3kWh/l. Converting these hydrogen values to MJ/l yields 8.5, 2.7 and 4.7MJ/L respectively.</p> <p>Therefore hydrogen weighs less than diesel for the same amount of energy, but occupies a larger volume.</p> <p>In addition to this the storage tank requirements for the hydrogen need to be considered including the structural strength to maintain a high pressure and the insulation to keep it cool. ²³⁴suggests that a comparable storage tank is 1.2 tonnes heavier than a full diesel tank.</p>
Refuel Speed	Green	Hydrogen can be refuelled at a comparable rate to diesel, with hydrogen cars fuelling in 3-5 minutes. ²³⁵
Propulsion Power Density	Green	Electric motors have higher power-to weight ratios than diesel engines, however hydrogen vehicles also require a fuel-cell to convert the hydrogen to electricity. A fuel cell for an HGV is of the order of 150kg in weight. ²³⁶
Emissions	Blue	<p>When hydrogen is used to generate electricity through a fuel cell, it emits only water vapour and heat, meaning there are no tank to tailpipe emissions of carbon or air pollutants.</p> <p>The whole lifecycle should also be taken into account; this only becomes an effective and environmentally sound technology if hydrogen is derived from low carbon sources which, as with synthetic fuel, may require changes to the grid and upfront investment in low carbon technology. Hydrogen is one of the least efficient methods for providing propulsion from electricity with a through-chain efficiency of 30%. These systems would have greater emissions than a battery/E-highway proposal because of this reduced production efficiency.</p>
Safety	Amber	Hydrogen presents a similar level of hazard/risk to natural gas or petrol, ^{237,238} in particular that hydrogen can explode if tanks are punctured or somehow ignited. This would be mitigated through a level of reinforcing of the fuel tanks and pipelines.

²³³ Fung M (2005) “Energy Density of Hydrogen”, 2005 available [online](#)

²³⁴ Fung M (2005) “Energy Density of Hydrogen”, 2005 available [online](#)

²³⁵ Mearian L. (Nov 2014) “Here’s why hydrogen-fueled cars aren’t little Hindenburgs” available [online](#)

²³⁶ Fung M (2005) “Energy Density of Hydrogen”, 2005 available [online](#)

²³⁷ Transport and Environment (Jul 2017) “Roadmap to climate-friendly land freight and buses in Europe” available [online](#)

²³⁸ Mearian L. (Nov 2014) “Here’s why hydrogen-fueled cars aren’t little Hindenburgs” available [online](#)

C.2. RAIL SHORT LIST

This section sets out the detailed discussions of the short-listed fuels and technologies for rail freight. – the assessments are summarised in the table below.

Table C.9: Summary of detailed assessment of the short-listed options for rail

Criteria	Battery	Electrification	Synthetic diesel	Hydrogen
Maturity evaluation	TRL 6	TRL 9	TRL 6	TRL 6
Technology Cost	Amber: Slightly worse than current diesel technology	Amber: Slightly worse than current diesel technology	Red: Significantly worse than current diesel technology.	Amber: Slightly worse than current diesel technology
Infrastructure Availability	Amber: Slightly worse than current diesel technology	Amber: Slightly worse than current diesel technology	Red: Significantly worse than current diesel technology.	Red: Significantly worse than current diesel technology.
Fuel Energy Density	Red: Significantly worse than current diesel technology.	Blue: Better than current diesel technology	Green: Comparable to current diesel technology.	Amber: Slightly worse than current diesel technology
Refuel Speed	Red: Significantly worse than current diesel technology.	Blue: Better than current diesel technology	Green: Comparable to current diesel technology.	Green: Comparable to current diesel technology.
Propulsion Power Density	Blue: Better than current diesel technology	Blue: Better than current diesel technology	Green: Comparable to current diesel technology.	Green: Comparable to current diesel technology.
CO ₂ emissions	Blue: Better than current diesel technology	Blue: Better than current diesel technology	Amber: Slightly worse than current diesel technology	Blue: Better than current diesel technology
Safety	Green: Comparable to current diesel technology.	Green: Comparable to current diesel technology.	Green: Comparable to current diesel technology.	Amber: Slightly worse than current diesel technology

C.2.1. Battery trains

In this mode, electricity is stored in a battery (i.e. as chemical energy) on board the vehicle that is then delivered to one or more electric motors. This assessment focuses on battery charging rather than battery swapping. The assessment around the vehicle would be much the same, but different infrastructure would be required for battery swapping.

Where electricity can be produced and utilised with a higher efficiency than diesel fuel, this can lead to significant energy savings. Systems can be recharged either by plugging to a power source or by “swapping out” used batteries for new ones. Electric trains offer lower exhaust emissions and quieter operation.

Many battery chemistries are available but lithium-ion batteries dominate due to their current mass manufacture, reasonable cost and relatively high energy density as compared to other batteries.

Battery-powered passenger trains were introduced on Eurostar in 2015,²³⁹ with further battery-powered trains expected to be introduced in the UK by 2019.²⁴⁰ Elsewhere, Bombardier has announced it will provide 300 trains for the Austrian Federal Railways from 2019 onwards, which it claims “are expected to enhance local passenger transport capacity”.²⁴¹

Table C.10: Detailed assessment of battery trains

Criteria	Score and reasoning for battery trains	
Maturity	TRL: 6	<p>Passenger trains have been demonstrated in the UK and are starting to be produced commercially however the power and energy densities required of freight trains are larger.</p> <p>Once a trial freight train has used battery power then this will increase to a 7.</p>
Technology Cost	Amber	<p>In our high level assessment, battery operated rail freight is likely to be more expensive than the current diesel technology, but could be one of the least expensive options relative to the other rail technologies.</p> <p>We did not find sufficient evidence on the cost of batteries in the rail context to form a firm conclusion, so our assessment is based on the strong assumption that costs will evolve in a similar fashion to road freight. The only study we found looked at the cost of battery technology relative other decarbonised modes was based on a network which is not directly comparable to the UK's.²⁴²</p> <p>We know in order to provide the required range and acceleration for a freight train, the battery would need to be of a significant size – probably comparable to a freight car. The capital cost of the new battery powered vehicle and battery is likely to be substantially more expensive than diesel in the near term. Over time the battery would degrade and require replacement at additional cost.</p> <p>Given that rail freight operators already operate on relatively tight margins,²⁴³ replacing a freight car with a battery tender could reduce the payload of each freight train, thus impacting on operator profitability. Battery technology may not be a commercially attractive option.</p>

²³⁹ Railway Technology “Powering the Trains of Tomorrow” available [online](#)

²⁴⁰ Vivarail (Feb 2018) “Battery Train Update” available [online](#)

²⁴¹ Bombardier (Dec 2016) “Bombardier and Austrian Federal Railways Sign Framework Agreement for up to 300 TALENT 3 Trains” available [online](#)

²⁴² SINTEF (May 2017) “Alternative Railway Electrification in Norway” available [online](#)

²⁴³ ORR (Jan 2018) “Rail industry financial information 2016-17 – data tables” available [online](#)

Criteria	Score and reasoning for battery trains	
		<p>However, electricity would be a cheaper and more efficient fuel that would reduce operating costs over the life of the train. It is uncertain to what extent this would offset the expected increase in whole life costs.</p> <p>Additionally, battery operated trains may not require the substantial infrastructure costs associated with overhead line electrification if the range can be sufficiently high. Although some charging infrastructure would be required at terminal/depot facilities, it might be possible to charge batteries via the overhead wires on electrified sections of the network.</p>
Infrastructure Availability	Amber	<p>The electrical infrastructure required for battery trains falls into two aspects, the grid to deliver the electricity and the charging capability required for trains. The grid is already in place and will require reinforcement for growth in electric vehicles and electric heat, therefore the scale of reinforcement can be increased. Batteries could be swapped, and battery tenders (with a battery taking up around 80% of such a tender) may be an effective approach to battery swapping.</p>
Incidence of economic cost	N/A	<p>The cost of procuring new electric freight rolling stock, batteries and any associated infrastructure (e.g. new depots or charging stations) would be incurred by freight operators. However, as we have noted above, investment in new rolling stock may not be commercially attractive to the freight operators.</p> <p>It should be noted that freight operators' access charges do not reflect the true economic costs they impose on the network; it is subsidised through taxes. Freight charges are set taking into consideration what the market can bear – as the sector typically faces low margins, additional costs on rail freight operators may lead to a requirement for lower access charges and a higher subsidy.</p> <p>Moreover, rail freight operators currently benefit from around £18m in (taxpayer funded) government grants to incentivise the movement of freight from road to rail (currently the “Mode Shift Revenue Support (MSRS) Scheme”²⁴⁴). If the cost of battery-powered rail freight increases relative to road freight, there could be pressure to increase the amount of government funding available through such schemes.</p>
Fuel Energy Density	Red	<p>The energy density of Li-ion batteries is, at most, about 7% that of diesel (up to 2.5MJ/l²⁴⁵ compared to diesel's 37MJ/l²⁴⁶). Any technological improvements in this area are unlikely to be meaningful enough to allow battery HGVs to compete with diesel in this area. The power density of batteries could become a limiting factor for large accelerating forces (e.g. for carrying a heavy load uphill).</p>
Refuel Speed	Red	<p>Current superfast chargers are up to around 350kW.²⁴⁷ Considering the diesel tank of a British Rail Class 66 with a capacity of 6550 litres²⁴⁸ against batteries with a total of 237GJ (37MJ/l * 6550l) or 66,000kWh this would take over a week (188 hours) to recharge.</p> <p>In theory Li-ion batteries can reach charge rates of around “1C” or faster meaning that their whole battery could be replenished in an hour or less. It seems reasonable this would be possible by 2050, but this is still significantly longer than current diesel technology. Depending on the length of time for loading/unloading this might be practical. Battery swapping may be more practical if efficient swapping procedures</p>

²⁴⁴ ORR (Oct 2017) “Rail Finance – 2016-17 Annual Statistics Release” available [online](#)

²⁴⁵ Panasonic (accessed Aug 2018) “Specifications for NCR8650GA”, available [online](#)

²⁴⁶ Neutrium (accessed Aug 2018) “Specific energy and density of fuels”, available [online](#)

²⁴⁷ Transport and Environment (Sep 2017) “Electric Trucks’ contribution to freight decarbonisation” available [online](#)

²⁴⁸ Booth A. “History of the Class 66s” available [online](#)

Criteria	Score and reasoning for battery trains	
		can be put in place, and assuming that having additional batteries for this purpose is not prohibitively expensive.
Propulsion Power Density	Blue	Electric motors have higher power-to weight ratios than diesel engines, offsetting some of the weight.
Emissions	Blue	<p>The tank-to-tailpipe emissions for an electric vehicle are negligible through the use of batteries on road and rail vehicles.</p> <p>The lifecycle environmental impact of producing the components required for these large batteries should also be considered. In particular there are environmental concerns associated with nickel mines, which can produce emissions of potentially toxic metals and sulphur dioxide and cause issues for disposal of potentially hazardous waste.²⁴⁹</p> <p>There are no studies for HGVs but it appears that the ‘whole life’ emissions are lower than diesel vehicles after only two years of operation.²⁵⁰ This assumes 2030 levels of CO₂ emission from electricity generation.</p>
Safety	Green	<p>Little specific discussion on the safety of battery trains has been found, however any trains would have to work within the stringent standards and regulations. Vivarail²⁵¹ has stated that the batteries are carefully monitored so that any incident would be contained and any gases could dissipate naturally.</p> <p>Key hazards come from the use of high-voltages, and the potential for chemical fires arising from damage to the batteries leading to thermal runaway. It seems that the risk of puncture/fire can be mitigated through the careful distribution and packaging of the batteries (allowing better structural design/mass distribution) as well as proper maintenance, while any battery malfunctions can be managed with a battery management system.</p>

C.2.2. Rail electrification

Electrified rail freight requires electricity delivered from an external source such as:²⁵²

- an overhead power line;
- a third rail; or
- inductive under the vehicle (wireless charging).

Electrified rail in the UK is mainly using overhead lines: catenary wires transmit energy to hybrid (diesel-electric) locomotives via a pantograph (roof mounted pole to make contact with wire). Locomotives can run fully electric when connected to catenary wires. The pantograph allows direct power transmission to the electric motor of the locomotive at 25kV. Locomotives are required to have fixed power if

²⁴⁹ The Guardian (Au 2017) ‘Nickel mining: the hidden environmental cost of electric cars’ available [online](#)

²⁵⁰ ICCT (Feb 2018) “Effects of battery manufacturing on electric vehicle life-cycle greenhouse gas emissions” available [online](#)

²⁵¹ Rail Network “Vivarail targets summer running for new battery unit.” available [online](#)

²⁵² Transport and Environment (Jul 2017) “Roadmap to climate-friendly land freight and buses in Europe” available [online](#)

disconnected from the wires, therefore it is likely that future electric locomotives would need to be hybridised with another storage technology (either diesel, battery or hydrogen).

Electrification of suburban rail has been available in the UK since 1904 with a railway line opened between Newcastle and Benton.²⁵³ Currently around 42% of the UK’s railways are electrified²⁵⁴ although this is almost wholly for passenger trains. Most freight trains in the UK are diesel powered however electric locomotives have been operated for many decades, for example the Class 86 which started operation in the 1960s.²⁵⁵ Electric locomotives also operate in the Channel Tunnel.²⁵⁶ Direct Rail Services (DRS) has purchased locomotives from Stadler in Spain that are dual electric and diesel; these began service in 2017.²⁵⁷

Table C.11: Detailed assessment of electrification

Criteria	Score and reasoning for electrified rail tracks	
Maturity	TRL: 9	Although there are far fewer electric freight locomotives than electric passenger locomotives, they have been used for freight since 1941. ²⁵⁸ They have also been operated on the Channel Tunnel since it was first commissioned
Technology Cost	Amber	<p>Fully electric powered trains running on the fixed electrified network are the most efficient and cost effective mode of rail transport.²⁵⁹ But the initial capital cost of electrification is very large and this has resulted in the UK government paring back plans for further electrification schemes, although Scotland has ongoing electrification projects.²⁶⁰ Full electrification of all freight routes would likely cost in excess of £10 billion, and the investment in new capacity around pinch points required to accommodate additional freight captured from the road network would also be substantial.</p> <p>It would not be economic to electrify all sections of the network, particularly where traffic volumes are relatively low. To the extent that freight trains operate on these sections, they would require an alternative power source. “Hybrid” technologies are traditionally more expensive (in terms of the capital, operating and maintenance costs of the rolling stock) and this would need to be factored in to the case for electrification.</p> <p>Freight operators would need to procure new electric rolling stock to realise the benefits of electrification. Electric traction costs are significantly lower than diesel, and so lower rolling stock operating costs may offset a small share of the initial infrastructure costs. As we have noted elsewhere, freight operators have historically been hesitant to voluntarily invest in new stock.</p>
Infrastructure Availability	Amber	The electrical infrastructure for electrification falls into two aspects, the grid to deliver the electricity and the power lines over the rails. The grid is already in

²⁵³ Network Rail (Accessed Aug 2018) “Key Dates in the History of Britain’s Railway” available [online](#)

²⁵⁴ Railway Technology (Jun 2018) “Will the UK ever get electrification back on track?” available [online](#)

²⁵⁵ Rail.co.uk (Accessed Oct 2018) “British Rail Class 86 Electric Locomotive” available [online](#)

²⁵⁶ Glasspool D. “Class 92”, available [online](#)

²⁵⁷ Edmunds P., (Jun 2017) “New dual electric and diesel locomotive shows rail freight is moving with the times”, available [online](#)

²⁵⁸ Rail.co.uk (Accessed Oct 2018) “Ex-Southern Rail Class 70 Electric Locomotive” available [online](#)

²⁵⁹ Institution of Mechanical Engineers (February 2018) “Decarbonising Rail: Trains, energy and air quality” available [online](#)

²⁶⁰ Transport Scotland (Accessed Oct 2018) “Electrification programme” available [online](#)

Criteria	Score and reasoning for electrified rail tracks	
		place and will require reinforcement for growth in other electric vehicles and electric heat, therefore the scale of reinforcement can be increased. 42% of the rail network is already electrified ²⁶¹ over a prolonged investment. More electrification is planned however there is discussion as to whether it has political support and if it is the most cost-effective approach. Some areas may not be suitable for electrification (such as in proximity to cranes in docks), while there are some regions with lots of freight traffic, where more modest electrification schemes would provide significant benefit.
Incidence of economic cost	N/A	Under the current model, electrification and enhancement of the rail network is delivered by Network Rail. The infrastructure costs would mostly fall on passengers as the main source of industry income (though this depends on government policy) and because there is presently limited scope to pass these costs through to freight operators without making rail freight less cost competitive. Taxpayers would also bear a share of the infrastructure costs. Given that freight operators would not be able to capture the social benefits generated by electrification, and because sector profitability is marginal, further taxpayer support would probably be required to encourage take up of electric rolling stock.
Fuel Energy Density	Blue	Using an electrification approach removes some, if not all of the need for energy storage on the locomotive, which may enable longer freight trains to run. If this is hybridised with other technologies then their respective fuel energy density should be considered.
Refuel Speed	Blue	Power is delivered directly to the locomotive and can be used immediately while charging a battery for use off the power lines.
Propulsion Power Density	Blue	Electric motors have higher power-to weight ratios than diesel engines.
Emissions	Blue	This technology benefits from zero tank to tailpipe carbon and air pollutant emissions compared with diesel, due to the use of electricity to power the road and rail vehicles. The technology could also use low carbon sources such as solar panels along the side of the roads to generate the required electrical power, meaning while electrified rail is used, direct and indirect emissions are negligible. Electrification is one of the most efficient uses of electricity from the grid with an overall efficiency of 73%. ²⁶² This is around twice as efficient as a diesel engine and can be powered from low-emission sources.
Safety	Green	Electrification has been demonstrated to be acceptably safe through the decades that it has been in place on the rail network – there are a range of regulations setting out the required standards. The infrastructure requires adjustment around gantries, bridges and existing flora/fauna to be safe.

²⁶¹ Institution of Mechanical Engineers (February 2018) “Decarbonising Rail: Trains, energy and air quality” available [online](#)

²⁶² Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

C.2.3. Synthetic fuels (rail)

The assessment of synthetic fuels for rail freight is the same as that for road freight: both modes would require production processes to be put in place, and would need installation of a significant amount of distribution infrastructure, but the synthetic fuel can readily be used in existing diesel technology.

C.2.4. Hydrogen (rail)

Hydrogen as a fuel is suitable for existing road and rail vehicles can currently be produced through reforming steam methane (SMR), although this requires carbon capture and storage.²⁶³ In the case of road vehicles this process provides a 10% reduction in well-to-wheel emissions when compared to diesel HGVs, so the difference is likely to be similar for rail. Hydrogen can also be produced from electrolysis, and research and development are underway for producing hydrogen through electrolysis of water, although there are some electrolysis stations in the UK.²⁶⁴ In Road to Zero,²⁶⁵ it is suggested that in 2050 electrolysis would be the least polluting (carbon dioxide) mechanism for the formation of hydrogen, (having 90% lower emissions than diesel, using a low-carbon grid) therefore it is assumed that this is the approach that would be pursued for rail. In turn this would require a growth in the electricity used to produce hydrogen. In all cases tailpipe NOx and PM is negligible.

The hydrogen is then stored cryogenically at high pressure (700bar), and then released through a fuel cell to generate electricity to drive one or more electric motors. The use of hydrogen on the railways is referred to as “Hydrail”.

The existing reforming steam methane method is more likely to require the hydrogen to be produced centrally and distributed via a gas or super-cooled set of pipes, whereas the electrolysis method allows production to be more easily decentralised as electrolysis can take place on-site where it is pumped into the vehicle. If produced locally then sufficient electrical power to do so is required.

Alstom has produced hydrogen powered passenger trains that are being tested in Germany,²⁶⁶ and There are plans to operate a pilot train in the UK by 2020.²⁶⁷ In China, hydrogen powered trams have been operational since 2015.²⁶⁸

Table C.12: Detailed assessment of hydrogen

Criteria	Score and reasoning for hydrogen	
Maturity	TRL: 6	Passenger trains have been demonstrated, but not in the UK. Globally hydrail is still in the trial phase (for passenger trains). Freight trains have higher power and energy density requirements.
Technology Cost	Amber	There is limited information on the potential cost of hydrogen freight trains available in the public domain, which makes it difficult to compare to the diesel counterfactual. We noted that for road freight, some studies estimate that hydrogen could be several times more expensive than diesel (excluding taxation). A significant driver of the cost of hydrogen would be the inefficiency in electricity use and the additional cost incurred in the development of associated hydrogen infrastructure (production, transmission, distribution and filling infrastructure),

²⁶³ Siegemund and Schmidt (Nov 2017) “E-fuels study: The potential of electricity-based fuels for low-emission transport in the EU,” Deutsche Energie-Agentur GmbH (dena)

²⁶⁴ ITM Power (Sep 2018) “ITM Power opens seventh hydrogen refuelling station at Johnson Matthey’s Swindon site on M4 corridor” available [online](#)

²⁶⁵ HM Government (Jul 2018) “Road to Zero” available [online](#)

²⁶⁶ Railway Technology “Powering the Trains of Tomorrow” available [online](#)

²⁶⁷ Railway Gazette (Feb 2018) “Hydrogen train to be tested in the UK by 2020” available [online](#)

²⁶⁸ Railway Technology “Powering the Trains of Tomorrow” available [online](#)

		<p>although this ‘overhead’ cost may fall if hydrogen is adopted for use beyond freight transport.</p> <p>There are specific characteristics of the rail network which might impact the cost effectiveness of hydrogen. For example, on routes with low traffic flows hydrogen might be more viable than electrification because the initial rail infrastructure costs would be much lower.²⁶⁹ On the other hand, in order to achieve the required vehicle range, the size of the hydrogen fuel cell and storage tank is likely to be large and this may displace some of the value of the freight carried per train. Geography will also be an important characteristic driving factors such as the cost effectiveness of deploying overhead cables, which would improve hydrogen’s relative cost benefit.</p>
Infrastructure Availability	Red	<p>Infrastructure covers three areas: the generation of electricity, the production of hydrogen and the distribution of hydrogen.</p> <p>A significant amount of grid capacity is required in order to deliver the amount of fuel required. This is because of the through-chain efficiency of hydrogen compared to batteries/electrification. From energy source to engine efficiency hydrogen has an efficiency of 22% compared to 73% for direct charging in road vehicles, and it is thought this would be similar for rail.²⁷⁰ A significant amount of low-emission generation would be required to support this demand.</p> <p>The production of these fuels would require a significant increase in production facilities, requiring significant capital expenditure.</p> <p>In addition, if hydrogen is to be produced centrally and distributed then there may be a need for a high pressure, super-cooled, distribution network – alternatively, it may be transported as a gas. There are also some novel solutions suggesting hydrogen is delivered through ammonia. Some trial hydrogen fuel infrastructure is available in London and hydrogen is already transported for some chemical processes</p>
Incidence of economic cost	N/A	<p>Under the current model, the cost of procuring new hydrogen freight trains would be borne by freight operators. However, as we have noted elsewhere, historically operators have been cautious about investing in new rolling stock and it seems unlikely that there will be a commercial case to do so here. Adoption of hydrogen technology would likely require intervention by government and some form of taxpayer subsidy to assist the freight industry in absorbing the additional costs.</p>
Fuel Energy Density	Amber	<p>Hydrogen contains around 130MJ/kg²⁷¹ compared to diesel’s 43MJ/kg. Diesel contains around 37MJ/l, while liquefied hydrogen (-253C) contains 2.36kWh/l when liquefied or 0.75kWh/l at 40MPa (gas).²⁷² Scaling to 70MPa (700bar) suggests approximately 1.3kWh/l. Converting these hydrogen values to MJ/l yields 8.5, 2.7 and 4.7MJ/L respectively.</p> <p>Therefore hydrogen weighs less than diesel for the same amount of energy, but occupies a larger volume.</p> <p>In addition to this the storage tank requirements for the hydrogen need to be considered including the structural strength to maintain a high pressure and the</p>

²⁶⁹ For example, see Ynni Glan (June 2018) “The Potential of Hydrogen in the Decarbonisation of Transport in Wales – a research project for Simon Thomas AM” available [online](#), and SINTEF (May 2017) “Alternative Railway Electrification in Norway” available [online](#)

²⁷⁰ Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

²⁷¹ Fung M (2005) “Energy Density of Hydrogen”, 2005 available [online](#)

²⁷² Fung M (2005) “Energy Density of Hydrogen”, 2005 available [online](#)

		insulation to keep it cool. SINTEF ²⁷³ suggests that a “H2 wagon” could have three times the amount of energy of batteries, but still notably less than diesel.
Refuel Speed	Green	E-fuel can be refuelled at a comparable rate to diesel, with hydrogen cars fuelling in 3-5 minutes. ²⁷⁴
Propulsion Power Density	Green	Electric motors have higher power-to weight ratios than diesel engines, however hydrogen vehicles also require a fuel-cell to convert the hydrogen to electricity.
Emissions	Blue	<p>When hydrogen is used to generate electricity through a fuel cell, it emits only water vapour and heat, meaning there are no tank to tailpipe emissions of carbon or air pollutants.</p> <p>The whole lifecycle should also be taken into account; this only becomes an effective and environmentally sound technology if hydrogen is derived from low carbon sources which, as with synthetic fuel, may require changes to the grid and upfront investment in low carbon technology. Hydrogen is one of the least efficient methods for providing propulsion from electricity with a through-chain efficiency of 30%. These systems would have greater emissions than a battery/E-highway proposal because of this reduced production efficiency.</p>
Safety	Amber	Hydrogen presents a similar level of hazard/risk to natural gas or petrol ^{275,276} , in particular that hydrogen can explode if tanks are punctured or somehow ignited. This would be mitigated through a level of reinforcing of the fuel tanks and pipelines. Something that is perhaps a greater risk for trains compared to HGVs is the potential damage in tunnels if the large hydrogen tanks are damaged and vent at very high pressure.

²⁷³ SINTEF (May 2017) “Alternative Railway Electrification in Norway” available [online](#)

²⁷⁴ Mearian L. (Nov 2014) “Here’s why hydrogen-fueled cars aren’t little Hindenburgs” available [online](#)

²⁷⁵ Transport and Environment (Jun 2017) “Roadmap to climate-friendly land freight and buses in Europe”, available [online](#)

²⁷⁶ SINTEF (May 2017) “Alternative Railway Electrification in Norway” available [online](#)



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