energy technologies institute

An ETI Insights Report

HGVS AND THEIR ROLE IN A FUTURE ENERGY SYSTEM

Contents

4% 2019

15% 2050

HGVs account for around **4%** of total UK **CO_2** emissions. In some **scenarios** this could rise to **15%** by **2050**

Fleet operator **purchasing behaviour** today is risk averse. To achieve the **decarbonisation** of the **UK energy system**, this must change

££££

Zero **CO_2 emission** tonne km are likely to be required to meet **2030** HGV **CO_2** targets already in place

A **plug-in hybrid** vehicle can act as a **bridging vehicle** (2025-2040)

Reducing overall **UK CO_2 targets** by **80% to 90%** or more will require zero emisson **HGVs**

10%

HGVS AND THEIR ROLE IN A FUTURE ENERGY SYSTEM

Electrification of **HGVs** will not be constrained by the **energy system**, but by the vehicle platform **solutions**

CCUS would be necessary for mass deployment of hydrogen in transport and **HGVs**

An **effective carbon price** across the **energy system** would enable an **HGV** and its **supporting infrastructure** to contribute towards overall **decarbonisation** of the energy system

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INTRODUCTION

By 2050 the UK energy system, including transport, will need to look significantly different to today if the UK is to meet its 2050 Greenhouse Gas (GHG) target. The Energy Technologies Institute's (ETI) Heavy Duty Vehicle (HDV) programme aims to challenge where heavy-duty transport, and the Heavy Goods Vehicle (HGV) sector in particular, can help the UK meet its climate change targets.

All transport sectors will be required to contribute towards decarbonisation. The car and van sectors are expected to be decarbonisation pioneers through the early introduction of battery electric, plug-in hybrid and hydrogen powered vehicles across the globe. For these sectors, technology costs are already reducing, and these powertrains are close to becoming practical and affordable for the mass market. However, in the freight sector there are significant cost and packaging challenges in the application of the same very low emission technologies, due to the powers and energies required by medium and heavy goods vehicles (MGV and HGV). There are no MGV or HGV vehicles available today which deliver zero CO_2 tailpipe emissions at a cost which is competitive for purchasers compared with current fossil fuel based vehicles.

Over the past 25 years, MGVs and HGVs operating on EU and UK roads have been forced to reduce emissions (carbon monoxide, hydrocarbons, NO_x, particulate matter (PM), particle number and smoke) through the introduction of Euro emission standards, but this has not included CO_2. Implementation of CO_2 reduction standards, as with cars, is expected to encourage the development of zero CO_2 tailpipe emission vehicles and, from the beginning of 2019, MGVs and HGVs should also begin to contribute to the overall CO_2 reduction.

Creating vehicles in the MGV and HGV sector which deliver zero CO_2 tailpipe emissions is possible and several solutions have been proposed utilising hydrogen or electricity, such as the Tesla Semi[1], Nikola[2], Arrival[3], Mercedes-Benz[4] and Volvo. However, many of these solutions are not suitable for full fleet deployment today, requiring significant reductions in cost, improvements in energy density (or limitations being placed on vehicle range), and significant future infrastructure development in order for them to become practical for the mass market.

Fleet operator purchasing behaviour today is usually economically rational, with each purchase based on an economic assessment over the first life of the vehicle. Original Equipment Manufacturers (OEMs) of MGVs and HGVs are therefore risk averse and tend to offer incremental improvements to customers which pay back in under two years. Transforming the vehicle fleet towards zero CO_2 tailpipe emission vehicles is likely to require solutions that don't fit with this traditional approach.

Decarbonising the UK energy system, including transport, will require technologies which will also be more expensive than like for like technology replacement. The result of this is an effective price to decarbonise the technology in each sector, which can be termed a "carbon price". Decarbonising the UK's energy system will therefore result in increased costs, and solutions to reduce CO_2 in transport should be considered alongside the possible changes and costs in other parts of the energy system, such as power, heat, industry and so on.

[1] https://www.tesla.com/en_GB/semi
[2] https://nikolamotor.com/
[3] https://arrival.com/
[4] https://www.daimler.com/sustainability/vehicles/climate-protection/electric-offensive.html

Transitioning a 44t HGV of today to zero emissions is the equivelant of removing 30 C/D category cars from the road.

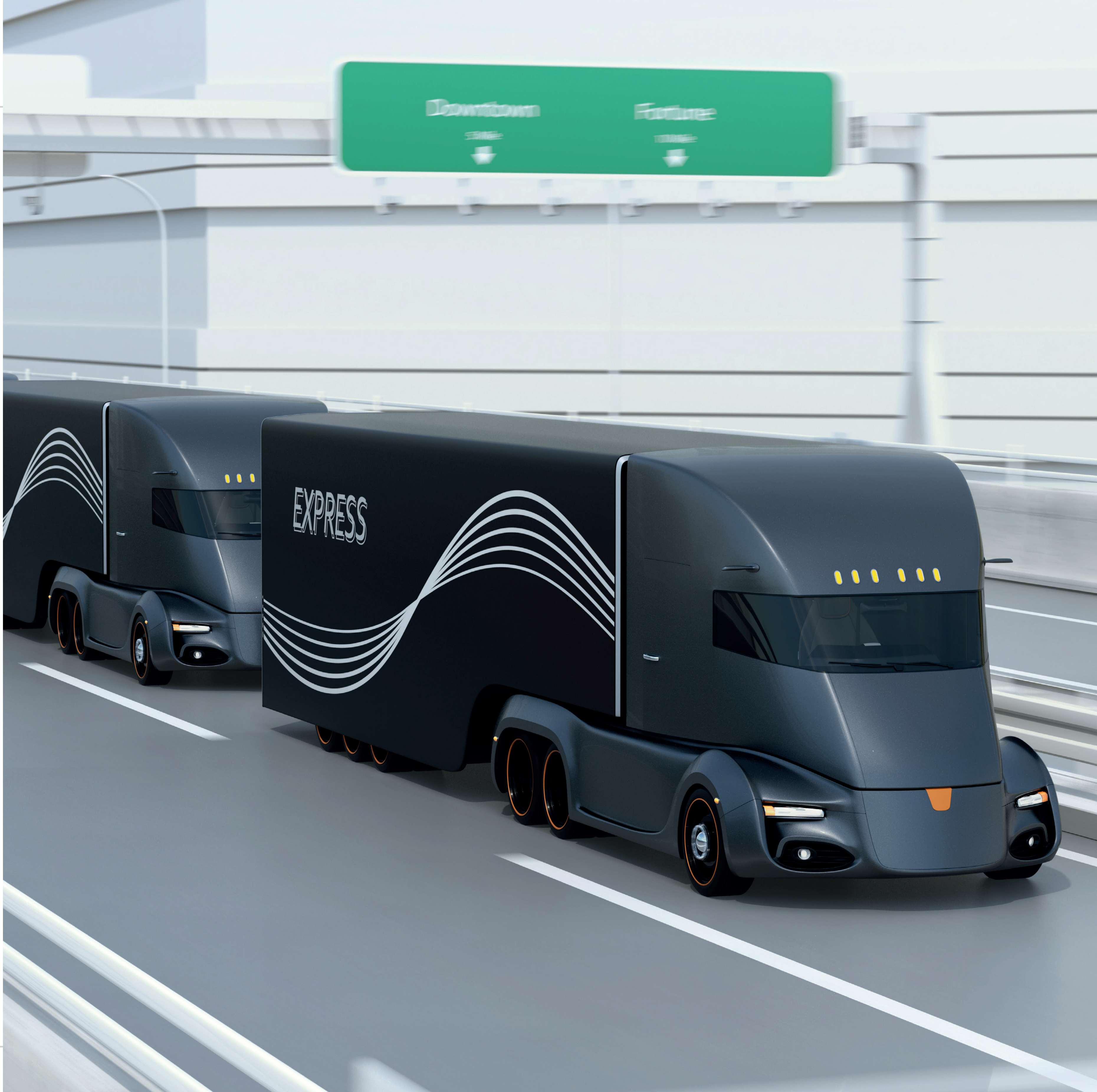
Comparing the requirement to decarbonise the whole energy system and how transport, MGVs and HGVs can best align with this decarbonisation raises questions which this insight sets out to address:

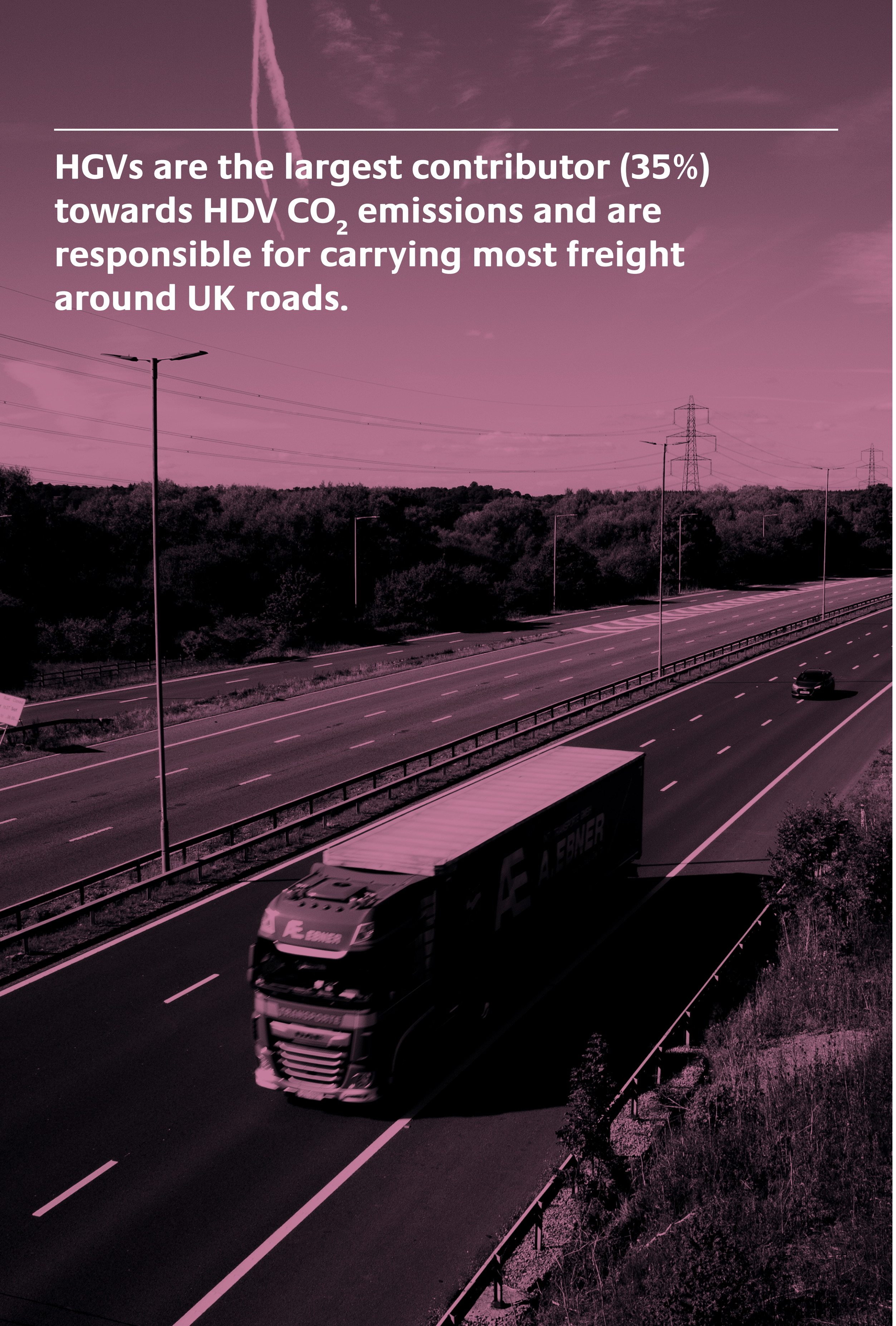
1. What is the maximum a zero (or near zero CO_2) emission HGV can cost in 2050 in order to achieve mass market deployment (assuming the whole fleet is constructed of these vehicles) within the energy system when there is a carbon emissions constraint?

2. How does the construction of the wider energy system affect the cost and the type of zero (or near zero CO_2) emission HGVs?

3. What effect does the selection of zero (or near zero CO_2) emission HGVs have on the rest of the energy system?

In this insight we set out to provide an holistic view, considering the HGV sector in context with the other parts of the energy system that also have to decarbonise if the UK is to meet its climate change targets.





HGVs are the largest contributor (35%) towards HDV CO_2 emissions and are responsible for carrying most freight around UK roads.

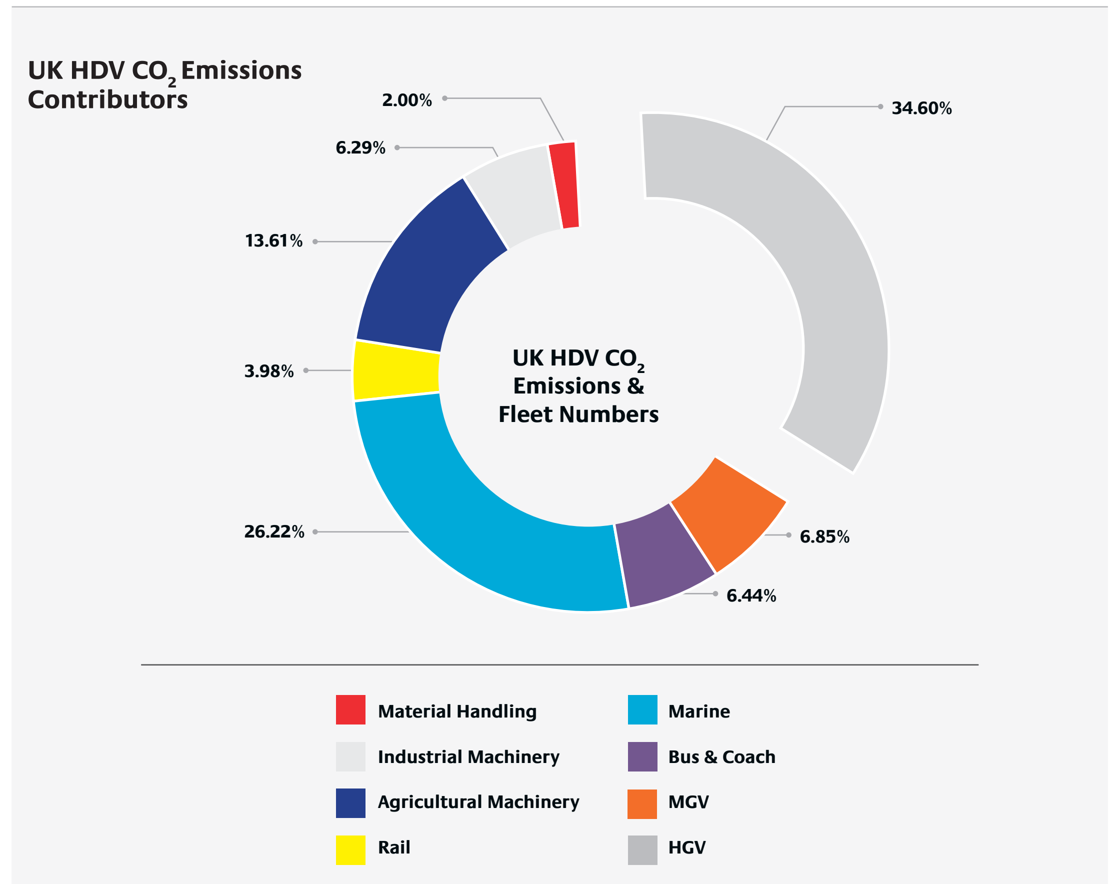
BACKGROUND

Transport and Heavy Duty Vehicle (HDV) Emissions in the UK

GHG emissions from the land and marine transport sector accounted for around a third of total UK GHG emissions in 2016 with CO_2 being the most dominant of these gases accounting for 99% [5]. Within the transport sector HDV CO_2 emissions accounted for just under a third of emissions with the remaining two thirds attributed to light duty vehicles. HGVs (>17t) are the largest contributor (35%) towards HDV CO_2 emissions and are responsible for carrying most freight around the UK roads.

The energy density of fossil fuels makes them especially suited to transport applications. Removing these fuels and reducing CO_2 from any of the HDV sectors is challenging, with each sector facing its own specific challenges. This insight is focused on the highest CO_2 emitting sector of HGVs, but the general high-level energy system impacts could plausibly be scaled and applied to other HDV sectors.

Figure 1
UK HDV CO_2 emissions contributions breakdown in 2010 - sourced from ETI HDV project data.



[5] Source: BEIS – 2016 UK Greenhouse Gas Emissions, Final Figures – 06/02/2018. Figures in this report specify 26% of GHG emissions originate from transport. Heavy duty vehicle emissions from off-highway vehicles such as excavators and mining trucks are reported in the business sector and agricultural vehicles such as tractors and sprayers are reported in the agriculture sector. Not all domestic marine vessels are reported, only fishing vessels, as such data reported in the ETI HDV programme has been used to determine the split of emissions and populate gaps.

Challenges for the HGV Sector

Electrification in the car sector is gathering pace and technology costs are starting to become feasible for mass market adoption. Whilst the majority of car journeys are likely to be satisfied with home charging[6], significant infrastructure challenges remain to cater for the wide range of journey lengths desired by many car users.

HGVs, on the other hand, are utilised in a very different way to cars and present a different set of requirements. One of the differentiators is the proportion of time spent on the road. Average distances for a 44t UK HGV are just under 450km/day[7] using around 150 litres of fuel (dependant upon the duty cycle). Some 44t Articulated HGVs carry over 1000 litres of diesel, almost 20 times that of an average passenger diesel car. This amount of fuel will be in the vehicle for more than a few days. Changing energy vectors from diesel to an alternative source presents both opportunities and challenges; there are potentially many vehicle and infrastructure solutions which can be cost optimised based on vehicle usage cases.

While CO_2 is the main climate centric challenge up to 2050, near-term factors such as air quality are likely to play a major role in technology choices. Air quality regulations have been in place for a number of years and have significantly affected vehicle powertrain designs, which in turn have had major capital cost implications for HGVs. In some cases, the reduction of pollutant emissions, which has improved air quality, has been claimed to increase fuel consumption or negate any fuel efficiency improvements and CO_2 emission reductions[8].

Many UK towns and cities currently fail to meet European limits for air quality. In response to increasing social and political pressures, the Department for Transport (DfT) and Department for Environmental Food & Rural Affairs (DEFRA) published a plan in July 2017[9] for tackling roadside nitrogen dioxide (NO_2) concentrations.

Highlighting the role conventionally fuelled cars have in producing roadside NO_2, the plan sets out to end the sale of new conventional petrol and diesel cars and vans by 2040, whilst promoting a reduction in roadside NO_2 in urban environments as soon as possible. Many towns and cities in the UK are going to charge older, more polluting vehicles to enter city centres whilst proposing even tighter limits in the future through zero emission zones, potentially banning internal combustion engine operations completely[10].

Further challenges come from the need to deploy infrastructure to support any change in energy vector. This is key to the successful penetration of alternatively fuelled vehicles in the fleet. Existing infrastructure in the UK has been set up and optimised to utilise those energy vectors (petrol and diesel) which have been in use for more than a century. While a transition to electricity or hydrogen might prove beneficial and relatively straightforward for some operators, a national infrastructure would still be required to support mass deployment. There are real examples of switching to alternative energy vectors in the HGV sector which have been slow to penetrate the market; adoption of natural gas for instance has been hampered in part due to the necessary implementation of supporting infrastructure. Further to the infrastructure issues, natural gas capable vehicle availability from OEMs has also been a hinderance which is slowly starting to change.

The challenges facing the HGV sector are numerous if it is to switch to vehicles which are capable of zero CO_2 tailpipe emission operation at both the vehicle and infrastructure level. Whilst many of these are not insurmountable, they highlight some of the major challenges in trying to decarbonise the HDV sector as a whole. Overcoming these challenges will require additional investment.

[6] ETI Report – Transport, An affordable transition to sustainable and secure energy for light vehicles in the UK
[7] ETI Data Analysis Optimisation project – collecting and analysis data from 10,000 truck in the UK to see how on road freight vehicles are used in the UK.
[8] ICCT - Overview of the heavy-duty vehicle market and CO_2 emissions in the European Union – Rachel Muncrief and Ben Sharpe – December 2015
[9] https://www.gov.uk/government/publications/air-quality-plan-for-nitrogen-dioxide-no2-in-uk-2017
[10] https://www.airqualitynews.com/2018/05/14/mayor-sets-2020-timetable-for-london-zero-emission-zones/
[11] Committee on Climate Change – UK climate action following the Paris agreement – October 2016

External Factors Influencing Transportation Decarbonisation within the UK Energy System

Various policy measures are already in place that impact the HGV sector and there are a number under development. HGV emission legislation in the UK is currently driven and set by the EU. The majority of HGVs sold in the UK are from European manufacturers and have been designed and built to meet the needs of the European market. There are currently several external factors that could have a direct impact on how the HGV sector decarbonises.

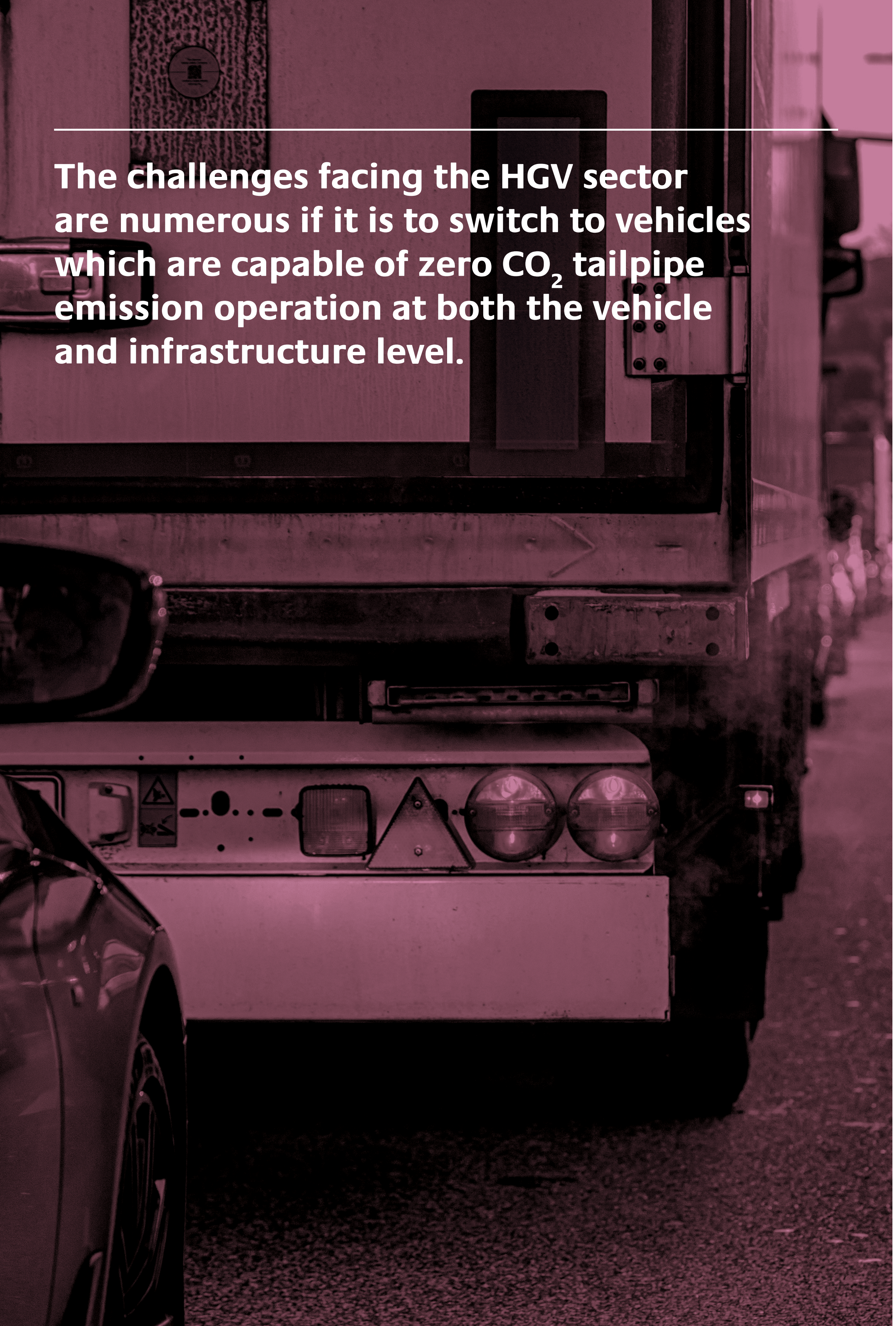
The overarching CO_2 target is for the UK to reduce its GHG emissions by 80% from 1990 levels by 2050. Intermediary targets for the UK, set and published by the Committee on Climate Change (CCC), are likely to have significant impacts on the shape of the energy system.

The United Nations Climate Change Conference, COP 21, was held in Paris in 2015. COP 21 sought to strengthen the global response to climate change and, while the implications for the UK are yet to be fully realised and published, the understanding is that for the global temperature rise to halt and stabilise there is a need for GHG emissions to fall to net zero. In response to the Paris agreement, the CCC acknowledged that the UK already had targets to reduce CO_2 emissions and there was little value in setting more stringent targets until the next review cycle, when the effectiveness of the current targets could be assessed and reconsidered. Remaining flexible in the solutions to be deployed for the current target, but acting as soon as possible, would help in the pursuance of further reductions in the CO_2 targets[11].

In response to the Paris agreement, the EU committed to reducing climate change by limiting global warming to well below 2°C, which has resulted in CO_2 emission limits for new HDVs in 2025 and 2030 which are 15% and 30% (respectively) lower than 2019 levels[12]. Monitoring of CO_2 emissions will take place during 2019[13] for all new vehicles introduced by each OEM to the fleet to assess the ‘base level’ CO_2 emissions of each OEM’s new vehicles. The proposed legislation is supported by fines for OEM’s if they fail to meet the fleet average emissions reductions for their products. Each OEM will have their own individual target based on the CO_2 emissions of vehicles sold in 2019 and will be penalised respective to their own base level. The penalty is set at €6,800 per gCO_2/tkm over the specified target. The incentive for the OEMs to avoid paying a penalty and to produce a fleet of vehicles that meet the target is large.

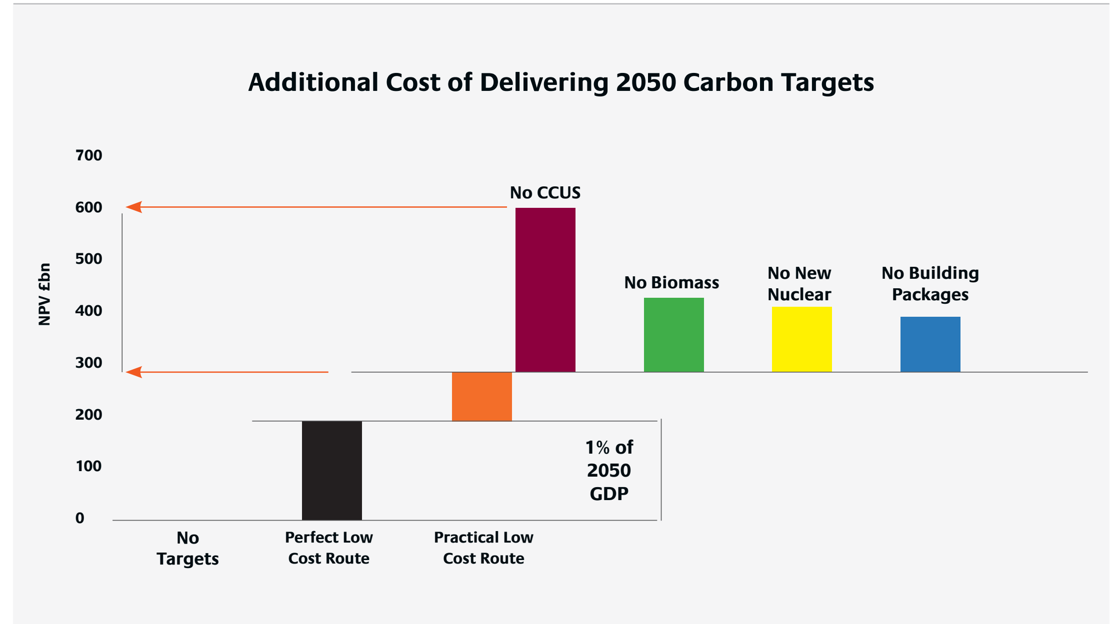
One of the key messages from the ETI over the past 10 years has been the importance of Carbon Capture, Utilisation and Storage (CCUS) to any future UK energy system. Developing CCUS capability in the UK with bioenergy (BECCS)[14] can produce negative CO_2 emissions, thus allowing the ‘harder to abate’ sectors to reduce less than would otherwise be necessary, reducing the overall cost of any future low carbon energy system. In 2015 the UK Government cancelled its £1bn CCUS competition[15]. This decision has inevitably delayed the introduction of CCUS in the UK. Removing CCUS completely will add billions of pounds to the overall cost of the UK’s energy system transition. If action is not taken on CCUS in the UK within the next 10 years, it is likely to have a significant long-term effect on the look, cost and flexibility of the UK energy system[16].

[12] European Commission – Proposal for a Regulation of the European Parliament and of the Council setting CO_2 emission performance standard for new heavy-duty vehicles – 17/5/2018
[13] https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en
[14] https://www.eti.co.uk/insights/the-evidence-for-deploying-bioenergy-with-ccs-beccs-in-the-uk
[15] https://www.theguardian.com/environment/2015/nov/25/uk-cancels-pioneering-1bn-carbon-capture-and-storage-competition
[16] https://www.eti.co.uk/insights/carbon-capture-and-storage-building-the-uk-carbon-capture-and-storage-sector-by-2030



The challenges facing the HGV sector are numerous if it is to switch to vehicles which are capable of zero CO_2 tailpipe emission operation at both the vehicle and infrastructure level.

Figure 2
The additional cost of delivering the 80% CO_2 reduction target from 1990 levels by 2050 when key technologies are removed. Highlighting the most valuable technologies, in monetary terms, for decarbonising the energy system to 2050.



Road to zero

In July 2018, the DfT published "Road to Zero", its long-term strategy for decarbonisation of transport, which reiterated the ambition to "end the sale of new conventional petrol and diesel cars and vans by 2040". By promoting the uptake of zero emission cars and vans, the DfT expects the transition to be industry and consumer led; albeit with the support of a more detailed DfT strategy. Transitioning heavy goods vehicles and road freight to lower carbon alternatives is discussed in the strategy, but the amount of decarbonisation required is not as clear as for cars and vans with the ambitions being predominantly near term (2025) while the market develops zero CO_2 emission options.

DESCRIPTION OF THE WHOLE SYSTEMS & MODELLING APPROACH

When assessing the role and requirement for HGVs to decarbonise it is vital to understand the requirement for the whole energy system to decarbonise towards the 2050 CO_2 reduction target.

The ETI has developed its Energy System Modelling Environment (ESME) – an internationally peer-reviewed national energy system design and planning capability – to identify the lowest cost decarbonisation pathways for the UK energy system. This involves running hundreds, even thousands of simulations, exploring the variation of cost-optimal designs within a range of assumptions and constraints in order to identify robust strategies against a broad range of uncertainties. ESME covers the whole energy system for the UK, enabling the ETI to look in detail at possible designs for infrastructure, supply and end-use technologies for heat, electricity, personal transport, freight, industry etc.

In 2015 the ETI published “Options, Choices, Actions – UK scenarios for a low carbon energy system”. This discussed in detail two exemplar scenarios for the UK along with their implications. This analysis was refreshed in 2018 and provides excellent context as to how ESME can be used[17]. These reports and the documentation on the ETI website provide a comprehensive explanation of ESME, how it has been developed and how it works.

ESME datasets are focused on the UK energy system but consider international markets including the possibility to import resources; biomass and liquefied natural gas (LNG) for example. Importing Hydrogen or Ammonia is not available as an option with the version of ESME used[18]. The ESME datasets are underpinned by detailed sector models and the ETI’s project work undertaken over the last 12 years. The transport input data for ESME considers transport and vehicle manufacturers operating in a global market and the UK is assumed to share many of the same vehicles as the EU with many HGVs on UK roads manufactured in Europe. Decisions taken within these markets will affect UK transport and this is reflected in the dataset. There is inherent uncertainty in the assessment of future technologies (viability, performance, cost etc). In addressing this, the technologies available to ESME have ranges of cost, availability and build rates which can be assessed using a Monte Carlo approach.

The transport sector in ESME comprises of many sub-sectors, each of which have several powertrain options:

- Cars are split into two sectors to represent the fleet at a high level - A/B sectors represent small vehicles and C/D represent the remaining vehicles. These are Society of Motor Manufacturers and Traders (SMMT) sectors defined by vehicle size and weight
- LGVs (Vans)
- Off-highway – split into several sectors that represent machine types and include agriculture
- Marine vessels which is split into two sectors: international and domestic
- Aviation
- MGV and HGV – Figure 3 shows detailed sector breakdowns for the HGV and MGV categories. The Capital Expenditure (CAPEX) for each powertrain in the detailed sector breakdowns is provided with 2018 and 2050 costs (in 2018 monetary value). A range of zero CO_2 tailpipe emission HGV and MGV powertrains are presented in this table. These are constructed from the ETI Zero Emission HDV database[19] and represent the most straightforward solutions with simple links to infrastructure, many more solutions may also be achievable with more complex links between infrastructure and vehicles.

ESME cost minimises by selecting from a range of discrete technology choices which it combines to create a coherent and viable energy system. To answer the questions raised in the introduction ESME had to be changed to scan a range of 2050 costs for the HGV sector using generic vehicles that utilise the energy vectors of interest. These vehicles are agnostic of the overall vehicle and infrastructure solution which allows the impact of using a hydrogen, electric or a gas and electric plug-in hybrid vehicle on the energy system to be assessed. Figure 3 shows the vehicles which are usually selected by ESME and the capital cost of each vehicle throughout the investment period. Alterations have been made to the availability of vehicles for this insight which are detailed in the table text.

[17] https://www.eti.co.uk/options-choices-actions-2018/
[18] Future versions of ESME will have the provision to import hydrogen
[19] This is publicly available to download from the Knowledge Zone of the ETI website

Figure 3
The mean capital investment costs for each vehicle type are all of 2018 monetary value. Values for 2018 and 2050 are provided for context. Other models are used to inform all vehicle costs in ESME which include technology deployment profiles, manufacturing improvements and cost reductions. Costs for the intervening years are not linear between the two values. Technology cost reduction curves are implemented and rolled up into the overall vehicle costs. 2050 values in the table are mean values with a minimum and maximum range around the mean value to represent the uncertainty in the technology development. These ranges are different for each powertrain and sector and are presented for the 2018 and 2050 44t HGVs in Fig 7, Fig 10 and Fig 13 for context. Table colours represent powertrain uptake rates in each of the sectors for typical ESME simulations for the ranges of costs specified.

- **Vehicles are never selected in 2050**
- **Vehicles are usually selected in 2050 (80%-100% of the sector)**
- **Vehicles are occasionally selected under some scenarios, usually below 40% of the sector**
- **Vehicles are occasionally selected under some scenarios, usually below 10% of the sector**
- **Vehicles are rarely selected under some scenarios. They have been removed from the dataset for the purposes of this work**

	CAPEX Investment Costs (2018 Monetary Value)													
	Example	MGV 7-8t		MGV 8-17t		HGV 17-25t Rigid		HGV >25t Rigid		2 axle HGV <33t Artic		44t Articulated HGV	
Powertrain	Powertrain Description	2018	2050	2018	2050	2018	2050	2018	2050	2018	2050	2018	2050
ICE Diesel	Conventionally fuelled diesel internal combustion engine vehicle as per today's vehicles	£51,345	£43,517	£60,775	£51,509	£71,695	£60,764	£84,237	£71,394	£85,464	£72,435	£94,821	£80,364
ICE Diesel Hybrid	Conventionally fuelled diesel internal combustion engine vehicle with the addition of a hybrid powertrian to provide energy recovery	£58,593	£48,869	£67,584	£56,548	£83,483	£65,170	£95,386	£75,335	£96,931	£76,654	£105,432	£83,914
ICE Natural Gas Dual Fuel	Diesel pilot internal combustion engine with natural gas injected in the inlet port with a typical ratio of 45% gas / 55% diesel in 2018	£64,785	£49,300	£73,550	£55,969	£83,389	£63,457	£94,992	£72,286	£96,498	£73,431	£104,783	£79,738
ICE Natural Gas Dual Fuel Direct Injection	Diesel pilot internal combustion engine with natural gas injected in the inlet port with a typical ratio of 96% gas / 4% diesel in 2018	£66,373	£46,589	£80,729	£56,665	£90,372	£63,433	£104,626	£73,438	£106,100	£74,473	£117,105	£82,197
ICE Natural Gas Spark Ignited	Dedicated natural gas engine which is similar to a petrol type engine with spark ignition	£53,150	£44,821	£61,937	£52,230	£71,801	£60,548	£83,433	£70,357	£84,941	£71,630	£93,249	£78,635
ICE Natural Gas Dual Fuel Direct Injection Hybrid	As the ICE Natural Gas Dual Fuel Direct Injection powertrain with the addition of a hybrid powertrian to provide energy recovery	£72,740	£53,646	£86,434	£63,251	£101,476	£70,019	£115,034	£80,024	£116,447	£81,059	£126,892	£88,783
ICE Natural Gas Spark Ignited Hybrid	As the ICE Natural Gas Spark Ignited powertrain with the addition of a hybrid powertrain to provide energy recovery	£62,115	£51,878	£70,923	£58,816	£86,468	£67,134	£97,954	£76,943	£99,444	£78,215	£107,646	£85,221
Hydrogen Fuel Cell with Regen Battery	Large fuel cell (100-300kW) which provides the majority of the energy to an electric motor with a small battery to support high power demands and energy recovery	£281,448	£102,590	£367,579	£130,273	£452,545	£154,063	£483,893	£165,945	£559,961	£186,363	£607,249	£214,060
Mid Size Battery & Mid Size Fuel Cell	Balanced split between fuel cell size and battery capacity. Fuel cell typically providing 30% of total power	£151,062	£70,232	£193,731	£87,130	£235,911	£100,332	£272,340	£113,696	£304,178	£123,106	£338,834	£147,685
Battery with Fuel Cell Range Extender	A relatively large battery system with a small fuel cell (20-50kW) to supplement and extend battery range	£138,879	£67,865	£177,489	£83,972	£216,854	£96,777	£262,654	£113,090	£289,018	£121,264	£323,202	£145,842
Battery	Battery only vehicle	£104,018	£59,826	£131,006	£73,255	£159,998	£83,773	£215,168	£103,033	£228,498	£108,083	£259,944	£132,093

Figure 4
Values for 2018 and 2050 are to provide context for the efficiencies of 44t HGVs used in ESME. This includes the 'new test vehicles' which replace the vehicles highlighted in purple in Figure 3 and any specific assumptions used for these vehicles in ESME.

Key: Diesel | Natural Gas | Hydrogen | Electricity

Powertrain	Powertrain Description	Energy Consumption Assumptions (kWh/km) for a 3 axle 44t Articulated HGV – Input 1 2018	Input 1 2050	Input 2 2018	Input 2 2050
ICE Diesel	Conventionally fuelled diesel internal combustion engine vehicle, as per today's Euro VI vehicles	3.89	2.64		
ICE Diesel Hybrid	Conventionally fuelled diesel internal combustion engine vehicle with the addition of hybridisation to provide energy recovery	3.16	1.93		
ICE Natural Gas Dual Fuel	Diesel internal combustion engine with natural gas injected in the inlet port with a typical ratio of 45% gas / 55% diesel in 2018 can fall back to diesel only	2.49	1.72	1.66	1.15
ICE Natural Gas Dual Fuel Direct Injection	Diesel pilot internal combustion engine with natural gas injected in the inlet port with a typical ratio of 96% gas / 4% diesel in 2018 cannot fall back to diesel only	3.02	2.08	0.76	0.52
ICE Natural Gas Spark Ignited	Dedicated natural gas engine which is similar to a petrol type engine with spark ignition	4.53	3.13		
ICE Natural Gas Dual Fuel Direct Injection Hybrid	As the ICE Natural Gas Fuel Direct Injection powertrain with the addition of hybridisation to provide energy recovery	2.37	1.55	0.59	0.39
ICE Natural Gas Spark Ignited Hybrid	As the ICE Natural Gas Spark Ignited powertrain with the addition of hybridisation to provide energy recovery	3.55	2.32		
Hydrogen	Hydrogen vehicle which is agnostic over the solution but uses a hydrogen input only (i.e. hydrogen ICE or large hydrogen fuel cell with a small battery)	2.78	2.36		
Natural Gas & Electric Plug In Hybrid	Split powertrain between a standard natural gas powered vehicle and an electric powertrain which utilises electricty as an input	1.56	1.23	0.82	0.65
Electric	Electric vehicle which is agnostic over the solution and on board storage capacity but uses an electricity input only. Can be split any way between infrastructure (i.e. catenary lines, charge points etc) and the vehicle (i.e. 1000kWh battery only, 200kWh battery and catenary power capability)	2.04	1.73		

General Sector Assumptions

All 44t HGVs are assumed to carry the same amount of average freight (11.32 tonnes) and freight efficiency is assumed to be constant until 2050. For the purposes of this work HGVs are assumed to do the same mileage per year (93,000km). All vehicles have the same maintenance costs per year (≈£13,000).

A 'flat' electric charging profile is imposed as a middle ground assumption to remain as agnostic as possible over the overall solution. A best case assumption would be for all vehicle charging to take place outside of electricity peaks while a worst case scenario would be for vehicle charging to occur in combination with other peak electricity loads.

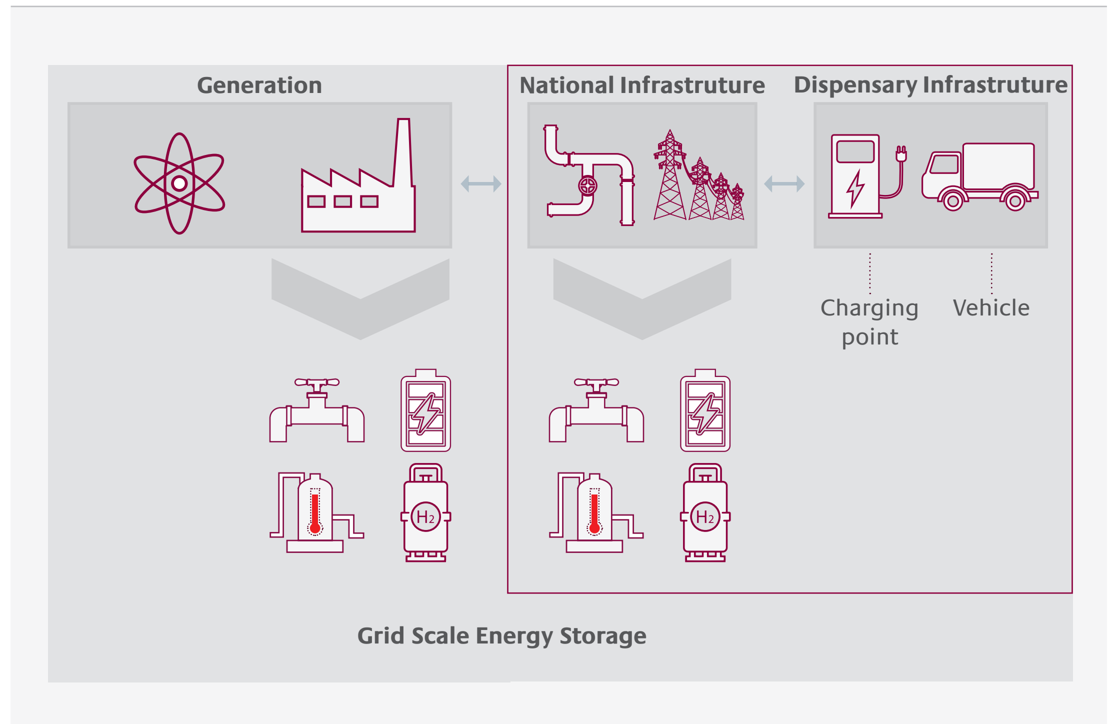
Specific Assumptions for Test Vehicles

Some elements of refuelling energy consumption are factored in to the overall vehicle consumption e.g. the energy required to compress hydrogen when refuelling the vehicle. The demand for hydrogen is 'flat' all year round 24/7/365.

ESME Modelling Changes

Typically, if an HGV is deployed in ESME, the required distribution and dispensing infrastructure to support the deployment is also built. Additional generation capacity (electric or hydrogen) is built or resources sought (gas or liquid fuel) to support the energy requirement of the deployed HGVs. Figure 5 shows the traditional path of optimisation in ESME for HGV deployment. There are many infrastructure and vehicle configuration options using electric, hydrogen or gas and electric energy vectors. To remain agnostic and to assess the impact on the energy system for each type of HGV (hydrogen, electric and gas and electric Plug-in Hybrid Electric Vehicle (PHEV)) the dispensing and distribution infrastructure has been grouped with the vehicle. Any further assessment of vehicle and infrastructure configurations will require the development of more detailed vehicle and systems models.

Figure 5
Each HGV (hydrogen, electric and gas and electric PHEV) and the required infrastructure to support them are grouped together for the purpose of this work. Infrastructure costs include distribution infrastructure from power generation point up to and including the dispensing infrastructure such as piping from a hydrogen generation point or electricity lines from an electricity substation. Dispensing infrastructure includes charge points, dynamic charging (pantographs or dynamic wireless power transfer) and hydrogen refuelling stations.



To establish the cost at which each HGV (and its supporting infrastructure) becomes economically viable when there is a CO_2 reduction target, the cost is uniformly varied between a maximum and a minimum in a Monte Carlo approach. All other energy system abatement technologies which have Monte Carlo ranges and types of distribution (i.e. triangular distribution around a maximum and minimum value) remain as they are in a standard ESME version.

Scenarios and Rationale

While a Monte Carlo approach incorporates some external factors as ranges, it does not account for discrete events. For example, there are major decisions (such as those made by policy makers) which completely remove technology options and/or promote certain technologies, which are not considered within the Monte Carlo analysis. To address some of these factors and some of the decisions that have already been taken, scenarios have been developed to test the robustness of HGV costs and the role of alternative fuels in the HGV sector within a future energy system. Five scenarios have been developed which draw on the external factors which could influence the decarbonisation of the UK energy system.

Scenario	Scenario Description
Base Case	All technologies, in the 2018 version of ESME, are available for selection.
No CCUS	Carbon Capture, Utilisation and Storage (CCUS) is the most valuable technology for ESME to select. Removing it as a technology option for ESME to select changes the overall energy system solutions drastically and dramatically increases the overall system cost.
Zero Emission Urban Transport	Cities in the UK are looking to implement zones to restrict the highest emitting vehicles in the short term and to create zero emission zones in the long term to reduce roadside air pollution. This scenario addresses this by restricting freight delivered by MGVs and LGVs to be zero CO_2 tailpipe emission from 2040. Cars follow the road to zero ambition of being zero CO_2 tailpipe emission from 2040.
Zero Emission Urban Transport No CCUS	This scenario combines the the Zero Emission Urban Transport Scenario and the NO CCUS scenario.
Reduced CO_2 Sensitivity Target	The CCC recently published a net zero CO_2 scenario and what that this would mean for the UK energy system. This scenario tests the sensitivity to increasing the current CO_2 reduction target beyond 80%.

Scenario	Transport Sector				System and Overall Constraints	
	HGV Sector	MGV Sector	LGV (Van) Sector	Car Sector	Other System Restrictions	CO_2 Target
Base Case	No restrictions over vehicle selection	No restrictions over vehicle selection	No restrictions over vehicle selection	No restrictions over vehicle selection	No other restrictions	80% reduction of GHG from 1990 levels
No CCUS	No restrictions over vehicle selection	No restrictions over vehicle selection	No restrictions over vehicle selection	No restrictions over vehicle selection	All technologies which use and store carbon (CCUS) are unable to be selected	80% reduction of GHG from 1990 levels
Zero Emission Urban Transport	No restrictions over vehicle selection	Progressive CO_2 reduction from today concluding in all new vehicles sold from 2040 must be $0gCO_2/km$	Progressive CO_2 reduction from the 2020 target of $147gCO_2/km$ concluding in all new vehicles sold from 2040 must be $0gCO_2/km$	Progressive CO_2 reduction from the 2021 target of $95gCO_2/km$ concluding in all new vehicles sold from 2040 must be $0gCO_2/km$	No other restrictions	80% reduction of GHG from 1990 levels
Zero Emission Urban Transport No CCUS	No restrictions over vehicle selection	Progressive CO_2 reduction from today concluding in all new vehicles sold from 2040 must be $0gCO_2/km$	Progressive CO_2 reduction from the 2020 target of $147gCO_2/km$ concluding in all new vehicles sold from 2040 must be $0gCO_2/km$	Progressive CO_2 reduction from the 2021 target of $95gCO_2/km$ concluding in all new vehicles sold from 2040 must be $0gCO_2/km$	All technologies which use and store carbon (CCUS) are unable to be selected	80% reduction of GHG from 1990 levels
Reduced CO_2 Target Sensitivity	No restrictions over vehicle selection	No restrictions over vehicle selection	No restrictions over vehicle selection	No restrictions over vehicle selection	No other restrictions	Increased GHG target to 90% reduction of GHG from 1990 levels

Figure 6
Producing scenarios provides context to decisions that might be made in the transport sector, or other sectors, and the implications these could have on the energy system solutions. Ranges of costs for each of the different vehicle types (hydrogen HGV, electric HGV and Gas Electric PHEV HGV) for full fleet deployment in each of the scenarios, provide information for OEMs and policy makers as to what these vehicle options could cost on an environmental or carbon cost basis within the energy system.

THE OPPORTUNITY FOR HGVs

In all of the scenarios the cost at which an HGV is deployed is presented against the probability that the whole fleet of 44t HGVs is constructed of that energy vectored HGV. All scenarios compare the cost of the three alternative vehicles (hydrogen, electric, gas and electric plug in hybrid) to a 'base vehicle' which, when these three alternatives are not available or cost too much, is deployed. This 'base vehicle' (Natural Gas Dual Fuel Direct Hybrid) is cost effective without a carbon price and follows the historical trajectory of OEMs of incremental improvements in efficiency for reasonable technology payback times (<2 years).

Base Case Scenario

Any or all of the three vehicle solutions is an attractive solution in a 2050 energy system under certain conditions. In the case of the two zero CO_2 tailpipe emission options (electric and hydrogen), these are preferentially deployed at up to around twice the cost of a natural gas dual fuel direct hybrid (including the respective supporting distribution and dispensing infrastructure for each energy vector on a per vehicle basis). Assessing the value of the three alternative vehicles against the powertrain options usually available to ESME provides useful context and reference. The costs of each of the powertrain options was previously mentioned (reference CAPEX Investment Cost table) and is provided here with the range of uncertainty in the projected 2050 cost.

Figure 7
Probability of vehicle deployment by vehicle powertrain type and its associated distribution and dispensing infrastructure cost base case scenario.

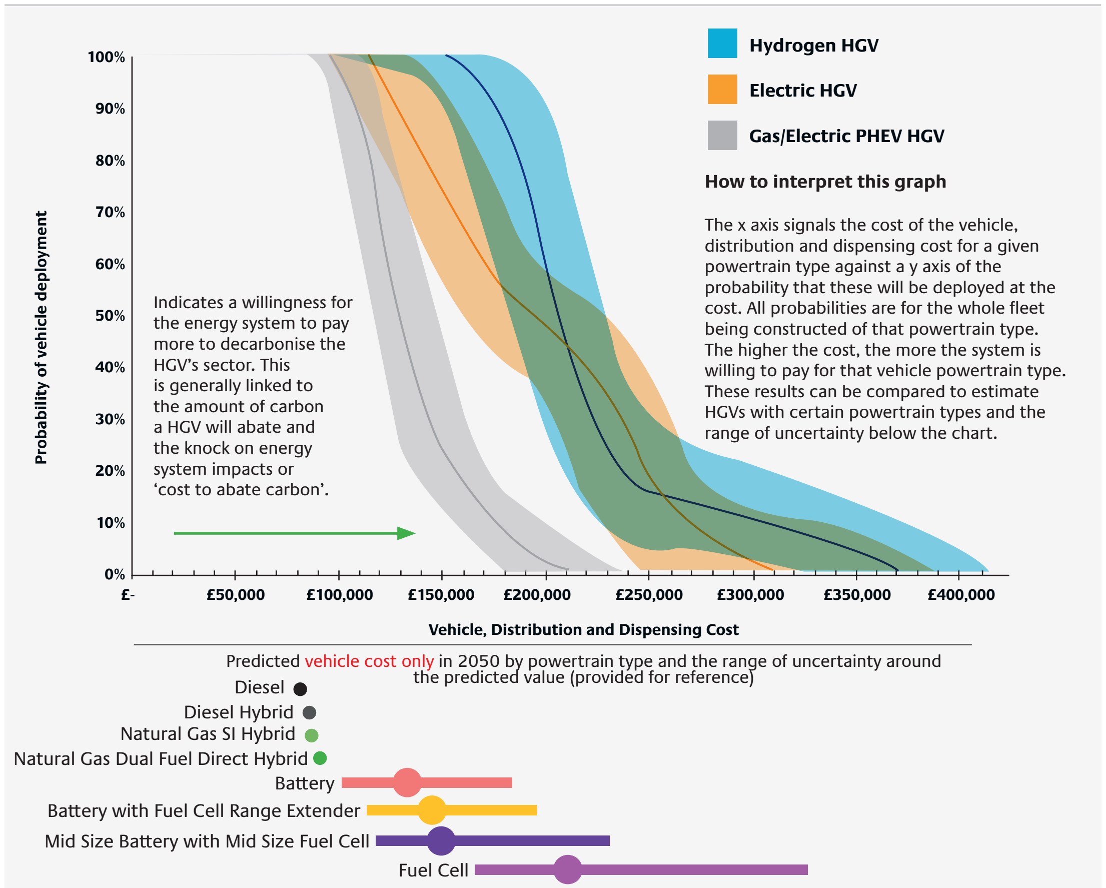
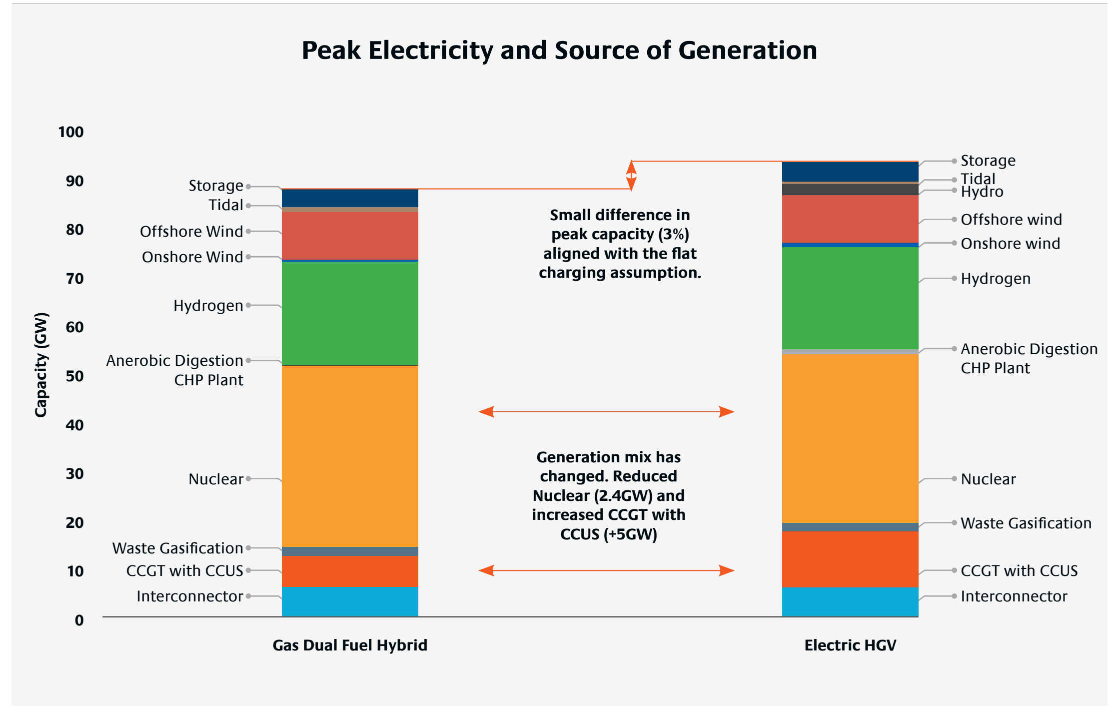


Figure 8
An example of the generation mix and the peak electricity generation capacity when an electric HGV is deployed in the system versus the 'base vehicle'. The input assumptions between the comparisons are identical with the exception of making the electric HGV available for selection. Multiple solutions for the power sector throughout the simulations have been produced and this is an example of a solution which is most common. Power sector solutions do vary to a large extent.

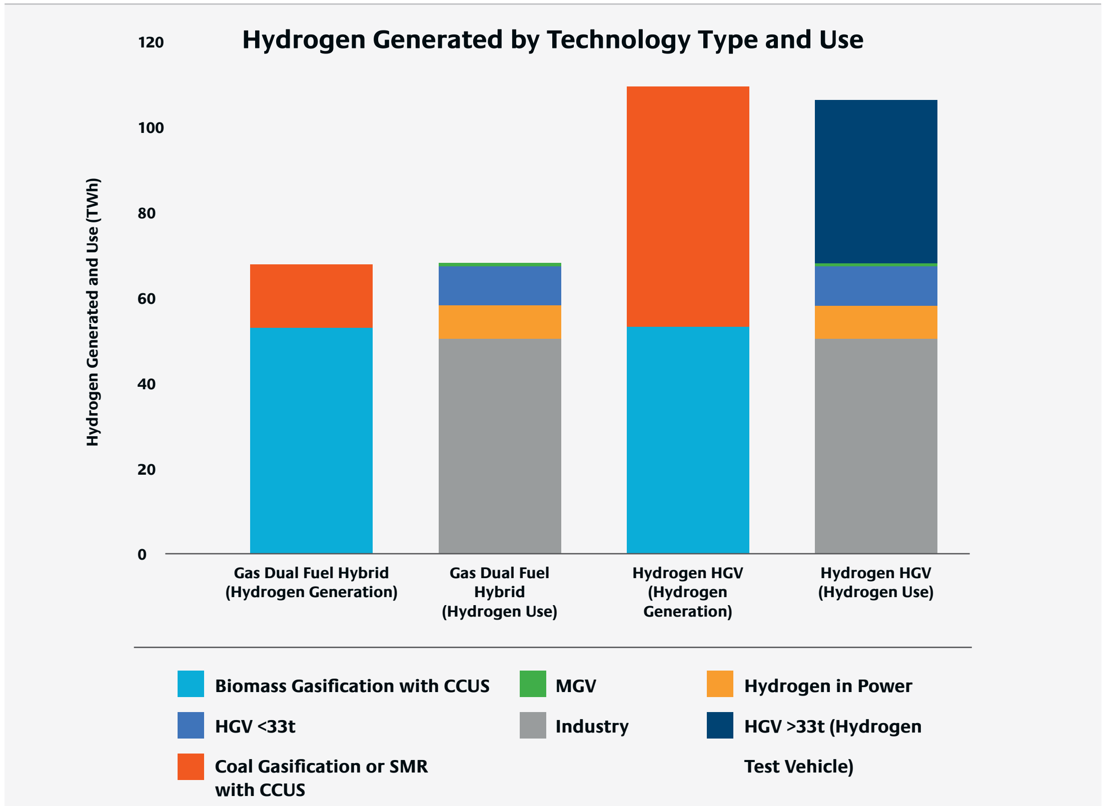


When comparing hydrogen and electric HGVs (including infrastructure costs), hydrogen is preferred to electric at most cost points in the base case scenario (i.e. when all technology options are made available).

To provide true zero emission transport the resource, generation and infrastructure pathway also needs to be zero CO_2 emission. The electric HGV requires the deployment of additional electricity generation to support the consequential additional peak electricity demand. Within the base case the overall cost of providing this additional electricity demand and the changing mix of electricity generation capacity is more expensive than the equivalent hydrogen production and distribution infrastructure using CCUS and Steam Methane Reformation. Note the additional electricity generating capacity is relatively small (Figure 8) and it might be possible to reduce its cost through managed charging and hence narrow the gap between hydrogen and electric technologies for HGVs.

Deploying hydrogen HGVs requires additional hydrogen generation capacity which is fulfilled by Steam Methane Reforming (SMR) with CCUS or coal gasification with CCUS, both of which are very low but not zero CO_2 (95% of CO_2 is captured). Other areas of the freight sector also utilise a small amount of hydrogen, with a very small penetration of hydrogen fuel cell and hydrogen range extender vehicles. Hydrogen is also utilised in the power sector, but accounts for only a small amount of the hydrogen generated. In most instances ESME exhausts the available production of hydrogen by biomass gasification with CCUS for the industry and power sectors. Any additional hydrogen generation requirement must be fulfilled from natural gas SMR or coal gas SMR with CCUS. As CCUS is available, ESME does not select electrolysis.

Figure 9
An example of the generation mix and the use of hydrogen when an hydrogen HGV is deployed in the system versus the 'base vehicle'. The input assumptions between the comparisons are identical except for making the hydrogen HGV available for selection. Multiple solutions for the hydrogen sector throughout the simulations have been produced and this is an example of a solution which is most common. Overall the hydrogen solutions do not vary widely from this example.



In each simulation instance the three alternative HGVs (Hydrogen, Electric and Gas & Electric PHEV) compete against the baseline HGV (Natural Gas Dual Fuel Direct Hybrid). When each HGV is deployed, it is deployed preferentially on cost and carbon abatement to the baseline HGV, including the system impacts (including carbon abatement) of deploying the vehicle. The overall energy system cost, when each of the three HGVs is selected, is also reduced. The size of the overall energy system cost reduction depends which vehicle is deployed against the baseline HGV (Figure 7 refers to the maximum cost which each vehicle stops being deployed). In this scenario the saving for the hydrogen HGV is up to £16.9bn, for the electric HGV it is up to £7bn and for the Gas & Electric PHEV HGV it is £3.6bn. This cost is not all at the vehicle and can be apportioned in any way between the vehicle and the required distribution and dispensing infrastructure to support it.

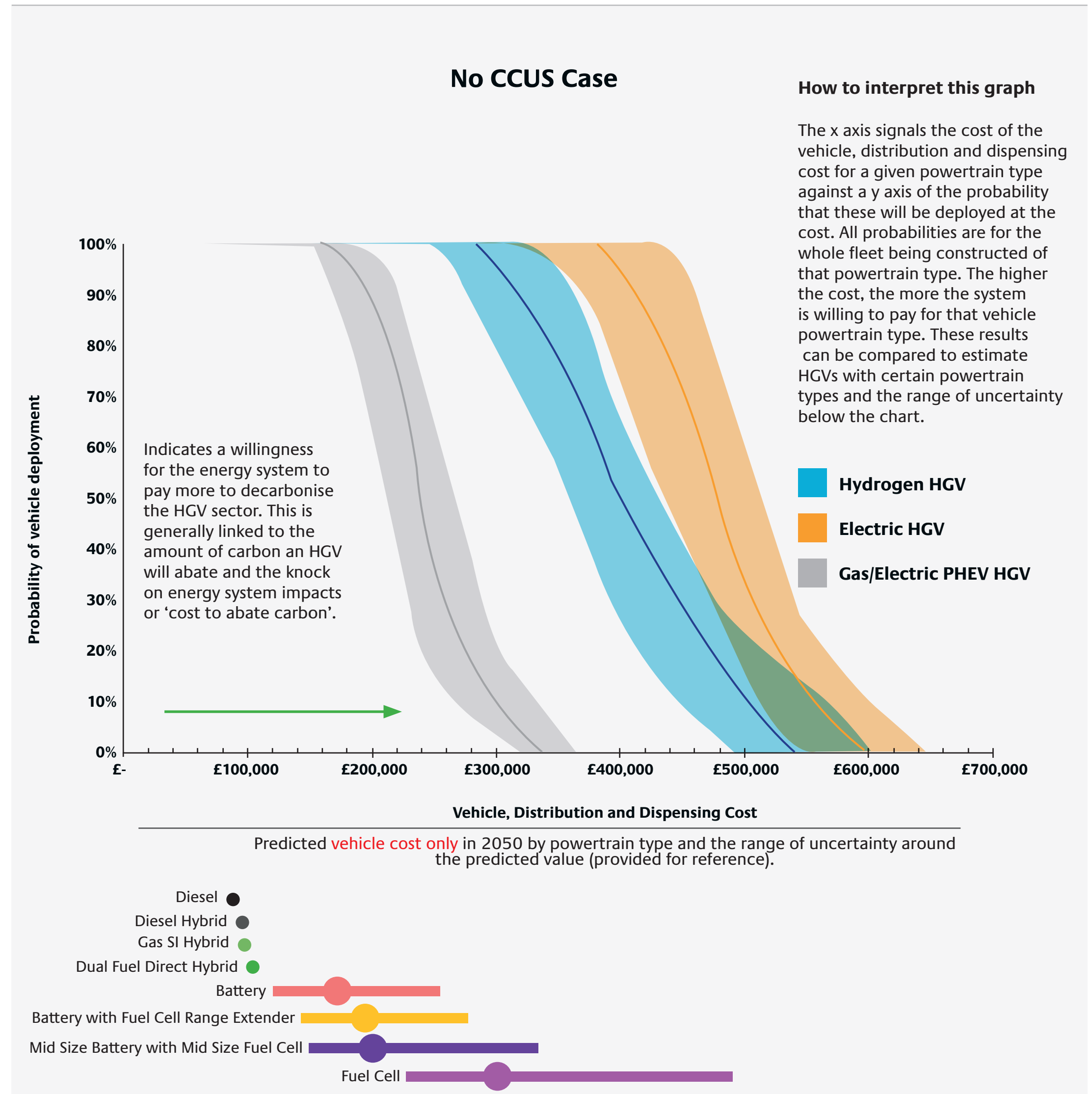
To provide some context for the additional cost for each vehicle type, one type of infrastructure which could be used to support the deployment of the electric HGV or the Gas & Electric PHEV HGV is catenary infrastructure. The estimated cost range of providing catenary infrastructure is €0.8 – €3.8m per km[20] per lane which would equate to around £5.6bn – £26.8bn to deploy catenary infrastructure on 80% of the UK strategic road network[21].

[20] ICCT – Transitioning to Zero-Emission Heavy Duty Freight Vehicles – September 2017
[21] Highways England – Strategic Road Network Initial Report Overview – December 2017

Scenario: No CCUS

Removing the availability of CCUS from the energy system has a significant effect on the overall energy system solutions. Increased deep decarbonisation is required in transport due to the removal of CCUS with bioenergy (BECCS). This drastically impacts the cost at which zero CO_2 tailpipe emission transport becomes an unattractive option, as such the two zero emission HGVs can cost up to three times more than the base vehicle and still have a 100% probability of full fleet deployment. Partial decarbonisation of the 44t sector in this scenario is also favourable with the gas and electric PHEV, but at a lower cost.

Figure 10
Probability of vehicle deployment by vehicle powertrain type and its associated distribution and dispensing infrastructure cost for No CCUS case.

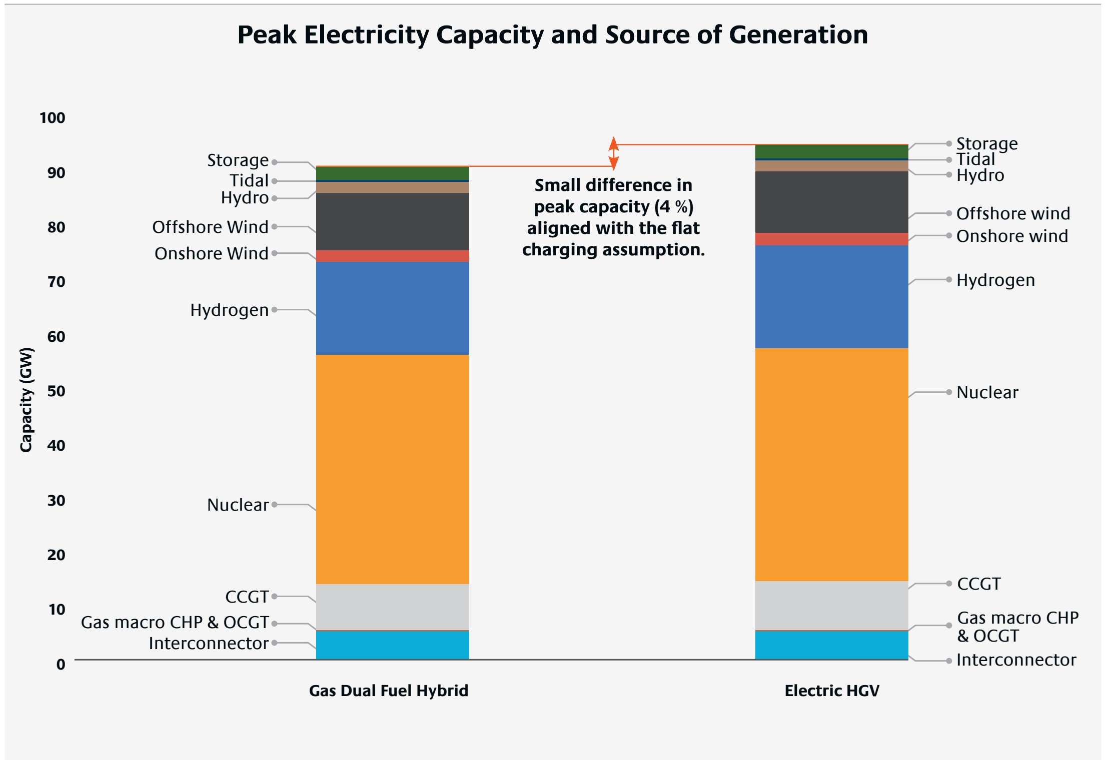


Removing CCUS requires hydrogen to be generated by electrolysis which could have significant cost impacts and hence reduce the appeal of any technologies which use hydrogen. Storing hydrogen rather than generating it as required is necessary with electrolysis. The cost of storage is such that ESME prefers to run hydrogen production through electrolysis as a base load hence requiring additional electricity generation capacity.

Providing hydrogen via electrolysis is significantly less efficient than providing electricity directly to the vehicle and explains the large discrepancy between the costs at which a hydrogen and electric HGV become unattractive. The efficiency difference between the electric HGV and hydrogen HGV pathways is highlighted by the differences in peak electricity generation capacity: 2.7GW additional peak electricity generation capacity for the electric HGV and 4.7GW additional peak electricity generation capacity for the hydrogen HGV (Figure 11).

In each simulation when one of the three alternative HGVs (Hydrogen, Electric and Gas & Electric PHEV) is deployed, it is deployed preferentially to the baseline HGV and the overall energy system cost is reduced. In this No CCUS scenario the saving for the hydrogen HGV is up to £34.5bn, for the electric HGV it is up to £58.8bn and for the gas & electric PHEV HGV it is £20.8bn. This cost is not all at the vehicle and can be apportioned in any way between the vehicle and its distribution and dispensing infrastructure.

Figure 11
An example of the electricity generation mix and the peak electricity generation capacity when CCUS is removed as a technology option and when an hydrogen HGV is deployed in the system versus the 'base vehicle'. The input assumptions between the comparisons are identical with the exception of making the hydrogen HGV available for selection. Multiple solutions for the power sector throughout the simulations have been produced and this is an example of a solution which is most common. Power sector solutions do vary to a large extent.



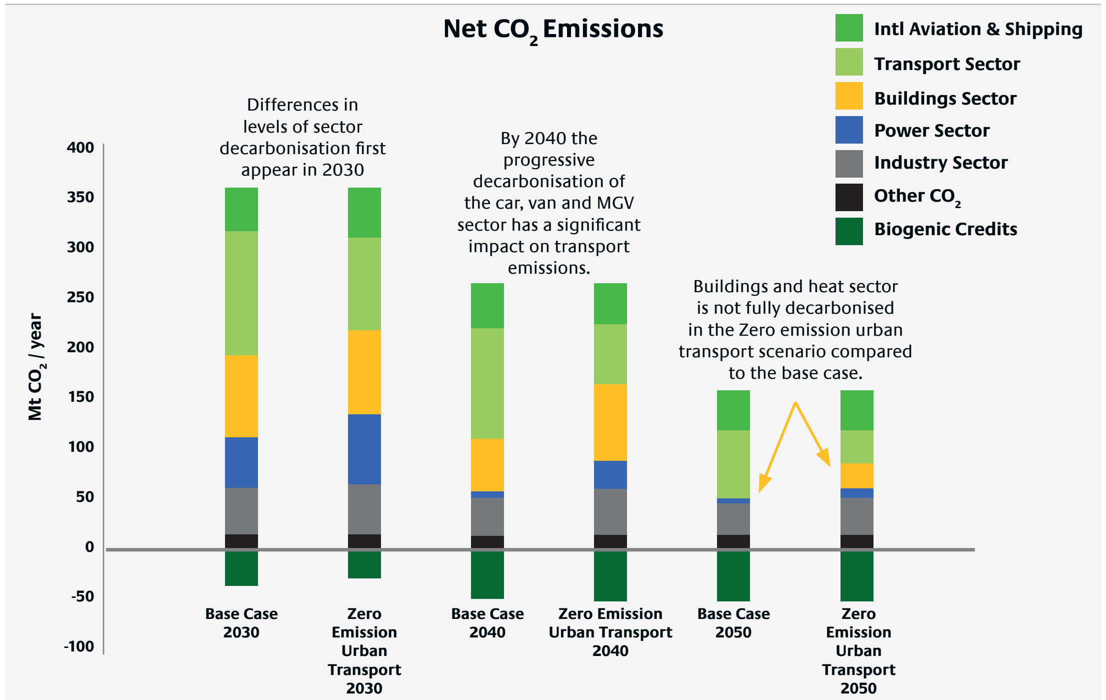
Scenario: Zero Emission Urban Transport

Progressively reducing the CO_2 limits for cars, vans and MGVs to be zero CO_2 emission from 2040 in this scenario relaxes the need to decarbonise the remainder of transport including the 44t HGV sector by 2050 and a reduced requirement to decarbonise other sectors, notably the industry, buildings and heat sector, to meet an overall 80% CO_2 reduction target[22]. Progressively imposed CO_2 targets for the car, van and MGV sector towards zero emissions from 2040 results in a mix of vehicle powertrains utilising both hydrogen and electricity across these sectors. Battery electric cars, vans and MGVs are generally preferred but the increased electricity generation capacity required to support the deployment of these vehicles means more expensive hydrogen vehicles are also deployed, up to 30% of the fleet in some scenarios.

Increased decarbonisation in the transport sector, driven by forcing cars, vans and MGVs to be zero CO_2 emission from 2040 displaces part of the decarbonisation and electrification of the buildings and heat sector which is replaced with natural gas heating (Figure 12) and still meets the 80% 2050 constraint[22].

Deploying any of the three alternative HGVs would require an increase in electricity generation capacity for the electric and gas and electric PHEV HGV and an increase in hydrogen generation capacity for the hydrogen HGV. These requirements, along with the increased decarbonisation in the rest of the transport sector (cars, vans and MGVs), as a result of forcing those parts of the transport sector to $0gCO_2$/km, mean that none of the three alternative HGVs are desirable, even at the lowest available cost.

Figure 12
An example of the net CO_2 emissions evolution differences between the base case scenario and by progressively forcing cars, vans and MGVs to decarbonise.



[22] The recent move towards "Net Zero" for 2050 will drastically reduce this relaxation and mean that almost all sectors will have to decarbonise more deeply.

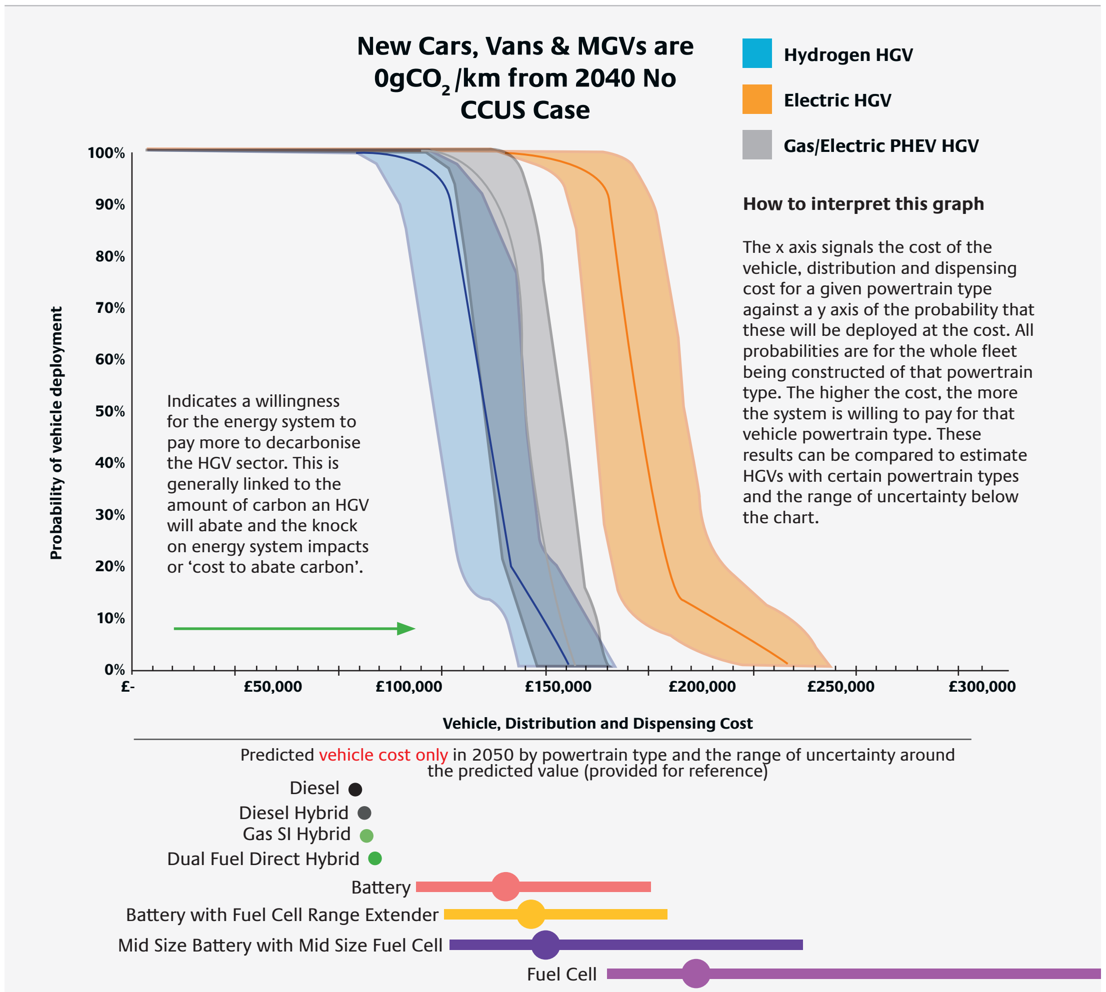
Scenario: Zero Emission Urban Transport No CCUS

In addition to progressively reducing the CO_2 limits for cars, vans and MGVs to be zero emission from 2040, the removal of CCUS technologies from the energy system means additional decarbonisation is required in transport and elsewhere. In this scenario, each of the three vehicle solutions is attractive, at similar cost to the base case but with a more binary probability of deployment (as shown by the vertical nature of Figure 13).

Removing CCUS requires hydrogen to be generated through electrolysis, which is a more inefficient pathway and consequently a less attractive pathway than the electric HGV. The gas and electric PHEV is also preferred to hydrogen for the same reason. Industry sector decarbonisation solutions are expensive without CCUS and as such industry decarbonises less than in the base case.

In each simulation when one of the three alternative HGVs (Hydrogen, Electric and Gas & Electric PHEV) is deployed, it is deployed preferentially to the baseline HGV and the overall energy system cost is reduced. In this Zero Emission Urban Transport (ZEUT) No CCUS scenario the saving for the hydrogen HGV is up to £5.2bn, for the electric HGV it is up to £13.8bn and for the gas & electric PHEV HGV it is £7bn. This cost is not all at the vehicle and can be apportioned in any way between the vehicle and its distribution and dispensing infrastructure.

Figure 13
Probability of vehicle deployment by vehicle powertrain type and associated distribution and dispensing infrastructure cost for new cars, vans & MGVs from 2040 No CCUS case.



Scenario: Reduced CO_2 Sensitivity Target

Increasing the overall GHG reduction target for the UK, from an 80% to a 90% reduction from 1990 levels by 2050, has significant impacts on all energy system sectors and the cost of deployment for each of the three alternative vehicles to meet the system GHG targets. CCUS is required to meet the reduced GHG target in this scenario and removing it results in the inability to meet the target in all instances (with the assumptions and constraints currently used in ESME).

With CCUS, road based transport needs to be close to fully decarbonised by 2050 in order to meet the target.

ESME selects each of the three alternative vehicles at costs up to the maximum value modelled, £600,000 for each of the zero CO_2 emission vehicles (fully electric and hydrogen), and up to £250,000 for the gas and electric PHEV. These costs are beyond the expected costs needed to produce and deploy these vehicles and infrastructure.

Direct Air Capture (DAC) of CO_2 is not currently available as a technology for ESME to select. DAC has the possibility to change the cost at which the HGVs are deployed and would likely have the largest effect in this reduced CO_2 scenario. It is also likely to change other aspects of the energy system.

Scenarios Discussion

In all the scenarios the comparative cost of the vehicle (and the supporting distribution and dispensing infrastructure) is the only factor determining whether it is selected. This cost includes operating expenditure and the cost of providing the generation capacity required. Between the scenarios however, there are large variations in the maximum vehicle and infrastructure cost at which there is certainty of deployment. Largely this cost is dictated by the constraints enforced in the scenarios and the resulting marginal carbon price of the energy system that is built. The additional cost of delivering each scenario compared to a no CO_2 target (which reflects a simple turnover of assets) is shown in Figure 14.

The Zero Emission Urban Transport scenario represents a practical and realistic way to decarbonise transport and follows the air quality improvement path that has already started with cars and vans. This progressive reduction of CO_2 emissions in the car, van and (within this scenario) MGV sectors is also imposed in the Reduced CO_2 Target scenario.

Progressive decarbonisation in the car, van and MGV sectors leads to similar average solutions in 2050 between the Zero Emission Urban Transport scenarios and the Reduced CO_2 Target scenario. In almost all instances throughout the Monte Carlo results there is no one powertrain solution for the car sector, with battery electric cars being favoured in many instances and hydrogen vehicles accounting for up to 30% of the fleet in some solutions.

Figure 14
The additional cost to abate carbon in each of the scenarios versus a scenario where there is no carbon target (simple turnover of assets). The perfect low cost route represents the base case which is elevated in cost to emphasise the barriers and practicalities of implementing energy system changes to a practical low cost route. All other scenarios are perfect optimisations based on cost under the technology constraints in that scenario and will also have practical cost increases.

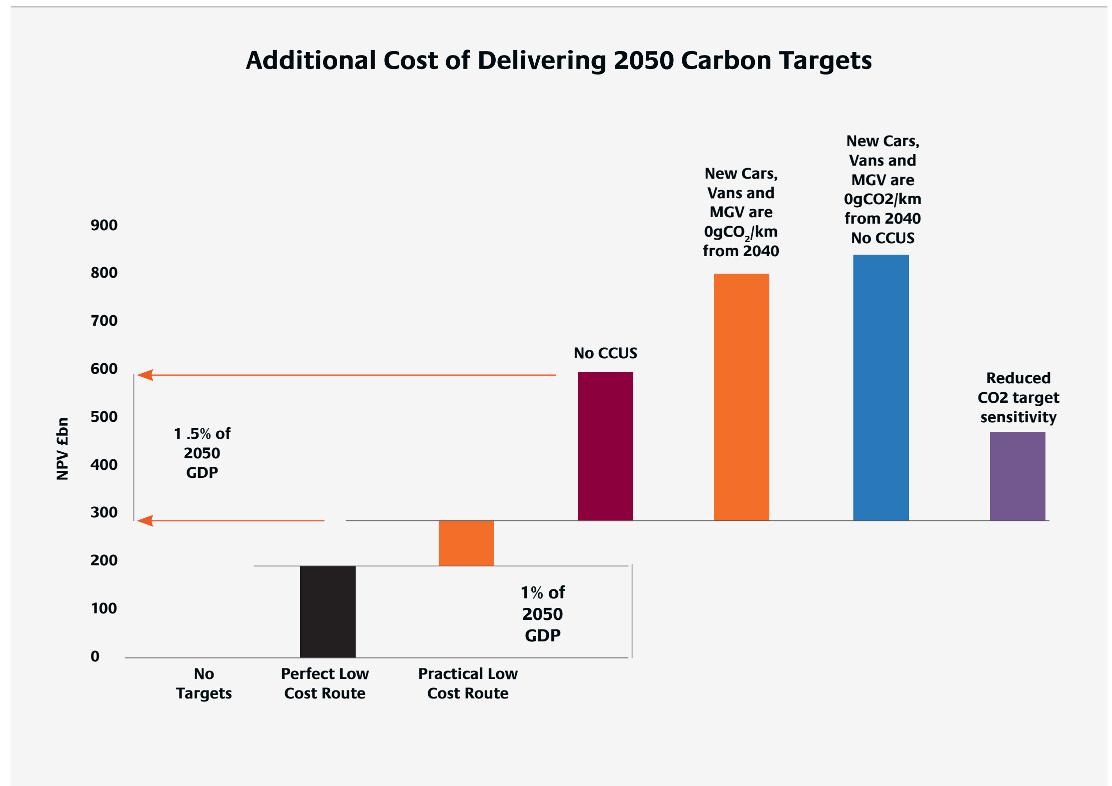


Figure 15
Difference in car parc powertrain selection and the effect of progressive decarbonisation between the Zero Emission Urban Transport Scenario and the Reduced CO_2 Scenario.

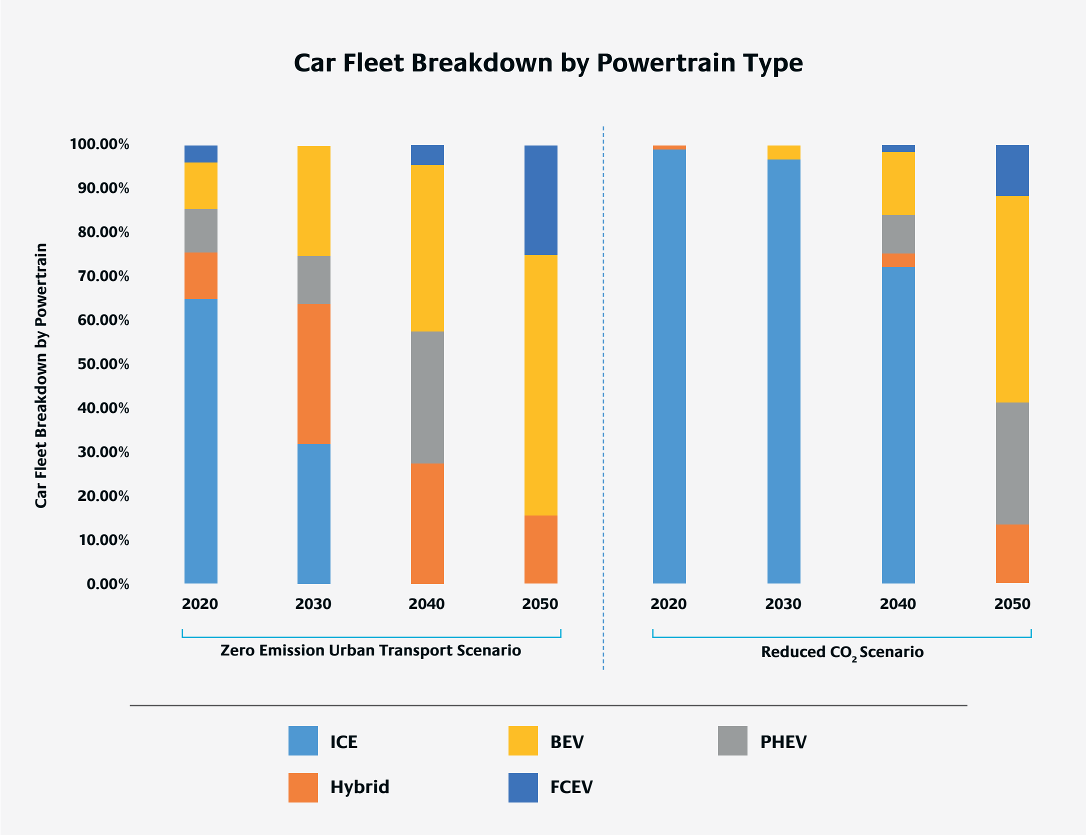
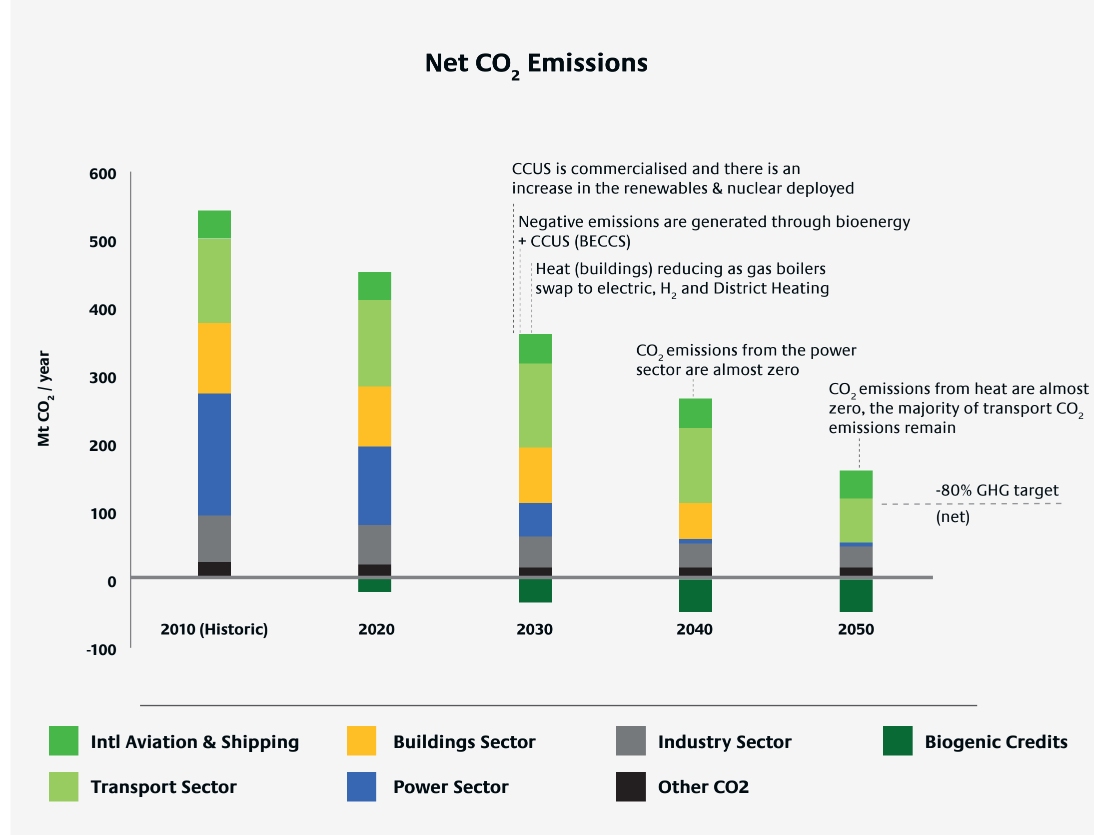


Figure 16
Path of least cost decarbonisation ESME takes to achieve the 80% CO_2 reduction target from 1990 levels by 2050.



The additional cost of delivering a system that achieves the CO_2 targets varies significantly between scenarios. Most striking is the additional cost of deploying Zero Emission Urban Transport from 2040. Solutions in the car, van and MGV sector are very similar in both Zero Emission Urban Transport cases and the reduced CO_2 target case. However, imposing a reducing CO_2 target for the car, van and MGV fleet concluding in only zero CO_2 emissions vehicles being permitted from 2040 onwards results in increased energy system costs up to 2050. Conversely the reduced CO_2 target scenario does not have a progressive target for these sectors, but rather an overall progressive CO_2 target which results in transport decarbonising last to meet the overall CO_2 target. The two Zero Emission Urban Transport cases reflect the reality of how the transport sector is likely to decarbonise. This also reflects the economic value of clean air and reducing emissions in urban areas.

In all instances where there is not a CO_2 target for parts of the transport sector, liquid fuels are still used in 2050. Although battery, fuel cell and hydrogen storage costs are expected to reduce they are still not currently projected to reduce to an equivalent cost of a conventionally fuelled vehicle[23].

The overall cost impact on the energy system of deploying the electric HGV is minimal. Additional peak electricity generation capacity is required, which is a product of the assumptions used for 'HGV charging'. However, this additional peak generation capacity, around 2.7GW, could be mitigated if 'charging' of the HGV fleet is managed.

Deploying the hydrogen HGV requires additional hydrogen generation capacity in all scenarios. CCUS is particularly important if hydrogen HGVs (and other hydrogen powered vehicles) are to be deployed. Without the deployment of CCUS production of hydrogen would be from electrolysis and significantly more expensive.

At the vehicle level, hydrogen HGVs (requiring 33TWh of hydrogen for the 44t HGV fleet) are more inefficient than electric HGVs (28TWh of electricity for the 44t HGV fleet). Providing hydrogen by electrolysis builds in additional inefficiencies at the generation system level. This efficiency difference is highlighted in the cost difference between the electric HGV and the hydrogen HGV in the No CCUS scenarios.

The importance of CCUS is particularly highlighted in the Reduced CO_2 scenario as removing CCUS results in an inability to meet the CO_2 reduction target.

Whenever CCUS is available, hydrogen generation through biomass gasification with CCUS is maximised and is preferentially used in industrial applications. Additional hydrogen generation capacity is required to support any additional deployment of technology which uses hydrogen – this includes hydrogen vehicle deployment.

The ETI Consumers, Vehicles and Energy Integration (CVEI) project linked distribution models with ESME

[23] The ETI has published a database of projected cost evolutions for battery and hydrogen powertrains for heavy duty vehicles and projected cost and performance characteristic for light duty vehicles on the ETI website (Knowledge Zone).

to assess how the energy distribution networks for transport would integrate with consumers and the energy system. The results from the first phase of this project showed that the potential for a transmission-only pipeline network for hydrogen (supported by local tanker distribution from the transmission network points into urban areas) should be assessed, as this could be commercially viable in the long-term – if the cost can be shared effectively with other sectors using hydrogen (such as the power or industry sectors)[24]. If hydrogen use does not propagate through transport and other energy system sectors (such as buildings and heat), the distribution of hydrogen would be most cost effective by tanker for the HGV sector.

The natural gas and electric PHEV HGV are selected in many scenarios as a viable option, at a lower cost to the zero emission options. Generally, this is aligned with the reduced GHG abatement of PHEV HGV versus a fully zero emission HGV. The impact of the gas and electric PHEV on the electricity generation system are minimal and a significant step below the fully electric HGV. The additional electricity generation capacity required to support the deployment of the gas and electric PHEV could be mitigated by managed charging.

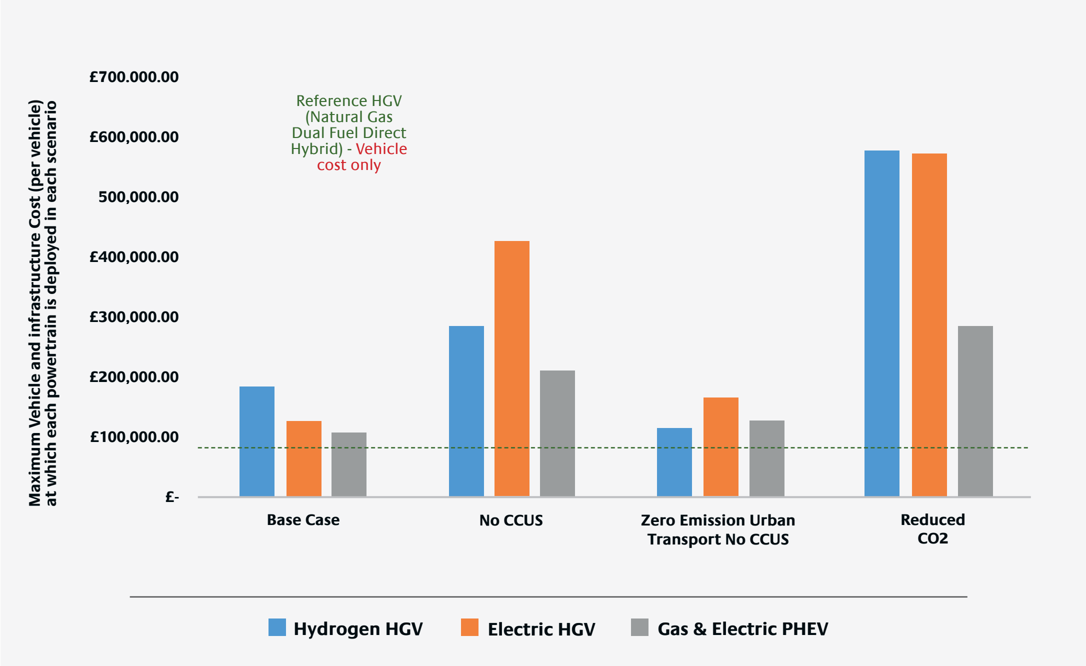
The PHEV HGV architecture is an attractive option and the PHEV HGV could act as a “bridging vehicle” between a conventional diesel HGV of today and a fully zero CO_2 tailpipe emission option. Zero CO_2 tailpipe emission miles could be increased as the cost of hydrogen / electric powertrains and infrastructures reduces.

The maximum acceptable cost of each HGV type and their supporting infrastructure can be compared to the natural gas dual fuel direct hybrid HGV. Figure 17 brings together the additional decarbonisation costs for the whole fleet, which is shown at the end of each scenario, normalised to an individual HGV to provide a comparison between the scenarios at the vehicle level.

[24] ETI CVEI Project – Deliverable 1.3. Publicly available on the ETI Knowledge Zone.

Part electrification of the HGV and MGV sector introduced from 2025 would be a good long term decision.

Figure 17
Cost comparisons between the tested scenarios of when vehicles stopped being deployed.



The selection of scenarios brings in the effects of policy measures and factors such as noxious and particulate matter emissions. One policy measure not explicitly accounted for is the HGV legislation limiting CO_2 emission for new HGVs in 2025 and 2030 at 15% and 30% (respectively) lower than 2019 levels.

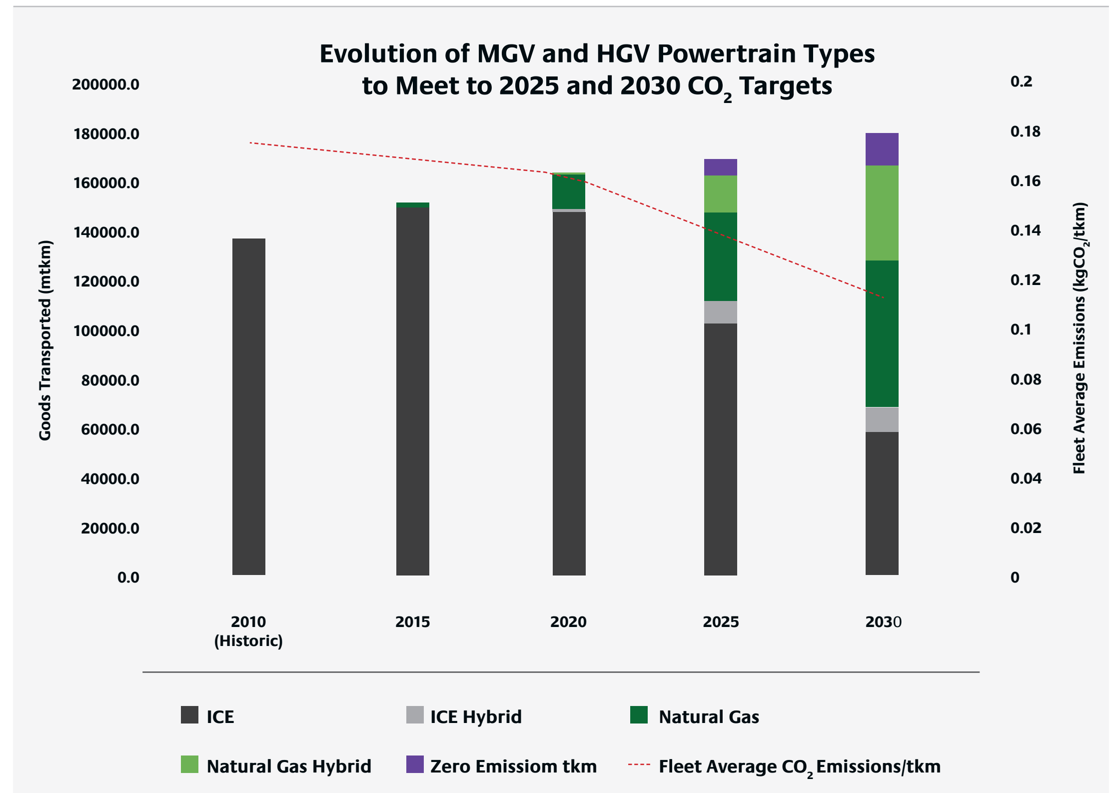
In the short term (up to 2030), the combination of improving urban roadside air quality and reducing overall CO_2 in the HGV sector is likely to result in a mix of solutions. Freight efficiency is fixed in EU legislation (defined payloads for certification), therefore improvements in vehicle efficiency extending to mild hybridisation are required - but this will not be enough to meet the EU CO_2 target in 2030. With relatively small penetrations (<10%) of natural gas, dual fuel hybrid HGVs and dedicated natural gas hybrid HGVs over the next couple of years, the increased demand for the movement of goods is likely to increase overall CO_2 emitted from the HGV sector, even if significant improvement in freight efficiency are made. A larger penetration (≈50%) of natural gas vehicles to 2030 could help contribute to a reduction in CO_2 emissions, especially if this is in all of the heavier categories of on-highway vehicles (3 and 4 axle Rigid HGVs and all Articulated HGVs). Early deployment of zero CO_2 tailpipe emission capable HGVs and MGVs (PHEV or full zero CO_2 tailpipe emission) is likely to be required for OEMs to meet their individual prescribed fleet CO_2 targets set by the EU (Figure 17).

New infrastructure is required to enable zero CO_2 tailpipe emission miles to be fulfilled. Zero emission miles can be fulfilled with either PHEVs or with zero CO_2 tailpipe vehicles. Policy measures could force urban delivery vehicles to have zero CO_2 tailpipe emission operation in urban areas, through enforcement of tighter air quality emission targets. Larger vehicles could then remain relatively similar to those of today, with modest reductions in CO_2 emissions through hybridisation and changes in the energy vector to natural gas. Emission control areas within urban environments are likely to be much less impactful on vehicle powertrain selection on the UK freight fleet in the short-term, due to their proposed introduction dates, than the fleet CO_2 constraint imposed across the EU. However, for some businesses and operators, urban delivery vehicles represent a sector which is relatively conducive to be a first adopter of zero CO_2 commercial vehicles.

The early penetration of vehicles capable of delivering zero CO_2 tailpipe emission miles to meet the 2030 30% reduction in CO_2 target is likely to be an early indicator of the powertrain solutions suited to each category of vehicle. Part electrification of the HGV and MGV sector introduced from 2025 is likely to be a good long term decision. Introducing plug-in hybrids could serve several purposes:

- Progressively introducing customers to alternative powertrains while maintaining the current powertrain.
- Developing infrastructure to support this near and long term electric HGV deployment.
- Provide a market for OEMs to develop long term electric powertrain solutions with reduced risk.

Figure 18
How the UK fleet could meet the 2025 and 2030 CO_2 targets for new vehicles sold from 2019 vehicle sales CO_2 emissions across the on-highway freight sector in the UK by powertrain and CO_2 emissions.



CONCLUSION

The requirement to decarbonise the UK energy system to achieve or exceed the 80% GHG reduction targets requires all energy system sectors to decarbonise at an expense which is much more than a simple turnover of assets - effectively incurring a 'cost' to reduce CO_2 emissions.

Any low or zero CO_2 tailpipe emission HGVs and supporting infrastructure, offering decarbonisation beyond a business as usual approach, contributes towards overall decarbonisation of the energy system.

It is clear that the maximum cost at which low or zero carbon HGVs are viable in a future carbon constrained UK energy system is higher cost than one which is currently acceptable by OEMs and fleet operators. Putting aside what may be currently market acceptable, these maximum costs are within the bounds of what the ETI believes is technologically achievable.

Based on current technology cost predictions, the use of hydrogen in HGVs is predicated on the deployment of CCUS. Without CCUS hydrogen, volumes will be too low and costs too high. Production would instead need to be through electrolysis, and the limited hydrogen available would be better prioritised in other sectors of the energy system.

One other hydrogen production pathway, which hasn't been explored in this work, would be through imports. However, as with biomass, the quantity of hydrogen available through international competition cannot be relied upon and is difficult to quantify.

Deploying any of the three HGV options (Hydrogen, Electric, Gas And Electric PHEV) has little overall impact on the high-level energy system in 2050 – assuming the target is an 80% reduction in emissions on 1990 levels.

There are several vehicle and infrastructure options available for electric HGVs which could have localised impacts on the energy system. Charging or electricity demand load profiles are the dominating factor, which, if they aren't managed, could add to the required peak electricity generation capacity.

Local infrastructure issues are likely to be the constraint and should be investigated in any further work.

Each of the Zero Emission Urban Transport scenarios investigated represent conditions which are realistic, based on the current legislation and ambition of the UK government. In addition, the reduced CO_2 scenario is a proxy for reducing carbon targets beyond 2050 but also for increasing the overall 2050 CO_2 reduction target towards net zero.

Proposed legislation in the HGV sector is expected to encourage the deployment of vehicles capable of delivering zero CO_2 emission miles. In the medium term (2030) these are expected to be purchased in small numbers and are not mass market ready.

Deploying electrification solutions in the car sector will drive a reduction in technology costs. HGVs today share very few components with the car sector, but electrification could change this and provide economies of scale to the HGV sector which have not been able to be leveraged previously. Individual technology solutions for vehicle and infrastructure are likely to have significant impact at a local level depending on the overall solution(s) that are implemented. This is especially the case with electric solutions which would need to be assessed to test the impact on the system in finer detail and at the local level.

Customer requirements need to be met in all instances when evaluating potential zero CO_2 emission solutions. Customer needs may be such that infrastructure is required to deploy both electricity and hydrogen HGVs to cope with duty cycle specific powertrain vehicles. Electrifying vehicle powertrains may mean OEMs can increase their product offering to consumers, enabling them to better tailor their energy storage and power usage.

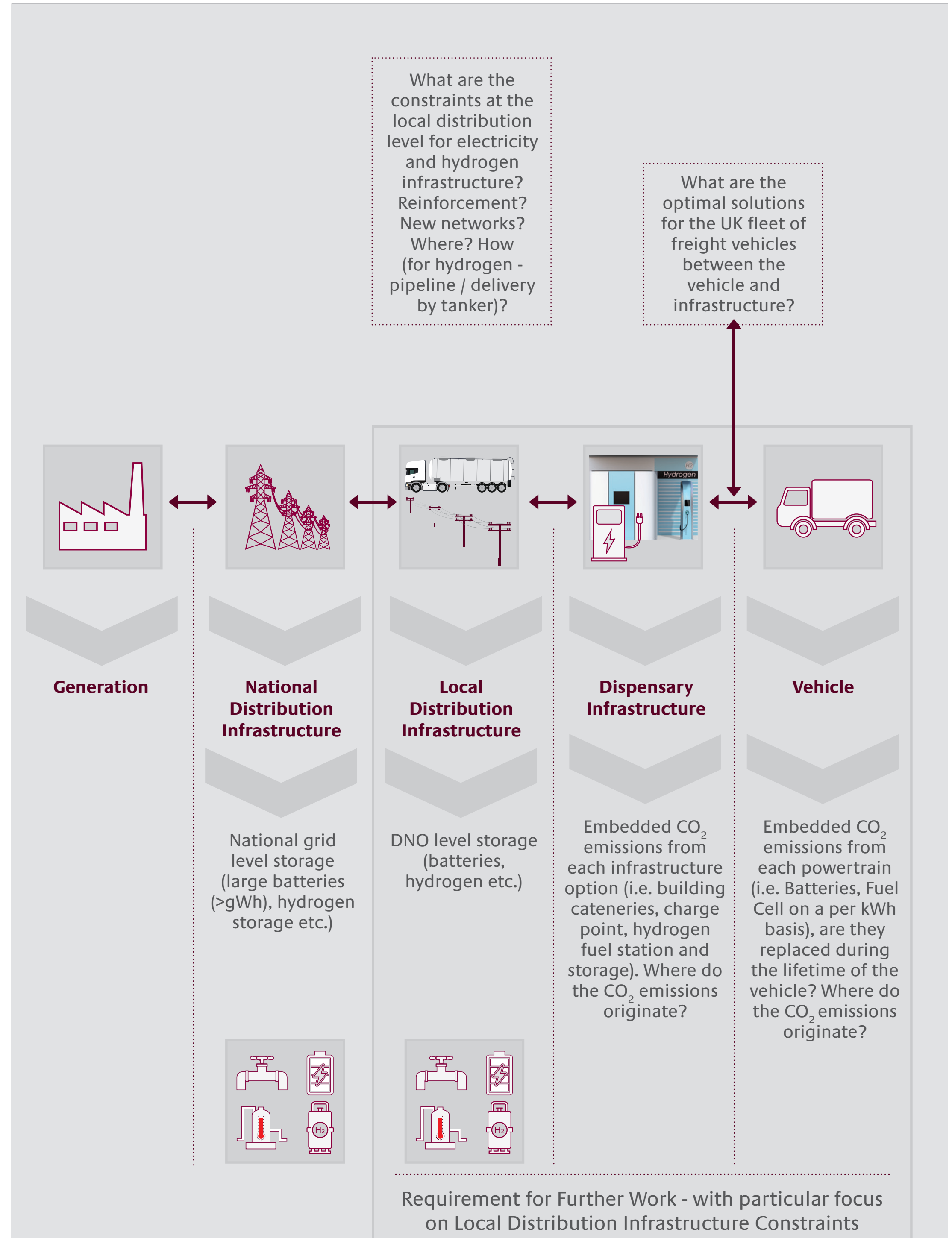
The increased flexibility of OEMs to modularise components to tailor vehicle builds for customers may lead to the market developing both hydrogen and battery powertrains, which in turn would lead to much more variation in vehicles than today.

Continuing to reduce the cost of zero tailpipe CO_2 emission HGV powertrain technologies is required, in keeping with the ETI's ESME estimates. The energy system value of zero CO_2 tailpipe emission HGVs is such that they can cost significantly more than conventionally fuelled HGVs and still be attractive.

Recommendations for Further Work

Remaining agnostic over the vehicle and infrastructure solution allowed the high level impact of deploying hydrogen or electric HGVs on the energy system to be tested, which was shown to be minimal. Given the marginal preference for electric or hydrogen depending on the scenario, the differentiating factor is likely to be down to the practicalities of the distribution and dispensing systems.

Figure 19
Graphic of questions raised from this work which require further in depth analysis.



GLOSSARY

BAU Business as Usual

BECCS Bioenergy with Carbon Capture and Storage

BEV Battery Electric Vehicle

BVCM Bioenergy Value Chain Model

CAPEX Capital Expenditure

CCC Committee on Climate Change

CCUS Carbon Capture, Utilisation and Storage

CVEI Consumers, Vehicles and Energy Integration

DEFRA Department for Environment Food & Rural Affairs

DFT Department for Transport

ETI Energy Technologies Institute

EU European Union

FCEV Hydrogen Fuel Cell Electric Vehicle

GVW Gross Vehicle Weight

HDV Heavy Duty Vehicle

HGV Heavy Goods Vehicle

MC Monte Carlo

MGV Medium Goods Vehicle

NOx Nitrogen Oxides

OEM Original Equipment Manufacturer

OPEX Operational Expenditure

PHEV Plug-in Hybrid Electric Vehicle

PM Particulate Matter (PM2.5 and PM10)

SMR Steam Methane Reforming

TCO Total Cost of Ownership

VED Vehicle Excise Duty

WHO World Health Organisation

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