Energy Innovation Needs Assessment

Sub-theme report: Road transport

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Lead:

vivideconomics
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Partners:

CARBON TRUST
E4tech Strategy | Energy | Sustainability
Imperial College London
FRAZER-NASH CONSULTANCY

Modelling support by:

CATAPULT Energy Systems

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The views expressed in this report are the authors' and do not necessarily reflect those of the Department for Business, Energy and Industrial Strategy.

Acronyms and abbreviations

Table 1. **Key acronyms and abbreviations**

Acronym/abbreviation	Definition
APC	Advanced Propulsion Centre
BCG	Boston Consulting Group
BEIS	Department for Business, Energy and Industrial Strategy
BEV	Battery Electric Vehicle
bhp	British horse power
BNEF	Bloomberg New Energy Finance
CAV	Connected Autonomous Vehicle
CapEx	Capital Expenditure
CCC	Climate Change Committee
CNG	Compressed Natural Gas
CO_2	Carbon Dioxide
DfT	Department for Transport
DOE	Department of Energy
DUKES	Digest of UK Energy Statistics
ECU	Electronic Control Unit
EINA	Energy Innovation Needs Assessment
EPCm	Engineering, Procurement, and Construction Management
ESC	Energy System Catapult
ESME	Energy System Modelling Environment
ETI	Energy Technology Institute

EU	European Union
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
GaN	Gallium Nitride
GHG	Greenhouse Gas
GLA	Greater London Authority
GVA	Gross Value Added
H_2	Hydrogen
HCCI	Homogenous Charge Compressed Ignition
HDV	Heavy Duty Vehicle
HEV	Hybrid Electric Vehicle
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
IEA	International Energy Agency
IoT	Internet of Things
IP	Intellectual Property
JLR	Jaguar Land Rover
KERS	Kinetic Energy Recovery System
LDV	Light Duty Vehicle
LOHC	Liquid Organic Hydrogen Carrier
MaaS	Mobility as a Service
MDV	Medium Duty Vehicle
MEA	Membrane Electrode Assembly

mpg	Miles per gallon
Mtoe	Million tonnes of oil equivalent
O&M	Operation & Maintenance
OEM	Original Equipment Manufacturer
OLEV	Office for Low Emission Vehicles
OPEX	Operational Expenditure
PHEV	Plug-in Hybrid Electric Vehicle
PPCI	Partially Premixed Compressed Ignition
PV	Photovoltaics
R&D	Research & Development
RD&D	Research, Development, & Demonstration
RDE	Real Driving Emissions
SAE	Society of Automotive Engineers
SiC	Silicon Carbide
TCO	Total Cost of Ownership
V2G	Vehicle to Grid

Glossary

Table 2. **Key terms used throughout this report**

Term	Definition
Learning by doing	Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards which tend to increase in direct proportion to capacity increases.
Learning by research, development, and demonstration	Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D); increases with spend in RD&D and tends to precede growth in capacity.
Sub-theme (relevant level for optional EINA reports)	Groups of technology families which perform similar services which allow users to, at least partially, substitute between the technologies. For example, a variety of technology families (heat pumps, district heating, hydrogen heating) have overlapping abilities to provide low-carbon thermal regulation services and can provide flexibility to the power system.
System value and Innovation value	Estimates of change in total system cost (measured in £ GBP, and reported in this document as cumulative to 2050, discounted at 3.5%) as a result of cost reduction and performance improvements in selected technologies. This is the key output of the EINAs and the parameter by which improvements in different technologies are compared. System benefits result from increasing deployment of a technology which helps the energy system deliver energy services more efficiently while meeting greenhouse gas (GHG) targets. Energy system modelling is a vital tool in order to balance the variety of interactions determining the total system costs. Innovation value is the component of system value that results from research and development (rather than from 'learning by doing')
Technology family	The level at which technologies have sufficiently similar innovation characteristics. For example, heat pumps are a technology family, as air-source, ground-source and water-source heat pumps all involve similar technological components (compressors and refrigerants). Electric vehicles (EV) are also a technology family, given that the battery is a common component across plug-in hybrids and battery electric vehicles (BEVs).
Gross Value Add	Gross Value Add (GVA) measures the generated value of an activity in an industry. It is equal to the difference between the value of the outputs and the cost of intermediate inputs.

Introduction

Box 1. **Background to the Energy Innovation Needs Assessment**

The Energy Innovation Needs Assessment (EINA) aims to identify the key innovation needs across the UK's energy system, to inform the prioritisation of public sector investment in low-carbon innovation. Using an analytical methodology developed by the Department for Business, Energy & Industrial Strategy (BEIS), the EINA takes a system-level approach, and values innovations in a technology in terms of the system-level benefits a technology innovation provides.[1] This whole system modelling in line with BEIS's EINA methodology was delivered by the Energy Systems Catapult (ESC) using the Energy System Modelling Environment (ESME^{TM}) as the primary modelling tool.

To support the overall prioritisation of innovation activity, the EINA process analyses key technologies in more detail. These technologies are grouped together into sub-themes, according to the primary role they fulfil in the energy system. For key technologies within a sub-theme, innovations and business opportunities are identified. The main findings, at the technology level, are summarised in sub-theme reports. An overview report will combine the findings from each sub-theme to provide a broad system-level perspective and prioritisation.

This EINA analysis is based on a combination of desk research by a consortium of economic and engineering consultants, and stakeholder engagement. The prioritisation of innovation and business opportunities presented is informed by a workshop organised for each sub-theme, assembling key stakeholders from the academic community, industry, and government.

This report was commissioned prior to advice being received from the CCC on meeting a net zero target and reflects priorities to meet the previous 80% target in 2050. The newly legislated net zero target is not expected to change the set of innovation priorities, rather it will make them all more valuable overall. Further work is required to assess detailed implications.

The road transport sub-theme report

The road transport sub-theme focusses on innovation opportunities that can reduce the energy consumption of light, medium and heavy-duty vehicles. The sub-theme was divided into seven technology families which are described below.

Light duty BEV (LDV BEV): vehicle with gross weight less than 3,500 kg, and using chemical energy stored in a battery for propulsion. This technology family also includes plug-in hybrid electric vehicles (PHEVs) where the engine and battery together provide propulsion energy.

Heavy duty BEV (HDV BEV): vehicle with gross weight exceeding 3,500 kg, and using chemical energy stored in a battery for propulsion. Note that for simplicity this category includes medium (MDV) and heavy-duty vehicles, though differences are drawn out where appropriate.

Heavy duty dual fuel vehicles: vehicle with gross weight exceeding 3,500 kg, with an engine capable of running on two different fuels e.g. diesel and natural gas. The two fuels are mixed and combusted in the same engine, but they are stored in separate tanks.

Heavy Duty Fuel Cell Electric Vehicle (HDV FCEV): vehicle with gross weight exceeding 3,500 kg, using a fuel cell (in combination with an electric battery) to power an electric motor for propulsion.

Connected Autonomous Vehicles (CAVs): vehicles which require no, or limited, driver input for control of steering, acceleration, or braking. These vehicles are designed such that the driver is not required, or only occasionally required, to monitor the road. This category encompasses the Society of Automotive Engineers (SAE)'s automation levels from 2 to 5.

Smart logistics: improvements to the transportation and storage of goods enabled via digital technologies such as the internet of things (IoT) and big data.

Mode shifting / Demand reduction: reducing the net demand for a given mode of transport either by displacement to another transport mode (mode shifting) or by elimination of that demand altogether.

The selection of these technology families was based on a combination of quantitative and qualitative criteria. The following road transport technologies were excluded:

HDV conventional internal combustion engines (ICEs): ESME simulations did not highlight high-innovation potential in this technology family. Innovations in ICEs are nevertheless captured in dual fuel vehicles. The expert group workshop felt strongly that there is innovation potential which could have a strong bearing upon energy consumption, especially in the near-to-medium term.

[1] The system-level value of a technology innovation is defined in the EINA methodology as the reduction in energy system transition cost that arises from the inclusion of an innovation compared to the energy system transition cost without that innovation.

LDV FCEVs: ESME simulations did not highlight high-innovation potential in this technology family as LDV FCEVs showed lower uptake relative to LDV BEVs in modelling. Some innovations in FCEVs are nevertheless relevant and these are like those applicable in HDV FCEVs, which are included.

It is important to consider that some technology families treated in this sub-theme cut across other sub-themes:

- FCEVs cut across Hydrogen and Fuel Cells, which includes innovations in hydrogen production, distribution and storage
- Smart logistics and mode shifting cuts across Smart Systems

Although these two technology families have been included in this sub-theme it is important to be aware of their interconnection with other sectors.

The report has four sections:

- **Road transport and the energy system:** Describes the role of road transport in the energy system, the current state, future scenarios, and benefits and challenges of road transport from a system perspective.
- **Innovation opportunities:** Provides lists of the key innovations available within road transport, and their approximate impact on costs.
- **Business opportunities:** Summarises the export opportunities of road transport, the GVA and jobs supported by these opportunities, and how innovation helps the UK to capture these opportunities.
- **Market barriers to innovation:** Highlights areas of innovation where market barriers are high and energy system cost reductions and business opportunities are significant.

Key findings

Innovation areas in road transport

The main innovations for the road transport sector are identified below. The list is not a substitute for a detailed cost reduction study. Rather, it is a guide for policymakers on key areas to be considered in any future innovation programme design.

The innovation priorities below select individual or groups of the top scoring innovations. Table 3 maps the top scoring innovations to individual technology components, and Tables 10 to 16 set out the full list of innovations.

Battery electric vehicles

Battery electric vehicles (BEVs) are expected to become more widespread, especially in the private car market. The battery is a significant cost component of these vehicles; therefore, innovations targeting this component are especially important.

- **Innovative battery designs and processes to reduce battery-embodied impacts**. Significant cost reduction and higher sustainability could be achieved by improvements throughout the battery life cycle, especially in the manufacturing and end-of-life stages.
- **Higher energy and power density of electric batteries, especially for medium and heavy-duty vehicles**. In the near-term this could be achieved through improving existing lithium-ion chemistry. In the longer-term novel battery chemistries could replace lithium-ion, providing further scope for cost reduction and performance improvements.

Dual fuel vehicles

Dual fuel vehicles could play an important role in the decarbonisation of the heavy-duty segment. In view of the uncertainty of zero emission technologies for HDVs, it is important to maintain options related to internal combustion engines, potentially beyond the short-to-medium term. The key innovations in this area address improvements in fuel economy and emissions.

- **Mild hybridisation of medium/heavy duty dual fuel vehicles, and improvement of medium/heavy duty ICE efficiency**. Mild hybridisation (e.g. 48V system, braking energy recovery) is particularly effective in reducing both high emissions and fuel consumption of ICE vehicles performing frequent stop/start duties. Novel engine architectures may provide larger efficiency gains, though these are currently in their infancy.

- **Innovation in exhaust gas after-treatment systems of dual fuel vehicles, and for ICE emissions in general.** Further component integration is required in the after-treatment system to improve both energy and pollutant abatement efficiency across the wide spectrum of engine operating conditions.

Fuel cell electric vehicles

The use of fuel cells is also gaining interest as an option to reduce emissions from heavy duty vehicles. They offer similar driving ranges to conventional diesel vehicles, but innovation is required to reduce FCEV cost. Innovation is required to reduce the cost of the fuel cell stack and hydrogen tank, given that these components are significant contributors to total cost of ownership (TCO).

- **Advanced and automated techniques for fuel cell manufacturing**. High-volume production methods, with a high degree of automation, could enable significant capital cost reduction for FCEVs. Fuel cells could play an increasingly important role in the decarbonisation of medium and heavy-duty vehicles, given the relatively high energy to weight ratio of hydrogen in comparison with batteries.

Connected and autonomous vehicles

CAVs could be a game changer for mobility, bringing a broad range of benefits spanning from CO_2 and pollutant emissions reduction to increased productivity. However, this technology is still in its infancy.

- **The priority for progress on CAVs is building a safety case around the technology**. Innovative validation and testing technologies and procedures are key to prove safety standards and are expected to drive down CAV capital cost. However, the UK needs to identify where it is best placed to succeed in CAV technology, before deciding in which areas to prioritise innovation.

Business opportunities for the UK

There are significant business opportunities associated with exports of low-carbon vehicles and components. In a scenario where the UK captures a larger market share in low-carbon vehicles than it currently does in ICE vehicles, exports directly related to low-carbon vehicles and the low-carbon powertrain could directly support 73,000 jobs and £11 billion GVA per annum by 2050. It is important to note that the automotive supply chain is complex, and this estimate does not include ‘indirect’ jobs supported. For example, jobs supported by parts which are common between low emissions vehicles and ICE vehicles are not included. In the business opportunities section below, GVA and jobs results are set out by component (Table 17).

- **Exports of light duty BEVs are the largest business opportunity, with CAV packages a potentially large emerging opportunity.** In 2050, exports of assembled LDV BEVs, the battery pack, and the rest of the powertrain could contribute £5.6 billion in GVA and 38,000 jobs per annum to the UK. Reflecting the current industry, LDV opportunities are likely three times as large as opportunities in low-carbon buses and trucks. CAV exports are a new and growing export opportunity and could contribute £4.3 billion in GVA and 24,000 jobs per annum by 2050 (including both CAV sensor manufacture and associated software). Smaller opportunities for the UK may be found in vehicle fuel cells, especially the export of expert design and advisory services and intellectual property (IP) associated with membrane electrode assembly (MEA).

- **Export opportunities are significantly larger than domestic business opportunities, which contribute £3.3 billion in GVA and support around 22,000 per annum by 2050.** This is driven by the highly traded nature of the sector, and the comparative sizes of the European and UK markets. Consequently, most vehicles produced in the UK are exported.

- **A large proportion of supported jobs are likely to transition from ICE vehicle assembly into EV assembly.** The UK's current automotive industry directly supports 186,000 jobs, the majority of which are in assembly.[2] As the UK industry moves towards low-carbon vehicle production, a large proportion of existing ICE vehicle assembly jobs will likely transition to low-carbon vehicle (particularly EV) jobs. That is, the approximately 95,000 supported jobs will not all be additional. Note, the EINA jobs estimate also does *not* imply the UK automotive sector will support fewer jobs in future than it does now, as set out in Box 7 in the business opportunities section.

- **The business opportunity for the UK is relatively uncertain.** Although European targets are increasingly setting sales-based CO_2 targets, substantial uncertainty remains over the future size of the low-carbon vehicle market, particularly, for buses and trucks. According to our analysis, low-carbon vehicle sales could be between 35 and 140 million per annum in 2050.[3] Furthermore, the share of key export markets the UK can capture is highly dependent on a small number of (large) investment decisions by original equipment manufacturers (OEMs). These decisions are driven by a combination of factors inducing marginal differences in the UK's relative attractiveness for automotive production. However,

[2] SMMT (2018). *Motor Industry Factors 2018.* Available from: https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Motor-Industry-Facts-June-2018.pdf

[3] Based on International Energy Agency (IEA) ETP vehicle stock predictions. This includes low-carbon cars, trucks, and buses.

they have a large impact on the UK’s productive capacity and hence the market share it might capture.

Market barriers to innovation in the UK

Opportunities for HMG support exist when market barriers are significant and cannot be overcome by the private sector or international partners. Most market barriers for road transport are moderate, due to the advanced level of maturity in the sector. In the market barriers section below, the barriers are set out by component where possible (Table 18). Industry identified the severe barriers to innovation as:

- High upfront costs and uncertainty in future demand make it difficult to justify investment in innovation to achieve economies of scale. The required investments focus on infrastructure and innovation for the manufacturing process and supply chain integration.
- The high cost and technical risk of innovation for novel vehicles incentivise a ‘wait and see’ approach, stalling innovation.

Key findings by component

Government support is justified when system benefits and business opportunities are high, but market barriers prevent innovation.

Table 3. **Cost and performance of road transport (see key to colouring below)**

Overall statistics for road transport: 2050 system value, including fuel cells = £190.4 bn (range: £89.6-218.8 bn), 2050 export opportunity (GVA) = £11bn, 2050 potential direct jobs supported by exports = 73,000				
Component	**Example innovation**	**Business opportunity**	**Market barriers**	**Strategic assessment**
Light duty BEV	Improved design and processes for battery reuse and recycling	High	Moderate	Significant cost reduction and higher sustainability standards can be achieved by improvements in the battery life cycle, especially in the manufacturing and end-of-life stages. The business opportunity from export is expected to be very large, although to a large degree supported jobs will transition from current ICE vehicle assembly. Without government intervention, innovation will likely occur at a lower scale and speed.
Medium and heavy-duty BEV	Higher battery energy density	High	Severe	Developing higher energy and power density of electric batteries, especially for larger vehicles, is a key priority. In the near-term, this could be achieved through improving existing lithium-ion chemistry, while longer term, moving to new battery chemistries could result in further cost reduction and performance improvements. It is unclear which of the heavy-duty powertrain technologies will represent the largest export opportunity, but all are expected to be large. Without government intervention, innovation, investment, and deployment would likely be significantly constrained.
Medium and heavy-duty dual fuel vehicles	Mild hybridisation (e.g. 48V system, braking energy recovery)	High	Moderate	Mild hybridisation is particularly effective in reducing both high emissions and fuel consumption of medium and heavy-duty dual fuel and ICE vehicles. It is unclear which of the heavy-duty powertrain technologies will represent the largest export opportunity, but all are expected to be large. Without government intervention, innovation will likely occur at a lower scale and speed.
Medium and heavy-duty FCEVs	Advanced manufacturing processes	High	Severe	High-volume production methods, with a high degree of automation, could enable significant capital cost reduction for FCEVs. Fuel cells could play an increasingly important role in the decarbonisation of heavy-duty vehicles, given the relatively high energy to weight ratio of hydrogen in comparison with alternatives such as batteries. Despite this advantage, it is unclear which of the heavy-duty powertrain technologies will represent the largest export opportunity, but all are expected to be large. It should also be noted that the UK has expertise in this area, particularly in the manufacture of fuel cell buses. Without government intervention, innovation, investment, and deployment would likely be significantly constrained.

Component	Example innovation	Business opportunity	Market barriers	Strategic assessment
Connected and autonomous vehicles	Novel validation and testing methods	High	Severe	The priority for progress on CAVs is building a safety case around the technology. Novel validation and testing methods can support the achievement of safety standards and capital cost reduction. Given UK strength in software, CAV packages represent a potentially large opportunity for the UK. The UK needs to identify where it is best placed to succeed in CAV technology, before deciding in which areas to prioritise innovation. Without government intervention, innovation, investment, and deployment would likely be significantly constrained.
Smart logistics	More efficient auxiliary equipment	Not quantified	Moderate	For Smart Logistics, it is questionable whether government intervention is needed, as innovation in this space is already taking place through private companies (e.g. supermarkets). Without government intervention, innovation will occur at a lower scale and speed.
Mode shifting / demand reduction	Enhanced real-time information enabling better journey planning	Not quantified	Moderate	For Mode Shifting (e.g. to rail) to occur, innovation is not seen as a priority for enabling this, with the view that this is more a matter of policy and regulatory choices than technology. Without government intervention, innovation will occur at a lower scale and speed.

Source: Vivid Economics, E4tech

Note: The main innovations per component are the innovations that score highest in the innovation inventory. This table only includes component-specific market barriers. Cross-cutting barriers are included in the market barriers section below. We only include export markets in this assessment because it is more directly linked to additional benefits to the UK economy. However, an assessment of the domestic market is included in the report below.

Table 4. **Key to colouring in the key findings per component**

Business opportunities	Market barriers
High: more than £1 billion annual GVA from exports by 2050	**Critical:** Without government intervention, innovation, investment and deployment will not occur in the UK.
Medium-High: £600-£1,000 million annual GVA from exports by 2050	**Severe:** Without government intervention, innovation, investment and deployment are significantly constrained and will only occur in certain market segments / have to be adjusted for the UK market.
Medium-Low: £200-£600 million annual GVA from exports by 2050	**Moderate**: Without government intervention, innovation, investment and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
Low: £0-200 million annual GVA from exports by 2050	**Low:** Without government intervention, innovation, investment and deployment will continue at the same levels, driven by a well-functioning industry and international partners.

Source: Vivid Economics, E4tech

Box 2. **Industry workshop**

A full-day workshop was held on 7th March 2019 with key delegates from the government and relevant government-industry bodies (see Appendix 1). Key aspects of the EINA analysis were scrutinised, including innovation opportunity assessment, and business and policy opportunities assessment. New views and evidence were suggested; these have been incorporated into an update of the assessments. The views of the attendees were included in the innovation's assessment.

In addition, several contextual issues were raised at the workshop:

- In the short term, slow fleet turnover means that new vehicle solutions deliver (CO_2) reductions slower than use of low-carbon fuels and technology retrofits that apply to existing vehicles. However, in the long-term new vehicles are expected to deliver higher carbon reductions.

- The UK automotive industry is – to a large extent – part of a global industry, so key strategic decisions may be taken by players far from the UK.

- Network effects (e.g. fuelling infrastructure) and high economies of scale for vehicle technology mean that investing in multiple technologies in parallel (batteries, hydrogen, and low-carbon liquid fuels) could be less efficient than a single technology approach.

- Innovation in ICE HDVs should not be ruled out, as there is a large potential for efficiency improvements which are particularly relevant in the short and medium term, and potentially longer.

These overarching messages, while not fitting within the limited scope of the EINA framework, are important for consideration in setting innovation policy.

Transport and the whole energy system

Current situation

The UK's largest final energy use is in the transport sector.[4] In 2017, transport was responsible for 56 million tonnes of oil equivalent (Mtoe) out of the country's total energy consumption of 149 Mtoe (including aviation).[5] This amounts to an almost 1% yearly increase from 2016 primarily driven by air transport growth. The flows of energy in the UK energy system.

In addition to being the largest final energy consumer, transport is the largest Greenhouse Gas (GHG)-emitting sector in the UK, accounting for 28% of total UK GHG.[6] 15% of total GHG emissions come from cars, 4% from freight HDVs, 4% from vans, 1% from buses, less than 1% from rail, and the remaining means of transport (including aviation) account for 2%.

Road transport is currently based almost entirely on liquid fossil fuels due to their energy density, but it is expected to become more integrated with the wider energy system in the future, particularly through electrification. There are currently 38 million licensed road vehicles in the UK.[7] Sales of EVs increased in 2018 to 2.6% of new cars. This represents approximately 61,000 vehicles in the year including BEVs, PHEVs, and FCEVs. However, despite sales growth the total fleet of EVs represent stands at approximately 200,000 vehicles, 0.5% of the total existing fleet.[8]

Future road transport outlook

Transport demand is still growing, though journey types are evolving. Since the 1970s, the average distances people travelled (by road, bike, or foot) have increased, but the number of trips and time spent travelling have stayed broadly the same. The average distance has increased primarily due to increased car uptake.[9] Furthermore, we expect to

[4] HMG (2018) Digest of U.K. Energy Statistics (DUKES) https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes#2018

[5] Ibid. In DUKES, total deliveries of aviation turbine fuel and aviation spirit cover deliveries of aviation fuels in the UK to international and other airlines, British and foreign governments (including armed services), and for private flying. In order to compile the NAEI, Ricardo Energy and Environment estimates that 95% of aviation spirit is used internationally. A further 5 per cent is estimated to be consumed by the military.

[6] Committee on Climate Change (2018) Reducing UK emissions, 2018 Progress Report to Parliament https://www.theccc.org.uk/wp-content/uploads/2018/06/CCC-2018-Progress-Report-to-Parliament.pdf

[7] DfT (2018) Vehicle Licensing Statistics: Quarter 3 (Jul - Sep) 2018 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/763792/vehicle-licensing-statistics-july-to-september.pdf

[8] Based on SMMT sales figures and analysis by Next Green Car. Available from: https://www.nextgreencar.com/electric-cars/statistics/

[9] DfT (2017) National Travel Survey: 2017 https://www.gov.uk/government/statistics/national-travel-survey-2017

see the emergence of Mobility as a Service (MaaS) as a new frontier; however, as a proportion of total journeys, this is currently relatively small.

Local pollution, CO_2 regulations, and ICE bans are forcing change. Local air quality concerns have led some cities around the world to restrict (older) combustion engine vehicles and encourage cleaner options. Several countries have signalled a date for the end of LDV ICE vehicle sales at national level (though hybrids may still be acceptable). This is currently 2040 in the case of the UK, though there is discussion as to whether a closer date is needed to drive near-term change. Vehicle certification tests for pollution emissions are now conducted based on more realistic simulations of real-world conditions (real driving emissions (RDE) for light duty). Tailpipe CO_2 regulations are now being tightened to 2025/2030 in the EU. This tightening extends to HDVs, where regulations have been agreed for the first time which will set CO_2 emission reduction targets for 2025 and 2030**.** Thus, the cost of compliance for combustion engines is rising, and so vehicle manufacturers are altering their technology offerings.

Road vehicles are partially or fully electrifying in response to changing and tightening regulation. Hybridisation enables LDVs to capture braking energy and reduce transient loads on engines, increasing efficiency and reducing emissions. Hybridisation, including both standard and plug-in hybrids, is already widely featured across most LDV ranges and likely to continue to grow in the short term. Most LDV manufacturers are developing such products, though some are ‘jumping over’ plug-in hybrids and moving straight to full electric. Hybridisation is also emerging for HDVs. Highly electrified vehicles open greater possibilities for digitisation and therefore for CAVs.

Technology options vary across vehicle weight classes. LDVs are likely to shift to battery solutions but remain hard to accommodate in HDVs due to weight challenges in all except short journey applications. Other electrification options for HDVs include overhead cables and inductive charging, while rapid charging could also aid uptake. Fuel cells are another option for HDVs and currently require less infrastructure upheaval. Especially in applications which have very high energy density and peak power requirements (e.g. for moving heavy loads) like Non-Road Mobile Machinery (NRMM), fuel cells could be a viable solution.

Off-board energy considerations are the key to success. The availability and type of EV recharging will have a strong bearing on the adoption of plug-in vehicles. Home and work recharging cannot meet all the needs of drivers. Hydrogen infrastructure is in its infancy, so is below critical mass for adoption by all but localised fleets, and simultaneously few vehicles are currently available on the market for consumers**.** Integration of BEVs into the energy system, as mobile storage, load balancing, and as dispatchable power, requires upgrades and overhauls of the distribution network and increased “smartness” of the system.

Sub-theme system integration: Benefits, challenges, and enablers

Energy innovation in the automotive sector offers benefits from a system-wide perspective, but at the same time it faces challenges. The following paragraphs summarise the main benefits, challenges, and enablers of energy innovation in road transport.

The benefits include accelerating decarbonisation, improved air quality, enabling grid load balancing, creating jobs, and spill-over technology improvement in other sectors. Electrification and use of hydrogen in the transport sector will lead to improvements in air quality, particularly in urban areas, and aid efforts to decarbonise the energy system as a whole**.** Electrification of transport, particularly cars, may enable future grid load balancing and associated benefits, such as cost savings. Changes in the transport supply chain will allow for the creation of jobs, and technology spill-over into other sectors such as stationary storage.

The challenges include grid integration, capital investment for upgrading infrastructure, driving range of EVs, and lack of consumer options in hydrogen mobility. Upgrades to the distribution grid will most likely be required in order to enable the increased loads required to charge (and discharge) EVs. This is expected to require a very large capital investment, the costs of which will ultimately be borne by consumers. Additionally, both the actual and perceived short range of EVs is a barrier to consumer adoption. On the other hand, the lack of offerings of FCEVs available to consumers, high upfront vehicle purchase price, and lack of hydrogen refuelling infrastructure limit consumers' ability to choose hydrogen mobility as an alternative to BEVs.

For BEVs, the enablers include charging infrastructure, smart grid deployment, and vehicle to grid (V2G) battery technology advances. Widespread installation of charging infrastructure, in conjunction with smart grid technologies, may help to overcome the EV range and grid challenges above. Improvements in battery technology and reduction in vehicle weight thanks to lighter materials will also increase EV range**.** Innovations in this area are also discussed in the Smart Systems sub-theme report.

For hydrogen fuel cell vehicles, increased deployment of hydrogen refuelling stations and large-scale, low-cost hydrogen production and distribution are major enablers. Both are expected to be stimulated by increased heavy duty vehicle deployment. Innovations relating to this area are discussed in more detail in the Hydrogen and Fuel Cell sub-theme report.

Improved manufacturing processes, improved modelling, and increased automation of production for lightweight materials are key enablers for all vehicle types. Conventional ICE vehicles are currently manufactured at high-volume employing advanced and automated production lines. Adopting equivalent processes for BEVs and FCEVs would drive down costs. In particular, scaling up production of lightweight (potentially multi-material) structures would be an enabler for BEVs, which are typically heavier than similar ICE vehicles.

Box 3. **System modelling: Road transport in the UK energy system**

Following the BEIS EINA methodology, whole energy system modelling was conducted using the ESME^{TM} Version 4.4. It estimates where innovation investments could provide most value to support UK energy system development.

ESME is a peer-reviewed whole energy system model covering the electricity, heat, and transport sectors, and energy infrastructure. It derives cost-optimal energy system pathways to 2050 meeting user-defined constraints, e.g. 80% GHG emissions reduction.[10] The model can choose from a database of over 400 technologies which are each characterised in cost, performance, and other terms (e.g. maximum build rates) out to 2050. The ESME assumption set has been developed over more than 10 years and is published.[11] ESME is intended for use as a strategic planning tool and has enough spatial and temporal resolution for system engineering design.

Like any whole system model, ESME is not a complete characterisation of the real world. It can provide guidance on the overall value of different technologies, and the relative value of innovation in those technologies.

The EINA Methodology prescribes the approach to be taken to assess the system-level value of technology innovation. This involves creating a baseline energy system transition without innovation (from which a baseline energy system transition cost is derived), and on a technology-by-technology basis assessing the energy system transition cost impact of “innovating” that technology. Innovation in a technology is modelled as an agreed improvement in cost and performance out to 2050.

For the EINA analysis, the technology cost and performance assumptions were derived from the standard ESME dataset as follows:

- In the baseline energy system transition, the cost and performance of all technologies is assumed to be frozen at their 2020 levels from 2020 out to 2050.
- The “innovated” technology cost and performance for all technologies are assumed to follow the standard ESME dataset improvement trajectories out to 2050 (these are considered techno-optimistic).

Whole system analysis using the BEIS EINA Methodology described above shows that there is significant value to the UK in continued (and accelerated) innovation in road transport.

The value to the energy system of innovation across the road transport sector has been evaluated to be ~ £190 billion cumulative to 2050 (discounted at 3.5%).

The insights on road transport obtained from the system analysis are:

- System costs associated with innovation in the transport sector are higher than those of any other energy sector and therefore innovation in transport technologies is highly valuable and needed to bring costs down.
- BEVs, along with all hybrid electric vehicles, have shown to be the most valuable technologies in the transport sector.

Additional considerations highlighted in the study are:

- While innovation is already being carried out by the private sector, further intervention may lead to faster deployment of these technologies.
- Innovation in the transport sector may also include less technology-focussed activities; demand reduction, mode shifting, and innovative business models should be considered as part of a deep dive into the transport sector.

Further work is required to estimate the value of innovations in road transport technology, or how these estimates may change in the case of different energy system scenarios.

[10] More details of the capabilities and structure of the ESME model can be found at eti.co.uk/programmes/strategy/esme. This includes a file containing the standard input data assumptions used within the model.
[11] The ESME assumption set has been developed is published with data sources at https://www.eti.co.uk/programmes/strategy/esme

Box 4. **Learning by doing and learning by research**

The total system value follows from two types of technology learning:

- **Learning by doing:** Improvements such as reduced cost and/or improved performance. These are driven by knowledge gained from actual manufacturing, scale of production, and use. Other factors, such as the impact of standards which tend to increase in direct proportion to capacity increases.
- **Learning by research:** Improvements such as proof of concept or viability, reduced costs, or improved performance driven by research, development, and demonstration (RD&D). It increases with spend in RD&D and tends to precede growth in capacity.

The EINAs are primarily interested in learning by RD&D, as this is the value that the government can unlock as a result of innovation policy. Emerging technologies will require a greater degree of learning by RD&D than mature technologies. Academic work suggests that for emerging technologies around two-thirds of the learning is due to RD&D, and for mature technologies it contributes around one-third.[12]

To reach a quantitative estimate of the system value attributable to RD&D, these ratios are applied to the system value. This implies that around £127 billion system value for innovation in road transport follows from RD&D efforts (of a total of £190 billion). Note, this is an illustrative estimate, with the following caveats:

- The learning-type splits are intended to apply to cost reductions. However, in this study, they are applied to the system value. As system value is not linearly related to cost reduction, this method is imperfect.
- In practice, learning by research and learning by doing are not completely separable. It is important to deploy in order to crowd-in investment to more RD&D, and RD&D is important to unlock deployment.

These estimates are used in the EINA Overview Report to develop a total system value that results from innovation programmes across the energy system.

[12] Jamasb, Tooraj (2007) "Technical Change Theory and Learning Curves", The Energy Journal 28(3).

Innovation opportunities within road transport

Introduction

Box 5. **Objective of the innovation opportunity analysis**

The primary objective is to identify the most promising innovation opportunities within road transport and highlight how these innovations may be realised and contribute to achieving the system benefit potential described above. This section provides:

- A breakdown of the costs within road transport across key components.
- A list of identified innovation opportunities, and an assessment of their importance to reducing costs and deployment barriers.
- Deep dives into the most promising innovation opportunities.

In response to numerous environmental and societal pressures, the road transport sector is embarking upon a period of unprecedented technological change that has the potential to revolutionise mobility.[13] Autonomy, connectivity, and electrification are the key trends that have been identified as changing the automotive sector and they continue to challenge the global engineering community. These changes will take place over future vehicle development cycles, so stakeholders should respond in a considered manner. The UK has traditional strengths in the automotive industry and could utilise these to position itself as a global leader in road transport innovation.

A series of key research areas in vehicle technology were identified throughout the screening process of the innovation opportunities. These research areas were mapped against the technology families of this sub-theme (see Table 5). The map highlights the families on which innovations in each specific area are likely to have the greatest potential to reduce the TCO of the vehicle. As can be observed, there are several cross-cutting innovation areas which affect multiple technology families. In the innovation tables later in this section, innovations belonging to the same research area have been simplistically assigned to a single technology family. However, Table 5 shows that innovation opportunities can impact multiple technology families. These overlaps should be considered when assessing the potential of each innovation opportunity.

[13] APC (2018) The roadmap report, https://www.apcuk.co.uk/opportunities-for-you/roadmap-report/

Table 5. **Mapping of research areas to technology families**

Research area	BEV LDV	BEV HDV	Dual Fuel HDV	FCEV HDV
Battery			n/a	
Electric motor			n/a	
Power electronics			n/a	
Fuel cell stack	n/a	n/a	n/a	
Thermal engine	n/a	n/a		n/a
Light-weighting				
Aerodynamics				
Tyre friction				

Key:
Large cost impact compared to total cost of ownership
Low cost impact to total cost of ownership

Note: *Many innovation areas cut across multiple technology families. Additional innovation areas affecting FCEVs (e.g. hydrogen infrastructure) are covered in the Hydrogen and Fuel Cell sub-theme report.*

Source: *E4tech*

The following sections of the report will highlight the key innovations needed in road transport. The technologies are presented separately in order to reflect their different cost structures and innovation needs.

Cost breakdown

This section provides indicative cost breakdowns of road transport technology families, to help guide innovation priorities. The cost breakdowns are presented in a set of tables which provide context for the innovation priorities. The inventory of innovation priorities highlights which innovations can contribute most to overall cost reductions of the technology family, taking the below cost breakdowns into account. The tables of current cost breakdowns show an overview of which components or areas contribute most to the cost of low-carbon vehicles today. Note, they are indicative and will vary depending on the vehicle model. Furthermore, they are heavily dependent on the assumed distance driven annually. The analysis assumes different annual usage per vehicle type, commensurate with vehicle range and other factors, and assumptions are highlighted. By understanding which areas contribute most to cost, these guide the discussion on where best to focus innovation priorities within technology families.

The cost breakdowns of different transport technologies highlight the different relative importance of up-front capex compared to fuel and running costs for different families. Typically, capex is the key cost component for low emission LDVs. Given HDVs are typically utilised to a much higher degree, fuel and other operating costs are a more important factor for HDVs. This suggest that on the whole, innovations which improve energy efficiency are more important for HDVs than LDVs (as highlighted in Table 5).

Table 6. **Current cost Model of LDV BEV**

Cost Element	TCO (approximate cost breakdown)	Assumptions
Capex	86%	• Nissan Leaf, full electric • 24 kWh battery • 107 bhp motor • 18.5% annual depreciation rate • £3,500 subsidy (plug-in vehicle grant)
Road Tax	0%	
Maintenance	3%	
Insurance	6%	
Electricity	5%	• 141.7 mpg equivalent • UK annual mileage 11,000 miles

Notes: *Total cost of ownership is assumed to be £11,800 (100%) with an ownership length of 3 years and 3.5% discount rate.*

Source: *Palmer et al. (2018) TCO and market share for hybrid and EVs in the UK, US, and Japan*

Most of the TCO of a light duty battery electric car is capital cost, accounting for 84%. BEVs are generally characterised by low fuel cost, in this case around 6%. The cost of the battery makes up half of the vehicle's (pre-tax) price, the other half is vehicle (40%) and powertrain (10%) components.[14] Nonetheless, battery cost is expected to come down fast, while vehicle and powertrain expenses will remain roughly the same. According to

[14] BNEF, 2017, When will EVs be cheaper than conventional vehicles?, http://www.automotivebusiness.com.br/abinteligencia/pdf/EV-Price-Parity-Report.pdf

recent studies, in a couple of decades battery cost may represent only a quarter of the BEV purchase price.[15]

Table 7. **Current cost Model of HDV BEV**

Cost Element	TCO	Assumptions
Vehicle Purchase Price	74%	• 18/19 t rigid truck • 120 – 240 kWh battery • 250 kW motor
Charging infrastructure	3%	
Electricity	7%	• 120 km/day mileage • €0.08/km
Maintenance & tyres	11%	
Insurance	5%	
Road Tax	0%	

Note: *Total cost of ownership assumed to be £325,000 (100%) based on a 10-year lifetime.*

Source: *FRevue project (2017) "Validating Freight EVs in Urban Europe"*

The bulk of the TCO of a medium-size rigid truck is capital cost, accounting for 74%. The cost breakdown for medium and heavy duty BEVs is like the light duty segments. Fuel cost makes up only 7% of the TCO. In the HDV BEV case, vehicle maintenance accounts for a greater percentage (11%) of the total cost compared to the LDV case, because of higher vehicle utilisation. Similar to LDVs, battery cost reductions could play a significant role in bringing capital cost down.

[15] Ibid.

Table 8. **Current cost model of heavy-duty dual fuel vehicle**

Cost Element	TCO	Assumptions
Capex	56%	• Rigid, dual fuel port injection (diesel + compressed natural gas (CNG)) • 30 t max gross weight
Fixed O&M	21%	e.g. maintenance and insurance
Fuel	24%	• 42,000 km/year vehicle usage • 3.5 kWh/km (5.9 mpg equivalent): 59% CNG, 39% diesel, 3% electricity for station compression at 700 bar • Gas price 31 p/kWh, diesel price 64 p/kWh, electricity price 92 p/kWh

Note: Figures do not sum due to rounding. Total lifetime (10 years) cost assumed to be £290,000.

Source: ESME v4.4 public datasheet, ETI Heavy Duty Vehicle Programme, accessed: Feb 2019; fuel prices from ICCT (2017) White paper Transitioning to Zero-Emission Heavy duty Freight Vehicle

The cost breakdown of a duel fuel truck is provided as representative for duel fuel, with a view towards possible (electric) hybridisation. Although capex is the largest contributor to costs, fuel cost are significant, representing roughly a quarter of the TCO. Typical dual fuel engines run on a fuel mix which is 60% natural gas and 40% diesel. Given the almost equal split of the mix, fuel cost is sensitive to the prices of both fuels. Greater hybridisation would reduce the importance of fuel costs, and increase the relative importance of capex.

Table 9. **Current cost model of heavy-duty fuel cell EV**

Cost Element	TCO	Assumptions
CAPEX	42%	• Archetype: tractor + trailer(s) • 400 kW electric motor • 350 kW fuel cell • 12 kWh battery
Maintenance	13%	Truck and trailer maintenance only
Fuel	44%	• Vehicle Use (total 10 years): 834,000 km • Fuel Efficiency: 2.6 kWh/km (7.9 mpg equivalent) • Fuel Price: 0.19 £/kWh (hydrogen from electrolysis) • Operated in EU

Note: Figures do not sum due to rounding. Total assumed cost £748,000 based on a 10 year lifetime and 10% amortisation rate.

Source: ICCT (2017) White paper Transitioning to Zero-Emission Heavy duty Freight Vehicles

The current TCO of a large fuel cell truck (including tractor and trailers) is equally balanced between capital cost (42%) and fuel cost (44%). The remaining part of the cost breakdown is essentially made up of maintenance. The fuel cell system and the hydrogen tank represent half of the truck capital cost. The rest of the capital cost is constituted of tractor, trailers, electric motor, and electric battery. Key innovations to help reduce these costs are listed in the inventory of innovation opportunities. The economic performance of FCEVs could significantly benefit from reducing fuel cost. The cost of green hydrogen produced via electrolysis could be lowered, for instance by increasing the utilisation rate of electrolysers. A recent study carried out by the German National Organisation Hydrogen and Fuel Cell Technology has shown that the hydrogen cost (€/kg) could be halved by running electrolysers at a high utilisation factor (8,000 hrs/year).[16] Alternatively, low cost blue hydrogen could help lower fuel costs. Additional considerations around how the hydrogen fuel cost could be lowered are also included in the Hydrogen and Fuel Cells sub-theme report.

The cost analysis for CAVs, smart logistics, and mode shifting has not been carried out. In terms of total cost of ownership, it is difficult to approach these technology families in the same way, as the concept of total cost of ownership does not straightforwardly apply. CAVs are still in their infancy and no commercial vehicles are available yet. Smart logistics and mode shifting are operating strategies and not vehicles that can be purchased and operated. For these reasons, a cost analysis of these technologies is not presented.

[16] NOW GmbH (2018) Industrialisation of water electrolysis in Germany, https://www.now-gmbh.de/content/service/3-publikationen/1-nip-wasserstoff-und-brennstoffzellentechnologie/indwede-studie_v04.1.pdf

Inventory of innovation opportunities

A summary of the key innovation priorities identified during desk research and in the workshop are given below, grouped by technology family. A more in-depth discussion relating to these is given in the Innovation Opportunity Deep Dive section.

LDV and HDV BEV

Innovations to improve the batteries, motor, chassis, and power electronics (including chargers) were identified as key priorities. Improving the energy density of batteries is particularly important for their application in HDVs, while reducing the life cycle impact of batteries is critical from a sustainability perspective. In the longer term, developing novel battery chemistries was viewed as being necessary to deliver a step change in performance. To reduce the cost of the motor and the chassis, innovation in novel materials for magnets and load-bearing materials is needed. Within the vehicle, improved power electronics are important for improving the safety and performance of BEVs but are less important for cost. Outside of the vehicle, improving the charging rate and reducing efficiency losses were viewed as being key to reducing both operating costs and barriers to EV uptake.

Dual fuel and FCEV HDVs

Hybridisation and improved after-treatment of dual fuel HDVs, and advanced manufacturing techniques for fuel cells, were viewed as the highest priorities. Hybridisation of medium and heavy-duty vehicles can have a material impact on reducing emissions associated with HDVs and was viewed by industry experts as a key priority. Additionally, innovation in the after-treatment systems of dual fuel HDVs is key to their long-term acceptability from an air quality standpoint. For FCEV HDVs, developing advanced manufacturing techniques for fuel cells was viewed as the top priority in order to bring down their manufacturing cost. Innovations needed to bring down the cost of hydrogen production and distribution are considered separately in the Hydrogen and Fuel Cell sub-theme report.

CAVs, Smart Logistics, and Demand Reduction/Mode Shifting

In these technology families, it was not clear where to focus innovation (for CAV) or whether government intervention is needed to spur innovation (for Demand Reduction/Mode Shifting). The UK should take steps to identify where it is best placed to succeed in terms of Connected and Autonomous Vehicles, before deciding in which areas to prioritise innovation. A clear distinction was drawn between acting in hardware, software, or services. Innovation spending should not be prioritised in Smart Logistics. Innovations are already occurring in the private sector, and not in Demand Reduction/Mode Shifting. Policy choices are the key drivers for the deployment of this technology family, rather than innovation.

Globally, the priority for progress on CAVs is building a safety case around this technology. Currently the validation and testing phase of autonomous vehicle is quite time-consuming and expensive. The principal reason is that the vehicle needs to be tested for an extremely broad range of conditions and possible scenarios. Innovative validation and testing technologies, procedures, and facilities are expected to drive down CAVs' capital cost.

Additional scope for consideration

The industry experts stressed that ICE HDVs, looking at vehicle life cycle impacts, and FCEV LDVs should all be added to the scope of future innovation work. Innovation in ICE HDVs should not be ruled out, as there is a large potential for efficiency improvements which are particularly relevant in the short- and medium-term, and potentially longer. Improving the sustainability (for example, the embodied energy) of the entire vehicle across its entire life cycle is a key priority. While it is important to consider the life cycle of key components, such as batteries, a more holistic approach is also needed to inform industry and policymakers and avoid unintended consequences. The potential for FCEVs in the light duty segment should not be dismissed. While ESME modelling did not identify light duty FCEVs as a key priority, innovation in this space should not be ruled out, particularly given that there is increasing interest from large automotive companies in this area.

The industry experts discussed the contents of the table and offered feedback. The updated table was circulated amongst experts afterwards with the opportunity to provide further comments, which have been included below.

In the tables below, magnitude of the contributions to cost reduction and reducing deployment barriers are described in qualitative terms relative to other innovation opportunities:

- Significantly above average = 5
- Above average = 4
- Average = 3
- Below average = 2
- Significantly below average = 1

An indicative timeframe for each innovation is provided. The timeframe given relates to the year the technology is deployed commercially at scale (gaining 10-20% market share).

Table 10. **Innovation mapping for LDV BEV**

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected	Impact on other energy technology families	Feasible timeframe
Battery	**Next-generation chemistries**. Novel battery chemistries could substitute lithium-ion in the long-term, providing an additional cost-drop and performance increase. Novel chemistries could also enable the removal of precious metals, with positive impacts on cost and ethical material sourcing. Examples of future chemistries include lithium-sulphur, sodium-ion, solid state electrolytes, and lithium-air batteries.	4	4	BEV, PHEV, HEV	HDV and MDV EV	2030
	Reduce the embodied energy and CO_2 of the battery. Embodied energy plays a strong part in battery CAPEX and embodied CO_2 may be targeted by future EU regulation.	3	4	BEV, PHEV, HEV	HDV and MDV EV	2025
	Develop an economically viable value chain for 2nd life reuse and recycling. This could involve modelling and testing aggregation of aged batteries for energy storage applications, development of repurposing facilities, designing battery packs for 2nd life to enable easy interoperability, and development of viable processes to meet expected higher recycling targets.	3	4	BEV, PHEV, HEV	HDV and MDV EV	2030
	Improve battery pack engineering. There is potential for batteries to be more thoroughly integrated into the vehicle structure, for thermal control systems to be more integrated with the battery pack, and for casing materials to be lighter.	3	3	BEV, PHEV, HEV	HDV and MDV EV	2020-2030

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected	Impact on other energy technology families	Feasible timeframe
Motor	**Improved materials, designs, and manufacturing processes for sustainability**. These measures would facilitate a sustainable and economically viable value chain for end-of-life recovery, reuse and recycling. Firstly, e-machines need to be designed for remanufacture. In addition, new recycling processes to enable sensing, sorting, separation, purification, and reprocessing of materials is required.	3	3	BEV, PHEV, HEV	HDV and MDV EVs	2030
	Improved materials for cost and performance. Different winding techniques and the replacement of copper with other materials are being investigated. These have the potential to significantly reduce costs and radically improve performance of electric motors. Magnets have been identified as a costly component of motors, and thus innovation is needed here to bring costs down. For lower-cost applications, aluminium windings have been identified as a cheaper, lighter alternative that is more readily recyclable than copper. Higher performance materials were also identified as being attractive for heavy duty vehicles. These applications need high power densities and greater torque densities which cannot be attained using existing approaches.	3	2	BEV, PHEV, HEV	LDV and MDV EVs	2025
Power Electronics	**Improved semiconductor materials and advanced converters**. New wide bandgap devices are smaller, faster, and more efficient than silicon, with greater tolerance to high temperatures, making SiC and GaN power semiconductors key enablers for more efficient electro-mobility. The introduction of new materials could also unlock high-performance converter topologies. These may include soft-switching topologies for high frequency applications; adaptive power inverters; higher frequency modulation schemes; resonant converters and multi-level converters.	3	3	BEV, PHEV, HEV	HDV and MDV EVs	2025

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected	Impact on other energy technology families	Feasible timeframe
Load-bearing structures	**Alternative materials for load-bearing parts to reduce weight**. High-strength steels will dominate in key load-bearing and body structures for high and medium volumes, but alternative metals (e.g. aluminium) and carbon fibre composites could be used in structures that are less integral to vehicle safety and in lower volume or niche applications. Examples: JLR and Ford (aluminium), Audi and BMW (composite: steel + aluminium + magnesium + carbon fibre). This may also require innovation in multi-material joining techniques and high-speed composite manufacturing.	3	3	BEV, PHEV, HEV	HDV and MDV EVs	2020-2035
Manufacturing	**Advanced manufacturing**. Leveraging advanced manufacturing techniques and establishing rapid prototype facilities are both key to mobilising a UK supply chain. This includes high-volume and automated processes for production and testing of motors, batteries, and power electronics components. Additionally, the upgrade of UK's EV manufacturing capabilities can be enabled by establishing better synergies across the mechanical, electrical, and chemical industries.	4	2	BEV, PHEV, HEV	HDV and MDV EVs	2020-2030
Design	**Light-weighting and 'right-sizing'**. Most vehicles are designed for personal ownership so must satisfy several different requirements such as large luggage capacity, five or more occupants, and the corresponding crash and safety regulations that all add significant weight. Designing vehicles specifically for certain applications, such as smaller vehicles for urban environments, would dramatically reduce vehicle weight through more appropriate design (e.g. shared vehicles). In the long-term, CAV equipped with geo-fencing should require lower crash protection levels, thus less material.	3	4	BEV, PHEV, HEV	HDV and MDV EVs	2030-2040

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected	Impact on other energy technology families	Feasible timeframe
Charging	**Faster and more efficient charging dispensers**. Fast battery charging incurs significant energy losses and yet is a key technology for the development of electric mobility. Therefore, more efficient and even faster charging stations are required.	2	4	BEV, PHEV	All EVs	2025

Source: Workshop consultation, APC (2018) The Roadmap Report

Table 11. **Innovation mapping for HDV BEV**

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected	Impact on other energy technology families	Feasible timeframe
Drivetrain	**Optimised and more efficient drivetrain**. Optimal drivetrain design (e.g. distributed motors) could enable downsizing of electric motors, thus achieving substantial cost savings.	4	2	BEV, PHEV, HEV	LDV and MDV EVs	2025-2030
Battery	**Increased energy and power density in existing lithium-ion chemistry**. This could be achieved through improving existing electrolytes, electrode structure, and cell packaging in known chemistries, or introducing elements into lithium-based cathodes that enhance energy density. Improving energy density could either reduce the vehicle weight or free up valuable payload space, which is currently taken up by large battery packs.	3	4	BEV, PHEV, HEV	LDV and MDV EVs	2025
Charging system	**Dynamic inductive charging**. Dynamic wireless charging is based on coils connected to electric cables which are fitted on/under the road surface. These coils emit an electromagnetic field that is picked up by vehicles driving over them and converted into electricity by a system built into the vehicle. Additional infrastructure would be required, which is expensive.	2	3		LDV EVs	2030-2040
	Overhead cable heavy duty vehicles. The vehicle draws power from overhead cables installed along motorways, similarly to existing trolleybuses in urban areas. Additional infrastructure would be required which is very expensive.	2	3			2030-2040

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected	Impact on other energy technology families	Feasible timeframe
Aerodynamic design	**Aerodynamic fittings**. A wide range of aerodynamic fittings (e.g. aft box tapers, aerodynamic tractor bodies, mud flats, trailer tails, box skirts, cab/box gap fairings) can reduce the drag coefficient, thereby reducing road load. Individual vehicle components reduce fuel use by 0.5-3%, depending on truck type and aerodynamic retrofit. Entire trailer device packages could bring saving up to 5-14%.	2	3		All vehicles, especially MDV and HDV	2020
Tyre friction	**Low-rolling resistance tyres** can be designed with various specifications, including dual tyres or wide-base single tyres with aluminium wheels and next-generation variants of these designs. Potential energy savings range from about 0.5% to 12% in the tractor-trailer market. Tyre pressure systems alone could reduce fuel use by 0.5-2%.	1	2			2020

Source: *Workshop consultation, IEA (2017) Energy Technology Perspective, ICCT (2017) Fuel Efficiency Technology in European Heavy-duty Vehicles: Baseline and Potential for the 2020–2030 Timeframe*

Table 12. **Innovation mapping for heavy duty dual fuel vehicles**

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Technology affected	Impact on other energy technology families	Feasible timeframe
Drivetrain	**Mild hybridisation (electric) of medium/heavy duty vehicles**. The degree of torque assists and energy recovery possible is likely to be determined by the duty cycle in which the vehicle is most frequently operated. Mild hybridisation (e.g. 48 V, KERS) is particularly effective in reducing the transients that greatly increase both emissions and fuel consumption of commercial vehicles with unsteady duty cycles.	4	4		LDV ICEs	2020-2025
Engine system and control	**Wide spectrum after-treatment systems**. Further component integration is required to improve energy and abatement efficiency across the wide spectrum of engine operating conditions. For example: extension of the pre-turbine operating range, efficient exhaust after-treatment at lower ambient temperatures, and after-treatment systems suitable for alternative fuels.	4	5		LDV ICEs	2020-2030
Engine	**More efficient combustion**. Low-temperature combustion regimes combine high combustion efficiency with low levels of engine-out pollutants. Examples are: Homogenous Charge Compression Ignition (HCCI), Partially Premixed Compression Ignition (PPCI) and natural gas extreme lean burn. In the longer term, the split-cycle engine has promising fuel economy. One cylinder is used for intake and compression and another for power and exhaust which facilitates efficient exhaust heat recovery and differential compression/expansion.	3	3		LDV ICEs	2025-2030
Manufacturing	**Advanced manufacturing**. Additive layer manufacturing, metal injection moulding, metal foams for engines.	2	2		All Vehicles	2025-2035

Source: Workshop consultation, APC (2018) The Roadmap Report

Table 13. **Innovation mapping for heavy duty fuel cell electric vehicles (HDV FCEV)**

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Impact on other energy technology families	Feasible timeframe
Manufacturing	**Advanced manufacturing techniques**. Unlocking advanced manufacturing techniques can significantly reduce the capital cost of fuel cells. A significant capital cost reduction can be delivered by shifting to high-volume and highly automated production methods. This is partially enabled by the scale-up of production rates. Examples of these methods include tape casting, expanded metal cutting, hydroforming, and additive manufacturing processes.	5	3	LDV FCEV, Stationary Fuel Cells	2025
Cell	**Innovative Materials**. Continuous innovation in material science will contribute to low-cost fuel cell stacks. Low-titanium bipolar plates, low-platinum catalyst loading, and alternative catalyst materials (non-noble metal, transition metal oxides, and bio-inspired catalysts) can directly reduce material cost.	3	3	LDV FCEV, Stationary Fuel Cells	2025
H_2 Storage	**Material-based and chemical H_2 storage**. Alternative hydrogen storage technologies could reduce the cost of vehicle on-board storage. Novel material-based H_2 storage technologies, characterised by high volumetric energy density, could deliver cheaper and simpler on-board storage. These novel technologies include metal hydrides and porous sorbents. Chemical H_2 storage options under investigation are LOHCs and ammonia.	2	3	LDV FCEV	2030

Source: Workshop consultation, E4tech (2016) Hydrogen and Fuel Cells: Opportunities for Growth – A Roadmap for the UK, IEA (2015) Technology Roadmap. Hydrogen and Fuel Cells, DOE (2015) Multi-year Research, Development and Development plan - Storage

Table 14. **Innovation mapping for CAVs**

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Impact on other energy technology families	Feasible timeframe
Validation and testing	**Novel validation and testing technologies and methods**. These are required to test CAVs in multiple conditions and scenarios.	4	5	BEVs (motor vehicle safety)	2020
Hardware	**Improved sensors**. Improvements can be made to the following sensors: GPS, Lidar, ultrasonic sensors, odometry sensors, and radar sensors. GPS can be improved along with combining readings from tachometers, altimeters, and gyroscopes. Lidar can be developed to monitor the vehicle's surroundings. Ultrasonic sensors can measure the position of objects very close to the vehicle. Odometry sensors can be used to complement GPS information. Radar sensors can be used to monitor the vehicle's surroundings. Innovations/improvements in these technologies are necessary to enable deployment of CAVs.	3	5	Smart logistics	2025
Hardware / Software	**Enhanced performance of ECUs**. The ECU analyses all sensor input, applies rules of the road, and operates the steering, accelerator, and brakes. Improved processing speed is required to analyse bigger amounts of data from sensors.	2	3		2020
Hardware	**Internet connectivity**. Improvements (e.g. 5G) needed to ensure constant and consistent access to internet, in order to enable smooth operation of connected services. At the same time, improving internet security is also highly important, and progress needs to be made here too.	1	4		2020

Source: Workshop consultation, BCG (2015) Revolution in the driver's seat

Table 15. **Innovation mapping for smart logistics**

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Impact on other energy technology families	Feasible timeframe
Vehicle	**More efficient auxiliary equipment**. Significant fuel consumption of commercial vans and trucks is attributable to auxiliary equipment (e.g. chillers) which absorbs power even when in idle-mode.	4	3	All commercial vehicles	2025
Software	**Freight information portal**. Enabling greater exchange of information between freight operators, the city council, and city planners to enable more efficient movement of freight.	3	4		2020
Hardware/ Software	**Cloud computing & big data**. Enabling data processing and data-based services. Increasing processing speed and volume is essential to unlock the full potential of improved hardware (sensors) and to enable fast and accurate computation of optimal logistics.	3	4		2025
Hardware	**Advanced sensors**. Improvements can be made to on-board sensors to enable data transmission, including increased use of GPS, real-time speed measurements, and traffic updates. Other examples include real-time monitoring of inventory/goods to enable optimisation of goods dispatch patterns.	2	3	CAVs	2020

Source: Workshop consultation, DHL (2015) IoT in logistics, GLA (2010) Mayor's Transport Strategy – Proposal to manage the demand for travel

Table 16. **Innovation mapping for mode shifting / demand reduction**

Component	Innovation opportunity	Contribution to cost reduction	Contribution to reducing deployment barriers	Impact on other energy technology families	Feasible timeframe
Software	**Enhanced real-time information**. Improvements to real-time information, allowing greater accuracy in journey planning, with potential to spread demand over multiple transport modes and shift time of travel.	3	3		2020
Capacity	**Increased rail capacity**. Enabling more journeys to be undertaken by rail in lieu of automobile, especially in key areas such as intra- and inter-urban centres with high volumes of automobile traffic. Key instances would include the replacement of commutes by car.	3	3		2025

Source: *Workshop consultation, GLA (2018) Mayor's Transport Strategy, GLA (2010) Mayor's Transport Strategy – Proposal to manage the demand for travel*

Innovation opportunity deep dive: LDV & HDV BEV

With batteries comprising around half of the overall vehicle capital cost, it follows that this should be a priority area of innovation spending.[17] It should be noted that battery innovations are also covered by the scope of the Smart Systems sub-theme report.

Improving the energy density of batteries is key, particularly for HDVs. Currently, the relatively low energy density of batteries (in comparison with fossil fuels) limits their usefulness in vehicles that are required to travel longer distances. If valuable cargo or passenger volume is occupied this reduces the attractiveness of using batteries. In both HDVs and LDVs, the cost of achieving long range increases roughly in proportion to the range as more batteries are added. Achieving these improvements requires continued research and development (R&D) by vehicle and battery companies working closely with their suppliers in the chemical and electronics sectors.

Reducing the overall energy and material impact of battery manufacturing will become more important. Industry experts stressed that minimising the overall life cycle impact of BEVs is key to their long-term sustainability. This includes designing for end-of-life, improving recycling of batteries, and their use in second life applications such as stationary storage. Currently the recycling of automotive lithium-ion batteries is not an established practice. This is due to the technical complexity of the recycling process and because there are few batteries which are currently close to being at the end of their life.[18] Given the predicted growth in their use, particularly in BEVs, this presents a large opportunity for conventional and new entrants to the recycling industry, supported by R&D with the battery and chemical industries. Battery recycling will also reduce the overall use of precious and rare metals.

In the longer term, moving to alternative chemistries will be key to delivering step changes in performance. There is still room for further optimisation of lithium-ion batteries. However, for a step change in energy density or cost, novel chemistries such as lithium-air, lithium-sulphur, and sodium-ion would need to become viable. However, most of these are at a relatively early stage and thus sustained R&D is needed within the battery and chemical industries.

[17] BNEF, 2017, When will EVs be cheaper than conventional vehicles?, http://www.automotivebusiness.com.br/abinteligencia/pdf/EV-Price-Parity-Report.pdf
[18] Gaines, L (2014), The future of automotive lithium-ion battery recycling: Charting a sustainable course, Sustainable Materials and Technologies 1-2 (2014) 2-7 https://doi.org/10.1016/j.susmat.2014.10.001

Nevertheless, it is important to recognise that other vehicle components also contribute to large proportion of overall cost and have room for energy efficiency improvements. The industry experts identified the key priorities as:

Finding alternative materials for motor magnets is key to reducing the overall costs of the motor. The permanent magnets of motors are particularly expensive and often involve the use of rare earth metals, which the UK needs to import. Finding ways to find lower cost or recycled materials, with higher performance, was deemed a priority.

Motor applications within different vehicle architectures should be explored, particularly for HDV. A systems approach to high-power vehicle applications, such as HDVs, may result in application of multiple smaller motors (e.g. one per wheel), avoiding the need to develop costly large motors and creating redundancy. This requires collaboration between vehicle and motor companies.

Improved power electronics are important in increasing the safety and performance of BEVs but are less important for cost. In power electronics, it was agreed by industry experts that innovation is needed, particularly in improving power semiconductor materials and developing advanced converter topologies. However, these innovations are needed less to reduce cost, but more to overcome other deployment barriers, such as vehicle performance, reliability, or safety concerns. Continued R&D collaboration between vehicle and electronics suppliers is needed.

Developing multi-materials for use in load-bearing structures will bring down the cost of the vehicle body. Innovation is needed in using multi-materials, with the aim of mass production to bring costs down significantly. Despite the UK’s abilities in the use of – for example - composites, aluminium, and high-strength steel, the communities working with these materials are less familiar in combining them. This requires collaboration between vehicle and materials companies.

Improving the charging rate and reducing efficiency losses of BEVs were key innovation priorities for chargers. There is a need to improve the efficiency of charging equipment, with estimated losses of 25% for fast charging significantly reducing the fuel cost competitive advantage of BEVs. This requires collaborative R&D between vehicle companies and their suppliers. Innovation is also needed to increase the rate of battery charging through improving the cooling design of battery packs, careful electronic management of charging, and improving charge acceptance through battery chemistry. All of these require close collaboration between vehicle companies and their suppliers. Additionally, there is a need to improve the interoperability of existing charging systems, which involves ensuring that cars are not limited to certain types of chargers. However, improving interoperability of charging systems is mostly a regulatory matter rather than a technology issue.[19]

Innovation opportunity deep dive: Dual fuel and FCEV HDVs

Hybridisation of medium and heavy-duty vehicles can have a material impact on reducing the emissions associated with HDVs. During the workshop, emphasis was placed on innovation in the hybridisation of medium and heavy-duty vehicles, which also have scope for energy efficiency improvements and cost reduction. Mild hybridisation, especially of urban vehicles, can reduce emissions and fuel consumption considerably through recovery of braking energy. This requires collaborative development between vehicle frame builders (e.g. bus makers) and their powertrain suppliers (e.g. diesel engine companies).

Innovation in the exhaust gas after-treatment systems of dual fuel HDVs is key to their long-term acceptability from an air quality standpoint. Focussing on after-treatment is key to the deployment of such vehicles, because increasingly strict air quality limits will hinder their deployment if exhaust quality is not improved. Specific solutions are needed for gas-fuelled vehicles, since 'standard' diesel exhaust after-treatment targets pollutants differently. To achieve this, engine developers need to work closely with after-treatment equipment producers.

Developing advanced manufacturing techniques for fuel cells can significantly reduce the cost of FCEV HDVs. With a significant portion of the capital costs of FCEV HDVs being attributable to fuel cells, reducing their cost is a key priority. The focus should be on improving manufacturing techniques, such as shifting to high-volume and highly automated production techniques, for example by developing tape casting, expanded metal cutting, hydroforming, and additive manufacturing processes. Costs can also be reduced through standardisation and modularisation of fuel cell stacks and balance of system design. This requires collaboration between vehicle companies and suppliers of fuel cells and related components. While outside the scope of this study, the UK does have capacity in both fuel cell and LDV development and manufacture. If combined, this could be a strong addition to innovation for HDV applications.

Innovation opportunity deep dive: CAV

The UK should identify where it is best placed to succeed in this area, before deciding in which areas to prioritise innovation. Connected and Autonomous

[19] This is currently under investigation by the Office for Low Emission Vehicles (OLEV), who are looking into the role of policy and regulation in enabling interoperability.

Vehicles is a novel area, with a key question emerging from the workshop being where the UK is best positioned to have a significant role, if any. Broadly, the CAV value chain can be broken down into hardware, software, and services (e.g. MaaS). Currently, in this nascent industry, there are no companies which operate in all three areas. It was also noted that while the hardware (sensors) have scope for cost reduction, the UK is not particularly strong at manufacturing these. A national strategic view is required across the CAV ecosystem to address this.

Globally, the priority for progress on CAVs is building a safety case around this technology. Currently, the validation and testing phase of autonomous vehicles is quite time-consuming and expensive as vehicles need to be tested for an extremely broad range of conditions and possible scenarios. Innovative validation and testing technologies, procedures, and facilities are expected to drive down CAV capital cost.

On-board sensor and electronic control unit (ECU) packages installed on CAVs are generally large, heavy, and not well integrated with the vehicle architecture. There is strong potential for weight and volume reduction through R&D. However, arguably the UK is likely to keep importing hardware from other countries rather than producing it. Hence, despite being an innovation priority globally, investing in sensor integration might not be a national priority.

Innovation opportunity deep dive: Smart Logistics and Mode Shifting/Demand Reduction

Smart Logistics and Mode Shifting/ Demand Reduction innovation is already occurring. For Smart Logistics, it was argued that it is questionable whether government intervention is needed, as innovation in this space is already taking place through private companies (e.g. supermarkets). Likewise, for Mode Shifting (e.g. to rail), it was questioned whether there is innovation needed, with the view that this is more a matter of policy and regulatory choices than technology (though certain technologies could enable the interoperability of different modes). Regardless of the nature of the government intervention, workshop participants stressed that shifting demand from road to rail could have larger energy- and cost-reduction benefits in freight rather than passenger transport.[20]

[20] CE Delft (2011) Study on the projected effects on GHG emissions and transport volumes, http://www.cer.be/sites/default/files/publication/2189_Modal_shift_study_final.pdf

Additional scope for consideration

Innovation in ICE HDVs should not be ruled out, as there is a large potential for efficiency improvements. Amongst the industry experts, there was consensus that innovations in ICE HDVs should be considered, as there is significant scope for improvement in energy efficiency through innovation. Roadmaps suggest that existing heavy-duty engines can continue to improve and that more fundamental changes in design could lead to step change improvements in the medium term, building upon academic and industrial R&D.[21] These improvements could bring the engine thermal efficiency up to 55% by 2025 for HDVs, compared to the correspondent 47% level in 2017.[22] Given the challenge of finding ways to cost-effectively decarbonise HDVs, such innovation work in ICE HDVs should be considered alongside alternative powertrain technologies, rather than as an alternative.

Improving the energy efficiency of onboard auxiliary systems can also make a valuable contribution. With components such as HVAC consuming a relatively large proportion of energy, innovation should be prioritised here in order to improve the overall efficiency of commercial vehicles. Thermal integration of increasingly electrified vehicles necessitates different approaches to heating and cooling, using a system view.

The potential for FCEVs in the light duty segment should not be dismissed. While ESME modelling did not identify FCEV LDVs as a key priority, innovation in this space should not be ruled out**.** For LDVs, hydrogen is being seriously considered again by senior automotive executives, as it could help to de-risk the reliance on electrification in this segment.[23]

[21] APC (2018) The Roadmap Report, https://www.apcuk.co.uk/opportunities-for-you/roadmap-report/
[22] Ibid.
[23] FuelCellsWorks (5th March 2019) Audi Increasing Investment into Hydrogen Fuel Cells, https://fuelcellsworks.com/news/audi-increasing-investment-into-hydrogen-fuel-cells/

Business opportunities within road transport

Introduction

Box 6. **Objective of the business opportunities analysis**

The primary objective is to provide a sense of the relative business opportunities against other energy technologies. To do so, the analysis uses a consistent methodology across technologies to quantify the 'opportunity'; in other words, what *could* be achieved by the UK. The analysis assumes high levels of innovation but remains agnostic about whether this is private or public. This distinction is made in the final section of the report. The two key outputs provided are:

- A quantitative estimate of the gross value added, and jobs supported associated with road transport technology, based on a consistent methodology across technologies analysed in the EINA. Note, the GVA and jobs supported are *not* necessarily additional, and may displace economic activity in other sectors depending on wider macroeconomic conditions.
- A qualitative assessment of the importance of innovation in ensuring UK competitiveness and realising the identified business opportunities. Note, the quantitative estimates for GVA and jobs supported cannot be fully attributed to innovation.

The following discussion details business opportunities arising both from exports and the domestic market. An overview of the business opportunities, and a comparison of the relative size of export and domestic opportunities, across all EINA sub-themes is provided in the overview report.

More detail on the business opportunities methodology is provided in the Appendix.

The automotive industry is one of the UK's largest industries and a major exporter. The UK is a large international vehicle producer, and has a long vehicle making history. The industry employs 186,000 people directly in manufacturing and accounts for 12.8% of the UK's exports by value.[24,25]

[24] 2017 exports based on HS8703. Data available from https://atlas.media.mit.edu/en/profile/country/gbr/

[25] SMMT. 2018. *Motor Industry Facts.* Available from https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Motor-Industry-Facts-June-2018.pdf

The transition towards low emission transport provides a business opportunity for the UK, but also represents a threat to aspects of the existing industry. UK GVA and jobs associated with the production of low emissions vehicles are likely to result from existing production capacity (and associated jobs) transitioning from the production of ICE vehicles towards the production of EVs. As the market for ICE vehicles shrinks, developing a competitive position in low emission vehicles is vital for the UK to maintain its existing industry. Furthermore, developing a strength in EVs, or, for example, hydrogen buses can help the UK capture a larger market share than it currently does for ICE vehicles. Nonetheless, there are some automotive jobs in the UK, such as those in engine manufacturing, which are at risk from the transition towards low-carbon vehicles.

This business opportunities analysis focusses on UK opportunities from exports in low-carbon road vehicles. The opportunity presented is an estimate of the *gross* number of jobs and GVA supported directly by the export of low-carbon vehicles and associated parts. Note, the intention of the analysis is *not* to forecast the size of the UK's automotive industry, but rather to feed into an assessment of how business opportunities in transport compare to other energy (intensive) sectors. Box 7 provides further notes on how the outputs of this analysis differ from forecasts of the UK's future automotive industry. The future jobs estimate is unlikely to be additional to the existing jobs in the UK's automotive industry. Domestic OEMs will likely switch production from fossil-fuelled vehicles towards low-carbon road vehicles as the uptake of low-carbon road vehicles increases internationally up to 2050, especially in the EU market.

The key export opportunities considered are:

- **Exports of LDV BEV.** We focus on BEVs in the LDV market as this is expected to be the dominant form of low emission vehicle (by sales) in the long term. This is a large potential opportunity, with complex dynamics determining the UK's competitive position.
- **Exports of key 'low emission' parts of LDV.** This includes battery packs, the broader electric power train, and connected and autonomous vehicles (CAV) packages.
- **Exports of low emission trucks.** Unlike LDVs, HDV sales are likely to be a mixture of battery electric, fuel cell, and dual fuel vehicles by 2050. There is significant uncertainty around the likely split between the different powertrains, and hence we quantify the export opportunity from low emission HD trucks.
- **Exports of low emission buses.** Buses are a relative export strength for the UK. They are likely to be a mixture of battery electric and fuel cell vehicles by 2050, but like HDVs, there is significant uncertainty around the split between

the different powertrains. Hence, we quantify the overall export opportunity from low emission buses.

- **Fuel cells for HDVs.** We consider the export opportunity for fuel cells for HDVs. Although fuel cells for transport are a significantly different technology from stationary fuel cells, there is some cross over. A broader discussion of UK competitive advantage in fuel cells is provided in the hydrogen and fuel cells sub-theme report.

There are wider business opportunities in transport, particularly around MaaS. Existing data analytics strength in UK industry and academia can deliver innovative new mobility services. For example, MaaS is already being piloted in the UK and provides users with a system that integrates the planning, booking, and payment for travel across a range of transportation modes. Services and software which enable smart fleet management or transport could provide significant opportunities. Software platforms which enable ridesharing, and 'floating' transport options like scooters or bicycles, could be a significant opportunity for the UK's tech industry. However, the ability to monetise services such as those provided by companies like Citymapper and start-ups such as Mute remains unclear and difficult to quantify.[26] It is hence not considered in detail in this analysis.

The business opportunities analysis is set out as follows

- An overview of the global market, with a focus on markets for exports
- A discussion of the UK's competitive position, with a focus on exports
- A discussion of the business opportunities from exports
- A discussion of the UK business opportunities in the UK's domestic market, including a comparison of the relative importance of export and domestic opportunities

[26] A UK startup providing pay-as-you-go e-scooters. See https://www.e-mute.com/

Box 7. **EINA estimates of future business opportunities in the automotive sector**

- The EINA estimates that UK business opportunities in low emissions vehicles could directly support around 95,000 jobs. This estimate is based on a methodology (see Appendix 2) designed to provide comparable estimates across a diverse set of energy technologies. It is not intended as a forecast for the UK's automotive sector specifically, or to provide a robust comparator against estimates of the current size of the UK automotive industry. This would require a significantly more detailed study of the complex future market dynamics in the automotive sector.

- The EINA estimate does not imply an expectation that business opportunities for the UK automotive sector will reduce. The SMMT estimates that the UK automotive sector currently supports approximately 186,000 jobs. However, the EINA estimate (95,000 jobs) is not directly comparable to this figure for the following reasons:

    - The bottom up EINA methodology, when applied to current ONS data, accounts for approximately 80% of the 186,000 jobs supported by the automotive sector as reported by SMMT.[27]

    - The EINA estimate only includes jobs supported by the manufacture of low emissions vehicles. It is possible that a significant number of jobs will still be supported by ICE vehicle exports, even in 2050.[28]

    - The EINA estimates assume sustained improvements in labour productivity, hence by 2050 the same volume of export would support significantly fewer jobs.

    - For consistency across sub-themes, the EINA estimates assume continued cost reductions in vehicles. The complexity and heterogeneity of the vehicle models in the UK is not explicitly modelled. It is possible, for example, that manufacturers chose to add additional functionality to their vehicles rather than passing all cost reductions through to customers, creating further business opportunities.

[27] The EINA methodology relies on standard industrial classification (SIC) codes and is conservative in allocating SIC codes to the automotive sector, which likely accounts for the discrepancy.
[28] Since large potential export markets for the UK are unlikely to phase out ICE sales

Box 8. **The UK's current automotive industry[29,30]**

- The UK automotive manufacturing industry produced 1,671,166 cars in 2017. Of these, 1,383,437 were exported, with 54% going to the EU. The UK produced 78,219 commercial vehicles in 2017, with 62.5% exported to global markets.
- UK car production has been trending upwards since the early 2000s and remains historically high, despite car production and exports declining year-on-year in 2017 by 3% and 1.1%, respectively.
- Commercial vehicle production declined between 2003-2012 but has broadly flat-lined since 2013; in 2017, UK commercial vehicle production and exports declined year-on-year by 17% and 11%, respectively.
- An estimated 44% of parts for UK-produced cars are domestically sourced compared to around 60% for France and Germany.[31]
- The overall GVA attributed to the automotive manufacturing is estimated at £13 billion in 2017, which was 8% of total UK manufacturing GVA.[32]

Market overview

The market for LDVs is expected to move primarily towards BEVs as costs reduce and passenger car ICEs are phased out. There is a strong LDV BEV market in some countries, notably Norway and the Netherlands, driven by government incentives.[33] Market and policy pathways, including charging infrastructure expansions, unit cost reductions, and further ICE phase-out commitments, are expected to drive exponential growth in the LDV BEV market. In the IEA's 2-degree scenario, EVs are expected to make up 40% of the LDV stock by 2050. The Bloomberg New Energy Finance (BNEF) scenario projects the EV share of new car sales to reach 55% worldwide in 2040, and 70% in Europe. Deployment

[29] Unless otherwise referenced, all figures for the UK's current automotive industry are taken from SMMT (2018, 2016, 2014, 2013) Motor Industry Facts. For 2018, see: https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Motor-Industry-Facts-June-2018.pdf
[30] All figures of the UK's current automotive industry are taken from SMMT (2018).
[31] Automotive Council UK (2017) Growing the Automotive Supply Chain Local Content Analysis https://www.automotivecouncil.co.uk/wp-content/uploads/sites/13/2017/06/Automotive-Council-UK-local-sourcing-content-research-2017-Final-1.pdf
[32] Figure for total manufacturing GVA from Office for National Statistics (ONS) Business Survey 2017.
[33] Clean Technica (2017) Top Electric Car Countries https://cleantechnica.com/2017/08/19/top-electric-car-countries-charts/

of passenger EVs, low-carbon buses and trucks, and CAV packages is shown in Figure 2. Further explanation of our methodology can be found in Appendix 2: .

The MDV and HDV market are expected to decarbonise more slowly than that for LDVs, with uncertainty over the dominant technology. Some cities, including Aberdeen and London, have already adopted low-carbon buses. However, the decarbonisation of the MDV and HDV market is expected to be slower than LDVs because hydrogen and battery solutions are less cost competitive and mature for these vehicles. For example, FCEV trucks are yet to enter volume production—the Nikola FCEV is scheduled to enter production in 2022-23.[34] Nevertheless, the IEA's 2-degree scenario forecasts FCEVs, BEVs, and natural gas-fuelled vehicles to make up 36% of the global stock of buses and 17% of trucks by 2050. Given the immaturity of low-carbon HDV technology, it is unclear which technology will dominate the sector. Although the IEA anticipates that batteries will dominate the HDV market, this would change in a scenario featuring low-cost hydrogen and high FCEV innovation, as in the Disruptive EINA sub-theme report.

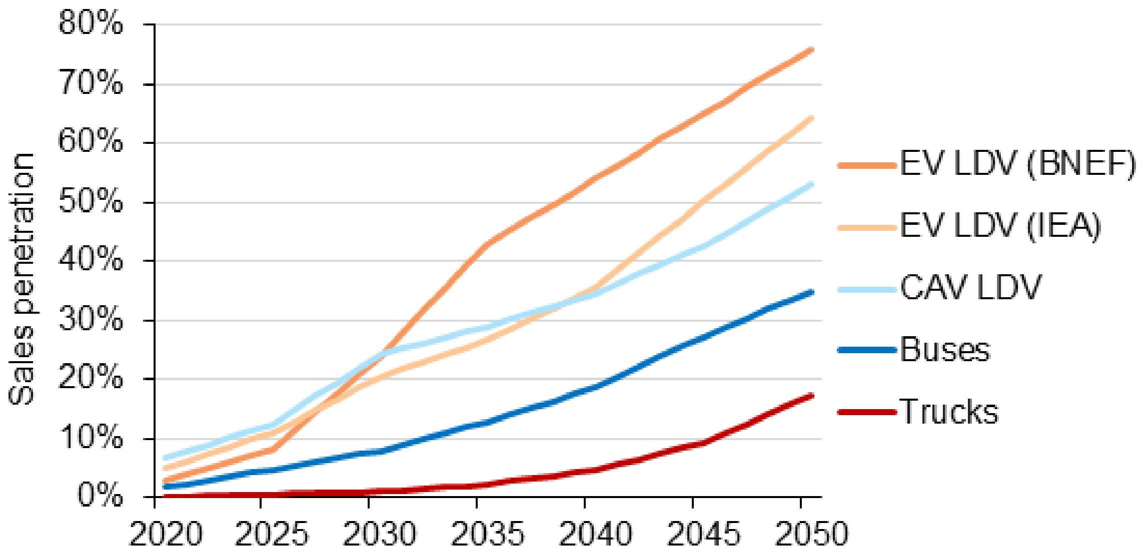
In parallel with the low-carbon transition, vehicles are expected to become increasingly autonomous. Although legislation and consumer attitudes may restrict early-stage adoption of CAVs in some markets, driver cost and safety considerations could drive significant penetration of CAVs by 2050. Moderate CAV uptake could see 25% of global vehicles sold with a CAV package by 2035.[35] This equates to a global market size for CAV packages of around £63 billion.[36] As the CAV package market evolves, software, likely a market opportunity for the UK, will be a stronger driver of market turnover as it comprises a greater share of package costs for more autonomous packages.[37] The software share of market turnover is expected to rise from 35% in 2020 to 44% in 2035.[38]

Despite large shifts in the vehicle market, existing market dynamics are likely to persist. There are some clear differences between ICEs and low-carbon vehicles. For example, a car's ICE has hundreds of moving parts whereas an induction motor has only a handful.[39] Nevertheless, there is still substantial crossover in parts for the

[34] The Drive (2018) website https://www.thedrive.com/news/24715/nikola-tre-is-a-stylish-hydrogen-powered-semi-truck-destined-for-europe
[35] Catapult (2017) Market forecast for connected and autonomous vehicles https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642813/15780_TSC_Market_Forecast_for_CAV_Report_FINAL.pdf The full list of components considered in the CAV package is data security software, HMI, other electronics and architecture, passive components, embedded modem, V2X, actuators, embedded controls, ultrasonic sensors, odemetry sensors, mapping, LIDAR, radar, and cameras.
[36] Ibid.
[37] Ibid.
[38] Ibid.
[39] Teq (2018) EV vs ICE: The Technicalities https://www.teqcharging.com/blog/2017/8/4/ev-vs-ice-the-technicalities

wider vehicle. The overall export market for vehicle parts is estimated at £340 billion.[40] Of this, 54% is expected to remain similar in low emission vehicles, indicating many existing suppliers will continue current operations as the automotive industry decarbonises.

Figure 2. **Estimated future global sales of BEVs and associated technologies**



Source: BNEF; IEA Energy Technology Perspectives; Catapult

[40] Based on a three-year average (2015-2017) for HS codes associated with car parts; 840734,840820,840991,840999,870810,870821,870829,870840,870850,870870,870880,870891, 870892,870893,870894, and 870899. Converted from USD using a 1.3 USD/GBP exchange rate.

Box 9. **Economics of the auto industry**

The market for vehicles and vehicle parts is highly traded. In 2017, 98.9 million motor vehicles were produced worldwide, 80.2 million of which were cars.[41] In the UK, 1.7 million cars were built in 2017, of which 1.3 million were exported.[42] A similar trend is seen in Germany, Italy, Spain, and France, with most cars produced exported.

Most trade is regional, rather than global. While large European nations export around 80% of the vehicles they produce, the EU only exports 25% of the vehicles it produces.[43] This is indicative of global manufacturers often opting for regional production centres of selected models. For example, European carmakers produce over 3 million vehicles in the US and Nissan produces around 0.5 million vehicles in the UK, primarily to supply the European market.

The high level of trade is driven by the large economies of scale in the industry. A typical passenger car assembly plant produces over 200,000 vehicles per year to create the require economies of scale to be competitive. The UK vehicle manufacturing sector is dominated by a handful of large players, with eight plants producing 93% of the vehicles produced in the UK.

The economies of scale in vehicle production, incentivise supply chain agglomeration. Large OEM assembly plants tend to be co-located with parts suppliers. This provides mutual benefits, with OEMS gaining easy access to a range of parts, arriving 'just-in-time', and part suppliers gaining certainty of demand. Although there is significant parts trade across Europe, the mutual benefits of co-location mean that there are clearly defined automotive hubs across, for example, the UK's Midlands and Northern Italy.[44]

[41] ACEA (2018) https://www.acea.be/statistics/tag/category/key-figures
[42] SMMT (2018) https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Motor-Industry-Facts-June-2018.pdf
[43] Approximately 5 million vehicles exported out of 20 million produced. Based on ACEA, 2018: https://www.acea.be/statistics/tag/category/key-figures
[44] Klier & McMillen (2013) Agglomeration in the European automobile supplier industry https://core.ac.uk/download/pdf/39414480.pdf

Figure 3. **The current and future road transport market**

Current market for road transport

- *Production:* Almost 100 million motor vehicles were produced in 2017, of which 80% were cars.
- *Trade:* Vehicles are widely traded, with a focus on regional exports. The UK exports around 80% of vehicles produced, with 94% of commercial vehicle exports and 54% of cars exports going to the EU
- *Markets:* China are expected to drive global demand and production of electric vehicles

Tradability of market

- *Goods:* Vehicles and parts are highly traded, driven by OEMs siting regional production in one or two locations to unlock economies of scale.
- *Services:* New mobility services and transport fuel cell design and advisory services will be highly tradable.
- *Trends:* As the transportation sector decarbonises, high tradability of vehicles and parts is expected to continue.

Trends in deployment

- *Global:* Deployment of low-carbon vehicles is expected to increase from less than 1% of the global stock today to 40% of the LDV stock, 14% of the lorry stock and 33% of the stock of buses by 2050.
- *Growth pattern:* Global growth expected, with strong demand in Europe, Asia and North America.
- *Uncertainty:* Unclear whether BEV or FCEV will drive the decarbonisation of transport, particularly for HDV.

Global and regional market size to 2050

- *Growth trend:* Near exponential growth of low-emission vehicles forecast out to 2050 to meet SDS targets.
- *Key markets:* Europe expected to move first on transport decarbonisation, but the rest of the world will primarily drive growth in low-carbon road vehicles up to 2050.

Source: Vivid Economics

UK competitive position

The UK has a competitive automotive industry, with the 2nd highest European car exports by value.[45] Currently, the UK has automotive strength in ICE assembly and the production of engines. There are 30 manufacturers and 2,500 component providers in the domestic supply chain that produce in excess of 70 vehicle models.[46] The UK has a focus on vehicle assembly rather than parts, with 69% of the GVA in the automotive industry associated with assembly.[47] An estimated 44% of parts for UK-produced cars are domestically sourced compared to around 60% for France and Germany.[48] However, the local content of UK-produced cars has grown in recent years, indicating a rise in competitiveness of vehicle parts.[49] Over 160

[45] World's Top Exports (2019) Car exports by country http://www.worldstopexports.com/car-exports-country/
[46] SMMT website. UK automotive industry https://www.smmt.co.uk/industry-topics/uk-automotive/
[47] Vivid Economics (2018) Accelerating the EV transition https://www.wwf.org.uk/sites/default/files/2018-03/Final%20-%20WWF%20-%20accelerating%20the%20EV%20transition%20-%20part%201.pdf
[48] Automotive Council UK (2017) Growing the Automotive Supply Chain Local Content Analysis https://www.automotivecouncil.co.uk/wp-content/uploads/sites/13/2017/06/Automotive-Council-UK-local-sourcing-content-research-2017-Final-1.pdf
[49] Ibid.

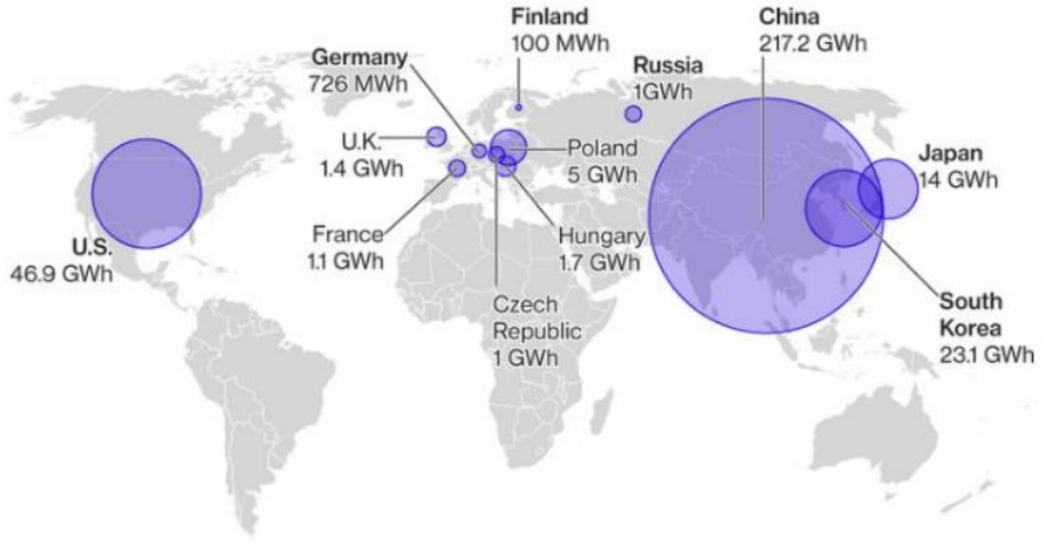
countries import UK-built vehicles, illustrating the strong international position of the industry.[50]

There are ongoing efforts to ramp up LDV BEV production in the UK. Although the global EV industry is immature, the UK has emerging strength in BEV production. The London EV Company manufactured the world's first electric taxi in the UK[51] and BMW is set to build electric-powered Minis in Oxford from 2019.[52] In 2016, the UK-produced Nissan Leaf captured 20% of the EU BEV market.[53] Since then, this market share has fallen and is expected to fall further as EV offerings become more varied. Nevertheless, it demonstrates the capability for the UK to be a leader in the industry, if OEMs site production in the UK.

In addition to BEV assembly, the UK hosts an EV battery production plant and could continue to capture a significant share of the European market. Workshop evidence indicates there are ongoing efforts to attract additional battery production to the UK. The Faraday Challenge seeks to drive battery innovation in the UK, but international competition in both this area and production will be intense.[54] Figure 4 provides a short-term view of existing and planned battery production plants globally, with the UK expected to maintain a significant share of European production capacity if the domestic supply chain continues innovating.

[50] SMMT website UK automotive industry https://www.smmt.co.uk/industry-topics/uk-automotive/
[51] House of Commons Business, Energy and Industrial Strategy Committee (2018) EVs: driving the transition https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/383/383.pdf
[52] BBC (2018) Electric Powered Minis to be built in China https://www.bbc.co.uk/news/business-43166956
[53] House of Commons Business, Energy and Industrial Strategy Committee (2018) EVs: driving the transition https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/383/383.pdf
[54] Innovate UK (2017) The Faraday Challenge—part of the Industrial Strategy Challenge Fund https://innovateuk.blog.gov.uk/2017/07/24/the-faraday-challenge-part-of-the-industrial-strategy-challenge-fund/
Financial Times (2018) Batteries are the next frontier of industrial competition https://www.ft.com/content/6229df22-58e4-11e8-bdb7-f6677d2e1ce8

Figure 4. **Existing and planned battery manufacturing capacity (EV and stationary)**



Source: BNEF

Global and UK production and exports of low-carbon medium and heavy-duty vehicles are more limited. Although less mature, the UK has established a competitive edge in low-carbon buses and has early-stage plans for low emission truck production.[55]

- **The UK has electric bus production at multiple sites,** which has already been leveraged to export units abroad.[56] Furthermore, UK firms have a leading position in the development of fuel cell buses. In 2018, Wrightbus unveiled the world's first double-decker fuel cell bus.[57] Later in 2018, Alexander Dennis also revealed a double-decker fuel cell bus.[58] As fuel cell technologies commercialise, UK innovation is essential to maintain its leading competitive position in a quickly evolving market.
- **Unlike buses, the production and export of low-carbon heavy duty trucks is mostly in the development stage**, with no high-volume facility in the UK. However, the UK is home to heavy-duty powertrain and non-road

[55] MotorTransport (2018) Tevva Motors to show benefits of range-extended electric trucks at Freight in the City Expo https://motortransport.co.uk/blog/2018/11/02/tevva-motors-to-show-benefits-of-range-extended-electric-trucks-at-freight-in-the-city-expo/
[56] House of Commons Business, Energy and Industrial Strategy Committee (2018) EVs: driving the transition https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/383/383.pdf
The Manufacturer (2018) UK bus manufacturer secures New Zealand export deal https://www.themanufacturer.com/articles/uk-bus-manufacturer-secures-new-zealand-export-deal/
[57] Electribe.com https://www.electrive.com/2018/11/01/wrightbus-presents-double-decker-fc-bus/
[58] Alexander Dennis (2018) ADL adds hydrogen fuel cell technology to the market's widest range of low and zero emission buses https://www.alexander-dennis.com/media/news/2018/november/adl-adds-hydrogen-fuel-cell-technology-to-the-market-s-widest-range-of-low-and-zero-emission-buses/

mobile machinery production, with battery and fuel cell innovation occurring within these companies. Given the immaturity of the global low carbon HDV market, it remains unclear whether heavy duty trucks will be predominantly BEV or FCEV. The market's immaturity however also provides potentially significant first mover advantage, and with the UK's expertise in fuel cells, there may be a significant opportunity.

The UK is well-positioned to gain a strong competitive position in CAVs. Workshop evidence suggests CAV packages can be broadly disaggregated into 3 categories: software, hardware, and new mobility services. Although the UK is unlikely to export significant hardware, with manufacturing sited in lower-cost locations, the UK can leverage existing software and service strengths to export part of the CAV package. UK artificial intelligence firms are already demonstrating autonomous vehicle technologies, which can act as a strong platform to grow exports.[59] This artificial intelligence strength, coupled with a growing digital services sector, can enable the UK to gain a competitive position in CAV software.[60] Furthermore, the UK's data analytics strength can foster domestic new mobility service business models that could be exported internationally.

The UK faces strong competition in low-carbon road transport from China, Germany, the US, and Japan. The UK was the 10th largest electric car exporter by value in 2017, far behind the US and Germany who held market shares of 39% and 18%, respectively. In the heavy-duty truck industry, the UK faces strong international competition from the US, with Nikola already trialling vehicles tailored for the European market.[61]

Innovation is rapid in the low-carbon vehicle sector. For example, EV energy storage patents have risen substantially since 2015, with China recently overtaking Japan as the world's primary patent filer.[62] For the UK to avoid quickly falling behind these fast-moving countries, there must be strong domestic innovation in low-carbon vehicle technologies.

[59] Oxbotica website https://www.oxbotica.ai/fleet-of-driverless-vehicles-using-uk-built-software-to-be-trialled-between-oxford-and-london-in-2019/
[60] *Financial Times* (2018) UK digital technology sector outpacing wider economy https://www.ft.com/content/401955c2-58f1-11e8-bdb7-f6677d2e1ce8
[61] Green Car Congress (2018) Nikola Motor introduces Nikola Tre heavy duty hydrogen-electric truck for Europe https://www.greencarcongress.com/2018/11/nikola-motor-introduces-nikola-tre-heavy duty-hydrogen-electric-truck-for-europe.html
[62] Eureka (2018) Electric car battery report shows China overtaking Japan https://www.patsnap.com/blog/china-electric-vehicle-batteries-energy-storage

Figure 5. **The UK's competitive position in trade of transport goods**

Current UK competitiveness

- *Shares (cars, electric cars, trucks, vehicle parts):*
  Global ~ 6%, 1%, 1%, 2%*
- *Strengths:* Innovative domestic industry with 20 R&D centres, and internationally competitive car assembly plants.
- *Weaknesses:* Relatively lower vehicle parts exports compared to other leading European manufacturers.

Competitor– Germany

- *Shares (cars, electric cars, trucks, vehicle parts):*
  Global ~ 21%, 18%, 8%, 16%*
- *Strengths:* World leading car, truck and vehicle parts industry; possesses many original equipment manufacturers with global reach.

Competitor – Japan

- *Shares (cars, electric cars, trucks, vehicle parts):*
  Global ~ 13%, 7%, 7%, 9%*
- *Strengths:* Leading original equipment manufacturers with global reach; deep strength in car assembly.

Competitor – China

- *Shares (cars, electric cars, trucks, vehicle parts):*
  Global ~ 1%, 1%, 3%, 8%*
- *Strengths*: Competitive in vehicle parts; produces more electric cars than the rest of the world combined.
- *Weaknesses:* Limited exports, including EVs, despite leading production.

**of content by value*

Source: *World's Top Exports (2019) http://www.worldstopexports.com/electric-cars-exports-by-country/ using data taken from the International Trade Centre*

Box 10. **Industry workshop feedback regarding business opportunities**

- If the UK innovates and attracts a few additional assembly plants, it can capture a higher market share in low-carbon vehicles compared to ICEs, particularly for BEV LDV assembly.
- However, under a low scenario it is entirely possible that the UK has close to zero low-carbon vehicle production in 2050.
- A CAV package is quite separable; the UK is likely to have a stronger business opportunity in the software component of a CAV package rather than hardware; the UK is weak in sensor manufacturing.
- Within HDVs, hydrogen buses offer a good opportunity for the UK following early deployment and innovation.

Table 17. **Export market shares and innovation impact – road transport**

Technology	Tradeable market 2050 (£bn)	Current market share of related goods and services	2050 outlook with strong learning by research			
			Market share*	Captured turnover (£m)	Captured GVA from exports (£m)	Rationale for the impact of innovation on exports of related equipment and services
LDV BEV (assembly)	**EU: 80** RoW: 680	**EU: 20%**[63] RoW: ~0%	**EU: 8%** RoW: 1.6%	**EU: 6,300** RoW: 11,000	**World: 4,100**	The UK market share falls because of substantial market expansion but is double LDV ICEs market share by 2050. This is driven by the UK leveraging a strong existing automotive industry and an early-stage competitive position in EVs.
HDV low emissions truck (assembly)	**EU: 28** RoW: 75	Not commercial	**EU: 4%** RoW: 1%	**EU: 1,100** RoW: 750	**World: 440**	The UK market share increases to equal current UK share in HDV ICEs by 2050. This is driven by existing producers switching to low- emissions vehicles.
HDV low emissions buses (assembly	**EU: 18** RoW: 73	**N/A**	**EU: 6%** RoW: ~1.5%	**EU: 1,100** RoW: 1,100	**World: 510**	The UK market share increases to double that of the current UK share of the HDV ICE market by 2050. This relies on the UK leveraging emerging electric and fuel cell bus expertise to enable exports.

[63] This is the figure from 2016. The general immaturity of the EV producer market drives this high 20% figure. As EV production expands regionally this figure is likely to fall. House of Commons Business, Energy and Industrial Strategy Committee (2018) EVs: driving the transition https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/383/383.pdf

Technology	Tradeable market 2050 (£bn)	Current market share of related goods and services	2050 outlook with strong learning by research			
			Market share*	Captured turnover (£m)	Captured GVA from exports (£m)	Rationale for the impact of innovation on exports of related equipment and services
Batteries (LDV)	**EU: 20** RoW: 150	**EU: 20%** RoW: ~0%	**EU: 8%** RoW: 1.6%	**EU: 1,400** RoW: 2,500	**World: 920**	The UK market share increases to double that of LDV ICEs by 2050. This is driven by electric battery production being co-sited with LDV BEV production. This relies on the UK innovating in BEVs and gaining a strong competitive position in vehicle assembly.
Rest of electric power train (LDV)[64]	**EU: 10** RoW: 100	**EU: 20%** RoW: ~0%	**EU: 8%** RoW: 1.6%	**EU: 910** RoW: 1,600	**World: 590**	The UK market share increases to double that of LDV ICEs by 2050. This relies on the UK innovating in BEV LDVs and gaining a strong competition position in vehicle assembly.
Fuel cells (MDV and HDV)	**EU: 5** RoW: 71	**N/A**	**EU: ~5%** RoW: ~3%	**EU: 280** RoW: 1,800	**World: 600**	The UK market share increases to a quarter of Germany's current market share by 2050. The UK supplies specialised components for a fuel cell stack as part of a global value chain.

[64] This excludes batteries.

Technology	Tradeable market 2050 (£bn)	Current market share of related goods and services	2050 outlook with strong learning by research			
			Market share*	Captured turnover (£m)	Captured GVA from exports (£m)	Rationale for the impact of innovation on exports of related equipment and services
CAV packages (LDV)	**EU: 22** RoW: 140	**N/A**	**EU: ~9%** RoW: ~3%	**EU: 1,800** RoW: 11,000	**World: 4,300**	The UK market share increases substantially to triple the current share for motor vehicles and electronic products. This is driven by the UK leveraging deep expertise in key techniques, such as artificial intelligence, to export primarily the software component of the CAV package.

Note: ** Future market shares are not a forecast, but what UK business opportunities could be potentially. The possible market share of the UK, and rationale for the impact of innovation, are based on stakeholder input gathered in a workshop. N/A indicates data is not available.*

Source: *Vivid Economics*

UK business opportunities from export markets

Box 11. **Interpretation of business opportunity estimates**
The GVA and jobs estimates presented below are *not* forecasts, but instead represent estimates of the potential benefits of the UK capturing available business opportunities. The presented estimates represent an unbiased attempt to quantify opportunities and are based on credible deployment forecasts, data on current trade flows, and expert opinion, but are necessarily partly assumption-driven. The quantified estimates are intended as plausible, but optimistic. They assume global climate action towards a 2 degree world and reflect a UK market share in a scenario with significant UK innovation activity.[65] More information on the methodology, including a worked example, is provided in Appendix 2, and a high level uncertainty assessment across the EINA subthemes is provided in Appendix 3.

Our analysis suggests that growth of UK exports in low-carbon road transport could support £11 billion to GVA per annum and 73,000 jobs by 2050, as shown in Figure 6 and 7. This is driven by large expected increases in the low-carbon road transport market. For example, according to the IEA, annual sales of battery electric LDVs are forecast to increase over 100x by 2050.[66] The size of the potential opportunity is partly driven by optimistic estimates of the future UK market share. As set out in Table 17, the opportunity is quantified using UK market shares which represent significant increases on its current share in ICE vehicles. Our analysis assumes the UK can capture 8% of the BEV LDV market in the EU by 2050, double the current ICE share. Although a large rise, the UK captured an 8% share of car exports to the EU in 1997, indicating that it can fluctuate.[67] A large contribution to the total opportunity comes from LDV BEV exports, which are expected to contribute £5.6 billion in GVA and 38,000 jobs by 2050. Whether this opportunity is realised will, to a large degree, depend on OEM investment decisions, as shown in Box 12.

Exports of low-carbon MDVs and HDVs are expected to support nearly £1 billion in GVA and 6,500 jobs by 2050. Low-carbon buses are expected to contribute £0.5 billion in GVA and 3,500 jobs by 2050. Low-carbon trucks can add

[65] Note, other IEA climate scenarios were also used as a sensitivity. Where the level of global climate action has a meaningful impact on market size, this is highlighted in the market overview section. Full results are available in the supplied Excel calculator.

[67] The 1997 market share figure is based on UN COMTRADE data. It uses 8703 as the HS code.

£0.4 billion in GVA and 3,000 jobs by 2050. UK firms are already winning electric bus contracts abroad and have a leading position in the development of fuel cell buses.[68] Workshop evidence suggests that these competitive strengths in low-carbon buses can drive further innovation and capture a high market share in an immature market.

Furthermore, autonomous vehicle packages can support nearly £4.3 billion to GVA and 24,000 jobs by 2050. Workshop evidence suggests the UK is likely to have a stronger competitive position in software and new mobility services compared to hardware, with manufacturing sited in lower-cost countries. The UK can leverage its strength in the digital technology sector to innovate in CAV software and capture market share. Given between 35-50% of the total cost of a CAV package is expected to be software, this represents a sizeable business opportunity for the UK supply chain.[69] UK firms can enter global value chains with overseas hardware manufacturers to supply a CAV package. Workshop evidence suggests this is feasible, with CAV packages not expected to be supplied by one firm alone.

Although relatively smaller, exports of transport fuel cells equipment can contribute £0.6 billion to GVA and 4,800 jobs by 2050. To determine fuel cell deployment, we deviate from the IEA ETP scenario because it forecasts very low fuel cell demand by 2050. To give a broad indication of what fuel cell business opportunities might be, we assume FCEV comprise 33% and 50% of low emissions truck and bus deployment, respectively.[70] Given this deviation from the IEA ETP, fuel cell business opportunities are caveated with a shaded area in Figure 6 and 7. The UK has existing strength in membrane electrode assembly components for polymer electrolyte fuel cell systems.[71] These components represent a good opportunity for the UK to capture market share in the transport fuel cell market. However, UK firms are likely to locate production close to market, reducing the potential of goods exports. Under this manufacturing outsourcing scenario, IP licensing business opportunities would remain. Additionally, there are good business opportunities for UK engineering consultancies to win expert design and advisory service contracts globally. UK firms have already offered expert design and advisory services for fuel

[68] House of Commons Business, Energy and Industrial Strategy Committee (2018) EVs: driving the transition https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/383/383.pdf
The Manufacturer (2018) UK bus manufacturer secures New Zealand export deal https://www.themanufacturer.com/articles/uk-bus-manufacturer-secures-new-zealand-export-deal/
Electribe.com https://www.electrive.com/2018/11/01/wrightbus-presents-double-decker-fc-bus/
[69] Catapult (2017) Market forecast for CAV https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642813/15780_TSC_Market_Forecast_for_CAV_Report_FINAL.pdf
[70] The percentage is smaller for low emissions trucks because dual fuel technologies are expected to play a stronger role here.
[71] Johnson Matthey website https://matthey.com/products-and-services/fuel-cells/membrane-electrode-assemblies

cell trucks, demonstrating their ability to access overseas service value in fuel cell services.[72]

A shift to low-carbon vehicles will reduce business opportunities in many existing areas of the automotive industry. Although the decarbonisation of transport represents a good business opportunity for the UK supply chain, it will displace numerous existing jobs in the automotive industry. Many jobs, such as ICE car assembly, can be replaced by similar jobs in a decarbonised transport industry. However, some jobs, for example in engine manufacturing, may not be replaced. As such, the 2050 GVA and jobs figures presented in this analysis should not be considered additive to the entire existing automotive industry.

Box 12. **Foreign direct investment (FDI) and the UK automotive industry**

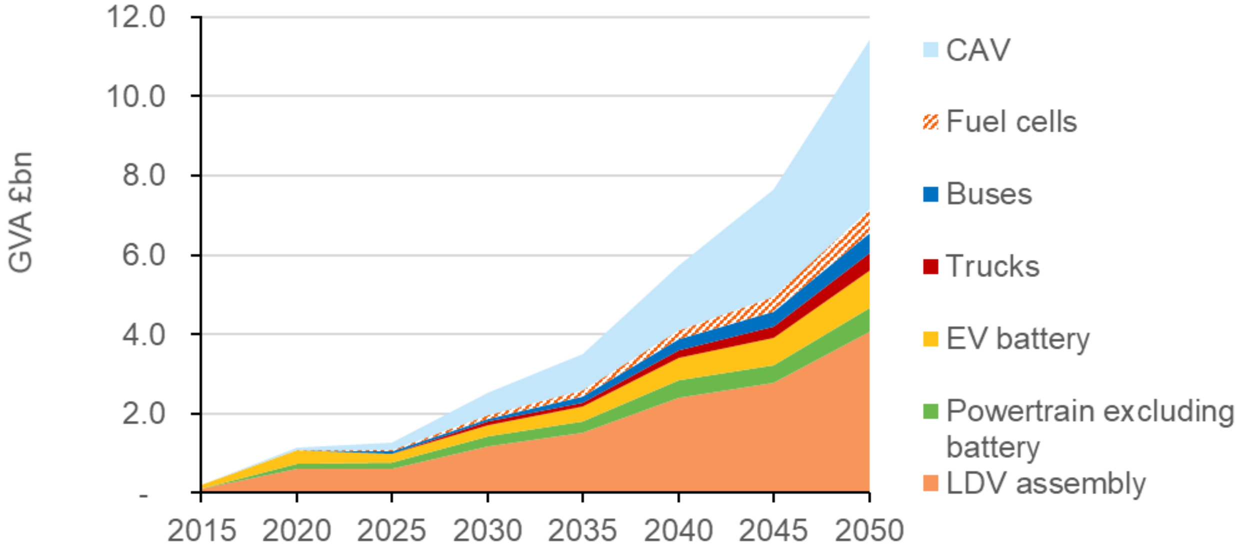
Large (foreign) investment decisions will play a key role in shaping the UK automotive industry. The automotive industry is characterised by large economies of scale, and large investment (often foreign) into manufacturing and assembly plants. As such, for the UK to double its current ICE market share in low-carbon road transport, only a few additional plants are required to increase output considerably. Conversely, for the UK to capture a substantially smaller share in low-carbon road transport compared to ICEs, only a few factories must be lost. In other words, a handful of investment decisions by OEMs will have a big impact. In this light, workshop participants suggested it is entirely plausible that the UK market share of low-carbon vehicle exports is close to zero in 2050, if OEM decisions go against the UK.

There are significant trends beyond innovation likely to affect where automotive FDI flows. Factors such as the fiscal environment, labour costs, energy costs, availability of key suppliers etc. all play a key role in determining the attractiveness of countries for investment in automotive manufacturing.[73] Innovation support, and the availability of innovative parts and skilled labour, may feed into OEM decision making. It is likely to be a relatively small part compared to other location-sensitive costs and benefits.

[72] Ricardo website https://ricardo.com/news-and-media/press-releases/ricardo-helps-toyota-create-second-fuel-cell-electric-zero-emissions-truck

[73]Autoanalysis. (2014). *The Wright Review of Manufacturing.* Available from: https://www.smmt.co.uk/wp-content/uploads/sites/2/The-cost-base-of-the-UK-supply-chain-SMMT-research-for-Wright-Review-April-2014-2.pdf

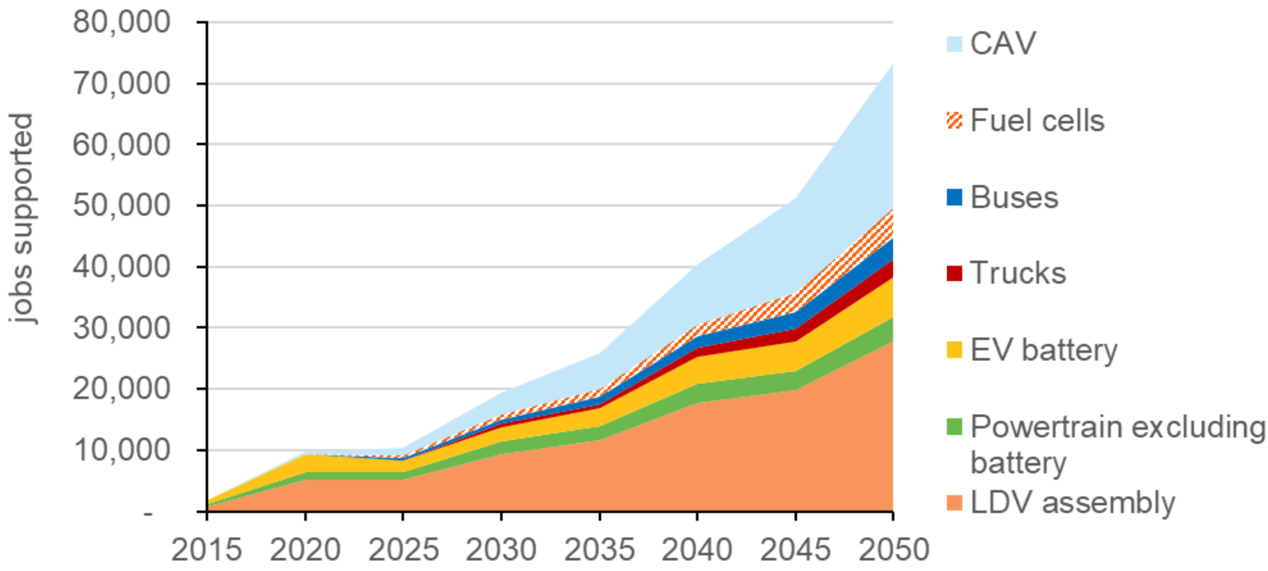
Figure 6. **GVA per annum from export markets by technology – road transport**



Notes: *Patterned line indicates deployment deviates from the IEA ETP scenario. Figures based on fuel cells comprising 33% and 50% of low emission truck and bus deployment in 2050.*

Source: *Vivid Economics*

Figure 7. **Jobs supported per annum from export markets by technology – road transport**



Notes: *Patterned line indicates deployment deviates from the IEA ETP scenario. Figures based on fuel cells comprising 33% and 50% of low emission truck and bus deployment in 2050.*

Source: *Vivid Economics*

UK business opportunities from domestic markets

Discussion

The transition of the vehicle stock to low-carbon can drive substantial domestic business opportunities in low-carbon light duty transport up to 2050. HMG has committed to ending the sale of fossil-fuelled cars and vans by 2040, suggesting strong growth in zero emissions vehicles over the next couple of decades.[74] The Committee on Climate Change recently cautioned this phaseout target may be insufficient to meet climate targets, indicating government may have to bring it forward.[75] ESME estimates indicate 34 million light duty battery-electric vehicles on UK roads by 2050, representing a complete replacement of light duty fossil-fuelled vehicle stock in the UK. Given the UK's automotive strength, the

[74] BBC (2018) How will the petrol and diesel ban work? https://www.bbc.co.uk/news/uk-40726868
[75] The Committee on Climate Change (2019) Net Zero The UK's contribution to stopping global warming https://www.theccc.org.uk/wp-content/uploads/2019/05/Net-Zero-The-UKs-contribution-to-stopping-global-warming.pdf

domestic transition to zero emission vehicles represents a substantial business opportunity.

Commercialisation of connected autonomous vehicle (CAV) technologies can drive new opportunities beyond the existing automotive sector. UK firms have a good opportunity to capture value in the CAV package, especially in software. These new business opportunities in CAV technology, coupled with opportunities in LDV manufacturing can enable the UK to successfully replace many of the existing opportunities in the fossil-intensive automotive sector and open new avenues for growth. Transport Systems Catapult supplies future estimates of CAV technologies in the UK as ESME does not include CAV.[76]

If the UK is a first mover in low-carbon vehicle deployment, it can attract OEM manufacturing. If the UK moves first in low-carbon vehicles, a strong domestic market can attract FDI in LDV manufacturing to bring production closer to its core market. But if these decisions go against the UK, as discussed in the export analysis, UK LDV production could fall substantially.[77] Given future LDV manufacturing in the UK is almost entirely reliant on a small number of FDI decisions, future business opportunities are highly uncertain.

UK business opportunities can build on existing strengths in automotive manufacturing and software to capture a high domestic market share of UK low-carbon vehicle sales and autonomous technologies. Across the components considered, the shares of the UK market captured by domestic businesses are outlined in Table 18, and detailed below:

- **LDV assembly, powertrain excluding battery, and EV battery**: the UK domestic market share grows to 20% by 2050, one and a half times the domestic share in ICE vehicles in 2017.[78] Although LDV assembly, powertrain excluding battery, and EV battery production may not necessarily be co-sited, the UK's relative domestic competitiveness in each of these three categories is assumed to be equal. For the UK to realise growth in domestic market share, its supply chain must remain at the forefront of automotive innovation and attract additional original equipment manufacturers (OEMs) to locate production in the UK. The UK is already proven in zero emissions LDV manufacturing, capturing 20% of the EU market in 2016, indicating domestic market share growth is plausible under a high innovation scenario.[79]

[76] Transport Systems Catapult (2017) Market Forecast for Connected and Autonomous Vehicles
[77] SMMT (2018) Motor Industry Facts 2018 https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Motor-Industry-Facts-June-2018.pdf
[78] The market share for ICE LDVs in 2017 was 13%. This 13% figure is calculated by dividing new car sales in the UK in 2017 by domestically manufactured cars sold domestically. Sourced from SMMT.
[79] House of Commons Business, Energy and Industrial Strategy Committee (2018) https://publications.parliament.uk/pa/cm201719/cmselect/cmbeis/383/383.pdf

- **CAV software**: the UK domestic market share can reach 20% by 2050, in line with LDV assembly. Domestic firms can leverage their existing strength in artificial intelligence, data analytics and software to drive innovation in CAV technology and supply the software to all UK-produced light duty vehicles sold to the domestic market.
- **CAV hardware**: the UK domestic market share can grow to 5% by 2050. Stakeholder evidence in the export analysis for low-carbon road transport indicated CAV hardware was likely to be a relative weakness of the UK, with most of the value imported from low-cost countries. Substantial imports prevent domestic firms capturing a high share of the hardware value.

Domestic business opportunities in low-carbon road transport could contribute £3.3 billion in GVA and support around 22,000 jobs per annum by 2050, as shown in Figure 10 and Figure 11. Domestic business opportunities are substantially smaller than export opportunities, as shown in Figure 8 and Figure 9, with production for the domestic market contributing £3.3 billion in GVA and supporting 22,000 jobs by 2050 compared to exports associated with light duty vehicles contributing £9.9 billion in GVA and supporting 62,000 jobs.[80] The structure of the international automotive industry can explain why, unlike most other EINAs sub-themes, export opportunities exceed domestic opportunities. As discussed in the export analysis, regional production for a car model is concentrated in 1 or 2 locations. Therefore, UK manufacturing facilities often must supply all or most regional demand for a model type, leading to a relatively small percentage of output supplied to the domestic market.

LDV assembly and powertrain production are the key drivers of business opportunities in light duty road transport, together contributing £3.1 billion in GVA and supporting over 21,000 jobs per annum by 2050. The UK has already demonstrated it can attract OEM low-carbon light duty vehicle production, with the Nissan Leaf produced and sold in the UK. Further OEMs must locate production in the UK if these business opportunities are to be realised. LDV assembly contributes the largest LDV opportunity with £2.3 billion GVA and supporting 15,000 jobs by 2050. Therefore, it is vital innovation in existing LDV assembly strengths can be leveraged to enable the transition to low-carbon LDV assembly.

CAV software can contribute £0.1 billion and support 700 jobs per annum by 2050, exceeding those in CAV hardware of <£0.1 billion in GVA and <500 jobs. Transport Systems Catapult indicates the cost of software and hardware in an advanced CAV package will be equal in 2035, suggesting equal market turnovers.[81]

[80] These export business opportunities figures do not include opportunities associated with medium and heavy duty vehicles and are therefore lower than the overall figures reported in the export analysis.
[81] Transport Systems Catapult (2017) Market Forecast for Connected and Autonomous Vehicles

However greater UK software expertise and a competitive disadvantage in producing hardware in bulk leads to greater domestic opportunities in CAV software. CAV sales by 2050 are under half ESME estimates for light duty vehicle sales, suggesting CAV business opportunities could be greater if prospects and innovations in CAV technology advance at a quick pace over the next decade than envisaged.

Quantitative results

Table 18. **Domestic market shares and innovation impact – light duty road transport**

Technology	Domestic market 2050 (£bn)	Current share of related UK market	2050 outlook with strong learning by research: Market share (%) *	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
LDV assembly	45	13%**	20%	9,500	2,300	The UK market share in LDV assembly and manufacturing increases to 20%, one and a half times the current ICE market share. The domestic industry leverages its strong existing automotive base to attract additional OEMs to base their regional production facilities in the UK.
LDV powertrain excluding battery	7	13%**	20%	1,400	320	
LDV EV battery	10	13%**	20%	2,200	510	
CAV software***	2	N/A	20%	380	130	The UK captures 20% of its domestic market by 2050, in line with the share for LDV assembly. The UK leverages its strong research base in artificial intelligence, data analytics and software to innovate in CAV software and supply CAV software for all domestically produced vehicles sold in the UK.

Technology	Domestic market 2050 (£bn)	Current share of related UK market	2050 outlook with strong learning by research			
			Market share (%) *	Domestic turnover captured (£m)	GVA (£m)	Rationale for the impact of innovation on domestic deployment of related equipment and services
CAV hardware***	2	N/A	5%	100	40	The UK captures 5% of the domestic market by 2050. UK innovation can enable some high-value manufacturing for domestic supply, but most CAV hardware will be imported from low-cost locations.

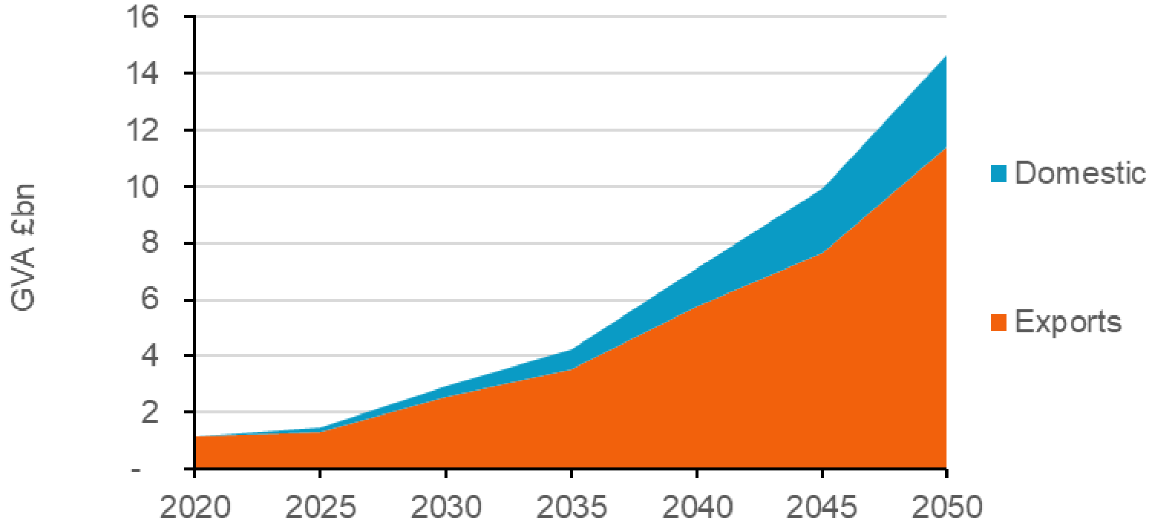
Note: ** Future market shares are not a forecast, but what UK business opportunities could be potentially in the context of the EINAs. The possible market share of the UK, and rationale for the impact of innovation, are based on PRODCOM analysis and additional market research. N/A indicates data is not available.*

*** Market shares for LDVs are based on current ICE market shares from SMMT Motor Industry Facts 2018.*

**** We consider the CAV domestic opportunities as CAV technology supplied to domestic manufacturers who supply their vehicles to their domestic market. The export analysis considers CAV technology supplied to domestic manufacturers who export, and CAV technology supplied to foreign manufacturers.*

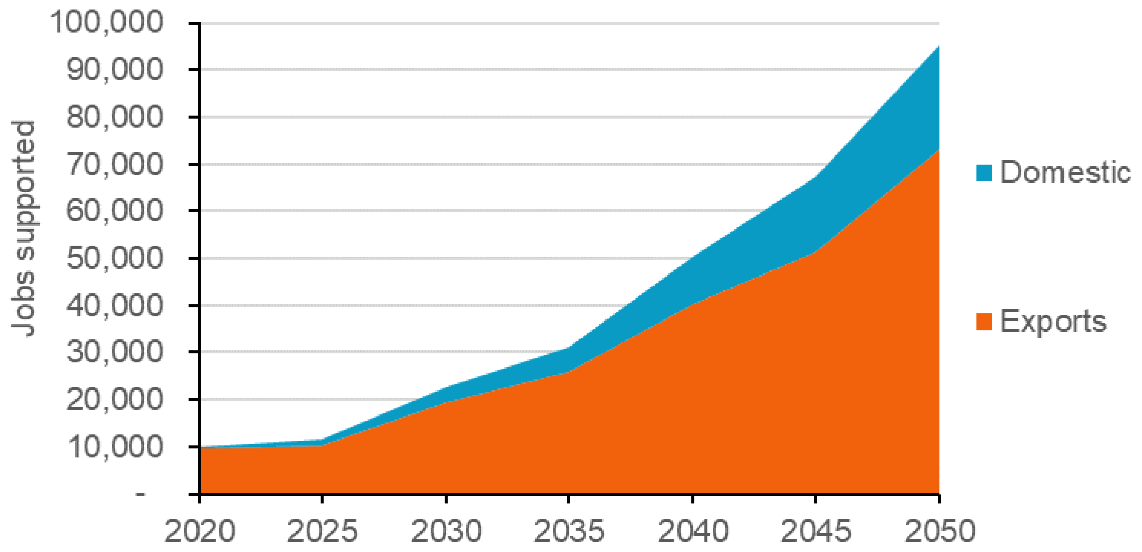
Source: *Vivid Economics*

Figure 8. **GVA per annum from export and domestic markets – light duty road transport**



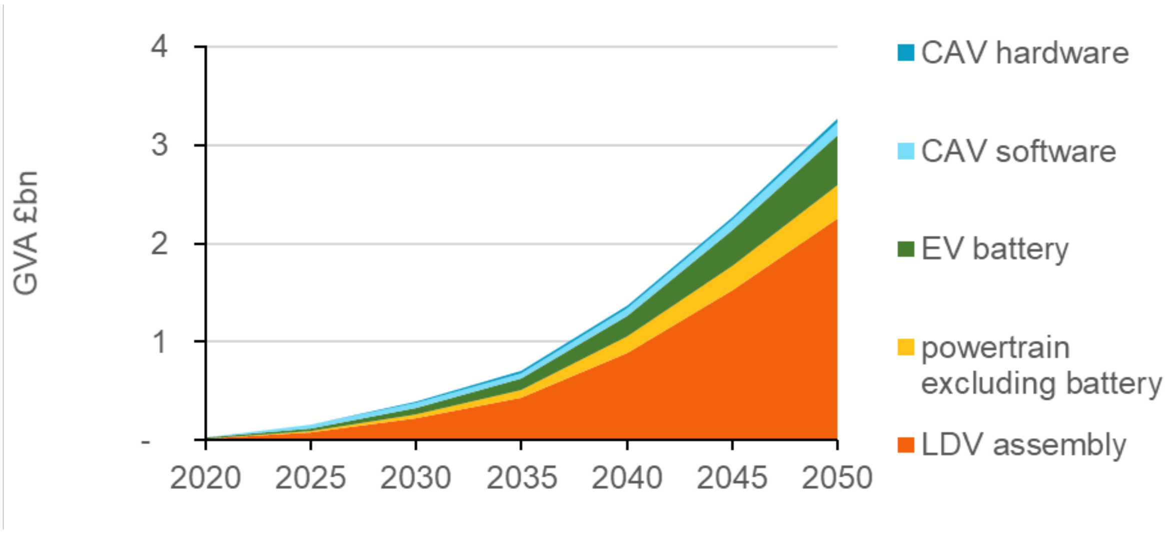
Source: *Vivid Economics*

Figure 9. **Jobs supported per annum by export and domestic markets – light duty road transport**



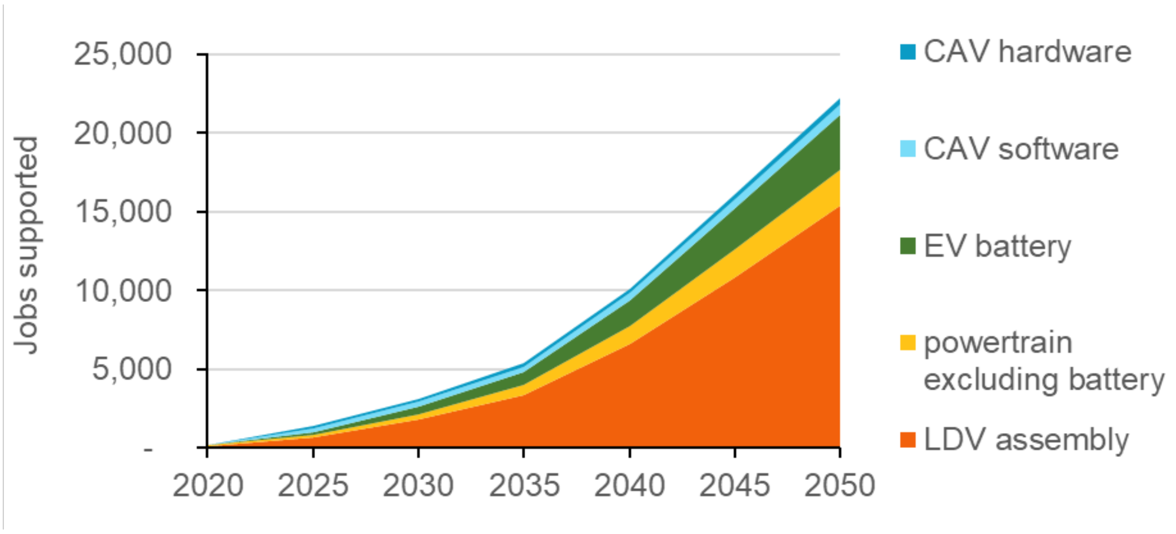
Source: *Vivid Economics*

Figure 10. **GVA per annum from domestic markets by technology- light duty road transport**



Source: Vivid Economics

Figure 11. **Jobs supported per annum from domestic markets by technology – light duty road transport**



Source: Vivid Economics

Market barriers to innovation within road transport

Introduction

Box 13. **Objective of the market barrier analysis**

Market barriers prevent firms from innovating in areas that could have significant UK system benefits or unlock large business opportunities. Market barriers can either increase the private cost of innovation to levels that prevent innovation or limit the ability of private sector players to capture the benefits of their innovation, reducing the incentive to innovate.

Government support is needed when market barriers are significant, and they cannot be overcome by the private sector or international partners. The main market barriers identified by industry are listed in Table 18, along with an assessment of whether HMG needs to intervene.

Market barriers for road transport

The long-term vision for sustainable, clean, and low-carbon transport is well established but can only be realised if technically and economically viable pathways can be found and sufficiently supported. The market for low-carbon transport technologies is growing globally and supported locally, including by the Road to Zero strategy in the UK. In the past, industry has responded to changing requirements incrementally, but the scale and speed of change taking place now is unprecedented and requires a more coordinated, whole system approach. With new technologies comes the requirement for new skill sets in the sector, which is another area where the government can support industry.[82]

Table 18 lists the main market barriers in road transport, along with an assessment of whether HMG needs to intervene. For each identified market barrier, an assessment of the need for government intervention is provided. The assessment categories are low, moderate, severe, and critical.

[82] Automotive Council (2017) The Roadmap Report https://www.apcuk.co.uk/app/uploads/2018/06/roadmap-report-26-6-18.pdf

- **Low** implies that without government intervention, innovation, investment, and deployment will continue at the same levels, driven by a well-functioning industry and international partners.
- **Moderate** implies that without government intervention, innovation, investment, and deployment will occur due to well-functioning industry and international partners, but at a lower scale and speed.
- **Severe** implies that without government intervention, innovation, investment, and deployment are significantly constrained and will only occur in certain market segments or must be adjusted for the UK market.
- **Critical** implies that without government intervention, innovation, investment, and deployment will not occur in the UK.

Table 19. **Market barriers**

Market barrier to innovation in road transport	Relevant for	Need for HMG support
The high cost and technical risk of innovation for novel vehicles incentivise a 'wait and see' approach, stalling innovation.	Vehicles	Severe
Deployment of FCEVs and refuelling stations requires a significant amount of coordination. Without a convenient and extensive network of refuelling stations, FCEV market growth is limited.	FCEVs	Severe
Appropriate regulation is needed before automated vehicles can be placed on the market. This includes defining and enforcing safety requirements, defining criminal and civil liability, and adapting road rules for artificial intelligence.	CAVs	Severe
High upfront costs and uncertainty in future demand make it difficult to justify investment in innovation to achieve the necessary economies of scale. This applies particularly to shared infrastructure and innovation for product and supply chain development.	All components	Moderate
The skills gap in manufacturing and servicing of EVs limits innovation capacity and uptake.	Vehicles	Moderate
International coordination around standard designs of refuelling and recharging stations would ensure interoperability. There is limited coordination currently, which reduces opportunities for cost savings.	Vehicles	Moderate

Market barrier to innovation in road transport	Relevant for	Need for HMG support
Current electricity distribution capacity is too low to accommodate the rising EV demand. National and local level coordination, planning, and investment are needed	All components	Moderate
The business case for EV charging and hydrogen refuelling points is limited. With stronger and more predictable demand, this barrier would potentially be resolved.	Vehicles	Moderate
To achieve large-scale mode switching, policy coordination that supports convenient, cost-effective, and integrated alternative transport modes is needed. In the absence of coordinated incentives, consumers do not internalise the wider societal benefits offered by mode switching.	Mode switching	Moderate
The lack of data sharing of vehicle positions and utilisation patterns hinders the development of charging infrastructure. Location planning of charging points would benefit from better data collection and analysis. Currently, data on where and when vehicles are charged is not shared.	Vehicles, smart logistics	Moderate
There is slow turnover of the legacy fleet, which prevents the adoption of new vehicles and better fleet management.	Smart logistics	Low

Source: Vivid Economics analysis and stakeholder input

Box 14. **Industry workshop feedback**

Industry experts raised several areas that require UK Government support:

- A skills gap exists in manufacturing and maintenance of EVs. The BMW mini electric concept could provide support in terms of sharing learnings across industry in the UK.[83]
- International coordination around standard designs is not a severe barrier for hydrogen fuelling, as frameworks are already established, including for required pressure levels.[84]
- EV service providers tend to lock in customers and charge premiums for using charging points of a different provider, making EVs less attractive for consumers.
- Key areas for policy coordination are between local and national levels of government. For example, local government is responsible for public transport caps and national government is responsible for fuel duties. To be effective alignment is needed.
- There is a lack of data sharing practices, licenses, and standards. Data security is a concern of industry and leads to data sharing options not being explored. Scotland is the most advanced in the UK, offering a public map of charging stations.[85] Coordination failures between multiple providers in England make it difficult to share data.

International opportunities for collaboration

International collaboration is valuable for high-cost technology development programmes. Replacing parallel development of work streams with coordinated RD&D efforts between international partners can contribute significantly to reducing time scales and optimising resources. This is particularly relevant for pre-competitive aspects of novel technologies, such as developing novel battery chemistries and fuel cell technology, where significant RD&D effort and expense is still needed. Currently, the UK participates in EU programmes and UK-US initiatives to build supply chains in battery production and fuel cells. Continued work offers potential to benefit from the successful development of technologies, potentially at lower cost than working alone.

[83] BMW Group (2017) The Mini Electric Concept https://www.press.bmwgroup.com/united-kingdom/article/detail/T0273884EN_GB/the-mini-electric-concept?language=en_GB
[84] IEA (2015) Technology Roadmap Hydrogen and Fuel Cells https://www.iea.org/publications/freepublications/publication/TechnologyRoadmapHydrogenandFuelCells.pdf
[85] See ChargePlace Scotland: https://chargeplacescotland.org/

Creating an attractive investment environment for foreign companies is key to the assembly of BEV LDVs and the production of batteries in the UK. These industries are somewhat dependent on foreign OEMs investing in developing production capacity in this country. For the UK to succeed in drawing in this foreign investment, the UK needs to create an attractive environment for these potential investors. In the case of vehicle assemblers, this requires ensuring a good local supply of manufacturing skills, ensuring that physical infrastructure is suited to just-in-time delivery and a supportive overall policy environment. For battery cell manufacture an additional requirement is a well-developed chemical supply chain, which the UK chemical industry has begun to engage on.

The UK's design and engineering capability offers an opportunity to participate in product development processes with foreign firms and attract inward investment. UK service providers are active in vehicle development programmes worldwide, placing them in cooperation with leading OEMs worldwide. This capability is then available to UK-based companies. In addition, the UK's engineering capabilities have already attracted some foreign OEMs to base their engineering centres in UK, despite their products not being sold in the UK.[86]

There are opportunities to learn from policy approaches in other countries. There are several examples of success in low-carbon road transport which the UK could learn from. In Japan, for example, the world's first commercial hydrogen-powered fuel cell car was released in 2014. Government support for a 'hydrogen society' gave OEMs the confidence to develop vehicles and fuel suppliers to invest in hydrogen infrastructure.

[86] For example, ChangAn Automotive and Tata Motors.

Appendix 1: Organisations at expert workshop

The following government departments and associations attended the sub-theme workshop:

- APC
- Centre for Connected and Autonomous Vehicles
- ESC
- Engineering and Physical Sciences Research Council
- Low Carbon Vehicle Partnership
- OLEV
- Transport Scotland
- UK Department for Business, Energy and Industrial Strategy
- UK DfT

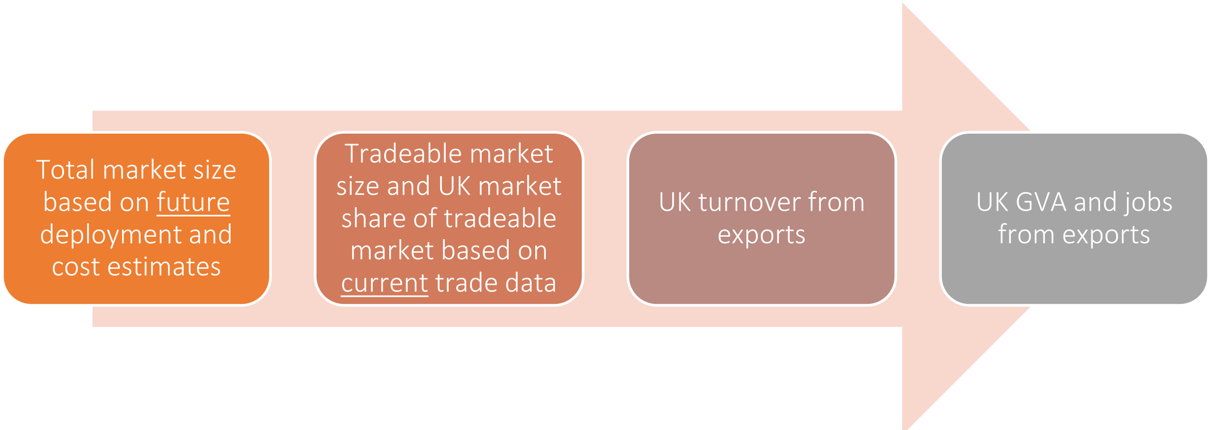
Appendix 2: Business opportunities methodology

Methodology for export business opportunity analysis

In identifying export opportunities for the UK, the EINA process uses a common methodology to ensure comparability of results:

- The **global and regional markets** to 2050 are sized based on deployment forecasts, which come from the IEA when available. For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market.
- The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs created**.

Figure 1 **Methodology for assessing export opportunities**



Source: *Vivid Economics*

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Export business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade data, where available. If the technology is immature or export levels are low, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to reach a market share in the EU and RoW by 2050. The potential future market share is intended as an ambitious, but realistic, scenario. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.
- Market share assumptions are validated at a workshop with expert stakeholders and adjusted based on stakeholder input.

Export business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The EINA methodology does not quantify opportunities associated with installation and operation and maintenance as these are typically performed locally. Exceptions are made if these types of services are specialised, such as in offshore wind.
- The key services to consider are based on desk research and verified through an expert workshop.
- The services considered in the CCUS EINA export analysis are EPCm services, transport and storage services.

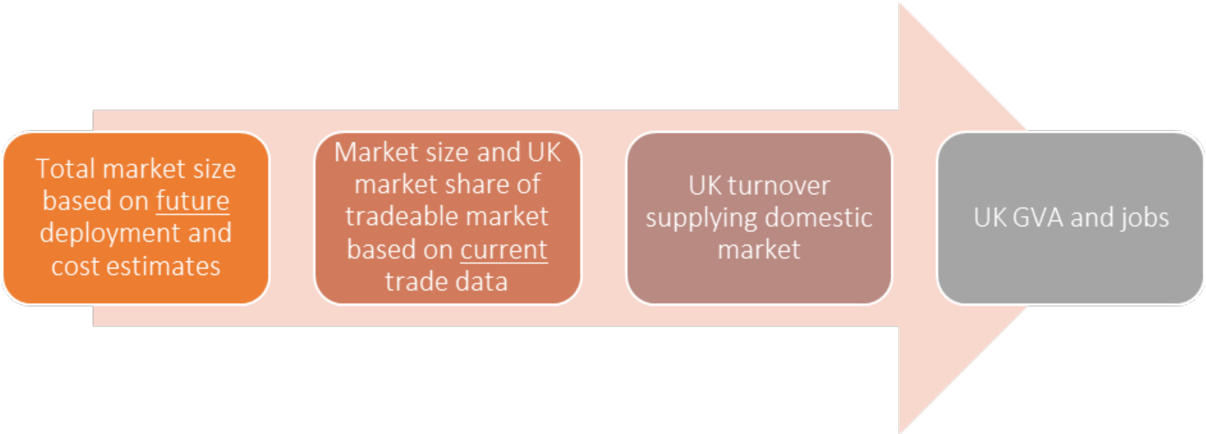
Methodology for domestic business opportunity analysis

To estimate the size of domestic business opportunities for the UK, the EINA methodology, as developed to size export opportunities, is adapted. The domestic analysis leans heavily on insight gleaned from the export analysis, particularly in estimating UK competitiveness and ability to capture market share in its domestic market. To estimate the domestic opportunity, the following methodology is used:

- The **domestic market** to 2050 is sized based on deployment and cost estimates. Deployment estimates are based on ESME modelling used for the EINAs and cost estimates are equal to those from the export work, and based on analysis for each of the EINA sub-themes.[87] For example, deployment of nuclear power is multiplied by costs to obtain annual turnover for the nuclear market.
- The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the UK's market is likely accessible for foreign firms (e.g. electric vehicles), and how much is likely to be exclusively provided by UK companies (e.g. heat pump installation).
- For the traded share of the UK market, the UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below.
- To estimate **UK captured turnover** the traded and non-traded markets are summed.
    - The UK's captured turnover of the UK traded market is estimated by multiplying the tradeable market by the UK's market share.
    - The UK's turnover from the non-traded market is equal to the size of the non-traded market.
- The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by productivity figures for that sector to obtain **jobs supported**.

[87] For detail on cost estimates used, please refer to the Excel calculators provided for each sub-theme, and the individual sub-theme reports.

Figure 2 **Methodology for assessing domestic business opportunities**



Source: Vivid Economics

For all EINA sub-themes, the assessment of the UK's future competitive position is informed by the UK's existing market share of goods and services, the market share of competitors, industry trends, and workshop feedback.

Domestic business opportunities for goods

- Current market shares of UK goods are evaluated based on existing trade (import) and domestic production data, where available. If the technology is immature, UK shares are based on trade data from trade in related goods.
- Based on the importance of innovation in unlocking markets, the UK is projected to potentially increase its market share in its domestic market. This estimate is informed by the previously performed export analysis. It is triangulated using:
    - Market shares of competitor countries, as a benchmark for what is a realistic share if a country is 'world leading'.
    - The maturity of the existing market, which affects the likelihood of market shares changing significantly.
    - The importance of innovation in the technology.

Domestic business opportunities for services

- The EINA focus on service exports directly associated with the technology and innovations considered within the sub-theme. For example, this could include EPCm services around the construction of an innovative CCS plant, but it will not include more generic service strengths of the UK, such as financial services.
- The domestic assessment explicitly quantifies services such as O&M and installation, which are typically not traded but can support a large number of

jobs associated with e.g. heat pumps. For these services, the estimate of potential service jobs supported is based on:
    - An estimate of the total turnover and GVA associated with the service
    - A ratio of GVA/jobs (adjusted for productivity increases) in analogous existing service sectors based on ONS data.
- The key services to consider are based on desk research, verified through stakeholder workshops.

Worked example

1. The **global and regional markets** to 2050 are sized based on illustrative deployment forecasts, which come from ESME when available.[88] For example, deployment of nuclear power (37 GW by 2050) is multiplied by O&M costs (~12% of total plant costs) to obtain annual turnover for the nuclear O&M market (~£2.5 billion by 2050).
2. The **tradability** of the market is estimated based on current trade data, where available, and informed by expert judgement. This determines how much of the global market is likely to be accessible to exports and gives a figure for the tradeable market. In the case of nuclear O&M, tradability is 0% being as it is not tradeable. For the domestic analysis, tradability does not directly feed into our model, but is vital to provide insight on the share of the domestic market UK firms will capture.
3. The UK's **market share** under a high-innovation scenario is estimated based on current trade data, research, and expert consultation. The determination of these shares is discussed in more detail below. For example, for nuclear O&M the UK domestic market share is 100% because the component is not tradeable and therefore foreign firms do not capture some of the value.
4. The tradeable market is multiplied by the market shares to give an estimate for **UK-captured turnover**. For nuclear O&M, market turnover (~£2.5 billion) is multiplied by the UK market share (95%) of O&M to obtain UK-captured turnover (~£2.5 billion by 2050).
5. The captured turnover figure is multiplied by a GVA / turnover multiplier which most closely resembles the market to obtain **GVA**. The GVA figure is divided by labour productivity figures for that sector to obtain **jobs supported**. For example, appropriate Standard Industrial Classification (SIC) codes are chosen for nuclear O&M. This leads to a GVA / turnover multiplier (49%) that is multiplied by market turnover (~£2.5 billion) to isolate GVA (~£1 billion by 2050), which is then divided by labour productivity (~70,000 GVA / worker by 2050) to isolate jobs supported (~16,000 jobs by 2050).

[88] If deployment information is not available from the IEA, alternative projections from, for example, Bloomberg are used. Please see individual sub-theme reports for further detail.

Additional notes

The below lists areas where the analysis under the EINA Road Transport subtheme deviates from the general approach and highlights any major caveats.

CAV deployment: CAV deployment estimates are taken from Transport System's analysis in the absence of ESME modelling for this category.[89] UK sales estimates are available for 2025, 2030 and 2035. Sales outside of this year range are estimated using a linear rate of growth up to 2050.

[89] Catapult Transport Systems (2017) Market Forecast for Connected and Autonomous Vehicles

Appendix 3: Assessment of business opportunities uncertainty

The assessment of business opportunities in the long term, associated with new technologies is uncertain. This assessment does not attempt to forecast what *will* happen. Instead, the business opportunity assessment attempts to provide a realistic and consistent assessment, based on current information, on the business opportunities that *could* be captured by the UK. Whether these opportunities are indeed realised depends on domestic and international developments, political decisions, macro-economic conditions, and numerous other complex variables.

As this assessment is not intended as a full forecast, a formal quantitative sensitivity analysis has not been performed. the below provides a high-level qualitative assessment of the uncertainty associated with the sized opportunity. Note, this is *not* an assessment of how likely the UK is to capture the opportunity, rather it is an assessment of the uncertainty range around the size of the opportunity. The assessment is based on three key factors driving the assessment

1. *The level of future deployment of the technology*. Technologies such as offshore wind are deployed at scale across different energy system modelling scenarios and hence considered relatively certain. In contrast, there is more uncertainty for e.g. hydrogen related technologies. The export analysis is based on 3 IEA scenarios (with numbers provided for the IEA ETP 2 degree scenario). Domestic analysis is based on a single ESME run used across the EINA process.
2. *The potential domestic market share* the UK can capture. This assessment attempts to estimate a plausible market share for the UK across relevant markets. Where this can be based on longstanding trade relationships and industries, this assessment is considered more robust.
3. *Future technology costs and production techniques* are a key driver of the future turnover, gross value added and jobs associated with a technology. For immature technologies for which manufacturing techniques may, for example, become highly automated in future, future costs and jobs supported by the technology may be significantly lower than assessed.

The ratings in the table below are the judgement of Vivid analysts based on the above considerations. The analysts have worked across all sub-themes and the ratings should be considered as a judgement of the uncertainty around the size of the opportunity relative to other sub-themes. As a rough guide, we judge the uncertainty bands around the opportunity estimates as follows:

- **Green**: Size of the opportunity is clear (+/- 20%). Note, this does not imply the UK will indeed capture the opportunity.
- **Amber:** Size of the opportunity is clear, but there are significant uncertainties (+/- 50%).
- **Red:** There are large uncertainties around market structure and whether the technology will be taken up at all in major markets. The opportunity could be a factor 2-3 larger or smaller than presented.

Table 20. **Assessment of uncertainty in business opportunities across sub-themes**

Sub-theme	Uncertainty rating	Comments
Biomass and bioenergy		• **Deployment**: Moderate deployment uncertainty; BECCS can produce negative emissions that have high value to the energy system under a deep decarbonisation pathway; there is moderate uncertainty as to whether BECCS will be used for hydrogen production, as in the ESME modelling, or for power generation. • **UK market share:** Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services and feedstocks. • **Costs and production techniques:** Relatively certain costs with most opportunities associated with labour input rather than immature technologies.
Building fabric		• **Deployment:** Depends on levels of retrofit that greatly exceed those seen to date. • **Market share:** Speculative for traded. However, majority of market untraded, highly likely captured domestically. • **Costs and production techniques:** High share of labour costs (independent of uncertain tech cost).
CCUS		• **Deployment:** Moderate deployment uncertainty; decarbonisation scenarios anticipate rapid uptake of CCUS, though there are few large-scale facilities today. • **Market share:** Moderate market share uncertainty; the UK is likely to be competitive in the storage of CO2 and EPCm services while component market shares are less certain given numerous technology choices and lack of clear competitors. • **Costs and production techniques:** Moderate cost uncertainty; the lack of large-scale facilities today makes estimating future costs difficult.
Heating and cooling		• **Deployment**: Expected to be deployed in most UK buildings by 2050. • **Market share:** some uncertainties, immaturity in markets such as for hydrogen boilers. • **Costs and production techniques:** Relatively certain given relative maturity of boilers and heat pumps. • **Deployment of hydrogen boilers or heat pumps** lead to similar opportunities for UK businesses, while heat networks present a 50 per cent smaller opportunity per household.

Hydrogen and fuel cells		• **Deployment**: Highly uncertain future deployment with a wide-range of 2050 hydrogen demand estimates across scenarios, particularly for export markets. • **UK market share**: Speculative market share for immature traded equipment, but majority of business opportunities associated with certain untraded services. • **Costs and production techniques:** Although deep uncertainty in future hydrogen production costs, for example electrolysis, most domestic costs are associated with labour input rather than equipment.
Industry		• **Deployment**: Relative certainty in deployment as it is based on the 2050 Roadmaps • **UK market share**: Some uncertainty due to poor quality of trade data that may not be representative of technologies within scope. • **Costs and production techniques:** Some uncertainty in costs, particularly for less mature technologies.
Light duty transport		• **Deployment**: Certainty in deployment; low-carbon vehicles will be required in any deep decarbonisation scenario. • **UK market share**: Speculative market share for a relatively immature market; a small number of uncertain future FDI investment decisions generates high uncertainty in overall business opportunities. • **Costs and production techniques:** Highly uncertain future costs, with substantial falls in battery costs a key enabler of BEV uptake.
Nuclear fission		• **Deployment**: Moderate uncertainty in future deployment with some proposed nuclear plants recently cancelled • **UK market share**: Relatively certain market shares based on robust estimates of current nuclear activity; market share growth is dependent on uncertain development of UK reactor IP; however, most business opportunities are associated with untraded activity or areas where the UK has existing strength • **Costs and production techniques:** Uncertain costs for nuclear new build, with dangers of construction overrun; deep uncertainty in costs for immature nuclear technologies, for example SMRs and AMRs.
Offshore wind		• **Deployment**: Offshore wind will be required in any deep decarbonisation scenario, with clear government commitments. • **UK market share**: Expected growth in current market shares given commitments and progress to date. • **Costs and production techniques:** Costs are relatively certain, with clear pathways to 2050.
Tidal stream		• **Deployment**: Global sites for tidal stream are relatively limited, and hence the potential market size well established. • **UK market share**: Although the market is immature, the UK has a an established (and competitive) position. • **Costs and production techniques:** Costs are relatively certain, although the impact of potential scale production is hard to anticipate.
Smart systems		• **Deployment**: High deployment uncertainty given immaturity of smart system market today and evolving business models and regulatory framework. • **UK market share**: Moderate uncertainty given immaturity of the market today and scalable nature of digital smart

		technologies, though there is UK leadership in aggregation services and V2G charging. • **Costs and production techniques**: Moderate uncertainty of cost reductions of batteries and V2G and smart chargers, though costs are expected to continue to fall.

Source: Vivid Economics

Contact us if you have any enquiries about this publication, including requests for alternative formats, at:

Department for Business, Energy and Industrial Strategy
1 Victoria Street
London SW1H 0ET
Tel: 020 7215 5000

Email: enquiries@beis.gov.uk