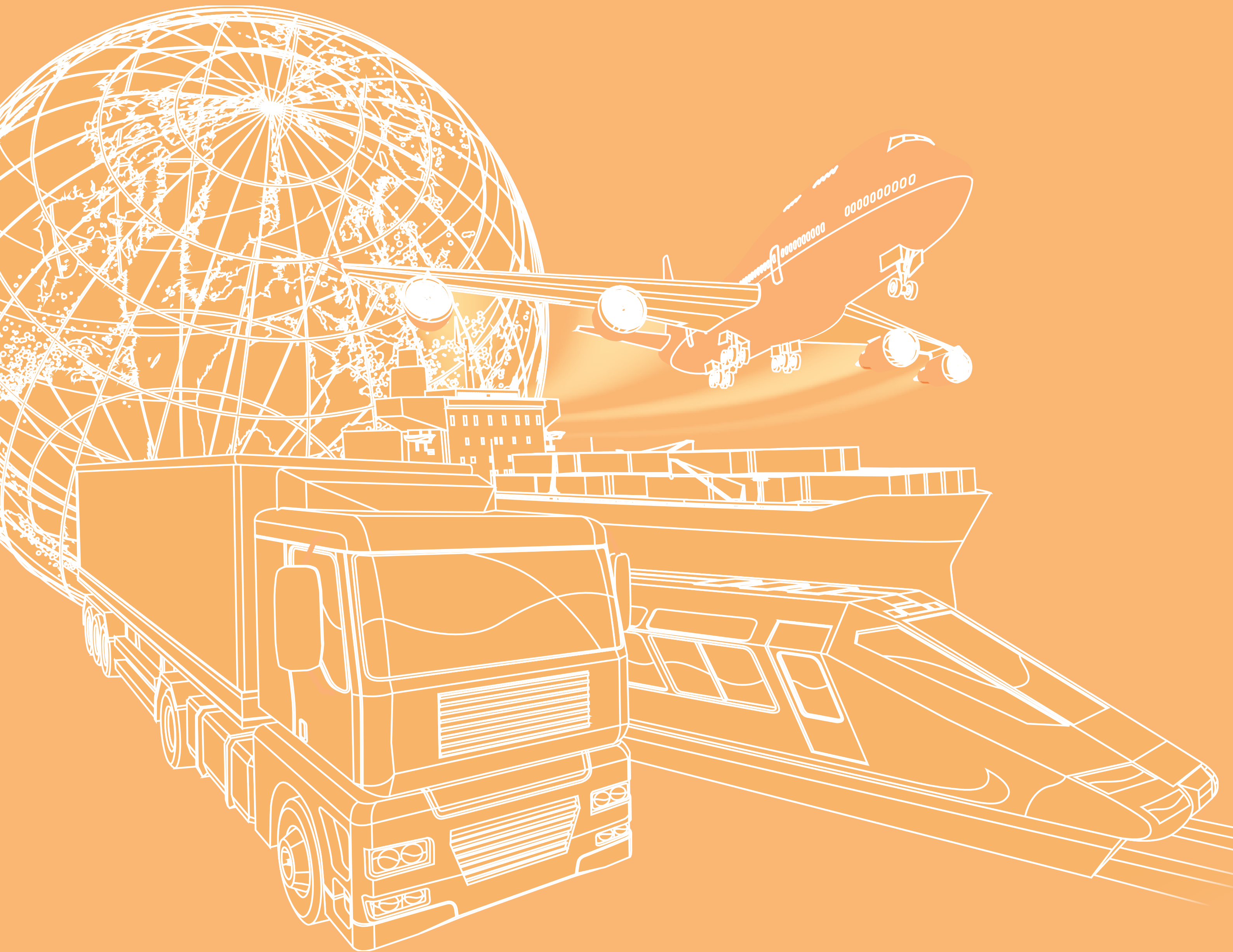
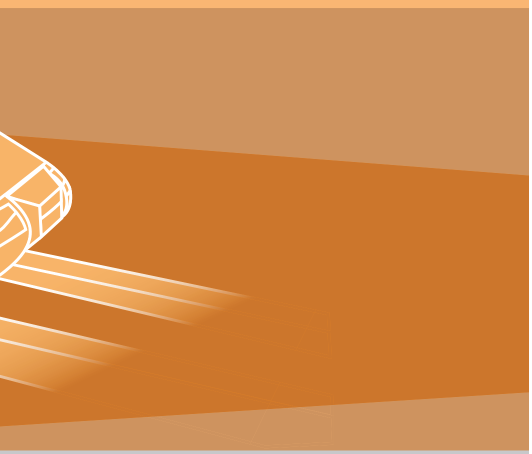
UKPIA

The Future of Mobility in the UK

March 2021





UKPIA

1. Executive Summary

The UKPIA Report “Future of Mobility in the UK” provides a comprehensive assessment of transport decarbonisation to identify important issues, challenges and possible solutions on how the UK’s biggest emitting sector can transform to meet Net-Zero by 2050. The report expands on themes first raised in UKPIA’s 2020 Transition, Transformation, and Innovation Report (the “TTI Report”) and goes into more detail on transport-specific issues, offering technical findings that offer greater evidence in support of UKPIA’s policy suggestions in the TTI Report. The findings can help shape future transport decarbonisation decisions by policymakers, consumers, and those industries most closely involved in the UK’s transport energy system and makes clear the central role of the downstream sector as partner in transport decarbonisation.

- By considering first today’s transport sector – which emits over a third of the UK’s GHG emissions – the report shows the many different ways that transport is used: from electric scooters making local deliveries to planes flying thousands of miles. Development of new and deployment of existing technologies can replace fossil fuel use over time, but given how transport is used, each technology will have challenges to overcome and some uses will be better suited for certain technologies.

- Second, the transition itself is considered. While, to date, policies have been successful in reducing vehicle tailpipe emissions and increasing biofuel content in petrol and diesel fuels, a change of greater magnitude will be needed to decarbonise more comprehensively. The Energy Vector Transition looks at the importance of accounting for all GHG emissions in transport – from manufacture of vehicles and their energy vectors, and even the recycling of some materials used, to highlighting the importance of a systems-based approach to decarbonisation.

- While technologies and how we introduce them will be absolutely vital to decarbonising the transport sector – as well as developing opportunities that could make the UK a world leader in new technologies – there are other trends that can play an important role too. Blockchain, the rise of mobility-as-a-service, changes in where we work from, and autonomous vehicles may all contribute to reduced overall demand for transport energies and make the enormous task of decarbonisation more manageable while improving economic performance and consumer experience.

- Drawing together the themes explored before, later chapters present snapshots of how each transport sector – roads, rail, aviation and shipping – might evolve as the UK strives to reach its Net-Zero by 2050 target.

The report's final chapter brings together technical and practical findings from each chapter. While the findings are focussed, an overarching theme is the sheer scale of change needed. The following overall views have been reached:

1. To meet Net-Zero, all stakeholders must work together in **pursuing all technology options** with low carbon fuels and hydrogen (both blue and green), along with battery electrification, having important roles to play across the UK's transport modes.

2. **A systems approach**, lifecycle analysis of transport GHG emissions, and frank assessment of transport mode energy provision, storage, and conversion demands are essential ingredients in a transport decarbonisation strategy to ensure significant, achievable GHG emissions reductions at the lowest societal cost.

3. A **mobility paradigm shift** is required, with new technologies and models disrupting existing mobility offers to improve transport energy efficiency.

The UK's downstream oil sector is already at the very heart of transport, both as a central part of product delivery but also in ensuring the mass delivery of energy vectors to the consumer. Changes are already being made to products and consumer offerings to develop new, low and zero-carbon energy solutions for transport. Companies – driven by strong competition, continuing demand for energy for transport in all its forms, and the need to operate sustainably - will continue to innovate and work across all transport modes to deliver fit for purpose products that improve logistics, reduce GHG emissions through the whole supply chain, and ultimately drive a transformed transport sector.

An overarching theme of this paper is the sheer scale of change needed and indeed expected in the Future of Mobility

2. Introduction

As a focal point of manufacturing, energy provision, powertrain technology, information technology, consumer convenience, and regulation, the transport sector is one of the most complex and diverse sectors in the UK economy. In order to meet the UK's ambitious Net-Zero by 2050 objective, all stakeholders must work together in pursuing all technology options to reduce today's transport energy demand, which stands at over 600 TWh/year.[1]

Today, more than 96% of energy for transport is provided by the downstream sector, making it the primary energy provider for UK transport.[1,2]

In the TTI Report, the progress made to decarbonise the UK downstream oil sector itself was highlighted along with the potential means to meet Net-Zero. The sector has made great strides in recent years in the energy vectors it provides – including liquid fuels and electricity:

- UKPIA member companies are developing their own EV charging brands such as bp pulse and Shell Recharge and members are seeking to expand their rapid charging networks in particular as well as creating dedicated EV charging hubs. The early adaptation of refuelling hubs is shown in that there were over 1000 public charging

devices on UK forecourts and service stations at the end of 2020 according to figures from ZapMap.[3]

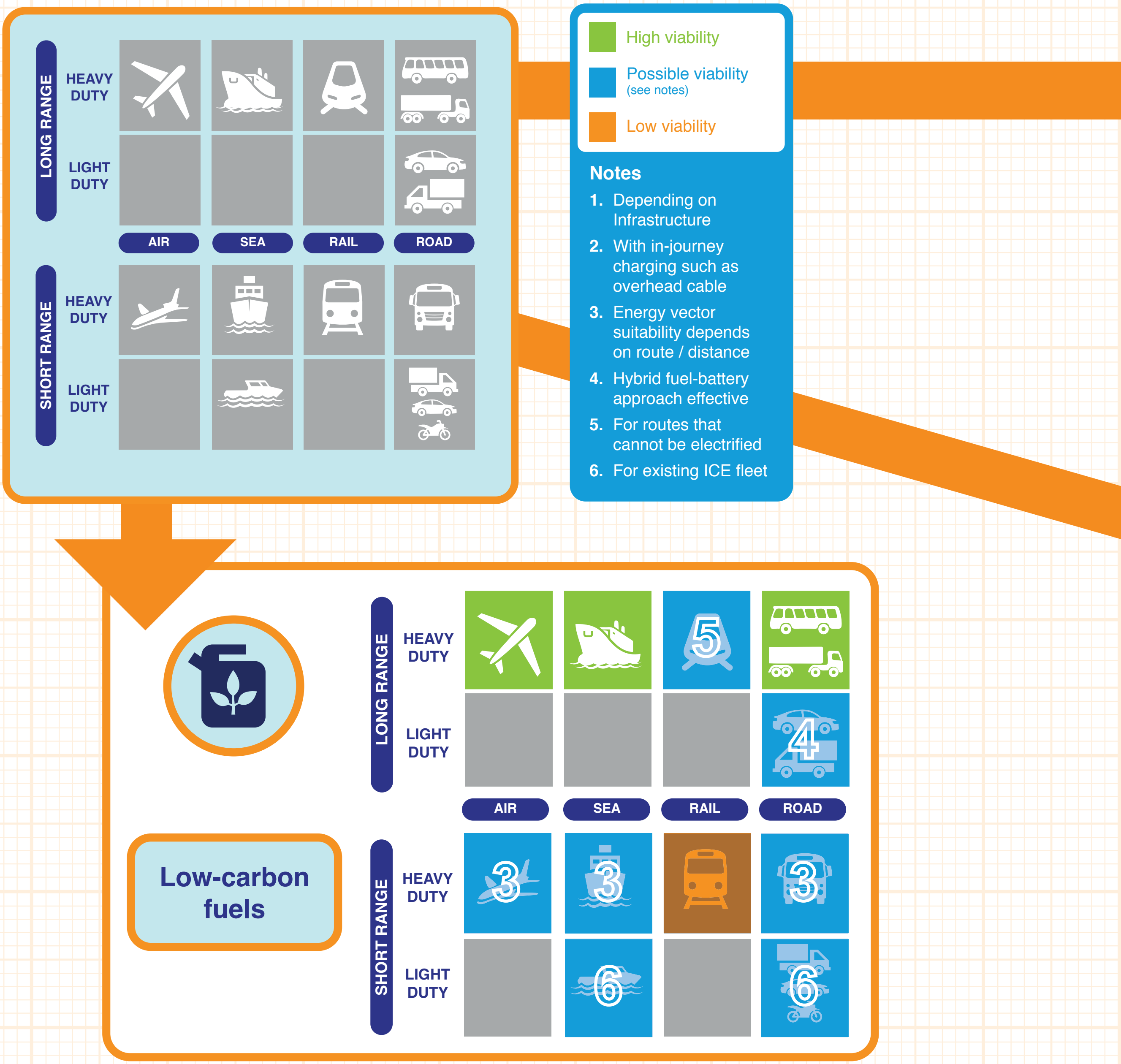
- Continuing renewable fuel blending in 2019 saved a total of 5.37 Mt CO_2e, which is equivalent to taking 2.5 million cars off the road for a full year, both of which demonstrate the sector's commitment and ability to contribute to transport decarbonisation.[4]

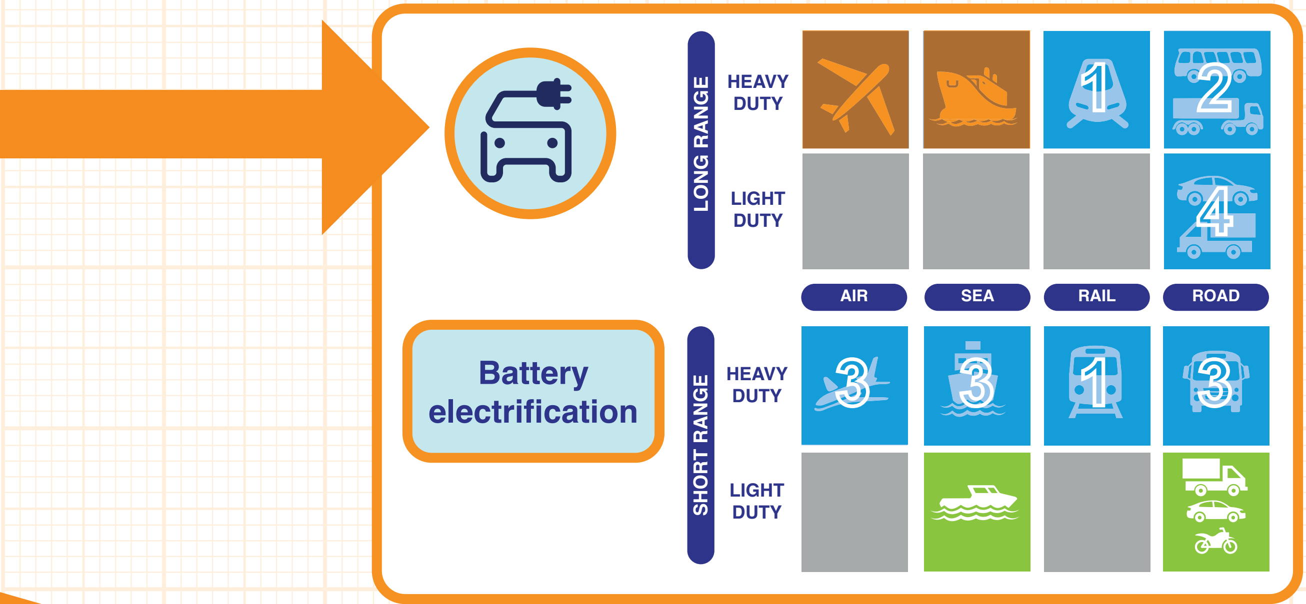
With new technological developments, and government interventions – as set out in the Ten Point Plan for a Green Industrial Revolution – the rate of change is only set to increase.

However, while changes are already being made, the pace of change needs to increase, delivering not just incremental improvements but changes in energy vectors, supply chains, infrastructure and consumer behaviours. A systems-based approach, lifecycle analysis of emissions, and a frank assessment of transport energy provision, storage, and conversion demands are all – in UKPIA's view – essential ingredients in the decarbonisation of transport.

What is clear at these early stages is that all transport energy vectors will need to be pursued, with no single technology able to meet our future mobility demands for every community, every industry, and ultimately every journey.

Figure 1: Potential energy vector suitability for transport modes – further detail on classifications can be found in the table which follows




Battery electrification
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SHORT RANGE
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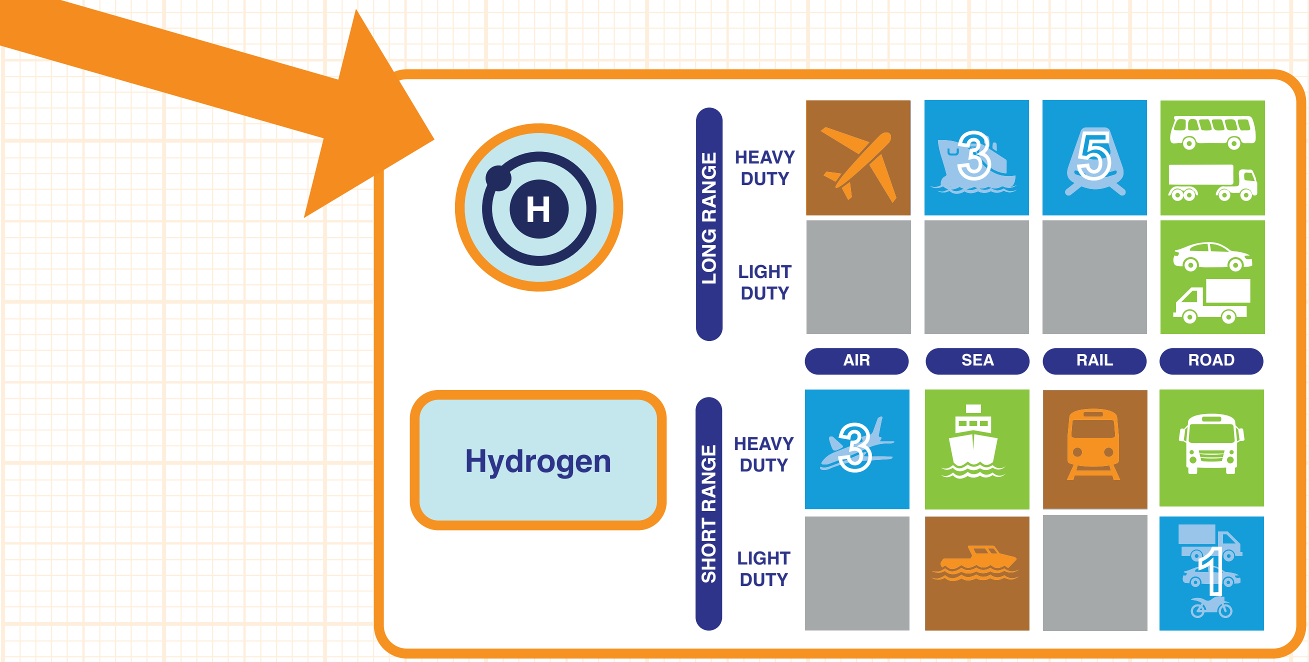
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1

Summary of the Ranges and Duty Cycles of the Main Transport Modes

Road	**Passenger Car**	The primary consumer transport mode accounting for 77% of the distance covered by consumers in 2019.[5] The majority of journeys are <10 miles with vehicles featuring lower utilisation and mass movement demands.
	Urban and Sub-Urban Van	One of two key transport modes for movement of goods and services equipment in cities and towns. Energy demands are similar to that of passenger cars other than potentially greater levels of utilisation.
	Powered Light Vehicle (PLV)	The other key transport mode for the movement of goods in cities and towns. Also used for personal transport. PLVs represent <0.5% of UK transport tailpipe GHG emissions[6] and are well-suited to battery electric propulsion due to their mass and range.
	Bus	Primary urban and sub-urban public transport mode with some longer-range rural routes also deployed. Duty cycle is more energy demanding than other vehicles owing to greater vehicle mass and transient speed demands.
	Large Van and Rigid Axle Lorry	Vans and small lorries supporting higher payload and distance requirements. Energy demands greater than those of smaller vans and passenger cars with longer periods of utilisation.
	High Mileage Car	Small proportion of passenger car segment – primarily utilised for commercial purposes. Greater average distances incorporating more highway use.
	Coach	Long-distance bus mode with reduced transient speed demands but greater range demands.
	Heavy Goods Vehicle	Primary road freight mode with significant energy demands owing to payload and distance requirements.

Off-Road	**Non-Road Mobile Machinery**	Heavy duty transport for commercial activity such as tractors and construction vehicles. Significant energy demands owing to challenging surfaces and need to pull and/or power supplementary equipment. Generally feature shorter ranges than other heavy duty vehicles.
Rail	**Commuter Rail**	Fixed route transport for urban and suburban passenger transport. Efficiency gains compared to road transport due to removed tyre deformation resistance. High energy demands due to vehicle mass requirements.
	Intercity and Freight Rail	Longer-range fixed route transport for intercity travel. High energy demands due to vehicle mass and distance requirements.
Sea	**Light and Leisure Boat**	Small boats with low energy and range demands. Light and leisure boats represent <0.5% of UK transport GHG emissions[7] and are not discussed in detail in this document.
	Inland Waterway or Port Ship	Larger ships used for inland transport (such as river passenger ferries) or port activities (such as tugboats). Greater energy demand owing to vessel mass generally required over short distances.
	International Shipping	Freight ships with high energy demand to meet significant mass movement requirements over long distances.
Air	**Domestic Aviation**	Aircraft meeting domestic/local aviation demand. Aircraft mass is lower (reduced passenger occupancy) and journeys are typically 350-500 miles.[6] Greater energy demand per unit mass moved compared to surface transport modes.
	International Aviation	Aircraft meeting international aviation demand. Aircraft are larger and heavier with greater passenger occupancy requiring significant energy demand for the smallest mass and volume of all modes.

3 Transport: Energy Provision, Storage, and Conversion

Transport is at the heart of the greenhouse gas emission (GHG) reduction challenge. Even with improvements in efficiency, more electric vehicles on our roads, and a greater percentage of biofuels blended into the fuel – sector GHG emissions have remained steady since 1990.[7]

The downstream sector is experienced in the manufacture and provision of all energy vectors and has demonstrable expertise in the accounting of their net well-to-tank (WTT) GHG emissions. Furthermore, in 2019, the UK's transport sector consumed 659 TWh of energy, of which 96% was provided by the downstream sector.

Decarbonisation of transport will be vital in reaching the UK's Net-Zero target, however, transport has other environmental impacts that must be considered as part of this transition, e.g. air quality, UK supply chain resilience, and raw material demand.

3. Transport: Energy Provision, Storage, and Conversion

3.1 The Greenhouse Gas Emission Reduction Challenge

In May 2019, the Climate Change Committee (CCC) published their Net-Zero Report,[8] and accompanying technical report,[9] recommending to the UK Government a new emissions target for the UK: Net-Zero greenhouse gases (GHG) by 2050. This target – a response to increased concentration of GHG emissions from human activity – was subsequently adopted by the UK Government and enshrined in law.[10]

By 2019 the UK had, in fact, already initiated economy-wide decarbonisation, with most sectors reducing their GHG emissions vs 1990 levels, but transport in-use emissions have remained broadly steady. There have been improvements – notably in the efficiency of internal combustion engine (ICE) technologies – that have improved average per-vehicle emissions. However, sector GHG emissions have remained level as overall distances travelled have increased.[7]

Not all emissions for the transport sector occur in-use and it is important to note the manufacture of a vehicle itself also has significant cradle-to-grave GHG emissions (see section 4.2.1)[1] that must be accounted for, particularly when considering a Net-Zero target. Currently, all motored transport modes have a lifecycle GHG emissions impact – even if their tailpipe GHG emissions are zero – and to meet Net-Zero, it is these emissions right across the lifecycle of all vehicles and their use that must be decarbonised. Climate scientists are clear that GHG reduction opportunities missed in the short-term will be more difficult and costly to abate in the long-term.

3.2 Transport Energy Provision in the UK

In 2019, the UK's transport sector consumed 659 TWh of energy, of which 96% was provided by the downstream sector,[2] with the remainder electricity.[11] To date, prioritisation of movement at the lowest cost has led to the proliferation of transport powered by fossil-derived fuels, but this could change in future to take into account other important factors – environmental in particular. The additional and urgent priority to reduce net GHG emissions of transport highlights the need to reduce the use of fossil-derived fuels and embrace the range of technologies available to meet the scale of demand currently supplied by crude oil derived energy.

There are three important facets to transport energy provision. In the UK, all motored transport – whether electric or combustion – is dependent on both energy transfer and energy conversion, with a third dependency for most transport operations (except where in-operation energy transfer can occur, such as rail) being the requirement for on-board energy storage.

The primary energy vectors available for transport include liquid fuels, carbon-based gaseous fuels, hydrogen, and electricity. Bringing together the current needs (energy transfer, conversion, and storage) together with the drivers (cost and sustainability), there are five considerations that can shape our thinking about future transport energy provision. These considerations are simply captured for the main energy vectors on the next page.

Vitally, all energy vectors can reach very low or Net-Zero carbon emissions. It is also noteworthy that no energy vector works for every consideration highlighted in the table, and when considering current capacity there are some limitations in the lowest GHG emission options such as hydrogen, highlighting the need for all technologies. The International Energy Agency (IEA) recently reinforced this point stating that "a broad range of different technologies working across all sectors of the economy" would be required to have a chance of achieving Net-Zero GHG emissions.[15]

The downstream sector is experienced in the manufacture and provision of all energy vectors and has demonstrable expertise in the accounting of their net well-to-tank and greenhouse gas emissions.

The downstream sector is experienced in the manufacture and provision of all energy vectors and has demonstrable expertise in the accounting of their net WTT GHG emissions. Furthermore, the sector plays a crucial role in enabling the storage of electricity, with the UK being the largest producer of high-grade graphite coke for anodes in lithium-ion batteries in Europe.[16] Similarly, new roles may emerge, as the wider energy systems transform, with the potential for use of existing downstream oil infrastructure for storage and distribution of renewably-sourced products like hydrogen or synthetic fuels. Surplus renewable electricity could also be converted via electrolysis of water into easier to store products, stored and distributed through these facilities.[17]

Table 1:
Summary of relative qualitative decarbonised transport energy vector considerations

Green = **high potential or viability**
Orange = **possible potential or viability**
Red = **low potential or viability**

	Liquid Fuels	Gaseous Fuels	Hydrogen	Electricity
Manufacture Cost	Intermediate for low Well-to-Tank (WTT) emissions	Intermediate for low WTT emissions	Currently high for low WTT emissions	Intermediate to low for low WTT emissions
WTT GHG Emissions Reduction Potential	Up to 90% reduction for bio-derived[12], up to 100% reduction if renewable energy derived	Up to 90% reduction for bio-derived[12], up to 100% reduction if renewable energy derived	Up to 100% reduction if renewable energy derived	Up to 100% reduction if renewable energy derived
Transfer/ Movement Complexity	Tankers and pipelines available, minimal input energy required	Energy required for compression, smaller unit size	Further energy required for compression and volatility considerations	Minimal at grid level other than intermittency management, some low voltage network challenges
Transfer / Infrastructure Readiness	Infrastructure and standards in place	Infrastructure development needed for transport, standards in place	Minimal infrastructure available but under development	Infrastructure development needed for scale, standards in place
On-Board Storage Energy Density	High by volume and mass	High by mass	High by mass	Limited by chemical battery energy density
Primary Energy Input and Availability	Finite biomass, highest renewable energy input for e-fuels	Finite biomass, highest renewable energy input for e-fuels	High renewable energy input for electrolysis-derived	Unlimited - limited only by generator capacity
Current Use in Transport (2019)[13,14]	3.2% of energy used in transport	0.13% of energy used in transport	0% of energy used in transport	0.83% of energy used in transport

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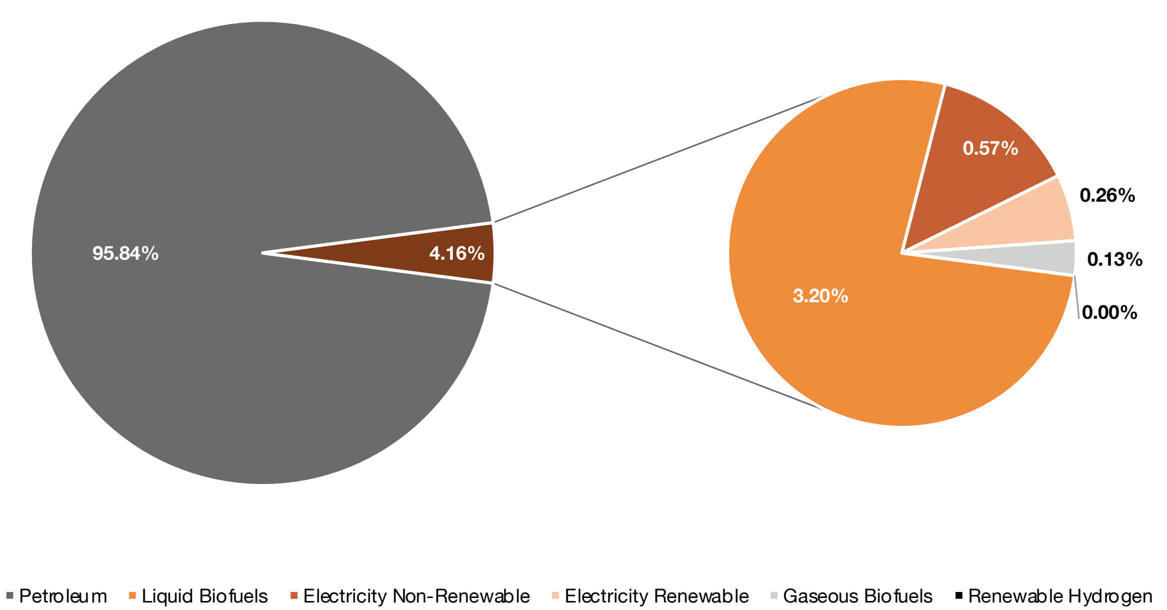
Relative shares of fuels used in UK transport, 2019



Source: Eurostat[13], BEIS[14]

3.3 Other Environmental and Socioeconomic Impacts

Decarbonisation of transport will be vital in reaching the UK's Net-Zero target, however, transport has other environmental impacts. These are outlined here as they will also shape the future of mobility in the UK, but are not discussed in detail in this document.

3.3.1 Air Quality

Vehicles have faced increasingly stringent tailpipe regulations to address air quality with excess levels of air pollutants in urban areas due to be tackled via the implementation of emissions zones. Sulphur oxide (SO_X) emissions have been reduced to near zero for UK road transport, with sulphur having been removed from road fuels, and 2020 saw the mandated global reduction of sulphur emissions for ships – although strict limits have been in place for UK waters for some time. Nitrogen Oxide (NO_X) emissions, while reduced from transport by 47% since 2000, will remain of concern while pre-Euro 6 and Euro VI vehicles remain a significant proportion of the vehicle fleet.[18] Particulate Matter (PM) emissions have decreased by over 40% over the last two decades but will not be easily reduced further with a change to electric vehicles, as road transport PM emissions are not only from the tailpipe (where even the latest diesel ICEs have very low emissions)[19] but also from road, tyre, and brake wear.

DEFRA have published a Clean Air Zone (CAZ) framework[20] offering a template approach for local authorities to adopt. The idea is that there will be similar ICE-vehicle emissions standards in the strictest emissions zone class (D) across cities, although some cities have already implemented ultra-low emissions zones.[21] The first in the UK applicable to passenger cars was the London Ultra Low Emissions Zone (ULEZ),[22] and it is planned that Birmingham and Bath will implement Class D and Class C CAZs respectively in 2021.[23,24] Some local authorities have opted to deviate from the DEFRA CAZ framework and plan to implement powertrain-specific restrictions – notably Bristol and Oxford.[25,26]

As the UK vehicle market is deeply intertwined with that of mainland Europe, it is expected that UK vehicle emissions standards moving forward will remain in line with those maintained by the European Union (EU).

3.3.2 Raw Material Demand

Increased powertrain technology diversity in the UK – particularly the proliferation of battery electric and fuel cell electric powertrains – will require growth in raw material extraction. For example, the increased manufacture of battery electric vehicles (BEVs) has implications for demand of multiple metal elements, and the proton exchange membrane (PEM) of hydrogen fuel cells requires platinum. This can have an impact on product lifecycle considerations such as toxicity, water use,[27] and social risks, where growing awareness will likely demand further supply chain transparency.[28]

Raw material availability, as well as extraction considerations, will play a part in shaping the future of UK transport. In 2019, many leading scientists in the UK sent a letter to the Committee on Climate Change highlighting that to achieve an entirely BEV car and van vehicle parc in the UK – even with the currently most resource-frugal NMC 811 batteries – would require double the current global production of cobalt, and three quarters of the world's lithium production.[29] Moving forward, the UK has the opportunity to become a world leader on the sustainable sourcing requirements for vehicles and energy vectors as well as ensuring that recycling of materials reduces the long-term need for virgin materials.

3.3.3 UK Supply Resilience

The shift to energy vectors based on renewable electricity and biomass will evolve the current UK energy supply dynamic – resulting in new benefits and risks. Increase in biomass demand will necessitate an improved domestic supply chain and is likely to also result in a reduction in the import of crude oil. Sustainable biomass with low indirect land use change (ILUC) emissions is a finite resource, with the likelihood that other countries will also be adopting competing transport decarbonisation policies. Encouragingly, an increase in domestically generated renewable energy could afford the UK some energy resilience benefits for EVs, as well as production of green hydrogen and e-fuels.

However, the increased demand for vehicles utilising these energy vectors is likely to result in a reduction in product supply resilience. There is currently limited battery manufacturing capacity in the UK, with demand due to be met predominantly by imports at least into the 2020s. Therefore, the UK's future of mobility may be underpinned by a shift in energy dependency to product supply dependency that may ultimately shift price volatility – and resultant costs on the end-user – from the in-use phase to the upfront phase of vehicle ownership.

4 The Energy Vector Transition

A systems-based approach is crucial to reducing emissions, especially when considering emissions must be Net-Zero across the whole economy, with knock-on effects in one policy area having the potential to cause problems in others.

The concept of product lifecycle GHG emissions is the next frontier in emissions accounting. To truly account for the net GHG emissions impact of transport (and indeed any product), one must consider the GHG emissions impact over the full lifecycle – 'from cradle-to-grave'.

Offering a quality end-user experience can help accelerate the transition to renewable based fuels and energy vectors.

Other GHG reducing initiatives such as offsetting and nature-based solutions or alternative fuel models can play an important role as part of the transition to Net-Zero in transport.

4. The Energy Vector Transition

4.1 Systems Approach to Decarbonisation

The DfT's Science Advisory Council (SAC) highlighted in their 2020 position – regarding transport research and innovation requirements to support the decarbonisation of transport – that the challenge of decarbonisation must be viewed through the lens of energy vectors and the net GHG emissions impact of these energy vectors.[30]

This principle is also highlighted by Energy Systems Catapult (ESC) who highlight in their 'Innovating to Net Zero' report[31] that a whole systems approach to energy uses and vectors must be adopted to understand and address the Net-Zero challenge.

The importance of a systems approach to transport decarbonisation is also recognised internationally. For example, The US National Renewable Energy Laboratory have recently published their vision for decarbonising transport highlighting the importance of considering interdependencies in the transport and buildings energy systems.[32]

The analysis also highlights the importance of assessing energy vector suitability based on duty cycle, reporting conclusions consistent with those of UKPIA's in section 4.3.

Whilst a systems approach may not perfectly align with existing regulations that focus mainly on in-use or well-to-tank (WTT) emissions, it will be important to deliver net GHG emissions reductions across the whole economy. Thinking about the whole lifecycle emissions of both a vehicle and the energy it uses will enable a system wide decarbonisation of transport while flagging dependencies and knock-on effects in other parts of the economy to reach Net-Zero.

4.2 Product Lifecycle GHG Emissions

4.2.1 Constituent Analyses

In-use emissions are only part of the GHG emissions footprint of transport – to truly account for the net GHG emissions impact of transport (and indeed any product), one must consider the GHG emissions impact over the full lifecycle – 'from cradle-to-grave' – in order to make effective decisions about where and how emissions can be most efficiently and effectively reduced. The constituent analyses of a cradle-to-grave lifecycle analysis (LCA) are:

- Cradle-to-gate (manufacturing including raw material extraction) emissions
- In-use (tailpipe and maintenance) emissions
- Energy vector well-to-tank emissions
- End of life (re-purposing or disposal) emissions

4.2.2 Existing Approaches and Studies

Each constituent analysis identified in 4.2.1 is well-understood in existing frameworks, with:

- Cradle-to-gate emissions analysis in widespread use by many Original Equipment Manufacturers (OEMs) for a number of years;[33]
- In-use tailpipe CO_2 emissions regulated in the UK since 2015,[34]

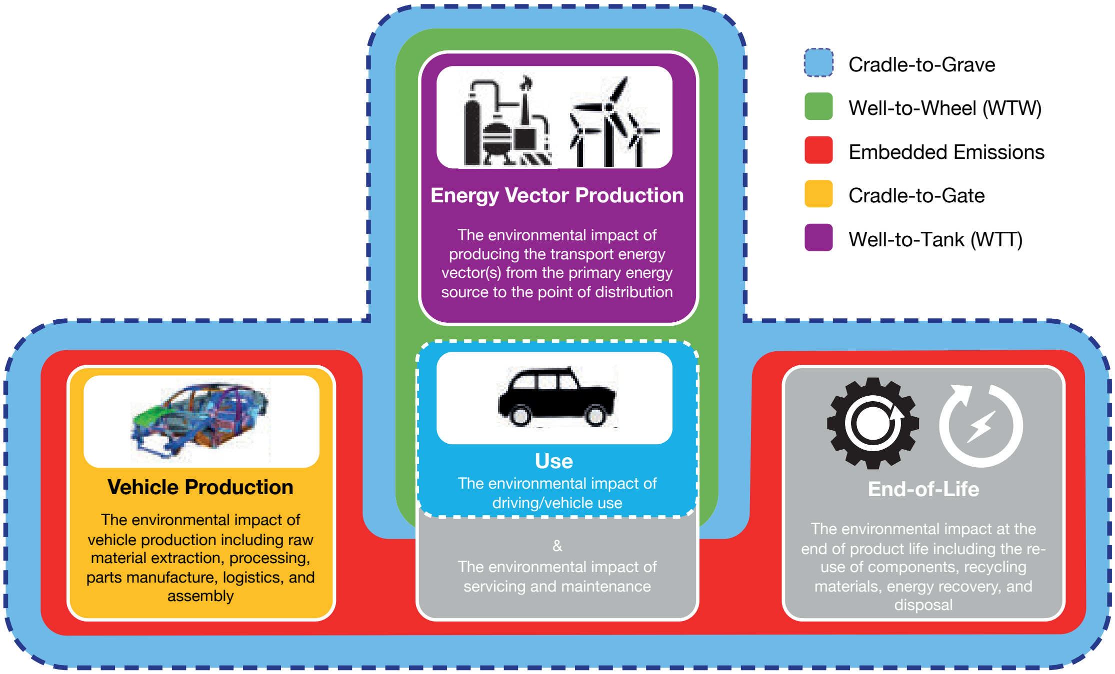


Figure 2: Schematic of cradle-to-grave lifecycle analysis and constituent analyses

- Well-to-tank GHG emissions of fuels an essential consideration for fuel suppliers of greater than 450,000 l/year under the UK's renewable fuels regulations[35,36];
- End of life of vehicles (ELVs) subject to minimum reuse and recovery targets since 2006[37] (although associated GHG emissions are not accounted for in the regulations).

The challenge to resolve in the short-term is to combine existing lifecycle GHG emissions assessments and assigning pragmatic and consistent boundary conditions. Extensive studies have been conducted on the lifecycle GHG emissions of road transport,[38-41] with studies also conducted on bunker fuel WTW GHG emissions[38] and sustainable aviation fuel (SAF) GHG emissions,[42] highlighting that this is an area of increasing focus for transport policymakers for all modes. Given the importance of such an approach in meeting the target of Net-Zero GHG emissions by 2050, and the complexity in combining partial lifecycle analyses, a move to frameworks that consider transport lifecycle GHG emissions is gaining increasing support amongst industries that view a holistic approach as essential for the cost-effective, technology neutral decarbonisation of products.[43-45]

Finding 1:
Considering full cradle to grave product lifecycle GHG emissions and regulation for primary transport modes is likely to contribute to the most efficient delivery of Net-Zero

4.2.3 Lifecycle GHG Emissions by Powertrain and Energy Vector

Whilst there is a degree of variation in lifecycle studies of passenger cars – predominantly due to variations in boundary conditions – the extent and refinement of studies has resulted in conclusions coalescing around several key themes:

- The cradle-to-gate GHG emissions of BEVs are greater than for ICE and hybrid vehicles (a range of 1.3-2x higher)[46], resulting in an 'emissions debt' at the point of sale.

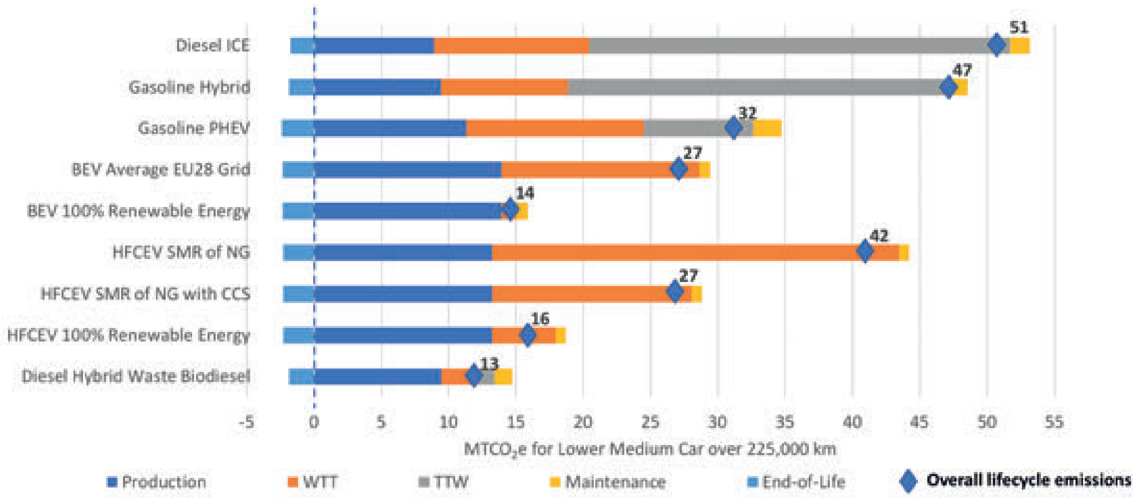
- With the UK grid, which has significant renewable generation, and a road fleet that is principally powered by fossil-derived fuels at present, the 'emissions debt' is surpassed under common ownership mileages (<50,000 miles[47]).

- The lowest lifecycle CO_2 emissions for cars combine the lower cradle-to-gate emissions of a diesel ICE vehicle with the low WTT emissions of biomass derived diesel.

- Hydrogen fuel cell vehicles (FCEVs) are generally assessed to result in cradle-to-gate emissions somewhere between ICEs and BEVs making use of low-carbon hydrogen vital to realise GHG savings.

A move to frameworks that consider transport lifecycle GHG emissions is gaining increasing support amongst industries that view a holistic approach is essential for the cost-effective, technology neutral decarbonisation of products

Figure 3: Lifecycle CO_2 emissions of mid-size vehicles propelled by liquid fuel, battery-electric, and fuel cell-electric powertrains.[48]



These conclusions can be used to identify significant areas enabling GHG emissions reduction – for example, the importance of lowering the cradle-to-gate emissions of vehicle manufacture. Companies are taking the lead, for example with Volkswagen's new ID.3, where VW claim carbon neutrality for several aspects of the vehicle lifecycle including the use of 'green energy' in the battery manufacture and vehicle assembly.[49] Another conclusion is of the importance of domestic manufacture of vehicles, which offers demonstrable benefits in terms of grid intensity, reduced logistics and, therefore, GHG emissions, although domestic supply routes may not always be the most carbon efficient. Nonetheless, investment from OEMs in growing UK manufacture needs to be attracted or such benefits risk remaining 'on-paper'. In 2019, the UK manufactured 1.38 million vehicles of which 1.056 million were exported, so while the UK is the fifth largest car manufacturer in Europe, carbon emissions would be lower if more of the vehicles produced stayed in the UK market.[50]

Finding 2:
Placing the downstream and automotive sectors at the forefront of COVID recovery and long-term UK trade strategies can grow domestic supply chains early while decarbonising long-term.

4.3 Transport Fuels: from Fossil-derived to Renewable

The energy production (well-to-tank) and use (tank to wheel) phases of GHG emissions can be combined to account for the well-to-wheel (WTW) emissions of a vehicle. The previous sections have discussed the current and potential GHG emissions of various energy vectors, however, thus far have not explored a critical component: availability to the end-user. This section considers the future development and likely experience of nation-wide provision for the primary energy vectors with conclusions outlined in this section consistent with the roadmaps highlighted in the latest Advanced Propulsion Centre (APC) Transport Energy Network report.[51]

4.3.1 Electricity

For light duty road vehicles, consumers are now offered a choice of powertrain technologies, as EVs gain far greater market share. Such choice is possible not only due to the vehicle availability for purchase, but also the availability of battery charging infrastructure. The downstream sector is at the forefront of charging provision, as well as battery material manufacture, with UKPIA members offering the largest public EV charger networks in the UK (also powered by certified renewable energy).[52,53] The sector's 8,390 retail forecourts[54] - which together with motorway service stations in 2020 had 1,066 available EV charging devices[3] - will continue to be the vehicle re-energising hubs for the consumer with new offers such as EV charging (see 5.5).

Across all transport modes, a shift to electrification may be limited by a number of challenges:

1. Suitable infrastructure deployment.
2. Battery energy storage density.
3. Availability of required materials and complexities involved in recycling (as considered in 2.3.2.)

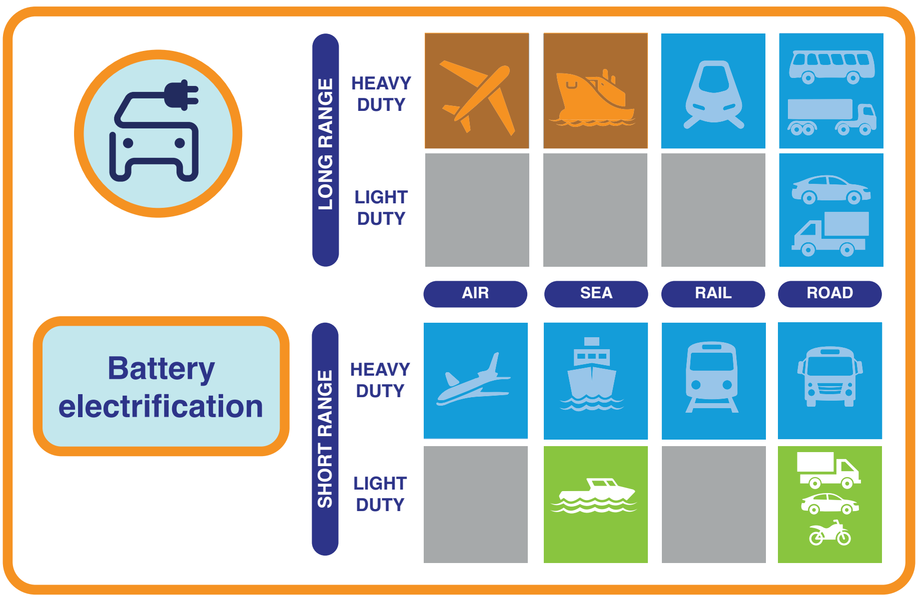
Infrastructure deployment is predominantly an economic and practical challenge. The adoption of EVs has in part been slowed by consumer concerns over charger availability, reliability, payment convenience and upfront cost.[55] However, as the portion of EVs in the UK vehicle parc grows, confidence in investing in EV charger infrastructure will increase.

The UK government has already made important steps to address some of these concerns, such as mandating that new 'rapid+' chargers must offer a pay as you go option for payment, and financially supporting EV charger installation.[56,57] However, significant strides must still be made in expanding the EV charger network, and ensuring similar levels of service and reliability to the consumer experience of liquid fuel dispensing, to support the adoption of this energy vector.

Finding 3:
Reducing or removing the regulatory burdens for Distribution Network Operators (DNOs) can enable local networks to be upgraded and support the installation of substations for EV charging e.g. allowing DNOs to invest ahead of need with regards to EV charging infrastructure.

Finding 4:
Publication of thorough, dedicated guidance for the safe installation of EV chargers at dedicated sites or existing retail forecourts may reduce local planning consent issues.

Figure 4: Transport modes suitable for battery (and OHC) electrification based on range and duty cycle



Even the most optimistic energy density predictions for batteries indicate future energy content an order of magnitude below liquid fuels – including accounting for ICE's lower conversion efficiency.[58] This will present particular challenges for long-range, heavy duty transport unless there is energy transfer during the journey such as via overhead catenary (OHC). Electric vehicles of the future could be split into (at least) two categories of on-board chemical battery storage for shorter range, light duty applications and OHC supply for fixed route applications (such as trains and guided busways where the infrastructure is practically implementable).

It should also be noted that the rapid electrification of UK and European vehicles will stretch the battery supply chain – even with its rapid rate of growth – with lithium demand currently forecast to outstrip all projects that are operational, planned, unfinanced and recycling initiatives.[59] Similar concerns could also emerge for other battery component materials like cobalt or nickel, although new battery chemistry is being developed which may change the resource demand to more abundant materials.[60] Recycling of battery materials also has significant potential to contribute alongside or ultimately instead of virgin materials – something that is already being considered by the Faraday Institution.[61]

Finding 5:
It is important that the finite pool of battery materials and batteries themselves are utilised in the most appropriate transport modes – short range and light duty – and in a sustainable framework where battery lifecycle planning pays more attention to responsible sourcing and end-of-life concepts than is currently the case.[62]

In terms of supply, increased electricity required to meet increased demand for vehicle charging must continue to be renewable (in addition to that required to further decarbonise existing supply), ensuring low (and eventually zero) WTW GHG emissions for this energy vector. This renewable energy will also need to be balanced at the local network level, with smart charging utilised to both support the consumer's residential vehicle re-energising needs whilst smoothing electricity demand.

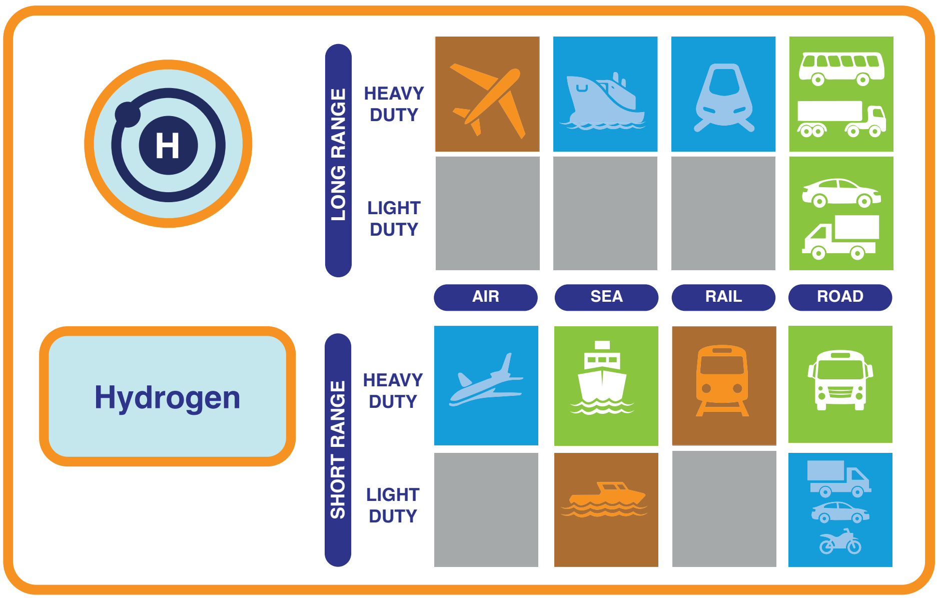
Finding 6:
Supporting the market-led introduction of smart-charging could boost cost-effective and innovative approaches for the consumer in the EV space.

4.3.2 Hydrogen

The last section explored the challenges for electrification highlighting why other technologies are likely to be needed alongside mass electrification of transport. Hydrogen is one such technology and offers greater energy density than batteries and more rapid energy transfer whilst still producing zero TTW GHG emissions.[63]

Hydrogen must be produced either from renewable electricity or via captured CO_2 to have low WTT GHG emissions (necessitating additional energy input versus direct electricity transfer), and requires dedicated infrastructure additional to that of electricity and liquid fuels. Therefore, on the road, hydrogen is most suitable for long range and/or heavier duty applications where there is a captive fleet returning to depots (such as suburban buses) or re-energising hubs may support long-range travel (such as heavy goods vehicles). Light duty vehicles with high levels of utilisation may also be better suited to hydrogen-based propulsion owing to the shorter re-energising periods offered (with Green Tomato Cars' use of the Toyota Mirai an early example).[64]

Figure 5: Transport modes suitable for hydrogen-based propulsion based on range and duty cycle



For now, a significant drawback of hydrogen use in road transport is the lack of infrastructure. The European Automobile Manufacturers Association (ACEA) have identified that at least 500 hydrogen refuelling stations are required across Europe by 2030 to satisfy hydrogen heavy goods vehicle (HGV) energy demands.[65] Recognising that whilst electric drive (motors) should be widely adopted for their conversion efficiency, multiple complementary input energy vectors can be pursued to power them – including hydrogen.

Finding 7:
Providing public funding support for a hydrogen HGV commercial demonstration project in the UK could help overcome early concerns over a lack of infrastructure.

For non-road transport, hydrogen is attractive for rail that is challenging to electrify via OHC, with the UK first trial of a hydrogen fuel cell train taking place in the Midlands.[66]

Arguably, the largest off-road future application for hydrogen lies with the difficult-to-decarbonise maritime sector where larger vessels, with high utilisation and minimal stationary or manoeuvring time, will be attracted to energy dense, quickly energised hydrogen powertrains. However, for the scale required the hydrogen may be supplied via an intermediate vector such as ammonia. The current limited availability of green and blue hydrogen means this must currently be considered a medium-to-long-term option as addressed in Chapter 8. However, allowing for development of hydrogen from all sources (at least low carbon intensity production technologies) should lead to earlier deployment at scale of hydrogen as an option.

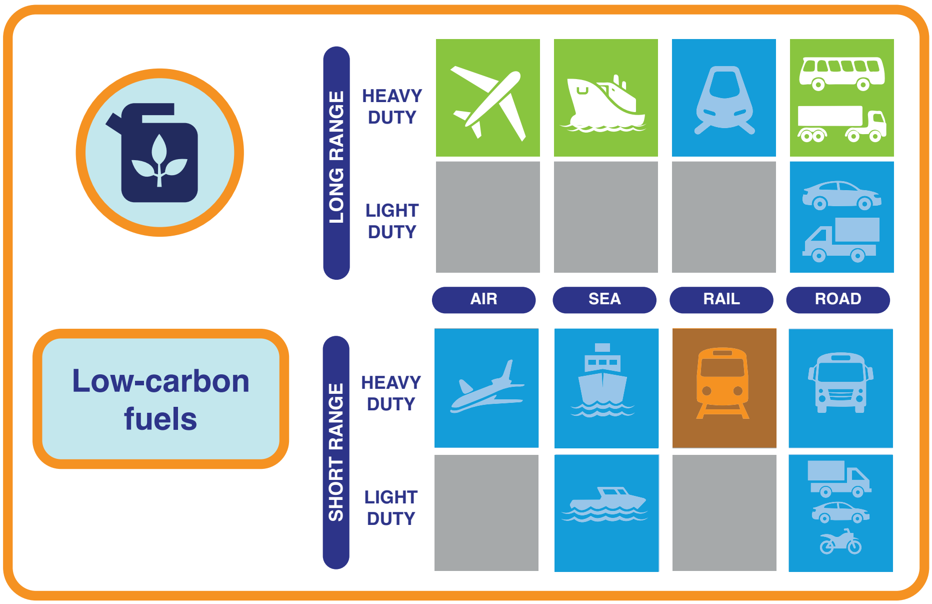
Finally, considering air travel, Airbus have confirmed their ambition to develop the world's first hydrogen propelled commercial aircraft by 2035.[67] The same aforementioned energy density, transfer, and zero WTT GHG emissions potential are drivers behind Airbus' pursuit of the concept. It is likely that hydrogen use in aircraft in the coming decades will be limited to short-range flights where battery electrification is not viable. A summary of the suitability of hydrogen for transport modes can be found in Figure 5.

4.3.3 Low Carbon Fuels

The potential for both electrification and hydrogen shows that – with increasing levels of renewable electricity production – widespread use of zero carbon energy vectors can become a reality for UK transport in the future. However, the climate challenge demands immediate action, and low carbon fuels offer the most readily available displacement of the currently predominant, fossil-derived, carbon-based fuels/chemical energy vector. Low carbon fuels for transport in the UK are defined by the sustainability criteria set-out in the Renewable Transport Fuel Obligations Order 2007 (as amended).[35]

Over time, low carbon fuels can be replaced by a wide range of climate neutral fuels (and fuelling models – see 4.4.2) to power UK transport with Net-Zero emissions. Their deployment can continue as needed depending on climate neutrality, other environmental factors and supply – for example in the case of limited feedstocks they can be diverted to aviation and marine as light duty vehicles are electrified. It is for these reasons that one of the recommendations by the IMechE in its ‘Accelerating Road Transport Decarbonisation’ report was for “substantial investment (similar to that provided for

Figure 6: Transport modes most suitable for low carbon fuel propulsion based on range and duty cycle (assuming limitations to renewable fuel feedstocks/primary energy)



battery electric vehicles and charging infrastructure) in sustainable and low-carbon fuel development and associated internal combustion engine technology."[44]

E-fuels may also play a role in the decarbonisation of high energy density demand sectors such as aviation. Losses incurred via the energy input phase may be offset by the efficiencies gained in infrastructure and fuel quality. E-fuels manufactured in markets with greater renewable energy resources – such as solar in North Africa – could be readily imported using existing UK import infrastructure.[68]

As explored in depth in the TTI Report, multiple options exist to produce low carbon fuels; from hydrogenated vegetable oil (HVO), to lignocellulosic residues as feedstocks, to the production of e-fuels for hard-to-decarbonise sectors such as aviation.

While vehicle and supply infrastructure could make use of low carbon liquid fuel options, the economic incentive to shift away from fossil-derived fuels to towards renewable options is currently limited. A product lifecycle emissions based regulatory framework, embedding WTT GHG emissions into UK fuels policies can accelerate the deployment of renewable fuels in the UK by making low-carbon options preferable to more carbon intensive equivalents. In Germany, a WTT GHG reduction target for fuels with a carbon cost for under-delivery of the target has proven to be an effective means of driving WTT GHG emissions reductions.[69]

The downstream sector has demonstrated its support for increased deployment of low carbon fuels in the UK in the immediate term by fully supporting the mandated introduction of E10 petrol and increasing the buy-out price of the Renewable Transport Fuel Obligation (RTFO).

A product lifecycle emissions based regulatory framework, embedding well-to-tank GHG emissions into UK fuels policies can accelerate the deployment of renewable fuels in the UK

Finding 8:

Accelerating the transition of liquid fuels from fossil-derived to biomass- or renewable energy-derived is a no-regret option for the UK as almost all transport modes could be at least incrementally decarbonised in the short term with such a change (aviation may be challenged due to strict fuel quality and supply requirements).

Longer-term, it is likely that low carbon fuels will then meet demand for applications technically or economically unviable via electricity or hydrogen. Figure 6 summarises these possible longer-term low carbon fuel deployment options in the coming decades:

Finding 9:
The UK renewable transport fuel regulations review in 2021 offers the opportunity to consolidate and develop a new UK GHG emissions reduction target. Opportunities to incentivise new technologies should include support for blue or green hydrogen used in manufacture of fuels as is already allowed in some other countries.

Finding 10:
Fuel duty offers a primary government lever to influence consumer behaviour towards low-carbon liquid fuels if scaled according to a fuel's carbon intensity, (captive fleets seeking to adopt higher blend biofuels may be an early adopter).

4.4 Other GHG Reducing Initiatives

In order to meet the challenge of Net-Zero by 2050, significant GHG reductions may also need to be made via other routes if total carbon-neutrality is not possible with the options explored so far. The many technologies available to reduce the carbon intensity of fuels have been explored in detail in other UKPIA reports (Future Vision, 2019, and TTI Report, 2020) but two other considerations that are relevant to the provision of transport energy vectors are outlined in this section - offsetting and nature-based solutions and alternative fuelling models.

4.4.1 Offsetting and Nature Based Solutions

Offsetting schemes are growing in popularity with new consumer offerings being developed. In recent years, downstream retailers such as bp and Shell have integrated carbon offsetting optionality into their fleet fuel card and consumer loyalty schemes,[70,71] enabling drivers to support initiatives offsetting the CO_2 emissions produced from their fuel use.

There are also products seeking to offer offsetting directly to the consumer, with apps such as VYVE providing the means for consumers to input their journeys by different transport types and offset their transport GHG emissions accordingly.[72]

Offsetting schemes are not limited to road transport. In order to reduce its net GHG emissions impact, the aviation sector has established the Carbon Offsetting and Reduction Scheme for International Aviation

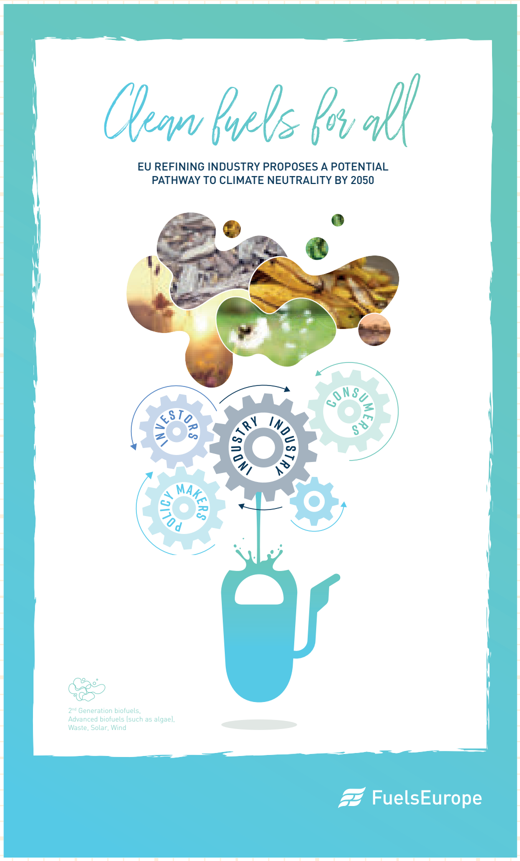
(CORSIA). The scheme is currently voluntary, with the pilot phase due to commence in 2021 and with a view to establishing a pan-industry approach via the International Civil Aviation Organisation (ICAO).[73] Similarly, it may be that offsetting of emissions can be achieved through use of technical solutions such as Direct Air Capture and Storage (DACCS) and other carbon capture techniques that permanently sequester carbon (industrial applications have been explored further in UKPIA's Future Vision report).[74]

4.4.2 Alternative Fuelling Models

A current limitation in terms of low carbon fuels development has been finding sufficient scale to improve their commercial viability. A potential solution to this is the implementation of an investment framework operating in parallel with an emissions regulation (e.g. tailpipe emissions standard) that can enable suitable levels of investment for low carbon energy scale-up. In turn, the investor (likely a vehicle manufacturer or fleet operator) may then claim GHG emissions savings towards their GHG obligation through fulfilment of the 'contract' – an approach that has been explored in depth by Cerulogy.[75] The wider policy frameworks that could incentivise investment in low carbon solutions are identified in the FuelsEurope "Clean Fuels For All" report.[75,76]

Such an approach does not require restructuring of existing GHG regulatory frameworks, but would complement them, and provide much needed upfront fiscal support for more difficult to decarbonise transport modes such as heavy goods vehicles, and could also be developed for adoption in passenger cars with some form of upfront fuel purchase providing suitable investment certainty.

Finding 11:
Developing a viable framework for low carbon energy vector investment contracts linked to existing emissions obligations could promote early adoption of low-carbon solutions in a technology neutral way.



5 Mobility Paradigm Shift

In addition to energy vectors transitioning to renewable sources (see Chapter 4), consumers' lifestyles and their associated approach to transport must also transform to meet Net-Zero.

The effect of COVID-19 has meant the UK population has changed its transport patterns significantly but the long-term continuation of these changes is uncertain.

Hyper-proximity of townsites and the development of mobility-as-a-service, such as ride-sharing companies can offer efficiencies in transport demand.

Technological advances such as block-chain, autonomous vehicles, consumer convenience technology and micro-mobility like electric scooters will all be critical to offering a more sustainable way of travelling.

5. Mobility Paradigm Shift

The UK faces a significant challenge in displacing and reducing its transport energy demand with low and eventually Net-Zero carbon energy vectors. Technologies explored in Chapter 3 will go a considerable way to displacing current emissions but reducing overall demand offers an efficient means to reduce GHGs too. Minimising transport requirements (such as reduced commuting), integrating transport systems (such as multi-modal routing), and aggregating journeys (such as by pooling and consolidation centres) will all play their part in ensuring UK transport is decarbonised as rapidly as possible whilst maintaining options for the consumer and economic growth.

In their Innovating to Net-Zero report, the ESC highlight that in addition to energy vectors transitioning to renewable sources, consumers' lifestyles and their associated approach to transport must also transform to meet Net-Zero.[31] This chapter will explore some non-energy variables that will influence consumer behaviour and provide more efficient energy vector use.

5.1 COVID-19 Movement Restrictions

National movement restrictions implemented to prevent the spread of COVID-19 have forced the UK population into practising new means of working and adopting new demand patterns on mobility. Demand for commuting into urban centres – and therefore public transport – has significantly decreased and it is unclear whether demand will recover to pre-COVID levels as remote working patterns are embedded into company operations.[77]

Social distancing requirements will further reduce demand on shared transport such as public transport and pooled/ride-sharing schemes. As these requirements are relaxed in the years ahead there may be some return in demand, however it is unlikely to return to pre-COVID levels as consumers increasingly adopt remote working and socially-distanced mobility offerings such as private car ownership or mobility-as-a-service (MaaS – see 5.3).[78]

While many societal changes seen during COVID might improve transport sector efficiency and decarbonisation (WFH, MaaS, micromobility), the potential shift to use of private cars could create a number of challenges. After significant improvements in air quality following the introduction of movement restrictions, NO_2 levels in London appear to be returning back to pre-COVID levels.[79] This supports the shift to private car use given overall passenger km travelled are still reduced compared to pre-COVID.[77] Other less desirable impacts are highlighted in Table 2.

Micromobility, a planned consideration for the government in 2020, has been given priority by COVID-19 with the government publishing and concluding an e-scooter rental consultation and Middlesbrough implementing a trial to enable urban mobility whilst discouraging consumers returning to passenger car use.[80,81] 2020 has also seen expansion of cycle lanes and a cycle repair scheme to encourage consumers to transition to cycling.[82]

Table 2: Summary of likely GHG emissions benefits and detriments due to COVID-19

GHG Emissions Benefit/Decrease	GHG Emissions Detriment/Increase
Reduction in overall passenger km travelled	Increased private car use
Increased use of micromobility options (reduction in passenger km travelled by car)	Social distancing requirements necessitating more public transport vehicles to meet equivalent demand
Flatter distribution curve of travel during the day	Consumer vehicle purchasing power weakened – hampering fleet renewal
Increased use of MaaS = higher modern vehicle utilisation	Reduced use of rail for long-distance journeys
Reduced aviation activity	Potential for increased congestion if revised traffic flows to give pedestrians/cyclists increased space are not managed properly

5.2 Hyper-Proximity

COVID-19 movement restrictions have highlighted the need for consumers to have local accessibility to essential services. In fact, a shift to such an approach in urban areas is likely to be needed to meet decarbonisation objectives as well. Also known as the '15 minute city', this describes when "citizens can have all their needs met – be they for work, shopping, health, or culture – within 15 minutes of their own doorstep."[83]

Several cities globally – including Paris, Ottawa, Melbourne, and Detroit – have committed to seeking reduced carbon footprints and improved quality of life via this concept.[84] Another observed benefit has been reducing urban habitant short-term/weekend travel to rural areas, further reducing transport energy demand.[85]

5.3 Mobility as a Service

MaaS is increasingly familiar to the consumer in the UK via 4 increasingly used offerings:

- On-demand journeys including ride-sharing schemes (e.g. Uber).
- Car club/shared ownership schemes (e.g. Zipcar).
- Vehicle subscription schemes (e.g. Pivotal).
- Multi-modal routing schemes (e.g. Citymapper).

All of these options, whilst providing different mobility offers to the consumer, also improve vehicle utilisation and/or routing efficiency with minimal burden on the consumer (e.g. maintenance). In the coming years, it is expected that more consumers will shift from mobility-as-an-asset (MaaA), such as 'traditional' car ownership, to utilising mobility as a service.

This is expected to decrease the number of vehicles on the UK's roads as each vehicle's utilisation increases and will place an increased importance on vehicle downtime – periods of maintenance and re-energising.[86]

Innovative approaches to data analytics and integration are enabling efficiencies in transport routing via multi-modal offerings. For example, the Citymapper app offers a mobility subscription and single payment platform enabling use on public transport, cycles, and taxis in London.[87] Such approaches are likely to grow in the 2020s and 2030s, integrating across greater distances and more transport modes.

5.4 Blockchain

Blockchain, or distributed ledger technology, is likely to offer three main benefits in the evolution of mobility:

1. Supporting decentralisation of electricity markets
2. CO_2 accounting/traceability
3. Logistics efficiencies

As the UK electricity market evolves to an increasingly decentralised model for efficiencies and resilience, there will be increased transactions between players, necessitating rapid trading recorded via tamper-proof, openly accessible digital ledgers – blockchain.[88] Such an approach is currently in its infancy, with distributed ledger technology currently utilised in restricted, private capacities but it could become an enabler to supporting cost-effective, flexible electricity provision to BEVs.

Further to facilitating the trading of renewable energy, blockchain may offer the means of rapidly and securely accounting for the WTT GHG emissions of renewable energy. Iberdrola S.A. are currently operating a pilot utilising blockchain to guarantee, in real time, that electricity at the point of use can be traced back to renewable generation.[89]

This approach could be extended to hydrogen and liquid fuels. Renewable fuels are currently assessed and certificated via voluntary schemes such as the ISCC, with fuel suppliers then using this to evidence renewability when claiming renewable transport fuel certificates (RTFCs) under the Renewable Transport Fuel Obligation (RTFO). Blockchain offers the opportunity to accurately and securely track a fuel's carbon footprint from feedstock to finished product – thus enabling more precise, transparent, and less onerous renewable fuel claims than in the current RTFO system. Such an approach – albeit even more complex – could one day be applied across a vehicle's lifecycle from production to end-of-life.[88]

Finally, blockchain is already being used for logistics, with TradeLens, a blockchain platform co-developed by Maersk and IBM for shipping, now hosting records for more than half of the world's ocean container cargo and similar uses expected to grow rapidly.[90]

5.5 Consumer Convenience Technology

Unlocking vehicles via smartphone or wearable kit[91] and interacting with vehicle features remotely are already practical realities, with similar evolutions in the vehicle re-energising phase such as app payments for fuel.[92]

The rapid growth of online shopping, consumer preference for 'on-demand' delivery, and need to optimise 'the last mile' has spurred efforts to align efficient, consolidated goods deliveries with consumer activities to maximise convenience. One such offer is the option to collect from delivery lockers – such as Amazon Locker[93] – at transport hubs such as train stations and forecourts. Going a step further, Amazon also offer Amazon Key in the US, which offers delivery of goods to the home or boot of a car while not in use.[94] This grants more flexibility for delivery timing to optimise routing.

Consolidation centres are also likely to increase in use as part of further efforts to consolidate delivery journeys in urban areas to minimise congestion and improve air quality. The primary challenge to overcome is in establishing the most suitable organisational model and ideally multiple companies using a single centre.[95]

5.6 Micromobility

As further explored in section 5.1, COVID-19 movement restrictions may have accelerated the growth of micromobility, with weak economic conditions in the early 2020s also offering the potential to increase demand for more affordable urban travel options such as bicycles and scooters versus cars.

This is an area featuring significant technology activity with offerings from established platforms such as TfL's cycle scheme, large technology platforms such as Uber, and innovative start-ups such as Bird all available in the UK. Micromobility is likely to provide important urban transport for restricted access cities (such as medieval cities) or filling 'gaps' in established public transport routes – Beryl in Norwich is one example of such a technology.[93] Given likely growth, we will see the UK regulatory framework evolve to accommodate micromobility options and possibly better integrate PLVs into urban and sub-urban personal transport (see 6.1).[97]

5.7 Connected and Autonomous Vehicle Technology

A disruptive technology to mobility, connected and autonomous vehicle (CAV) technology will play a potentially large role in the decarbonisation of transport by reducing energy demand per km travelled. The main means by which this is achieved includes:

- Deploying more efficient operational patterns
- Enabling vehicle 'right-sizing'
- Minimising vehicle downtime
- Improving (air)port operational efficiency

On the road, vehicle to vehicle connected technology can enable the execution of more efficient driving patterns to reduce energy consumption. The European Commission Horizon 2020 'ENSEMBLE' project aims to demonstrate a functioning HGV platooning programme in the early 2020s that will minimise the aerodynamic drag, synchronise acceleration and braking and, ultimately, improve efficiency and reduce energy demand.[98]

This same concept can be made applicable to cars and vans as they adopt increasing levels of autonomation. This concept was demonstrated by the EC's Safe Road Trains for the Environment (SARTRE) project back in 2012.[99] On-board CAV technology offers further potential in-use energy reductions, however, this must be carefully balanced with the increased energy demand of the

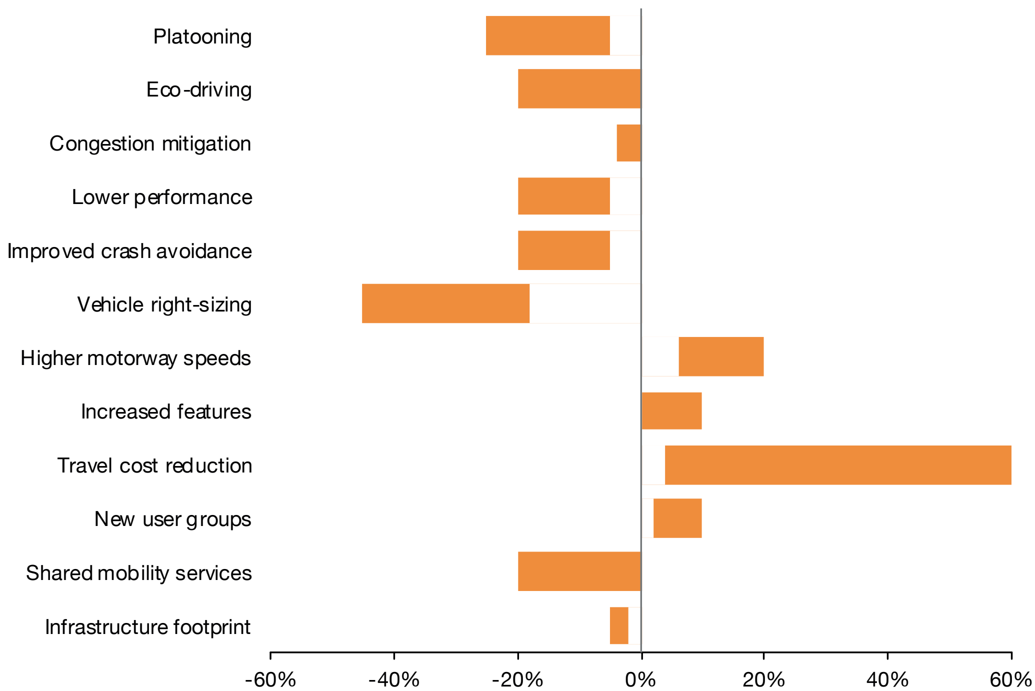


Figure 7:
Impacts of vehicle automation on energy use.[99, 100]

technology (see Figure 7).[100] Whilst the advent of 5G may enable the most energy-intense processing to take place off-board the vehicle, this then increases reliance of the system on telecommunications infrastructure. It is likely that the most energy efficient option with respect to CAV technology adoption in passenger cars is a degree of automation, where lower processing demand connected technology is put to best effect.[101]

As can be seen in Figure 7, independent of the computational processing energy consumption, the benefits of CAVs are offset to some extent by other sources of energy demand – most notably the likely increase in demand (passenger km travelled may increase as travel cost reduces) owing to reduced cost and improved convenience.

There is still a high degree of uncertainty regarding when significant CAV technology deployment may feasibly occur, although potential vehicle efficiency gains through connected vehicle initiatives are significant 'low hanging fruit' for transport decarbonisation.[102] It is expected that improvements in safety may also be an important policy driver. The Connected Places Catapult's Multi User Scenario Catalogue for Connected Autonomous Vehicles (MUSICC) offers a foundation for CAV scenario planning and simulation.[103]

Connected technologies offer benefits for maritime and aviation fleets too – improving airspace and port operations both offer opportunities to further reduce energy vector demand. They may therefore be popular with these sectors, where energy costs represent a significant proportion of operational expenditure.[39, 104]

6 Changes on the Road

This Chapter and those which follow explore what changes explored in the report so far will feel like 'on the ground'.

The modes of transport that we see on the roads: scooters and electric bikes; cars and vans; HGVs; and buses and coaches are all set to see changes in their powertrain technology but will vary according to technical and usage needs.

The role of the UK's forecourts in acting as hubs of road transport re-energising will remain as UK transport evolves, however, the consumer will be presented with a different experience and different energy products to today to meet local demand.

6.Changes on the Road

6.1 Powered Light Vehicles

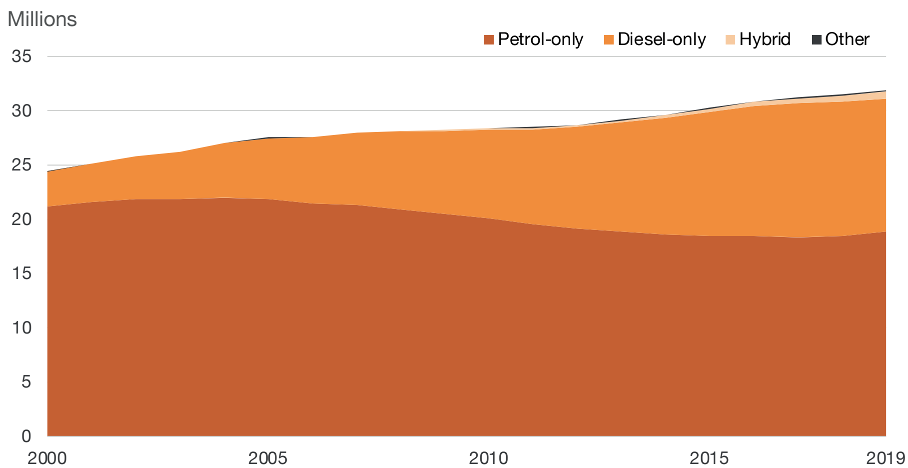
Whilst accounting for less than 0.5% of UK transport GHG emissions,[6] PLVs – which include mopeds and electric scooters – already feature in some urban goods delivery models – particularly as part of the 'gig economy.' As society progresses to active travel such as cycling and walking, PLVs may offer the most energy efficient solution to intermediate distances in urban and sub-urban areas.[105]

On-demand PLVs could offer home-to-transport hub travel such as a rail station rather than a privately-owned car. For freight, PLVs might increase the energy efficiency of 'the last mile' from distribution hubs – at least until consolidation centre models are developed and adopted.[105]

6.2 Cars & Vans

As the most prevalent vehicle type in the UK, and most significant source of transport energy demand, a range of technologies and initiatives will be needed to decarbonise cars and vans at the lowest societal cost. In the coming decade, the UK will see an unprecedented diversification of powertrain type in its vehicle parc. However, with the average age of a vehicle in the UK being 8.3

Figure 8
Great Britain Car Parc, by Propulsion



Source: UKPIA 2020 Statistical Review[18]

With the average age of a vehicle in the UK being 8.3 years, it will take time to significantly reduce GHG emissions given the small base the hybrid and EV market is growing from in the UK

years,[106] it will take time to significantly reduce GHG emissions given the small base the hybrid and EV market is growing from in the UK. A legacy fleet in need of decarbonising will exist well beyond the 2035 milestone.

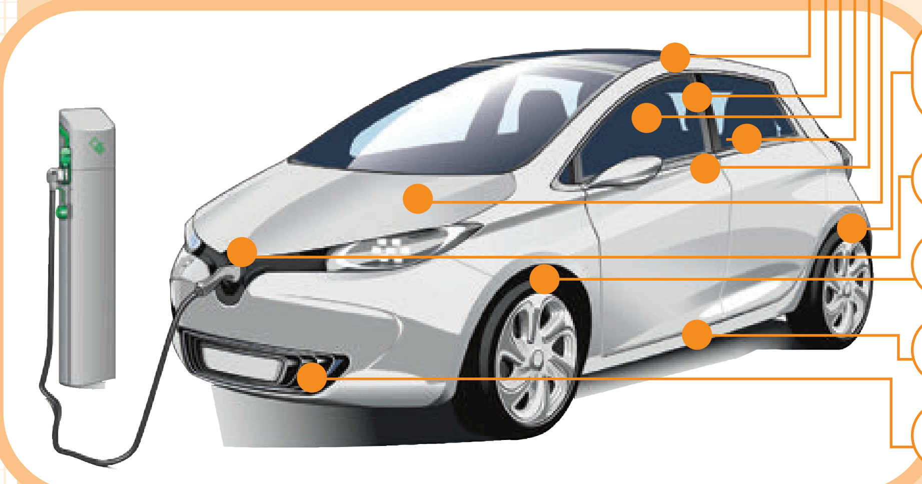
BEVs offer opportunity to lower the lifecycle GHG emissions of passenger cars provided they are utilised beyond the GHG emissions debt (see 3.2.3), and will continue to track rapid growth in sales. Even with unprecedented levels of new EVs being purchased, and ICE vehicles scrapped, decarbonisation only by changing to EVs may only be one part of the solution. The reason for this, is that consumers continue to have significant concerns[55] around range, charging options and upfront cost[107] let alone further issues relating to uptake with supply chain bottleneck[58,108] of limited end use products a possible additional barrier.
Given the huge amount of energy required to power cars and vans, pursuing all low carbon energy vectors and powertrain technologies offers the best and most efficient means to change at scale.[51] Whilst policy will stop the sale of new petrol and diesel vehicles by 2030, the UK will also need to accelerate a range of other transport decarbonisation measures before that date as well.
In the 2020s, the RTFO will continue increasing renewable fuel content of road fuels reducing the lifecycle emissions of today's ICEs.[34,35] In 2019, renewable fuel blending under the RTFO saved a total of 5.37 Mt CO_2e – this is equivalent to taking 2.5 million cars off the road for a full year and is expected to increase as the RTFO mandate continues to rise until 2032.[4]

Whilst policy will stop the sale of new petrol and diesel vehicles by 2030, the UK will also need to accelerate a range of other transport decarbonisation measures before that date

The Future Vehicle Supply Chain

The Downstream Sector in the EV Supply Chain

While the downstream sector can contribute to decarbonising the transport energy vector supply chain, the sector has an equally important role in supporting future vehicle manufacturing. **Petrochemicals, lubricants, and graphite are essential feedstocks – provided by the downstream sector – that will continue to be required in vehicles as they evolve to provide the mobility demands of a Net-Zero UK.**



Electric vehicles (EVs) are only able to be manufactured thanks to numerous components that comprise materials derived from petroleum products.

Petrochemicals

A modern light vehicle is currently 50% plastic by volume but less than 10% by mass[111], with automotive sector demand accounting for over 10% of petrochemicals industry sales. The proportion of plastics in road vehicles is likely to increase in the coming decades – not only supporting battery assemblies, but also vehicle lightweighting as energy efficiency becomes as cost-effective (or necessary) as battery capacity increases.[112-114]

Petrochemical-derived materials play an essential role throughout a car – fire retardants, fittings, comfort, and more are all provided by plastics and will continue to be in electric vehicles. Petrochemical-derived materials may also play an increasing role in the generation of renewable energy – such as lightweight plastics in future generations of wind turbine blades.[115]

Lubricants

Lubricants and greases also provide an essential role in mobility by protecting, cooling, sealing, and reducing friction in mechanical systems. Whilst there will continue to be a role for lubricants improving ICE efficiency, lubricants and greases will also play an essential role as the transmission, coolant, and motor fluids of EVs.[116] The downstream sector not only provides the raw materials for these sophisticated formulated products, but also stands at the cutting edge of research and development for the next generation of e-fluids.[117-119]

Battery Materials

Increased demand for EVs will increase demand for graphite for lithium-ion battery anodes – another specialist raw material provided by the downstream sector. The UK is well-placed to support regional demand as the largest producer of high purity graphite in Europe.[16]

Therefore, the UK downstream sector is well-placed to be integrated into a domestic EV supply chain and, in fact, can act as an enabler to supporting domestic employment and lowering the cradle-to-gate GHG emissions of EVs.

Reutilising Plastics

The provenance and end of life (EOL) fate of utilised plastics are crucial considerations in the lifecycle of a product and reusing and repurposing plastics an important part of a circular economy. Some vehicles already use many recycled plastics[120] whilst, moving forward, more sophisticated plastics such as carbon fibre reinforced plastic (CFRP) may be increasingly utilised - although this will need more reuse to see a lifecycle GHG emissions benefit.[121]

Harder to reuse plastics may be most suitably repurposed via a refinery[122] – further demonstration of the support the downstream sector can provide in an efficient automotive product lifecycle.

EV and hydrogen infrastructure developments will progress in the 2020s and 2030s, ensuring these energy vectors are both increasingly renewable and reliably available to the consumer. Battery technology improvements, increased charging infrastructure and use of second-life batteries will all decrease existing consumer concerns regarding BEVs.

Reducing the unnecessary proliferation of oversized vehicles offers a big opportunity to reduce emissions through vehicle efficiency.[109] The implementation of policies that scale vehicle taxation and licensing costs based on efficiency variables such as weight, drag coefficient, and tailpipe emissions will deliver efficiencies for all vehicles.

The implementation of a lifecycle CO_2-focused vehicle policy measure can be expected to result in new light duty vehicles that are mostly electrified with ICE-containing (Plug-in Hybrid Electric Vehicles or range-extender) vehicles operating on very low carbon fuels for longer range applications that will prevent stretching renewable resources for electricity or low carbon fuel production.[95]

Whilst vans have a wider range of loads and duty cycles compared to passenger cars, they will see a similar progression. Urban-only vans are likely to be well placed to transition to BEVs sooner due to advantages in fleet operating costs, charger proximity, and consistent low range demand.[110] However, larger vans will have to balance space for energy on board with load space and distances travelled. Some will move to full BEV, while a low carbon fuel – and longer term hydrogen fuel cell electric – powertrain may be the only viable options for some applications.

6.3 Buses & Coaches

Urban and sub-urban bus routes are likely to be well-placed to transition to electric or hydrogen fuel cells – contingent on suitable infrastructure being rolled-out – owing to their shorter-range requirements and return to localised depots. This is already happening with London offering the largest – and growing – electric bus fleet in Europe[123] as well as a hydrogen fuel cell bus route.[124] Electric buses are also forming increasing parts of bus fleets in other UK cities such as Manchester and Birmingham.[125,126]

Longer routes with existing bus fleets are likely to be best served by a combination of low carbon fuels, hybridisation and hydrogen (depending on local energy vector availability) owing to increased energy density requirements:

- The Cambridgeshire Guided Busway, the longest guided busway in the world connecting Cambridge with satellite towns up to 16 miles away, is currently served by a Euro V and VI fleet propelled by ICE utilising 30% renewable diesel.[127]

- Utilising geofencing technology some hybrid buses will operate in electric-only mode in urban centres, such as in Bristol and Brighton while replacing the liquids with higher renewable blends.[128,129]

- Hydrogen fuel cell buses will grow with deployment of the first hydrogen fuel cell bus in Northern Ireland planned by the end of the year.[130] Hydrogen from electrolysis utilising electricity from an onshore wind farm in North Antrim is embedded into the project.[131]

Buses are also likely to embrace automation. The CAVForth programme in Scotland is Europe's first full-size autonomous bus service with a 30 mile stretch being served by five 42-seat buses operating level 4 autonomation.[132] Increased deployment of autonomous buses is likely for routes featuring dedicated bus lanes and guided busways where integration with non-autonomous vehicles is reduced.

Coaches, which generally operate intercity routes with more significant range demand, are likely to be reliant on liquid fuels for the longer-term – at least until sufficient hydrogen refuelling infrastructure and low carbon supply become available, with some early support for hydrogen in the Government's Ten Point Plan importantly envisaging development of both blue (CCUS) and green (renewable) hydrogen solutions.[133] These powertrains are likely to coexist for some considerable time.

6.4 Heavy Goods Vehicles

HGV engines are typically the most efficient available in road vehicles (up to 47% thermal efficiency) with efficiencies expected to continue to improve through the 2020s and 2030s.[134] Heavy duty cycles and competition between cargo and fuel or energy storage space have and continue to drive these efficiency improvements, but the volumetric efficiency of high energy density liquid fuels and their conversion into power makes this a difficult-to-decarbonise sector.

Given energy densities for batteries are unlikely to come close to liquids (even accounting for ICE's conversion efficiency)[58] electricity is only likely to become a suitable energy vector option for most HGVs if in-journey charging, such as via OHC systems, is possible. Such an approach would be a significant infrastructure undertaking – costing at least £20 billion as well as the disruption to highly used motorways.[135]

There are some applications where e-HGVs will emerge with Volvo currently making two rigid axle trucks[136] whilst Daimler's rigid axle e-Actros has completed field testing and is due to commence production in 2021.[137] These trucks may prove particularly suited to urban goods movements from local hubs as increasingly stringent air quality measures are implemented.

Hydrogen, if the current infrastructure barrier can be overcome through strategic hydrogen fuelling networks, offers a well-suited means to decarbonise HGVs.[135] The Hyundai Xcient Fuel Cell can travel 400 km with Hyundai already developing a truck with a 1000 km range.[138,139] Other vehicle manufacturers like Daimler and Toyota are bringing to market hydrogen fuel cell heavy duty trucks too.[140,141]

Low carbon fuels also offer a highly cost-effective means of decarbonising HGVs, including the existing vehicle fleet. There are proven renewable fuels such as fatty acid methyl ester (FAME) and HVO that can be increasingly utilised. In addition, ownership and regulatory models of HGV fleets present opportunities to introduce policies that stimulate low carbon fuels development (see 4.3.3).

Regardless of powertrains, connected vehicle developments such as platooning (see 5.7) can offer further energy efficiency benefits. The European Commission Horizon 2020 'ENSEMBLE' project aims to demonstrate a functioning platooning programme in the early 2020s.[98]

Logistics improvement technologies such as warehouse digital (and potentially physical) clustering, blockchain, and automation of HGVs are likely to bring significant improvements in road freight efficiency in terms of carbon emitted per kilogram of freight moved but with expected growth in demand for freight shifts to other routes like marine may also need focus.[142]

6.5 Forecourts of the Future

The role of the UK's forecourts in acting as hubs for road transport re-energising will remain as the UK transport sector evolves, with changes in the consumer experience and supply of different energy products to today to meet demand.

Early examples of a forecourt energy 'pivot' are emerging like Shell's forecourt in Fulham, London, which has ceased the retail of liquid fuels and is undergoing refit to become an EV charging site.[143] Similarly, a new, purpose-built site is the Gridserve 'electric forecourt' offering 30 chargers alongside a supporting retail experience.[144] It is likely that in the coming decades the UK will see further dedicated EV sites (Gridserve are planning 100 such sites in total) whilst existing forecourts seek to evolve their offers to serve a broader range of customers.

In the longer-term, it is likely that urban areas – particularly where tailpipe emissions limits are in place – will feature community-serving mobility hubs, that combine vehicle recharging with MaaS offers (such as car club parking) with other transport links (such as bicycles and buses). Whilst certainly resembling the retail forecourts of today, these may offer more locally-tailored conveniences such as community information, parcel lockers, and fresh groceries (see 5.5). Figure 9 is a picture of the new bp mobility hub, which is London's first multi-transport hub and brings multiple mobility offers together in one place. EV charging, car clubs and bicycles can be accessed through a digital platform and the same site has a café and parcel delivery location for users' convenience.

The role of the UK's forecourts in acting as hubs for road transport re-energising will remain as the UK transport sector evolves

Figure 9:
bp's multi-transport hub located on the Greenwich Peninsula, which opened in 2020.

Source: bp

6.5.1 Energy Vector Provision

Colocation of ultra-rapid EV charging points for the growing BEV vehicle parc may be the most visible change to the consumer in coming years. These chargers are particularly important for users without home charging available (such as on-street parking) and high utilisation vehicles such as ride-hailing services with charging times likely to be around 10 minutes. Charger availability will be flagged to the driver either upon approach to the forecourt or when set as a destination in mobile navigation.

Given ICEs will be prevalent well into the 2030s and likely beyond, liquid fuel dispensers will continue to feature at the vast majority of UK forecourts. In line with the RTFO and other incentives to decarbonise that may emerge, liquid fuels offered are likely to be increasingly renewable in content such as bio-oxygenates, biodiesel, and HVO with updated EN 228 and EN 590 standards likely to be needed in future. In the short-term, increased blending of renewable fuels will be needed within the existing standards, or utilising current higher blend fuel standards such as the B10 and B20+B30 standards. The UK downstream sector has already made efforts to ensure it has an active role in UK biofuel provision but from a consumer perspective, little has changed or will need to change at the pump.[145]

In the medium term, dedicated hydrogen refuelling forecourts are likely to increase in number – especially on the critical road network to accommodate fuel cell HGVs. Larger forecourts may install hydrogen provision as a second or third energy vector.

6.5.2 Consumer Convenience

The increased adoption of MaaS (see 5.3), and resultant increase in vehicle utilisation, may result in greater throughput demands on the forecourt of the future – with practical and technological innovations implemented to accommodate it.

- Drivers will know in advance the offering of the forecourt from improved onboard satnavs and any wait required will be managed digitally – ensuring no ‘traditional’ queuing takes place.

- Drivers can enjoy in-vehicle and site conveniences whilst waiting; for example, a coffee pre-ordered and brought to the vehicle by customer support staff to be enjoyed whilst safely watching a media streaming service in-vehicle.

- Payment will likely be managed digitally either via the vehicle or via smartphone/wearable.

- Forecourts’ retail offerings may grow with scan and go services increasingly offered, freeing forecourt staff to provide more dedicated customer support and oversee site operations.[146]

- Forecourts are also well-placed to support the continuing increase of e-commerce with parcel lockers consolidating goods delivery journeys and offering convenient, simultaneous top-up re-energising or ‘grazing’ for goods vehicles as they unload to locker banks.

Figure 10:
Aral mobility hub, Berlin.[148]

Source: Aral

Figure 11:
Aerial photo of Leeds Skelton Lake services[150]

Source: Extra Motorway Services

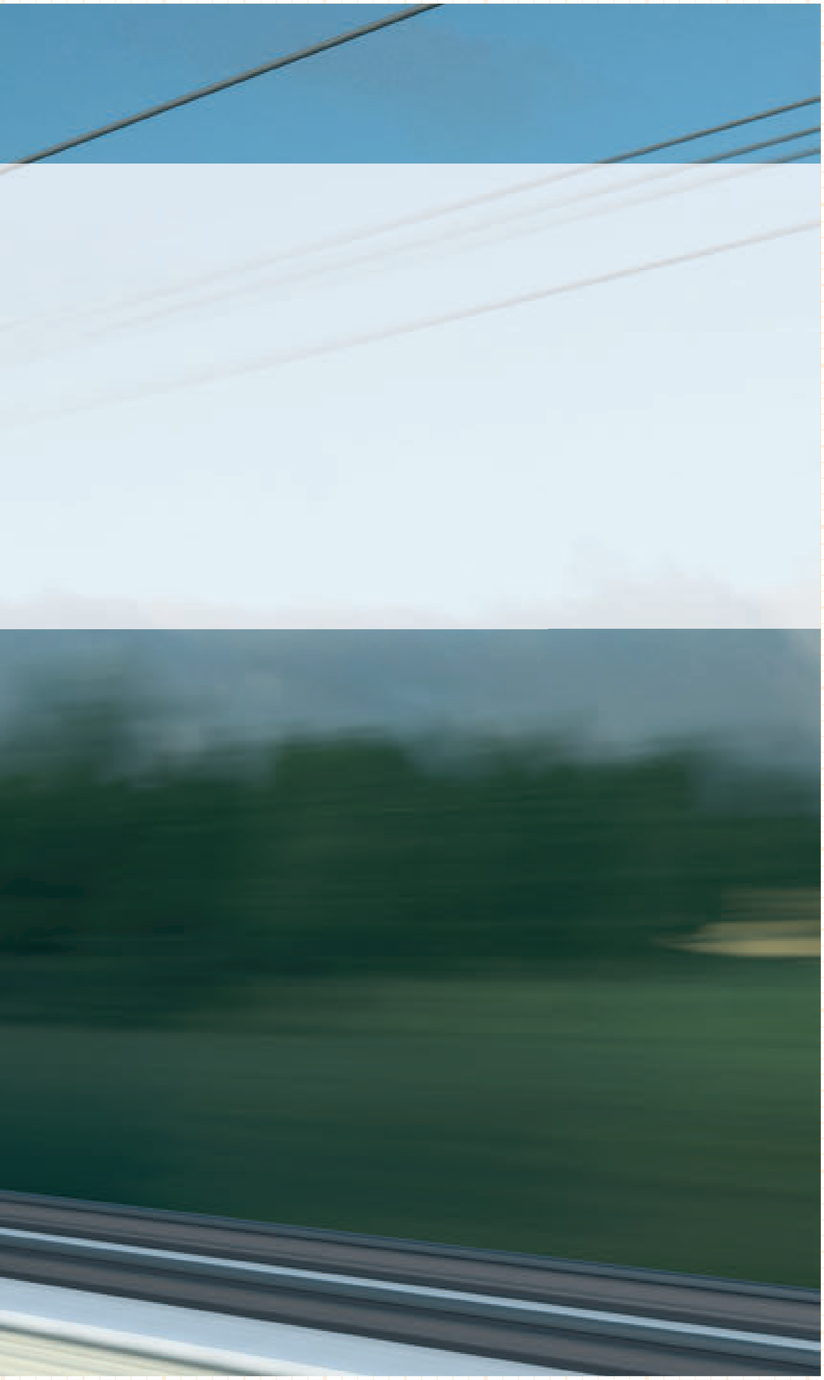
The recently launched Aral 'mobility hub' in Berlin is an example of this combination of services we are likely to see proliferate in the UK in the coming years.[147]

6.5.3 Motorway Service Areas

Motorway service areas (MSAs) will continue to play an essential role for road transport in the coming decades and are likely to grow into destinations in their own right as work operations 'decentralise' (see 5.1). Many sites already feature EV chargers, liquid fuels, and dedicated dispensing for HGVs and will likely expand these offers as the vehicle parc evolves.

The sites will be integrated with the local environment – offering breaks with nature, strategically located to re-energise the UK's long-distance travel needs, and possible entry points to developing commercial zones and industrial clusters. An early example of such a site is the recently opened Leeds Skelton Lake services, offering standard facilities and refreshments, but also a business centre and workspace, access to a nature reserve, ultra-rapid 350 kW chargers, and a hotel.[149]

7 Changes off the Road



Rail is a popular form of transport across the United Kingdom, with much of the network electrified already, especially for metropolitan services. However, many intercity rail units still use diesel fuels offering an opportunity for low carbon fuels, hydrogen or further expansion of electrified routes to decarbonise.

The stations of the future will be deeply integrated into other transport systems, becoming a community hub with technology enabling a universal 'digital ticket' and use of 'big-data' as part of a multi-modal mobility as a service platform.

Non-Road Mobile Machinery predominantly serves the agriculture and construction sectors. Their decarbonisation potential will be shaped by limited range requirements but high energy intensity operation.

7. Changes off the Road

7.1 Rail

7.1.1 Metropolitan and Suburban Rail

The combination of fixed, shorter routes in urban areas means short range rail such as trams, subway/metros, and commuter rail are well-placed to be electrified with this largely already having taken place. Overhead cabling means there are no energy storage issues and decarbonising the electricity for these short journeys is possible and efficient. The main evolution for light rail – beyond Net-Zero carbon electricity supply – will be seamless integration into other transport systems with unified ticketing/travel pass offers. There are already applications to this end, such as Citymapper in London, however, longer-term it is expected that more demand responsive services serve consumers.[87]

7.1.2 Intercity Rail

Intercity and freight trains can also electrify with OHCs and as they are heavy duty this will have large efficiency benefits. For now 28% of the UK passenger rail fleet remains diesel operated (on 58% of the physical rail network), so infrastructure will be the principal challenge for decarbonisation especially in rural locations.[151]

Low carbon fuels could replace the 1.7 billion litres currently used per year for rail, with return-to-depot refuelling meaning rail is well-suited to dedicated, high blend biofuel supply utilising existing (or slightly modified) infrastructure while OHC is built.[152]
Electrified intercity rail featuring hydrogen fuel cells may also be a suitable long-term solution. The HydroFLEX hydrogen fuel cell train is an example of such technology and is currently being trialled in the Midlands and can be powered up to 75 miles by 20 kg of compressed hydrogen via a hydrogen fuel cell system.[66,153] The electrified powertrain is also compatible with existing infrastructure for an easy and flexible option. Other hydrogen powered trains are in service with a range of up to 600 miles meaning such trains may prove the long-term solution to the UK's 'unelectrifiable' rail.[153]
Rail freight may pose the biggest challenge, with only 16% of the UK's freight locomotives currently electric.[151] The operational needs for unrestricted overhead access means this mode may prove challenging to fully electrify – a third rail likely to be the only practical option. Low carbon fuels may prove the most viable short- and medium-term means of decarbonising rail freight.

7.1.3 The Station of the Future

The stations of the future will be deeply integrated into other transport systems becoming a community hub, with technology enabling a universal 'digital ticket' and use of 'big-data' as part of a multi-modal MaaS platform creating a more flexible, demand responsive rail offering.[154]

Stations are also likely to play an increasingly important community role. In urban areas, the station of the future could be the core of a '15-minute' neighbourhood, supporting local services and businesses. In rural areas, the station of the future is likely to focus on 'transient' convenience offerings, such as parcel lockers, offering consumers convenient collection as part of their return journeys whilst improving efficiency of goods movement for a rural community. For all locations, accessibility will continue to improve to ensure stations offer an inclusive means of transport for all passengers, including those with a disability or the elderly.

7.2 Non-Road Mobile Machinery

Non-Road Mobile Machinery (NRMM) predominantly serves the agriculture and construction sectors and may be broadly grouped by limited range requirements but high energy intensity operation. This is due to their significant mass and need to power ancillary equipment such as hydraulic pumps and attached or towed equipment.

There is potential to make NRMM early adopters of renewable liquid fuels as they tend to have their supply for fuels from tanks brought to sites. Longer term, some machines could use batteries but for many farms, the ICE is likely to remain – even if acting as an on-board generator – powered by low carbon distillate fuels. Hydrogen seems an option only through fuel cells given lack of storage infrastructure on construction sites.

UK agriculture may look to automation of vehicles to reduce costs with some autonomous tractor concepts already being developed.[155,156]

Given NRMM tends to create rather than move goods, different regulatory approaches to other transport could work e.g. regulating the lifecycle emissions impact of a building will account for the GHG emissions impact of the construction phase, and therefore can encourage technology neutral low carbon solutions for NRMM.[157,158]

Finding 12:
Broadening lifecycle analysis and regulation of construction to include energy intensive processes used in their production may incentivise the decarbonisation of some Non-Road Mobile Machinery.

8 Changes at Sea

Decarbonising the marine sector offers unique challenges. For the lightest crafts like dinghies, liquid fuels are likely to remain as their long-term energy storage stability are well-suited to intermittent operation but battery-electric propulsion is likely to prove most suitable for other light boats with marinas offering charging points for docked vessels.

International shipping currently produces 2.9% of global GHG emissions and technology such as LNG, methanol, batteries and hydrogen will most likely be required to decarbonise it.

The port of the future will integrate developments in vessel automation, low carbon energy provision, and intelligent port operations to improve logistics efficiency and throughput. It will also likely host new energy vector filling stations and be supported by smaller Net-Zero craft.

8. Changes at Sea

8.1 Inland Shipping and Leisure Craft

Light and leisure craft account for <0.5% of UK transport GHG emissions[6] and typically operate light-duty ICEs. For the lightest crafts like dinghies, liquid fuels are likely to remain as their long-term energy storage stability are well-suited to intermittent operation but battery-electric propulsion is likely to prove most suitable for other light boats with marinas offering charging points for docked vessels.

Short range vessels used for activity in domestic waterways or port operations have more demanding duty cycles, however these vessels typically 'return to base' within one day so will see an increasingly 'hybridised' approach matching the range and duty cycle. In Norway, the Yara Birkeland is a battery electric small container ship currently being trialled to do short range goods movement tasks along the Norwegian coast, albeit with a 30 nautical mile range and limited routes.[159] However, the Yara Birkeland's most notable feature is that it is the world's first commercial autonomous ship,[159] with plans to displace 40,000 HGV journeys. This approach could also be adapted for the UK – by establishing a zero carbon coastal highway to displace road freight demand.[160]

Also in Norway, the Havyard Group are currently developing the largest ever maritime hydrogen fuel cell system to retrofit existing coastal passenger ferries[161] demonstrating the feasibility of hydrogen as an energy vector in all but the largest ship applications.

Low carbon fuels will act as both a transitional and long-term solution for operations that cannot feasibly operate solely on batteries nor deploy hydrogen infrastructure.[51] A switch back to renewables such as via the use of sails[162] could also reduce storage demand for certain applications.

8.2 International Shipping

International shipping currently carries around 90% of world trade by volume and has integrated itself as an essential route for trade.[163] The sector produces 2.9% of global GHG emissions[164] and the International Maritime Organisation (IMO) have set GHG emissions targets for international shipping by 2030 (40% reduction in carbon intensity) and 2050 (70% reduction in carbon intensity and 50% absolute reduction).[165] Given the scale of this sector and its importance in supporting other economic activity, there are many technologies being considered to reduce GHG emissions, although each has its limitations:

<u>LNG</u>

LNG may offer lower lifecycle emissions than some heavy fuel oil ships – although the degree to which this is the case will depend on variables such as operational utilisation and methane slip control as considered in recent studies.[166] In any case, methane of fossil origin will serve principally as a transitional energy vector for the decarbonisation of maritime. Increased use of biomethane, or liquid biogas (LBG) may offer more significant GHG emissions reductions and a route to further decarbonisation of existing fleets – it remains to be seen to what extent maritime could be supplied with LBG as other sectors compete for limited biomass availability.[167]

Battery

The GHG reduction potential for battery powered vessels is offset by energy density limitations. Using current technologies, a battery mass of 130,000 tonnes would be needed to store enough energy for an established route such as Felixstowe to Xiamen in China; this is more than twenty times the current fuel oil storage mass and would drastically reduce cargo space.[58,168–170]

Hydrogen

The potential for use of hydrogen for longer international shipping routes may also be limited, although it has been proposed that hydrogen could be a viable energy source for 43% of current China-USA trade.[171] The HySTRA hydrogen transport project (of which Shell is a partner) transporting liquefied hydrogen from Australia to Japan,[172] may demonstrate the viability of low carbon (blue) hydrogen supply via long-distance tanker.

Current infrastructure for hydrogen supply at ports is currently limited and needs to be in place at both departure and arrival locations before long distance use can be considered. Hydrogen production and supply would also need to increase, but the proposed hydrogen port in Teesside referenced in the Ten Point Plan is an encouraging early move in the right direction.[133] Designs are emerging for liquefied hydrogen bunkering vessels; however, none have yet commenced construction.[173]

Ammonia

The volumetric challenge presented by hydrogen may be surmountable by using ammonia as either a hydrogen carrier for PEMFC applications or a fuel in its own right for combustion or solid oxide fuel cells.[174] Whilst such applications may require complex NO_x management/after-treatment systems, these may be more than compensated for economically by the volumetric energy density improvements.

Ammonia production currently accounts for approximately 1.8% of global CO_2 emissions,[174] highlighting the importance of decarbonising its manufacture if it is to meet any maritime energy demand, but as with e-fuels the additional energy and GHG emissions required to produce ammonia will need to be offset against its benefits.

The maritime industry itself is taking action to support low carbon ammonia: Maersk are working with a consortium to establish Europe's largest production facility of green ammonia, with energy from wind turbines.[175] Ammonia production of this kind could significantly decarbonise fertiliser feedstocks and transport energy, however whether sufficient renewable energy can be provided to ultimately meet a significant proportion of maritime energy demand remains to be seen. Liquid organic hydrogen carriers may also present a route to carry larger volumes of hydrogen, however, many of these technologies require further development to be economically scalable.[176]

Methanol

The most economically promising energy vector in this regard is methanol.[176] Whilst a methanol fuel cell produces CO_2, 100% renewable-derived methanol may present a Net-Zero energy vector for shipping

with benefits to energy density, bunkering (supply of fuel for ships), and supply logistics compared to hydrogen and ammonia.
It is unclear at this stage if ship operators see a long-term role for renewable methanol and there is little evidence of this technology being developed at scale.

Given the above, shipping will probably follow a trend of increasing the renewable content of liquid fuels until supply and infrastructure enable economic deployment of hydrogen propelled ships. Two-stroke shipping engines are well placed to utilise low carbon fuels to decarbonise and, as with HGVs, could offer suitable application for distillate fuel-type components manufactured by sustainable aviation fuel (SAF) plants unsuitable for SAF deployment.

Figure 12: Architect's impression of the East of England Energy Park at Shell Quay, Lowestoft including quayside frontage suitable for offshore wind support vessel berthing.[180]

Source: Chetwoods Architects and Associated British Ports

The UK's unique position as an island with an ambitious decarbonisation target, significant renewable energy potential, and well-established, coastal hydrogen manufacturing presence (the UK's petroleum refineries), means it could be well-placed support the ships and ports of the future with appropriate policy frameworks and investment incentives.

Finding 13:
Early assessment of hydrogen bunkering opportunities at strategic UK ports could be key to encouraging hydrogen uptake for shipping.

8.3 The Port of the Future

Previous UKPIA publications have highlighted work at the port of Rotterdam, which is currently integrating developments in vessel automation, low carbon energy provision, and intelligent port operations to improve logistics efficiency and throughput.[177] The port is also integrating into a broader industrial cluster – providing valuable learnings the UK could emulate at strategic ports.

The UK's port of the future can implement all of the above and will have implemented a range of other innovative solutions to support a decarbonised shipping fleet:

- Port support vessels such as tugboats and tenders are likely to be principally electric or running on low carbon fuels and fully autonomous with inputs from the harbour as needed.[178]

- The port's tanks are likely to be filled with low carbon liquid fuels for re-energising large, long-distance ships with some ports featuring liquefied hydrogen storage either on-shore or via hydrogen bunker vessels with hydrogen supplied from the UK's low carbon industrial clusters.

- Ports may be linked by a fleet of battery electric/hybridised small container ships, reducing pressure on roads and loading and unloading efficiency will be increased with sophisticated logistics operations guiding autonomous cranes and other NRMM on-shore.

- Some ports may offer a dedicated maintenance service for the UK's significant off-shore wind farm capacity (see Figure 12)[179]

9 Changes in the Air

The aviation sector presents the most significant energy demand per km travelled. With no viable alternative to jet engines identified,[181] and strict fuel quality control measures for safety,[182] aviation is the most challenging mode to decarbonise with few alternatives to kerosene-type fuel as an energy carrier.

Fortunately, such fuels can be made with lower lifecycle GHG emissions with SAFs already utilised in some markets[183] and their use expected to rapidly grow as the aviation sector seeks to further decarbonise.[184]

The airport of the future will allow technology to further streamline the airport experience for users, with reduced queues, increasingly tailored retail experiences, and possibly the use of digital passports underpinned by blockchain technology.

9. Changes in the Air

9.1 Domestic Aviation

Domestic aviation demand in the UK is likely to continue reducing into the coming decades as services such as high speed rail improve in speed and personnel capacity.[185,186] However, some demand will remain, with more efficient aircraft deployed utilising a blend of SAFs for propulsion. Longer-term, (2035+) short flights may be served by hydrogen propelled aircraft, such as those recently announced by Airbus.[67] The growth of hydrogen for short-haul flights will be highly contingent on the implementation of hydrogen refuelling infrastructure at UK and European airports as well as the ability to deal with the challenge of safe storage and safe carriage.[187]

Very short-range flights (<20minutes), may be well-served by battery electric aircraft, such as the Loganair commercial flights for the Orkney islands.[188] However, it is likely that opportunities for such aircraft will be limited, exemplified by Airbus and Rolls-Royce deciding to discontinue their joint hybrid-electric demonstrator programme.[189]

Overall, given the UK's leading role in international aviation, it is likely that domestic aviation will be powered, and organised, by the same energy vectors and efficiency technologies utilised for long-distance travel.

9.2 International Aviation

For long-distance aviation, there are no current alternatives to kerosene-type fuels and even in the long-term, hydrogen as an option is unlikely to meet this challenge. Rather, hydrogen as an energy vector may prove a viable alternative for short and intermediate range flights.[67] For flights greater than 2,000 nautical miles, SAFs are likely to be the only option even beyond the year 2050, meaning the recent positive announcements in the UK Government's Ten Point Plan for a Green Industrial Revolution on SAFs should be considered a no regret investment for the UK.[133]

An advantage of there being only one viable energy vector solution for international aviation, and it being essentially a decarbonised equivalent of today's jet fuels, is that minimal supply infrastructure changes will be needed (Figure 13).

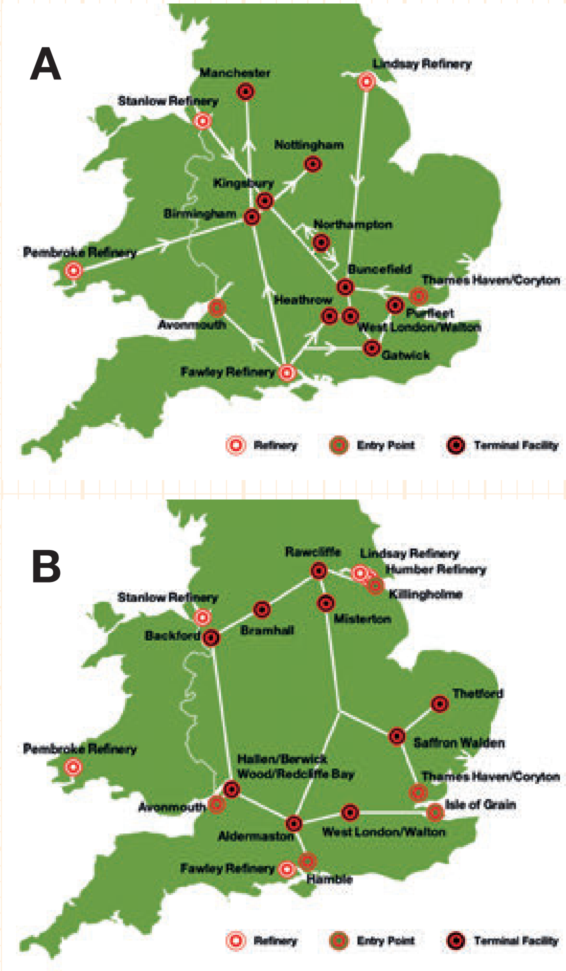


Figure 13:
UK refineries, entry points, terminal hubs, and fuel product pipelines.
A. privately owned pipeline systems
B. Exolum pipeline system[190,191]

Achieving large scale SAF production in the UK is not without its challenges – significant government support and collaboration amongst a range of industries and sectors will be required to achieve meaningful volumes of fuel. These volumes must then be deployable and resilient, with novel plants requiring financial support through their early production phases to understand their full range of failure modes whilst providing dedicated airport supply (e.g. road tankers). Other challenges to consider will be in making sure SAFs have necessary approvals for use. The US government has provided precedent for championing SAF production – supporting the establishment of a US Clearing House and testing novel SAFs in military hardware – and it is notable that the UK has already announced its own SAFs Clearing House in the Ten Point Plan.[133]
Once technical and supply readiness has been proven, SAFs may be deployed via established supply routes.
There are early, encouraging signs of SAF manufacture in the UK, with the Altalto waste-to-fuels plant – a joint venture between British Airways and Velocys – being granted planning permission to construct a plant in Immingham, North Lincolnshire.[192]
The plant plans to utilise 500,000 tonnes of non-recyclable waste when production commences in the mid-2020s.[193] In 2021 Fulcrum BioEnergy and Essar announced plans for a new £600m waste-to-fuel plant in the North West of England, which could be operational in 2025, and will convert several hundred thousand tonnes of pre-processed household waste into approximately 100 million litres of low carbon SAF every year.[194]

Even when considering generous Fischer-Tropsch yields, and assuming 100% SAF of such yields, a plant such as Altalto Immingham at full operation would supply only ~3% of current aviation turbine fuel demand.[195] Given aviation demand is forecast to grow to 2050 (even taking into account the impacts of COVID on short and long-term demand), a future UK will require more such SAF manufacturing operations to be built.[196,197]

Finding 14:
Encouraging close industry-local government partnerships when planning and constructing renewable fuel plants can reduce barriers and increase UK SAFs production capability.

While SAFs offer major decarbonisation potential, aviation may need to consider other non-technology options. The International Civil Aviation Authority's Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) programme is currently undergoing a pilot period with likely deployment in the mid-2020s.[198] The future UK aviation industry is likely to participate in such schemes to offset the most challenging to decarbonise aspects of its operations to achieve Net-Zero.

9.3 The Airport of the Future

From a consumer perspective, the airport of the future is likely to bear many similarities to that of today.[199] Technology will further streamline the airport experience, with reduced queues, increasingly tailored retail experiences, and possibly the use of digital passports underpinned by blockchain technology.[88]

Technology will have an even greater impact on aviation operations, with improved efficiency of ground activities[200] and increasingly electrified ground support equipment (GSE) such as pushback tractors.[201,202] Due to the exceptionally high operational standards required at airports, autonomous vehicles are unlikely to see widespread adoption until proven in other port applications (see 8.3), however, connected and remotely controlled GSE is likely to grow in the coming years.

Changes will take place above the airport as well, with efficiencies gained via improved use of airspace and increased achievement of continuous descent operations.[203,204] The former will present efficiencies in both passenger/freight movement and energy vector demand reduction, with the latter reducing local environment noise and further reducing energy demand.

Figure 14:
Swedavia's Vision image year 2070. Future plans for Stockholm's Arlanda airport include integrated connected technology for operational and passenger experience improvements.

Source: Swedavia, Architect: BAU

10. Summary of Report Findings

Overall Findings

To meet Net-Zero, all stakeholders must work together in **pursuing all technology options** with low carbon fuels and hydrogen (both blue and green), along with battery electrification with important roles to play across the UK's transport modes.

A systems approach, lifecycle analysis of transport GHG emissions, and frank assessment of transport mode energy provision, storage, and conversion demands should be essential ingredients in a transport decarbonisation strategy to ensure significant, achievable GHG emissions reductions at the lowest societal cost.

A **mobility paradigm shift** is required with new technologies and models disrupting existing mobility offers and improving transport energy efficiency.

Practical Findings

Finding 1: Considering full cradle-to-grave product lifecycle GHG emissions and regulation for primary transport modes likely to contribute to the most efficient delivery of Net-Zero.

Finding 2: Placing the downstream and automotive sectors at the forefront of COVID recovery and long-term UK trade strategies can grow domestic supply chains early while decarbonising long-term.

Finding 3: Reducing or removing the regulatory burdens for Distribution Network Operators (DNOs) can enable local networks to be upgraded and support the installation of substations for EV charging.

Finding 4: Publication of thorough, dedicated guidance for the safe installation of EV chargers at dedicated sites or existing retail forecourts may reduce local planning consent issues.

Finding 5: It is important that the finite pool of battery materials and batteries themselves are utilised in the most appropriate transport modes – short range and light duty – and in a sustainable framework where battery lifecycle planning pays more attention to second life and recycling concepts than is currently the case.

Finding 6: Supporting the market-led introduction of smart-charging could boost cost-effective and innovative approaches for the consumer in the EV space.

Finding 7: Providing public funding support for a hydrogen HGV commercial demonstration project in the UK could help overcome early concerns over a lack of infrastructure.

Finding 8: Accelerating the transition of liquid fuels from fossil-derived to biomass- or renewable energy-derived is a no-regret option for the UK as almost all transport modes could be at least incrementally decarbonised in the short term with such a change (aviation may be challenged due to strict fuel quality limits).

Finding 9: The UK renewable transport fuel regulations review in 2021 offers opportunity to consolidate and develop a new UK GHG emissions reduction target. Opportunities to incentivise new technologies should include support for blue or green hydrogen used in manufacture of fuels as is already allowed in some other countries.

Finding 10: Fuel duty offers a primary government lever to influence consumer behaviour towards low-carbon liquid fuels if scaled according to a fuel's carbon intensity, (captive fleets seeking to adopt higher blend biofuels may be an early adopter).

Finding 11: Developing a viable framework for low carbon energy vector investment contracts linked to existing emissions obligations could promote early adoption of low-carbon solutions in a technology neutral way.

Finding 12: Broadening lifecycle analysis and regulation to energy intensive products such as buildings and food could promote transport decarbonisation.

Finding 13: Early assessment of hydrogen bunkering opportunities at strategic UK ports could be key to encouraging hydrogen uptake for shipping.

Finding 14: Encouraging close industry-local government partnerships when planning and constructing renewable fuel plants can reduce barriers and increase UK SAFs production capability.

Glossary

APC	Advanced Propulsion Centre
BEV	Battery Electric Vehicle
Blue H_2	Hydrogen produced from a fossil-derived feedstock where the resultant CO_2 emissions are captured and stored, or reused.
CAZ	Clean Air Zone
CCUS	Carbon Capture Utilisation and Storage
CDO	Continuous Descent Operations
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DAC	Direct Air Capture (for CCUS)
DNO	Distribution Network Operator
ESC	Energy Systems Catapult
FAME	Fatty Acid Methyl Ester (also known as biodiesel)
FCEV	Fuel Cell Electric Vehicle
GHG	Greenhouse Gas
Green H_2	Hydrogen generated from renewable energy sources via the electrolysis of water. No CO_2 emissions are produced by the electrolysis reaction.
GSE	Ground Support Equipment
HGV	Heavy Goods Vehicle
HVO	Hydrogenated Vegetable Oil
ICE	Internal Combustion Engine
LCA	Lifecycle Analysis
LNG	Liquefied Natural Gas
MaaS	Mobility-as-a-Service
MSA	Motorway Service Area
NRMM	Non-Road Mobile Machinery
OHC	Overhead Catenary / Cable
OEM	Original Equipment Manufacturer
PEM(FC)	Proton Exchange Membrane (Fuel Cell)
PHEV	Plug-in Hybrid Electric Vehicle
PLV	Powered Light Vehicle
RTFO	Renewable Transport Fuel Obligation
SAF	Sustainable Aviation Fuel
TEU	Twenty-foot Equivalent Unit
TTW	Tank-To-Wheel (Tailpipe)
ULEZ	Ultra Low Emissions Zone
WTT	Well-To-Tank
WTW	Well-To-Wheel (or Wake in Aviation and Maritime)

References

1. Patterson, J. Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies. 54 (2018).
2. BEIS. Energy White Paper: Powering our Net Zero Future. 170 (2020).
3. Zap-Map. Zap Map – Charging points and electric vehicles UK 2020. Zap-Map https://www.zap-map.com/ (2021).
4. DfT. Renewable fuel statistics 2019: Final report. GOV.UK https://www.gov.uk/government/statistics/renewable-fuel-statistics-2019-final-report (2020).
5. DfT. National Travel Survey: England 2019. GOV.UK https://www.gov.uk/government/statistics/national-travel-survey-2019 (2020).
6. BEIS. 2018 UK Greenhouse Gas Emissions, Final figures. 41 (2020).
7. BEIS, E. and I. S. Final UK greenhouse gas emissions national statistics. https://data.gov.uk/dataset/9568363e-57e5-4c33-9e00-31dc528fcc5a/final-uk-greenhouse-gas-emissions-national-statistics (2020).
8. CCC. Net Zero – The UK's contribution to stopping global warming. (2019).
9. CCC. Net Zero – Technical Report. (2019).
10. BEIS. UK becomes first major economy to pass net zero emissions law. GOV.UK https://www.gov.uk/government/news/uk-becomes-first-major-economy-to-pass-net-zero-emissions-law (2019).
11. Digest of UK Energy Statistics (DUKES): petroleum. GOV.UK https://www.gov.uk/government/statistics/petroleum-chapter-3-digest-of-united-kingdom-energy-statistics-dukes (2020).
12. LowCVP. Renewable Fuels Guide. (2020).
13. European Commission. SHARES (Renewables) - Energy. Eurostat https://ec.europa.eu/eurostat/web/energy/data/shares (2021).
14. BEIS. Energy Flow Chart 2019. (2020).
15. IEA. Energy Technology Perspectives 2020 – Analysis. https://www.iea.org/reports/energy-technology-perspectives-2020 (2020).
16. Phillips 66. Refining UK. Phillips 66 https://www.phillips66.co.uk/EN/about/refining_ops/Pages/index.aspx (2020).
17. FuelsEurope. Vision 2050: A Pathway for the Evolution of the Refining Industry and Liquid Fuels. 28 (2018).
18. UKPIA. Statistical Review 2020. 29 (2020).
19. White, L., Miles, A., Boocock, C., Cooper, J.-G. & Mills, S. A comparison of real driving emissions from Euro 6 diesel passenger cars with zero emission vehicles and their impact on urban air quality compliance. https://www.concawe.eu/wp-content/uploads/2018/04/Rpt_18_8.pdf (2018).
20. DEFRA. Clean Air Zone Framework: Principles for setting up Clean Air Zones in England. 35 (2020).
21. HM Government. Check if you'll be charged to drive in a Clean Air Zone. GOV.UK https://www.gov.uk/check-clean-air-zone-charge (2020).
22. TfL. Cars. Transport for London https://www.tfl.gov.uk/modes/driving/ultra-low-emission-zone/cars (2020).
23. Birmingham City Council. A clean air zone for Birmingham. Birmingham City Council https://www.birmingham.gov.uk/info/20076/pollution/1763/a_clean_air_zone_for_birmingham (2020).
24. Bath and North East Somerset Council. Bath's Clean Air Zone. Bath and North East Somerset Council https://beta.bathnes.gov.uk/bath-clean-air-zone (2020).
25. Oxford City Council. Oxford Zero Emission Zone (ZEZ). Oxford City Council https://www.oxford.gov.uk/info/20299/air_quality_projects/1305/oxford_zero_emission_zone_zez (2020).
26. Bristol City Council. Clean Air for Bristol. Clean Air for Bristol https://www.cleanairforbristol.org/ (2020).
27. Ricardo. Life Cycle CO2e Emissions from Electric Vehicle Production and Wider Sustainability Impacts. (2020).
28. Mancini, L., Eslava, N. A., Traverso, M. & Mathieux, F. Responsible and sustainable sourcing of batteries raw materials: insights from hotspot analysis, corporate disclosures and field research. https://data.europa.eu/doi/10.2760/562951 (2020).

29. Natural History Museum. Leading scientists set out resource challenge of meeting net zero emissions in the UK by 2050. National History Museum https://www.nhm.ac.uk/press-office/press-releases/leading-scientists-set-out-resource-challenge-of-meeting-net-zer.html (2019).

30. DfT. Position statement on transport research and innovation requirements to support the decarbonisation of transport. GOV.UK https://www.gov.uk/government/publications/research-and-innovation-to-support-transport-decarbonisation-2019/position-statement-on-transport-research-and-innovation-requirements-to-support-the-decarbonisation-of-transport (2020).

31. Energy Systems Catapult. Innovating to Net Zero: UK Net Zero Report. https://es.catapult.org.uk/reports/innovating-to-net-zero/ (2020).

32. NREL. Lighting the Path to Net Zero: NREL's Strategy Drives Deep Transportation Decarbonization. NREL https://www.nrel.gov/news/program/2021/lighting-the-path-to-net-zero-nrels-research-strategy-drives-deep-transportation-decarbonization.html (2021).

33. ACEA. ACEA Position on Life Cycle Assessment. https://www.acea.be/uploads/publications/ACEA_position_on_Life_Cycle_Assessment.pdf (2012).

34. European Parliament. Regulation (EC) No 443/2009 of the European Parliament and of the Council of 23 April 2009. (2009) doi:10.1007/978-1-137-54482-7_27.

35. UK Government. The Renewable Transport Fuel Obligations Order 2007. (2007).

36. UK Government. The Motor Fuel (Road Vehicle and Mobile Machinery) Greenhouse Gas Emissions Reporting Regulations 2012. (2012).

37. UK Government. The End-of-Life Vehicles (Producer Responsibility) Regulations 2005. (2005).

38. IMO. Draft life cycle GHG and carbon intensity guidelines for maritime fuels. https://www.ics-shipping.org/wp-content/uploads/2020/08/draft-life-cycle-ghg-and-carbon-intensity-guidelines-for-maritime-fuels-1.pdf (2020).

39. LowCVP & APC. Embedding LCA into automotive manufacturing & future vehicle policy. (2019).

40. Powell, N. et al. Impact Analysis of Mass EV Adoption and Low Carbon Intensity Fuels Scenarios – Summary Report. 37 (2018).

41. LowCVP. Vehicle lifecycle CO2e emissions – integration into vehicle policy and automotive design. (2019).

42. Stratton, R. W., Wong, H. M. & Hileman, J. I. Life Cycle Greenhouse Gas Emissiosns from Alternative Jet Fuels. https://ascent.aero/documents/2020/02/life-cycle-greenhouse-gas-emissions-from-alternative-jet-fuels-version-1-2.pdf/ (2010).

43. World Steel Association. Position paper on life cycle assessment. http://www.worldsteel.org/publications/position-papers/lca-public-policy-paper.html (2020).

44. Institution of Mechanical Engineers. Accelerating Road Transport Decarbonisation. 18 (2020).

45. Peake, L., Ritson, J. & Cripps, I. Fixing the System: Why a circular economy for all materials is the only way to solve the plastic problem. 64 (2020).

46. European Environment Agency. Electric vehicles from life cycle and circular economy perspectives. https://data.europa.eu/doi/10.2800/77428 (2018).

47. APC UK. Vehicle Emissions – Widening the Lens. (2020).

48. European Commission Climate Action. Road transport: Reducing CO2 emissions from vehicles. Climate Action - European Commission https://ec.europa.eu/clima/policies/transport/vehicles_en (2016).

49. Volkswagen. How we make ID.3 carbon-neutral. Volkswagen https://www.volkswagenag.com/en/news/stories/2019/11/how-volkswagen-makes-the-id-3-carbon-neutral.html (2019).

50. SMMT. SMMT Motor Industry Facts 2020. https://www.smmt.co.uk/wp-content/uploads/sites/2/SMMT-Motor-Industry-Facts-Nov-2020.pdf (2020).

51. Atkins, P., Oldham, P. & Esposito, G. Transport Energy Network, a collaborative approach to understanding decarbonised transport in 2050: Cross sector energy and propulsion roadmaps. 42 (2020).

52. BP. BP Pulse. BP Pulse https://bpchargemaster.com/home/uks-largest-ev-charging-network/ (2021).

53. Shell UK. EV Recharge. Shell United Kingdom https://www.shell.co.uk/motorist/ev-charging.html (2021).

54. Energy Institute. Energy Institute Retail Marketing Survey 2020. https://knowledge.energyinst.org/search/record (2020).

55. EV Taskforce, LowCVP, OLEV & ESC. Energising our Electric Vehicle Transition. (2020).
56. DfT & OLEV. All new rapid chargepoints should offer card payment by 2020. GOV.UK https://www.gov.uk/government/news/all-new-rapid-chargepoints-should-offer-card-payment-by-2020 (2019).
57. OLEV & OZEV. Grant schemes for electric vehicle charging infrastructure. GOV.UK https://www.gov.uk/government/collections/government-grants-for-low-emission-vehicles (2019).
58. The Faraday Institution. High-energy battery technologies. https://faraday.ac.uk/wp-content/uploads/2020/01/High-Energy-battery-technologies-FINAL.pdf (2020).
59. Benchmark Mineral Intelligence. Sustainable Supply Chains. (2020).
60. Lienert, P., Shirouzu, N. & Nellis, S. Exclusive: Apple targets car production by 2024 and eyes 'next level' battery technology - sources. Reuters (2020).
61. The Faraday Institution. ReLiB: Recycling and reuse of EV lithium-ion batteries – The Faraday Institution. The Faraday Institution https://faraday.ac.uk/research/lithium-ion/recycle-reuse/ (2020).
62. European Commission. Questions and Answers on Sustainable Batteries Regulation. European Commission https://ec.europa.eu/commission/presscorner/detail/en/qanda_20_2311 (2020).
63. ARUP. Establishing a Hydrogen Economy. 9 (2011).
64. Ryan, A. Green Tomato Cars racks up 1m miles in Toyota Mirai hydrogen cars. FleetNews https://www.fleetnews.co.uk/fleet-management/future-fleet/green-tomato-cars-racks-up-1m-miles-in-toyota-mirai-hydrogen-cars (2019).
65. ACEA. Position Paper Charging and re-fuelling infrastructure required for heavy-duty vehicles. https://www.acea.be/uploads/publications/ACEA_Position_Paper-Charging_and_re-fuelling_infrastructure_heavy-duty_vehicles.pdf (2020).
66. DfT. UK embraces hydrogen-fuelled future as transport hub and train announced. GOV.UK https://www.gov.uk/government/news/uk-embraces-hydrogen-fuelled-future-as-transport-hub-and-train-announced (2020).
67. Airbus. ZEROe. Airbus https://www.airbus.com/innovation/zero-emission/hydrogen/zeroe.html (2020).
68. Bothe, D. Indirect Electrification for a Successful Transport Transition. ATZ worldwide vol. 120 20–25 (2018).
69. Giuntoli, J. Advanced Biofuel policies in select EU member states: 2018 update. 16 (2018).
70. Shell UK. Drivers set to go carbon neutral with Shell. Shell United Kingdom https://www.shell.co.uk/media/2019-media-releases/drivers-set-to-go-carbon-neutral-with-shell.html (2019).
71. BP UK. BP launches BPme – the new way to pay for fuel | News | Home. BP United Kingdom https://www.bp.com/en_gb/united-kingdom/home/news/press-releases/bp-launches-bpme-the-new-way-to-pay-for-fuel.html (2018).
72. BP UK. VYVE: a new way to understand, track and reduce carbon. BP United Kingdom https://www.bp.com/en_gb/united-kingdom/home/news/press-releases/vyve-a-new-way-to-understand-track-and-reduce-carbon-from-your-phone.html (2020).
73. ICAO. Carbon Offsetting and Reduction Scheme for International Aviation FAQs. ICAO Environment https://www.icao.int/environmental-protection/CORSIA/Pages/CORSIA-FAQs.aspx (2019).
74. UKPIA. UKPIA Future Vision: The Downstream Oil Sector in a Low-Carbon World. https://www.ukpia.com/media/2219/ukpia-vision-july-2019.pdf (2019).
75. Malins, C. Truckin' on: Using the heavy duty CO2 standard to drive investment in fuel decarbonisation. (2019).
76. FuelsEurope. Clean Fuels for All: EU Refining Industry Proposes a Potential Pathway to Climate Neutrality by 2050. https://www.fuelseurope.eu/wp-content/uploads/FuelsEurope-Clean-Fuels-for-All-Final.pdf (2020).
77. DfT. Transport use during the coronavirus (COVID-19) pandemic. GOV.UK https://www.gov.uk/government/statistics/transport-use-during-the-coronavirus-covid-19-pandemic (2020).
78. Hertzke, P., Middleton, S., Neu, G. & Weaver, H. Moving Forward: How COVID-19 will affect future mobility in the United Kingdom. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/moving-forward-how-covid-19-will-affect-mobility-in-the-united-kingdom (2020).

79. Carpenter, J. London lockdown: Are pollution levels rebounding in the capital as Covid controls are eased? Ends Report https://www.endsreport.com/article/1678367/london-lockdown-pollution-levels-rebounding-capital-covid-controls-eased (2020).

80. DfT. Legalising rental e-scooter trials: outcome and summary of responses. GOV.UK https://www.gov.uk/government/consultations/legalising-rental-e-scooter-trials-defining-e-scooters-and-rules-for-their-use (2020).

81. Tees Valley Combined Authority. Tees Valley E-Scooter Trial. Tees Valley Combined Authority https://teesvalley-ca.gov.uk/transport/tees-valley-e-scooter-trial/ (2020).

82. DfT. Fix Your Bike Voucher Scheme: apply for a voucher. GOV.UK https://www.gov.uk/guidance/fix-your-bike-voucher-scheme-apply-for-a-voucher (2020).

83. OECD. Cities policy responses - OECD Policy Responses to Coronavirus (COVID-19). OECD http://www.oecd.org/coronavirus/policy-responses/cities-policy-responses-fd1053ff/ (2020).

84. Reimer, J. The 15-minute infrastructure trend that could change public transit as we know it. Here 360 https://360.here.com/15-minute-cities-infrastructure (2020).

85. ETI Chair. Paris Northgates Project: 15 min. city - 30 min. territory. http://chaire-eti.org/wp-content/uploads/2019/11/Anglais-Booklet-ETI-v3-2.pdf (2019).

86. Farenden, A. & Lee-Williams, T. The Future of Mobility and MaaS Governance and Orchestration. 72 (2019).

87. Citymapper. Citymapper PASS. Medium https://medium.com/citymapper/citymapper-pass-17c56da5dfa0 (2019).

88. Nguyen, B. et al. Blockchain and the built environment. (2019).

89. Iberdrola. How can blockchain be used to certify the source of green energy? Iberdrola https://www.iberdrola.com/innovation/blockchain-energy (2020).

90. Maersk. TradeLens blockchain-enabled digital shipping platform continues expansion with addition of major ocean carriers Hapag-Lloyd and Ocean Network Express. Maersk https://www.maersk.com/news/articles/2019/07/02/hapag-lloyd-and-ocean-network-express-join-tradelens (2019).

91. BMW. Digital Key. BMW ConnectedDrive Services https://connecteddrive.bmwlaunchpad.co.uk/services/digital-key (2020).

92. Nissan. NissanConnect Services. Nissan https://www.nissan.co.uk/ownership/nissan-infotainment-system/nissanconnect-services.html (2020).

93. Amazon. Key by Amazon In-Garage Delivery. Amazon https://www.amazon.com/b?ie=UTF8&node=17861200011 (2020).

94. Amazon. Amazon.co.uk Help: About Amazon Hub Locker. Amazon https://www.amazon.co.uk/gp/help/customer/display.html/ref=hp_left_v4_sib?ie=UTF8&nodeId=201910660 (2020).

95. Cherrett, T. & Allen, J. Last mile urban freight in the UK: how and why is it changing? 34 (2019).

96. Ames, C. Beryl takes micromobility multimodal. The Transport Network https://www.transport-network.co.uk/Beryl-takes-micromobility-multimodal/16794 (2020).

97. DfT. Future of mobility: urban strategy. 78 (2019).

98. Tobar, M. & Martinez, E. ENSEMBLE regulatory framework. (2019).

99. Ricardo Consulting. Safe Road Trains for the Environment; developing strategies and technologies to allow vehicle platoons to operate on normal public highways with significant environmental, safety and comfort benefits. CORDIS https://cordis.europa.eu/project/id/233683 (2017).

100. Baxter, J. A., Merced, D. A., Costinett, D. J., Tolbert, L. M. & Ozpineci, B. Review of Electrical Architectures and Power Requirements for Automated Vehicles. in 2018 IEEE Transportation Electrification Conference and Expo (ITEC) 944–949 (2018). doi:10.1109/ITEC.2018.8449961.

101. Advacned Propulsion Centre UK. The Roadmap Report Towards 2040: a Guide to Automotive Propulsion Technologies. https://www.apcuk.co.uk/app/uploads/2018/06/roadmap-report-26-6-18.pdf (2018).

102. TSC. Market Forecast for Connected and Autonomous Vehicles. https://s3-eu-west-1.amazonaws.com/media.ts.catapult/wp-content/uploads/2017/09/08094421/15780_TSC_Market_Forecast_for_CAV_Report_FINAL.pdf (2017).

103. DfT & CPC. MUSICC - Highly Automated Vehicle Certification. https://s3.eu-west-1.amazonaws.com/media.cp.catapult/wp-content/uploads/2020/07/21112647/01331_Highly-Automated-Vehicles-Case-Study_FINAL.pdf (2020).

104. DfT. Technology and innovation in UK Maritime: the case of autonomy. 60 (2019).

105. MCIA & LowCVP. The Route to Tomorrow's Journey: Powered Light Vehicles - Practical, Efficient & Safe Transport for All. (2019).

106. DfT. Vehicles statistics. GOV.UK https://www.gov.uk/government/collections/vehicles-statistics (2020).

107. Lucas, K., Stokes, G., Bastiaanssen, J. & Burkinshaw, J. Inequalities in Mobility and Access in the UK Transport System. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/784685/future_of_mobility_access.pdf (2019).

108. Blagoeva, D. T., Dias, P. A., Marmier, A. & Pavel, C. C. Wind power, photovoltaic and electric vehicles technologies, time frame: 2015-2030. 196 (2016).

109. Cozzi, L. & Petropoulos, A. Growing preference for SUVs challenges emissions reductions in passenger car market – Analysis. IEA https://www.iea.org/commentaries/growing-preference-for-suvs-challenges-emissions-reductions-in-passenger-car-market (2019).

110. Tsakalidis, A. et al. Electric light commercial vehicles: Are they the sleeping giant of electromobility? Transp. Res. Part Transp. Environ. 86, 102421 (2020).

111. Automotive Plastics. Automotive Plastics in Modern Cars. Automotive Plastics https://www.automotiveplastics.com/automotive-plastics-today/ (2021).

112. Birkhold, S., Moder, M., Orthofer, A. & Spamann, A. What the future of mobility holds for chemical players. McKinset & Company Chemicals https://www.mckinsey.com/industries/chemicals/our-insights/what-the-future-of-mobility-holds-for-chemical-players (2020).

113. Moore, S. PP makes its case in next-generation EVs. Plastics Today https://www.plasticstoday.com/automotive-and-mobility/pp-makes-its-case-next-generation-evs (2019).

114. Rouilloux, G. Plastics. The future for automakers and chemical companies. Kearney https://www.kearney.com/chemicals/article?/a/plastics-the-future-for-automakers-and-chemical-companies (2020).

115. IEA. The Future of Petrochemicals. https://www.iea.org/reports/the-future-of-petrochemicals (2018).

116. Lubes 'n' Greases. EV Lubricant Technology. http://upisecke.za.net/EV-LubeTech-Guide.pdf (2019).

117. Castrol E-Fluids. Castrol UK & Ireland https://www.castrol.com/en_gb/united-kingdom/home/technology-and-innovation/castrol-e-fluids.html (2020).

118. Mobil EVTM. Mobil EV https://www.mobilev.com/en/ (2020).

119. Electric vehicle fluids: Lubricating the future of mobility. Shell Global https://www.shell.com/business-customers/lubricants-for-business/products/shell-efluids.html (2020).

120. Vlugter, J. Scaling Recycled Plastics across Industries. https://www.ellenmacarthurfoundation.org/assets/downloads/ce100/Scaling-Recycled-Plastics-across-Industries.pdf (2017).

121. Tapper, R., Longana, M. L., Norton, A., Potter, K. D. & Hamerton, I. An evaluation of life cycle assessment and its application to the closed-loop recycling of carbon fibre reinforced polymers. Compos. Part B Eng. (2019) doi:10.1016/j.compositesb.2019.107665.

122. Rinofner, A. OMV transforms plastic waste into crude oil. OMV Group https://www.omv.com/en/news/omv-transforms-plastic-waste-into-crude-oil (2018).

123. Mayor of London. London's electric bus fleet becomes the largest in Europe. London City Hall https://www.london.gov.uk//press-releases/mayoral/london-has-europes-largest-electric-bus-fleet (2019).

124. Mayor of London. Cleaner buses. London City Hall https://www.london.gov.uk//what-we-do/environment/pollution-and-air-quality/cleaner-buses (2015).

125. Stagecoach. Be Greener, Go by Bus. Stagecoach https://www.stagecoachbus.com/promos-and-offers/manchester/electric-buses (2020).

126. National Express. Electric buses. NX Bus West Midlands https://nxbus.co.uk/west-midlands/electric-buses (2020).

127. The Busway. About. The Busway - connecting Huntingdon, St Ives & Cambridge https://www.thebusway.info/about.shtml (2020).

128. First Bus. Bristol Green Buses. First Bus https://www.firstgroup.com/about-us/facts-and-stats/case-studies/bristol-green-buses (2020).

129. Go-Ahead. Go-Ahead rolls out UK's first geo-location zero-emission buses. The Go-Ahead Group https://www.go-ahead.com/media/press-releases/go-ahead-rolls-out-uks-first-geo-location-zero-emission-buses (2019).

130. Fuel Cell Electric Buses. The UK to become a pioneer in the development of hydrogen fuel cell buses. Fuel Cell Electric Buses https://fuelcellbuses.eu/public-transport-hydrogen/uk-become-pioneer-development-hydrogen-fuel-cell-buses (2020).

131. Translink. Hydrogen Bus Contract. Translink https://www.translink.co.uk/corporate/media/pressnews/hydrogenbuscontract (2020).

132. CCAV & Innovate UK. CAVForth: creating Europe's first full-sized autonomous bus. GOV.UK https://www.gov.uk/government/case-studies/cavforth-creating-europes-first-full-sized-autonomous-bus (2020).

133. HM Government. The Ten Point Plan for a Green Industrial Revolution. 38 (2020).

134. Automotive Council UK & APC UK. Thermal Propulsion Systems Roadmap. (2018).

135. Hill, N., Hilton, G., Morgan-Price, S. & Weldon, P. Zero Emission HGV Infrastructure Requirements. 111 (2020).

136. Volvo. Our Electric trucks. Volvo Trucks Global https://www.volvotrucks.com/en-en/trucks/alternative-fuels/electric-trucks.html (2020).

137. AG, D. T. The eActros in everyday operation. Daimler Truck AG https://www.daimler-truck.com/innovation-sustainability/efficient-emission-free/eactros-innovation-fleet.html (2020).

138. Hyundai. Our Truck. Hyundai Hydrogen Mobility https://hyundai-hm.com/en/unser-truck/ (2020).

139. Hyundai. Hyundai XCIENT Fuel Cell Heads to Europe for Commercial Use. Hyundai Media Newsroom https://www.hyundai.news/eu/brand/hyundai-xcient-fuel-cell-heads-to-europe-for-commercial-use/ (2020).

140. AG, D. T. Daimler Trucks presents technology strategy for electrification. Daimler Truck AG https://www.daimler-truck.com/innovation-sustainability/efficient-emission-free/mercedes-benz-genh2-fuel-cell-truck.html (2020).

141. CORPORATION, T. M. Toyota and Hino to Jointly Develop Class 8 Fuel Cell Electric Truck for North America. Toyota Motor Corporation Official Global Website https://global.toyota/en/newsroom/corporate/34009225.html (2020).

142. MDS Transmodal. National Infrastructure Commission: Future of Freight Demand. https://nic.org.uk/app/uploads/Future-of-Freight_Future-of-Freight-Demand_MDS-Transmodal.pdf (2019).

143. Boulton, M. Shell plans to replace forecourt with EV-only charging hub. Forecourt Trader https://forecourttrader.co.uk/news/shell-plans-to-replace-forecourt-with-ev-only-charging-hub/644122.article (2019).

144. Errity, S. UK's first Gridserve Electric Forecourt opens for business. DrivingElectric https://www.drivingelectric.com/news/982/uks-first-electric-forecourt-open-november (2020).

145. Significant expansion of biofuels capacity for Phillips 66. Fuel Oil News https://fueloilnews.co.uk/2020/09/significant-expansion-of-biofuels-capacity-for-phillips-66/ (2020).

146. Nott, G. Why coronavirus is driving a scan & go shopping revolution. The Grocer https://www.thegrocer.co.uk/store-design/why-coronavirus-is-driving-a-scan-and-go-shopping-revolution/646695.article (2020).

147. BP Global. Aral opens Berlin mobility hub. bp global https://www.bp.com/en/global/corporate/careers/life-at-bp/our-stories/aral-opens-berlin-mobility-hub.html (2020).

148. Aral. Tankstelle der Zukunft. Aral https://www.aral.de/de/global/retail/presse/tankstelle-der-zukunft.html (2020).

149. Extra. The Experience. Leeds Skelton Lake Services https://www.leedsskeltonlakeservices.co.uk/the-experience/ (2018).

150. Extra. Leeds Skelton Lake Services is now open. Extra Motorway Services https://extraservices.co.uk/news/leeds-skelton-lake-services-is-now-open/ (2020).

151. Shirres, D. Could hydrogen trains be the future of rail? Institution of Mechanical Engineers https://www.imeche.org/news/news-article/could-hydrogen-trains-be-the-future-of-rail (2018).

152. UKPIA. The Economic Contribution of the UK Downstream Oil Sector. https://ukpia.com/media/1005/the-economic-contribution-of-the-downstream-oil-sector-evidence-paper.pdf (2019).

153. Hirschlag, A. Next stop, hydrogen-powered trains. BBC Future https://www.bbc.com/future/article/20200227-how-hydrogen-powered-trains-can-tackle-climate-change (2020).

154. ARUP & Network Rail. Tomorrows Living Station. (2019).

155. Akam, S. Driverless Tractors Are Getting Ready for Harvest Season. Bloomberg.com https://www.bloomberg.com/news/articles/2020-06-02/driverless-tractors-are-coming-soon-to-u-k-farms (2020).

156. John Deere. The Future of Farming Technology. John Deere https://www.deere.co.uk/en/agriculture/future-of-farming/ (2020).

157. Giesekam, J. Reducing carbon in construction: a whole life approach. 4 (2018).

158. Cucurachi, S., Scherer, L., Guinée, J. B., Tukker, A. & Leiden, C. voor M. Life Cycle Assessment of Food Systems. One Earth 1, (2019).

159. Nordal, K. & Kremer, J. Yara Birkeland press kit. Yara International https://www.yara.com/news-and-media/press-kits/yara-birkeland-press-kit/ (2018).

160. Southampton innovations for decarbonised shipping integral to proposed Zero-carbon Coastal Highway. University of Southampton https://www.southampton.ac.uk/news/2020/10/decarbonised-shipping-smmi.page (2020).

161. Havyard. Prototype for hydrogen - one step closer. Hayvard https://www.havyard.com/news/2019/prototype-for-hydrogen---one-step-closer/ (2019).

162. Smith, T., Lewis, C., Faber, J., Wilson, C. & Deyes, K. Reducing The Maritime Sector's Contribution To Climate Change And Air Pollution. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/816015/maritime-emission-reduction-options.pdf (2019).

163. Gencsu, I. & Hino, M. Raising Ambition to Reduce International Aviation and Maritime Emissions. 24 (2015).

164. Marine Environment Protection Committee. Fourth IMO GHG Study 2020 – Final report. https://safety4sea.com/wp-content/uploads/2020/08/MEPC-75-7-15-Fourth-IMO-GHG-Study-2020-Final-report-Secretariat.pdf (2020).

165. IMO. Action To Reduce Greenhouse Gas Emissions From International Shipping. (2018).

166. Pavlenko, N., Comer, B., Zhou, Y., Clark, N. & Rutherford, D. The climate implications of using LNG as a marine fuel. 40 (2020).

167. Nelissen, D. et al. Availability and costs of liquefied bio- and synthetic methane: The maritime shipping perspective. (2020).

168. Fuel Consumption by Containership Size and Speed. The Geography of Transport Systems https://transportgeography.org/contents/chapter4/transportation-and-energy/fuel_consumption_containerships/ (2020).

169. MI News Network. Maersk Triple-E Vessels: Why Size Matters? Marine Insight https://www.marineinsight.com/shipping-news/size-matters/ (2017).

170. Maersk. AE1 Eastbound. Maersk https://www.maersk.com/local-information/shipping-from-europe-to-asia-pacific/ae1-east-bound (2020).

171. Mao, X., Rutherford, D., Osipova, L. & Comer, B. Refuelling assessment of a zero-emission container corridor between China and the United States: Could hydrogen replace fossil fuels? 13 (2020).

172. HySTRA. HySTRA. HySTRA http://www.hystra.or.jp/ (2020).

173. Wilhelmsen. New design makes liquefied hydrogen bunker vessels a reality. Wilhelmsen https://www.wilhelmsen.com/media-news-and-events/press-releases/2019/new-design-makes-liquefied-hydrogen-bunker-vessels-a-reality/ (2019).

174. Royal Society. Ammonia: zero-carbon fertiliser, fuel and energy store. Royal Society https://royalsociety.org/topics-policy/projects/low-carbon-energy-programme/green-ammonia/ (2020).

175. Maersk. Maersk backs plan to build Europe's largest green ammonia facility. Maersk https://www.maersk.com/news/articles/2021/02/23/maersk-backs-plan-to-build-europe-largest-green-ammonia-facility (2021).

176. Niermann, M., Drünert, S., Kaltschmitt, M. & Bonhoff, K. Liquid organic hydrogen carriers (LOHCs) – techno-economic analysis of LOHCs in a defined process chain. Energy Environ. Sci. 12, 290–307 (2019).

177. All about Port of the future. Port of Rotterdam https://www.portofrotterdam.com/en/doing-business/all-about-port-of-the-future (2018).

178. Lloyd's Register, QINETIQ & University of Southampton. Global Marine Technology Trends 2030 Autonomous Systems. https://cdn.southampton.ac.uk/assets/imported/transforms/content-block/UsefulDownloads_Download/F9AFACCCB8B444559D4212E140D886AF/68481%20Global%20Marine%20Technology%20Trends%20Autonomous%20Systems_FINAL_SINGLE_PAGE.pdf (2017).

179. ARUP. Ports for offshore wind: A review of the net-zero opportunity for ports in Scotland. (2020).

180. Associated British Ports. Port of Lowestoft Master Plan 2018-2036. https://www.abports.co.uk/media/kfmlemiq/port-of-lowestoft-masterplan-2018.pdf (2018).

181. Schaeffer, R. et al. Transport. in AR5 Climate Change 2014: Mitigation of Climate Change (2014).

182. Energy Institute. EI/JIG Standard 1530 Quality assurance requirements for the manufacture, storage and distribution of aviation fuel to airports (A4). (2019).

183. Sustainable Aviation Fuel (SAF). SkyNRG https://skynrg.com/sustainable-aviation-fuel/saf/ (2020).

184. Sustainable Aviation. Sustainable Aviation Fuels Road-Map. https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_FuelReport_20200231.pdf (2020).

185. BAA believes that by 2032 HS2 will cut Heathrow domestic flights. Numbers have been falling over the past 10 years anyway. Airport Watch https://www.airportwatch.org.uk/2012/01/emirates-non-stop-to-anywhere-breakthrough/ (2012).

186. Number of domestic UK flights falls 20% in decade. Financial Times.

187. Hydrogen in aviation: how close is it? Airbus https://www.airbus.com/newsroom/stories/hydrogen-aviation-understanding-challenges-to-widespread-adoption.html (2020).

188. The world's shortest flight may soon be its greenest, too. The Economist (2019).

189. E-Fan X. Airbus https://www.airbus.com/innovation/zero-emission/electric-flight/e-fan-x.html (2020).

190. UKPIA. Statistical Review 2018. (2018).

191. Exolum. Where we operate. https://exolum.com/en/where-we-operate/ (2021).

192. Parr, K., Swinburn, S., Watson, D. & Swinburn, K. Planning Application Summary - DM/0664/19/FUL. (2011).

193. Jeffery, R. Plans submitted for the first waste to jet fuel plant in the UK and Europe. Velocys https://www.velocys.com/2019/08/20/plans-submitted-for-the-first-waste-to-jet-fuel-plant-in-the-uk-and-europe/ (2019).

194. Gosden, E. Stanlow refinery to make jet fuel from household rubbish. The Times (2021).

195. Digest of UK Energy Statistics (DUKES). GOV.UK https://www.gov.uk/government/collections/digest-of-uk-energy-statistics-dukes (2020).

196. Bouwer, J., Krishnan, V. & Saxon, S. Airline industry recovery from COVID-19. McKinsey https://www.mckinsey.com/industries/travel-logistics-and-transport-infrastructure/our-insights/will-airline-hubs-recover-from-covid-19 (2020).

197. Sustainable Aviation. Decarbonisation Road-Map: A Path to Net Zero. https://www.sustainableaviation.co.uk/wp-content/uploads/2020/02/SustainableAviation_CarbonReport_20200203.pdf (2020).

198. ICAO. What is CORSIA and how does it work? ICAO Environment https://www.icao.int/environmental-protection/pages/a39_corsia_faq2.aspx (2020).

199. ARUP. Future of Air Travel: The Future Ready Airport. (2017).

200. Sustainable Aviation. Aircraft on the ground CO2 reduction programme. 19 (2016).

201. Fully-electric aircraft pushback tractor undergoing trials at major international airport. Electrification Story https://www.electrificationstory.com/fully-electric-aircraft-pushback-tractor-undergoing-trials-at-major-international-airport/ (2020).

202. Playing the long game. Airside International https://www.airsideint.com/issue-article/playing-the-long-game/ (2020).

203. CAA. Airspace Modernisation Strategy. https://publicapps.caa.co.uk/docs/33/CAP%201711%20Airspace%20Modernisation%20Strategy.pdf (2018).

204. Sustainable Aviation. A Guide to Continuous Descent Operations. https://www.sustainableaviation.co.uk/wp-content/uploads/2018/06/A-Guide-to-CDOs-Booklet1.pdf (2018).

About UKPIA

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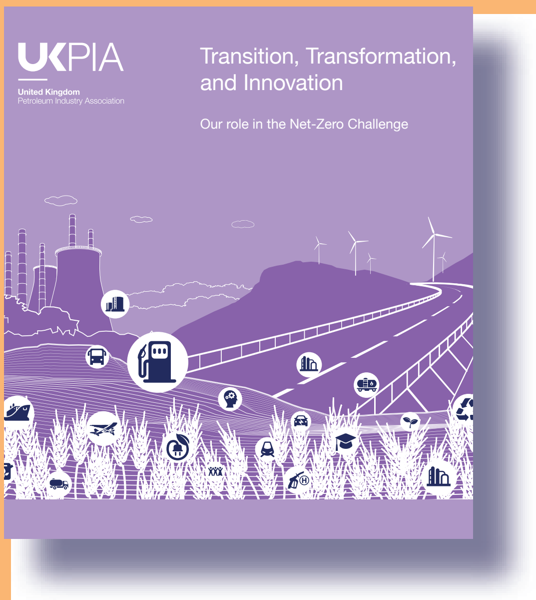

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