Transport Energy Network

A collaborative approach to understanding decarbonised transport in 2050

Cross sector energy and propulsion roadmaps
November 2020

ADVANCED PROPULSION CENTRE UK

LowCVP
Low Carbon Vehicle Partnership

University of Brighton
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Introducing the Transport Energy Network

The Transport Energy Network was initiated to accelerate transport decarbonisation, supported by the Advanced Propulsion Centre, LowCVP and the University of Brighton. Set up to address 2050 targets for Net-Zero GHG emissions, it considers different transport modes (on road, off highway, marine, rail and synergies with aerospace sector), looking at strengthening the UK supply chain. Network activities are designed to encourage collaboration between communities and provide evidence to support policy development in this area.

Contents

Executive summary

As evidence of the detrimental impacts of climate change increases, rapid reductions in emissions of greenhouse gases are vital. The transport sector is both the largest emitter of greenhouse gases (GHG) in the UK and one of the most difficult to decarbonise. Urgent action is needed to develop and drive adoption of technologies to rapidly reduce emissions in this sector.

In response to this challenge, the Advanced Propulsion Centre (APC) and Low Carbon Vehicle Partnership (LowCVP) initiated the Transport Energy Network (TEN) which is working collaboratively to accelerate transport decarbonisation. The network held a programme of workshops to share and improve understanding in the technology and fuels needed to deliver the net zero 2050 targets across the transport modes. These workshops focused on two key questions:

- What are the technology pathways to net zero across transport sectors?
- What are the enablers for these pathways?

Roadmaps were then developed considering different transport modes, energy vectors and propulsion solutions. Key findings and recommendations from these workshops are captured in this report.

Key findings and recommendations

There is no 'silver bullet' technology to decarbonise transport

Widespread electrification of propulsion can deliver significant efficiency benefits, with batteries having a key role for lighter vehicles and applications with lower stored energy demands. However, the diversity of transport use patterns means that a portfolio of technology solutions is needed to deliver net zero GHG emissions by 2050. TEN roadmaps show that synergies across transport sectors can be leveraged to help accelerate the development of the technology and growth within UK manufacturing.

Recommendation for Government

Support for development and roll out of technologies to decarbonise transport should be technology agnostic; recognising the diversity of solutions that will be necessary to reach net zero.

Recommendation for Industry

Continue development of low carbon vehicle technology, including propulsion systems, energy storage, and power electronics, electric machines and drives across all vehicle segments.

Recommendation for TEN

Investigate potential for cross sector R&D activities and grow new collaborations.

Scale up and commercialisation of low carbon sustainable fuels is essential to reach net zero GHG emissions

Low carbon sustainable liquid and gaseous fuels are essential to medium and long term decarbonisation in high energy sectors such as aviation, marine and some parts of the heavy duty (HD) on and off road sectors, potentially making up more than 75% of transport energy demand in 2050. These fuels also offer an important route to decarbonisation in the short to medium term for lighter vehicles, during the introduction of electrified and fuel cell technologies. A whole systems approach is needed to consider energy pathways through generation, transmission, delivery, storage and ultimately propulsion to ensure the optimum use of primary resources.

Recommendation for Government

Work together with stakeholders to develop a clear strategy for the use of sustainable energy vectors, with a particular focus on supporting the quickest possible roll out of sustainable fuels to enable rapid decarbonisation.

Recommendation for Industry and TEN

Support the urgent revision of the Automotive Council energy and fuels roadmap.

Recommendation for TEN

Understand the sensitivity of final energy use to the developing technology landscape, and project the resource and infrastructure requirements for these sustainable energy vectors.

Adopting a lifecycle approach to emissions is vital

A lifecycle approach to the assessment of GHG from transport is a key enabler for long term decarbonisation, ensuring emissions from one part of the vehicle lifecycle are not shifted to another.

Recommendation for Government

Adoption and harmonisation of lifecycle analysis and sustainability criteria across different government departments and sectors to ensure net zero GHG emissions are achieved without wider negative environmental impacts. Vehicle emissions legislation must move away from current tailpipe based measures towards an LCA approach.

Recommendation for Industry

Develop lifecycle assessments of the GHG emissions and energy use for new transport solutions to support understanding of the implications of the adoption of different pathways.

Decarbonising transport cost-effectively requires a shared vision

Policy and market drivers have a key influence on investment and destinations for sustainable energy. An efficient transition to net zero transport will therefore require cooperation between a wide range of stakeholder groups based on a shared vision.

Recommendation for Government

Work with stakeholders to ensure that policy is in place to enable solutions to meet the UK's decarbonisation agenda, for both on vehicle technology and low carbon energy vectors.

Recommendation for TEN and Industry

Engage with government consultations to provide a holistic view of the transport sector.

Introduction

In 2019 the UK committed to reach net zero greenhouse gas emissions (GHG) by 2050 to mitigate the effects of climate change. At this time, the transport sector had become the UK's largest contributor of GHG emissions, emitting 28% of UK GHG, while other sectors rapidly decarbonised. Taking into account all sectors, the UK has demonstrated leadership by achieving the greatest level of decarbonisation in the G20 since the year 2000 as a result of being the first country to legislate for legally binding GHG emissions targets, and was the first country in the G7 to legislate for net zero emissions.

Acknowledging the gap between our expected emissions for 2050 and our zero emissions commitment

Recent analysis by the Committee for Climate Change (CCC) and the Department for Transport (DfT) showed that existing policy does not go far enough, with projected GHG reductions only achieving half the decarbonisation needed to be on track in 2032 (see Figure 1). Urgent action is clearly needed to ensure that the transport sector supports the UK commitment to mitigate the effects of climate change.

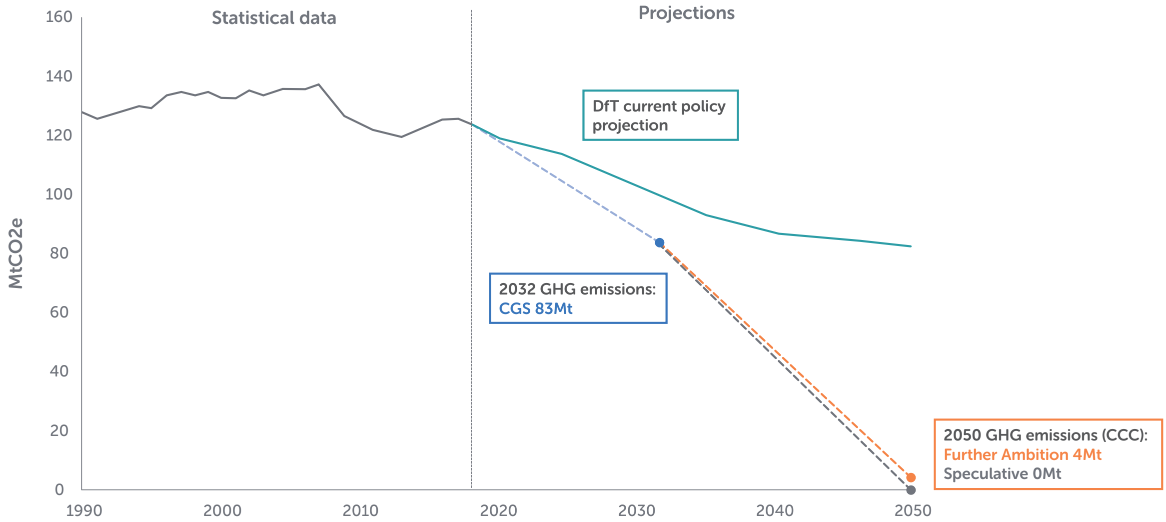
Transport decarbonisation is a complex picture, with many vehicle types operating in different environments, from small passenger cars and heavy duty trucks operating at 44 tonnes over ranges of hundreds of kilometres (km), to aeroplanes and ships with ranges of thousands of km and power output of many megawatts (MW). No single technology will support decarbonisation across all these applications, and it is likely that multiple solutions will be needed within sectors to support the range of user needs. Indeed, reliance on a single solution carries a number of risks, particularly where the technology is in development. For example, the technology may not ultimately meet market needs leaving no alternative solution, or the timing of the introduction of that technology may mean that transitional measures are necessary to meet short to medium term decarbonisation requirements.

Developing a portfolio of power options will accelerate closing the gap

The transport sector will need a portfolio of options over the next three decades to transition to net zero GHG emissions. Technology pathways are expected to cover a range of propulsion systems (thermal and electrical), low carbon fuels and energy vectors.

Many of these technology pathways are under development with further progress in fundamental science, engineering development, manufacturing supply chains and infrastructure needed to bring them to market.

Figure 1: GHG projections based on current policies, compared to clean growth strategy and CCC net zero targets (source DfT)



DfT's latest domestic GHG emissions projections based on current policies, compared to Clean Growth Strategy (CGS) targets and CCC Net Zero 'Further Ambition' and 'Speculative' scenarios.

Source: Decarbonising Transport: Setting the Challenge (2020)

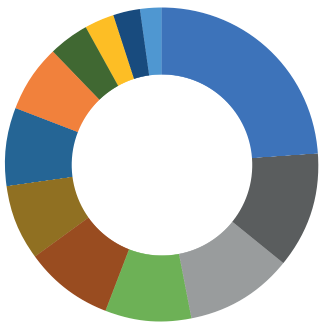
The importance of evidence-based policy planning and implementation

Policy has a key influence on the introduction of new transport technology, from R&D funding, through to support for supply chain development and incentives for adoption by users. For example, in 2019 the Renewable Transport Fuel Obligation (RTFO) supported sales of 2680 million litres of sustainable fuels, representing 5.1% of road and non road fuel. It is vital that evidence based policy, harmonised across sectors, is developed to support the most efficient achievement of transport decarbonisation objectives.

Consultation for this report

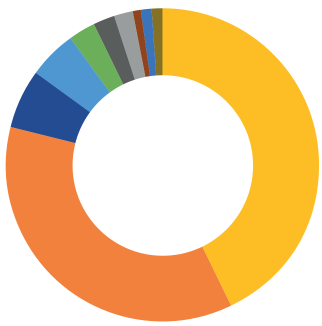
In 2019, TEN held a programme of workshops to understand the required trajectory of our transport modes to deliver the net zero 2050 targets, which has led to the development of a roadmap considering different transport modes, energy vectors and propulsion solutions. These workshops had a broad cross sector participation with attendees from industry, academia, vehicle OEMs, consultancies, government and non-government organisations (see Figures 2 and 3).

Figure 2: TEN workshop attendees by organisation type



Acedemia	24%	Tier 2+	8%
SME	12%	Consultancy	7%
Engineering services	11%	Trade Association	4%
OEM / Prime	9%	Financial	3%
RTO / NGO	9%	Other	3%
Tier 1	8%	Government	2%

Figure 3: TEN workshop attendees by sector



Cross sector	43%	Maritime	2%
Automotive	36%	Chemical	2%
Government	6%	Infrastructure	1%
Energy	5%	Aerospace	1%
Financial	3%	Rail	1%

Workshop activities focused on two key questions

- What technology pathways could reach net zero across transport sectors?
- What are the enablers for these pathways?

In March 2020, after these workshops had taken place, the Department for Transport (DfT) set out its ambitions for meeting the net-zero targets through the document 'Decarbonising Transport: Setting the Challenge'[1]. This document focused on six strategic areas within which the DfT would be consulting to form a Transport Decarbonisation Plan (TDP). Of these six strategies three of them are related directly to some of the outputs from our TEN workshops: Decarbonising how we get our goods; UK as a hub for green transport technology and innovation; and reducing carbon in a global economy.

This report seeks to

- Identify technologies and fuels which are particularly suited to lowering the emissions for specific transport sectors
- Identify areas where improvements in regulation, funding and industry and/or government collaboration would be most effective
- Recommend a range of next steps that can be taken to decarbonise transport at a faster rate

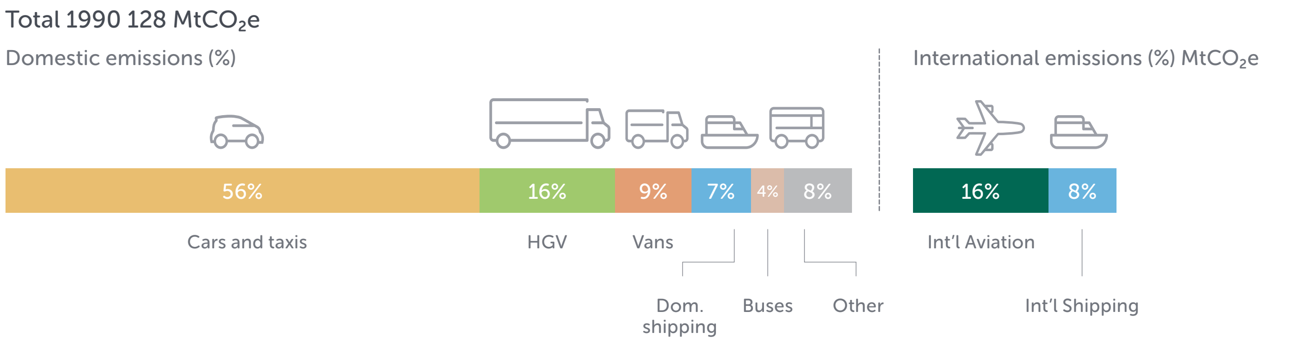
1 Department for Transport, Decarbonising transport: Setting the Agenda, March 2020 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/878642/decarbonising-transport-setting-the-challenge.pdf

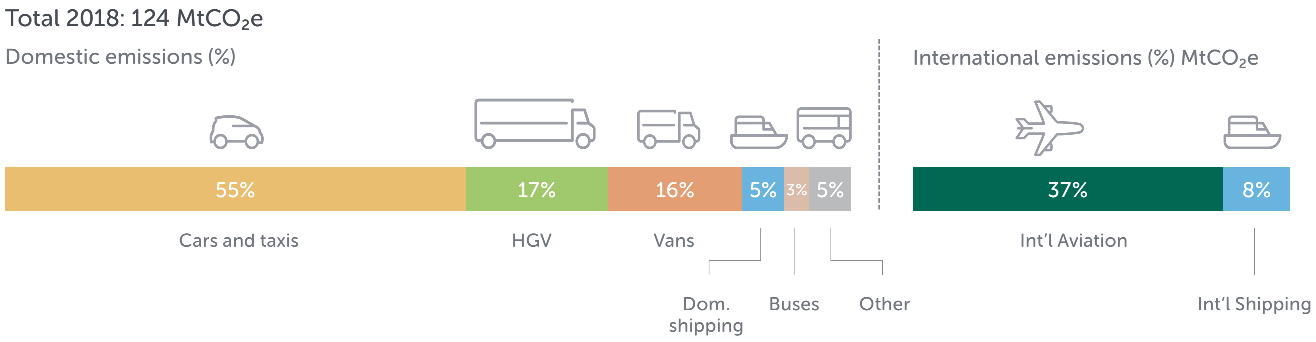
The story so far

Reducing emissions from smaller vehicles has been the focus to date

In 2018, 55% of UK transport GHG emissions were produced by cars and taxis (see Figure 4), therefore to date there has been significant focus on decarbonisation in the passenger car sector, with electric vehicles (EVs) widely expected to provide a viable solution. An increasing number of EV models, improvements in consumer acceptability of vehicles, e.g. increased range, coupled with incentives for ownership and a growing charging infrastructure mean that sales have now grown to around 8% of passenger car sales to date in 2020[2], of which approximately 50% are battery electric vehicles (BEVs) , and 50% plug in hybrid vehicles (PHEVs).

Figure 4: UK transport GHG emissions by mode, 1990 and 2018 (source DfT)





2 Society of Motor Manufacturers and Traders, Electric Vehicle and Alternatively Fuelled Vehicle Registrations, https://www.smmt.co.uk/vehicle-data/evs-and-afvs-registrations/ accessed 7 August 2020

HGV, off-highway, aviation and shipping are now becoming more significant

As cars and taxis electrify, decarbonisation of other transport sectors including HGV, off highway, aviation and shipping will become more important. Therefore, increased focus on these sectors is needed to ensure that progress in transport decarbonisation is maintained.

Roadmaps for the adoption of low carbon technologies by sector

Through the TEN workshops, high level roadmaps for these hard to decarbonise sectors were developed, collating the views of stakeholders. These roadmaps link energy vectors and propulsion technologies, identifying potential combinations which could be applied in the transition to net zero.

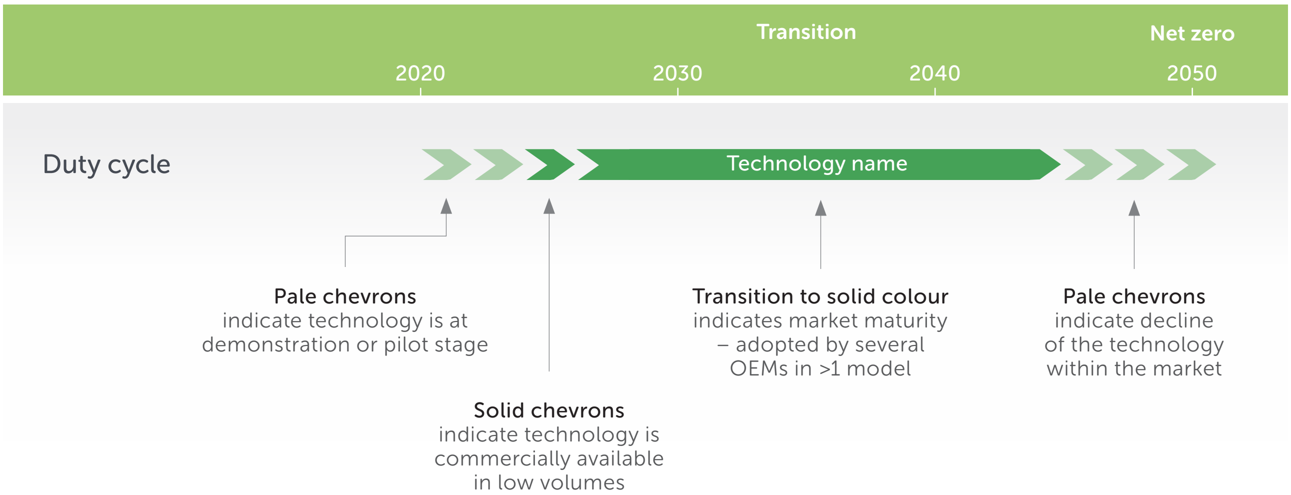
Fuel sustainability

A sustainable energy vector is considered to have low GHG intensity and no unintended environmental impacts due to resources used to produce these fuels for on road transport and off highway machinery. A recent Royal Academy of Engineering report[3] recognises the breadth of issues that should be considered: costs of production, competitiveness with fossil fuels, food, energy and water security, employment provision, rural development and human health impacts. The Renewable Transport Fuel Obligation (RTFO), which applies to road transport and non road mobile machinery, sets a GHG emission threshold for low carbon fuels and sustainability criteria for various feed-stocks.

Net Zero

In this report, net zero is understood to mean achieving a state in which the activities within the value chain of a company or country result in no net impact on the climate from greenhouse gas emissions. This can be achieved by balancing the impact of any remaining greenhouse gas emissions with an appropriate amount of carbon removals.

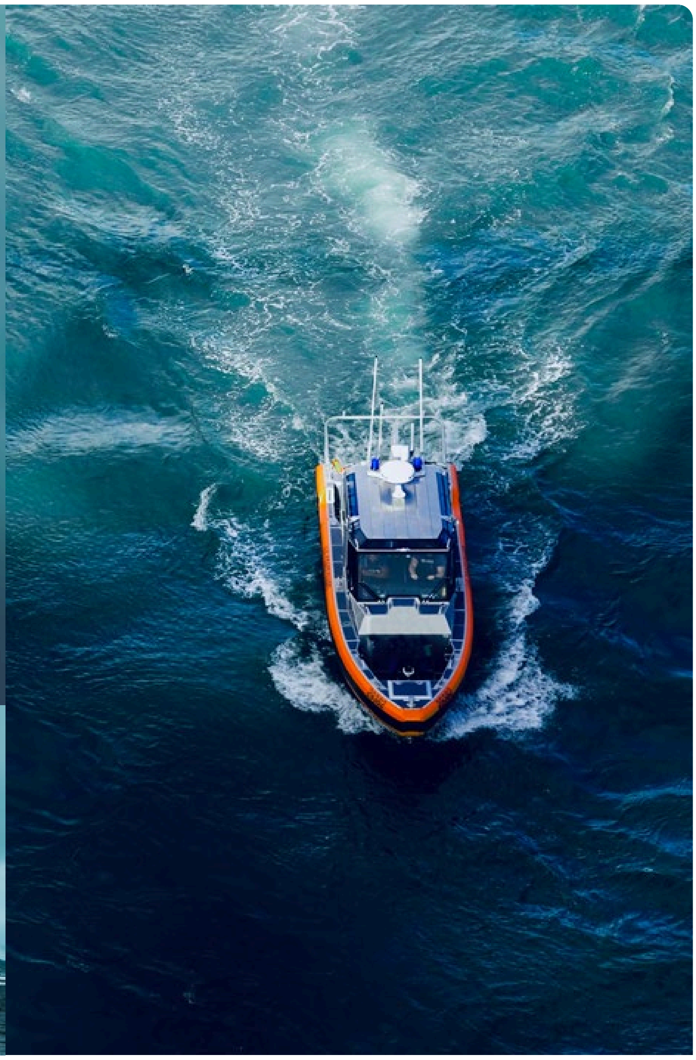
How to read a roadmap



3 Sustainability of liquid biofuels, Royal Academy, July 2017 https://www.raeng.org.uk/publications/reports/biofuels

Maritime Sector

In the Maritime sector, stakeholders envisaged an evolution from the current dominance of fossil fuels in the form of Marine Diesel and Heavy Fuel Oil (HFO) towards the use of more sustainable, low carbon alternatives for longer range journeys, as shown in Figure 5. These include sustainable diesel, e.g. hydrotreated vegetable oil (HVO) and liquid natural gas, e.g. biomethane. Fuels which are carbon emission free at the point of use, e.g. hydrogen and ammonia, are currently in demonstration in the maritime sector, and TEN recognised the potential for the use of these fuels in fuel cells (FC) or internal combustion engines (ICE). Battery electric propulsion was recognised as an option for only the shortest journeys.



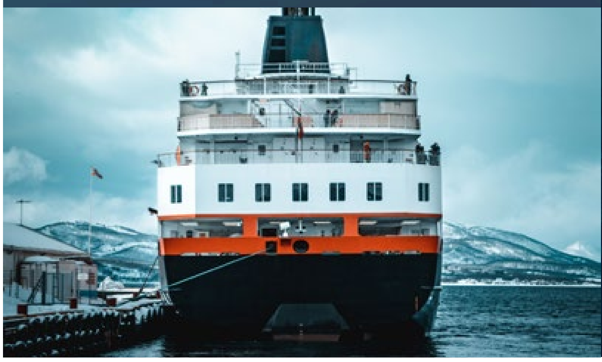
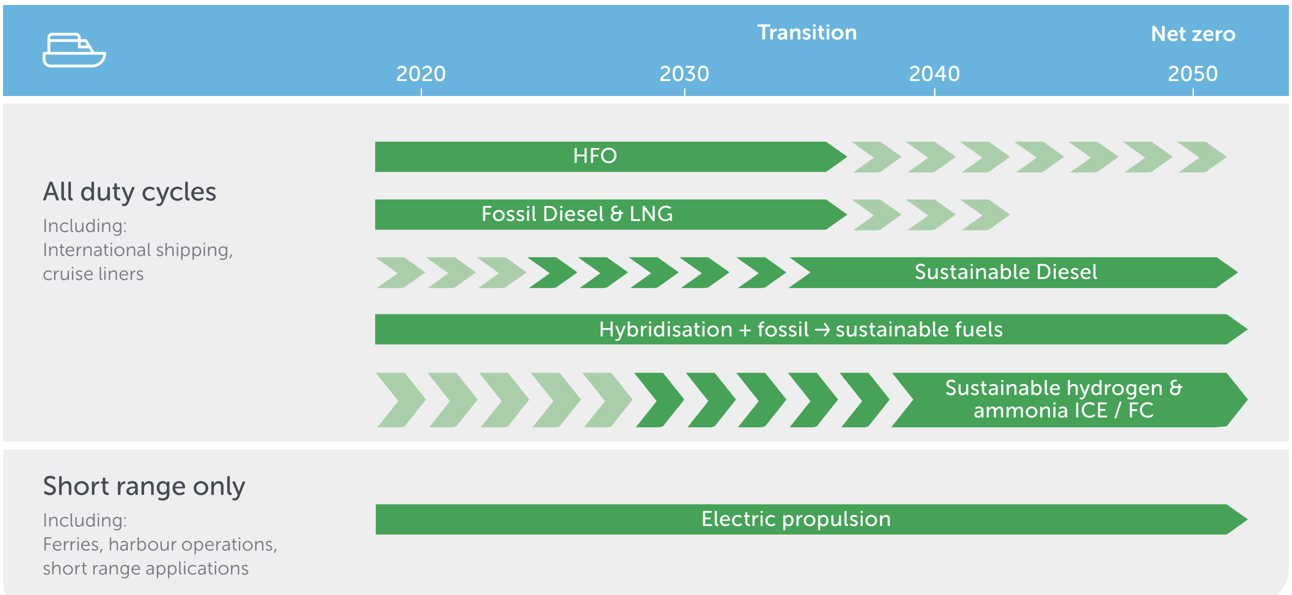


Figure 5: TEN maritime sector roadmap



Heavy duty on road sector

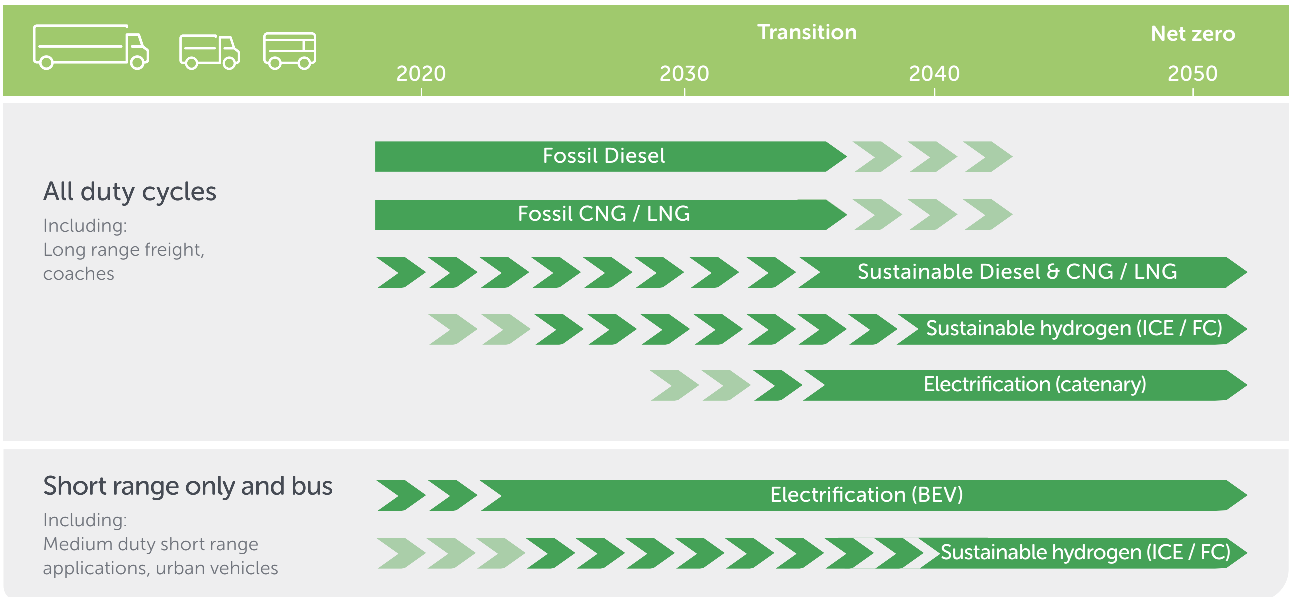
The heavy duty vehicle parc in the UK is currently predominately fuelled by diesel ICE, with an average of 6.4% sustainable diesel use to date in 2020[4]. Low carbon powertrain use is growing in some sectors: in 2019, 5% of bus sales and <1% of new van sales were electric vehicles, and biomethane powered circa 950 vehicles[5]. However, considering the overall heavy duty on road vehicle parc, just 0.1% of vehicles are battery electric or gas powered[6]. Solutions identified by TEN acknowledge the variation in technological challenges presented by different applications (see Figure 6). For short range commercial vehicles and bus, battery electric vehicles (BEVs) were viewed as a feasible solution, alongside reductions in grid carbon intensity. For higher energy duty cycles, sustainable low or zero carbon fuels were recognised as an important potential route to decarbonisation for these vehicles, with stakeholders identifying ICE or FC powertrains powered by sustainable diesel, biomethane or low carbon hydrogen. Electricity could also be supplied via catenary (overhead cables) enabling the increased level of energy without the need for larger batteries.

4 HMRC oil bulletin https://www.gov.uk/government/statistics/hydrocarbon-oils-bulletin accessed 28 September 2020

5 LowCVP market monitoring statistics, renewable fuels and ultra low emission vehicles, August 2020

6 UK Government Statistical Data Set, Heavy Goods Vehicles, VEH0503 Heavy goods vehicles by propulsion and fuel type, https://www.gov.uk/government/statistical-data-sets/veh05-licensed-heavy-goods-vehicles, Accessed 7 August 2020

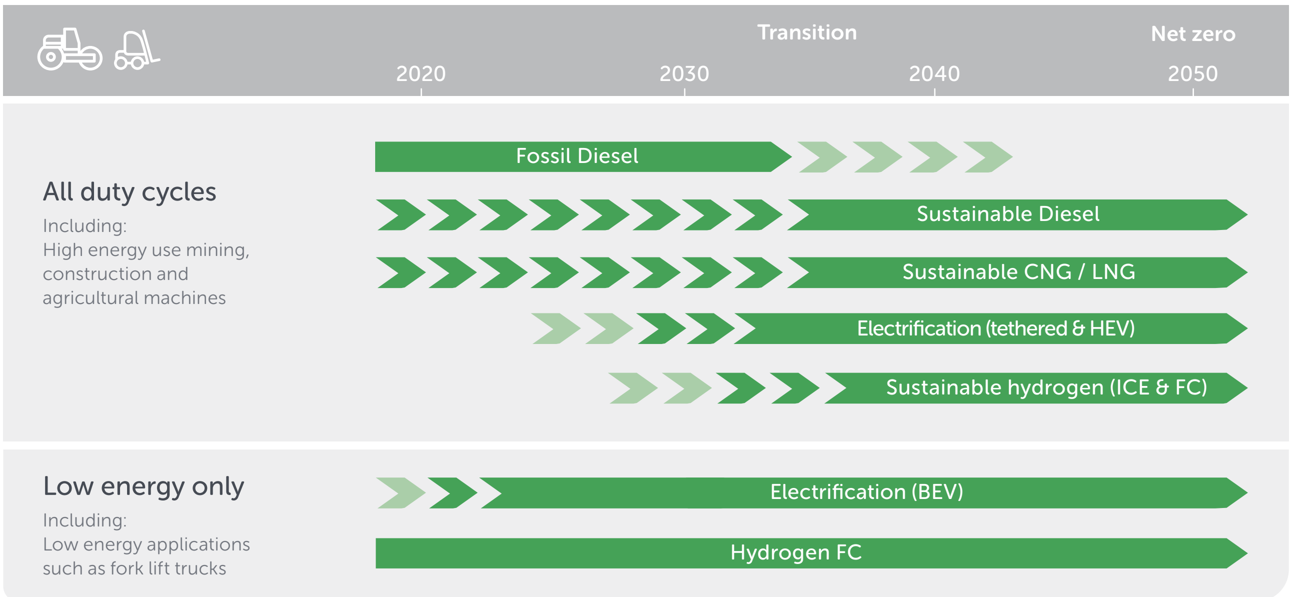
Figure 6: Heavy Duty on road roadmap



Off-highway sector

The off highway sector encompasses a wide range of machines from forklift trucks and tractors to very large mining and construction vehicles, and is overwhelming powered by diesel ICE. Sustainable fuels powering ICE or FC were seen as important solutions, with the option for tethered power identified as a route to electrification for high power/energy vehicles with limited physical movement (see Figure 7).

Figure 7: Heavy Duty off road sector roadmap

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E-TEC
JCB

There is no silver bullet to decarbonise the full range of transport needs, a portfolio of solutions will be needed

Developing a range of powertrains to close the emissions gap

These roadmaps show the divergence from a one size fits all solution envisaged to reach decarbonisation targets, demonstrating the need for a portfolio of solutions both for on board propulsion technologies and energy vectors to meet the varying needs of different transport sectors. There are clearly common decarbonisation pathways across transport modes, which implies that cross sectoral collaboration in their development could both accelerate the route to market as well as reduce final costs through aggregated demand.

Challenges to the implementation of these pathways span the TRLs requiring development of fundamental science, product engineering and supply chain development to achieve a successful market introduction.

Iveco Stralis NP 460 natural gas truck

Ford Transit PHEV

Nissan battery

Battery electric and hybrid electric powertrains

Fully electrified powertrains present an opportunity for energy efficient conversion of electricity to motion, with machine efficiencies of >90% in optimal conditions. Vehicles have zero tailpipe emissions, but well-to-wheels (WTW) GHG emissions depend on degree of decarbonisation of the electricity supply, and lifecycle emissions are critically influenced by battery production emissions. Hybrid powertrains can provide a transitional pathway to electrification in market sectors where BEVs do not meet market needs. Here the use of mature technologies, such as geofencing, can ensure zero tailpipe emissions within clean air zones. Potential challenges exist with the supply chain for materials for batteries and electric machines, particularly lithium, cobalt and neodymium. A recent Faraday Institution report predicts growth in demand for Lithium and Cobalt of three and five times respectively between 2018 and 2035 to meet predicted global demand for EVs[7]. Research is underway on battery recycling and reducing the use of these materials to minimise the impact of these challenges.

For light duty vehicles, battery electrification is an increasingly acceptable solution with a growing market share, although challenges for consumer adoption remain in the provision of reliable charging infrastructure and vehicle first cost. For heavy duty on and off road vehicles, the use of BEV is increasing for lower energy duty cycles, i.e. for lighter, shorter range, on road commercial vehicles. For vehicles with higher energy/power duty cycles, the low energy density of Lithium-Ion (Li-ion) battery technology compared to liquid or gaseous fuels leads to a large battery size (adding considerable mass and cost to the vehicles) and results in recharging times that can impact operational requirements. New battery chemistries are in development which could provide improved performance, for example Lithium Sulphur or Sodium-Ion, although these technologies are not expected to reach mass market use until late 2030s[8]. Alternative electricity supply options have been proposed to reduce battery size, with the approach varying by sector: catenary for on highway, tethering for off highway and shore power for ships in port. However, significant infrastructure investment and engineering development is needed to implement these solutions.

7 Faraday Insights, Issue 6, updated June 2020, 'Lithium, Cobalt and Nickel: The Gold Rush of the 21st Century', https://faraday.ac.uk/wp-content/uploads/2020/06/Faraday_Insights_6_Updated.pdf, accessed 7 July 2020

8 Faraday Insights, Issue 6, updated June 2020, 'Lithium, Cobalt and Nickel: The Gold Rush of the 21st Century', https://faraday.ac.uk/wp-content/uploads/2020/06/Faraday_Insights_6_Updated.pdf, accessed 7 July 2020

Fuel cell powertrains

Fuel cells (FC), either Solid Oxide (SOFC) or Proton Exchange Membrane (PEM FC), present advantages over battery electric powertrains due to higher energy density of their fuels (typically methane or hydrogen) compared to Li-ion batteries and faster refuelling times. Overall powertrain system efficiencies of 40-60% are reported, with efficiency sensitive to load (reducing at higher outputs). WTW GHG emission reduction depends on the fuel production pathway. Current high volume hydrogen pathways have large GHG emissions compared to fossil fuels, although these are expected to reduce with new methods of hydrogen production. Key challenges to vehicle implementation are the high level of required hydrogen purity and durability for PEM FC, and high temperatures and transient performance for SOFC.

PEM FC is relatively well developed for passenger cars, with products such as the Toyota Mirai available to the public, but vehicle cost and refuelling infrastructure deployment remain barriers to widespread adoption.

PEM FC solutions for buses are currently at pilot stage, with grant funded fleets in operation in Aberdeen and London.

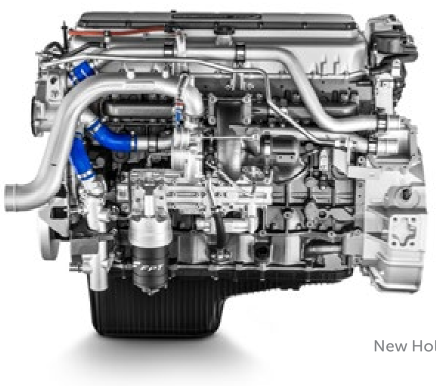
Higher power/energy FC applications such as on road heavy commercial vehicles and maritime applications are due to enter the UK market from around 2024. Key challenges for these propulsion systems are durability for higher mileage duty cycle, scale up for higher power applications and propulsion system cost. Additionally for marine, FC reliability is critical to maintain safety of life at sea.

Toyota Sora fuel cell bus

Internal Combustion Engines

ICE powertrains are dominant in the current vehicle parc. Efficiencies of between 30-50% are possible currently, with technology in development to give 55-60% efficiency. The high energy density of liquid or gaseous fuels and capability at high power outputs mean that ICE can provide an important solution for high power/energy applications where electric or fuel solutions are in development, and may not reach mass market until the medium or long term. Additionally, the long lifespan of vehicles in some sectors (passenger car – up to 12 years, HD truck – up to 15 years, Marine >25 years) will mean that ICE will be part of the transport mix for a significant period. This means that the supply of sustainable low carbon fuels is critical to decarbonise these applications. However, 'Diesel gate' led to significant reputational damage to ICE in recent years, with justifiable criticism of harmful tailpipe emissions and high GHG emissions due to reliance on fossil fuels.

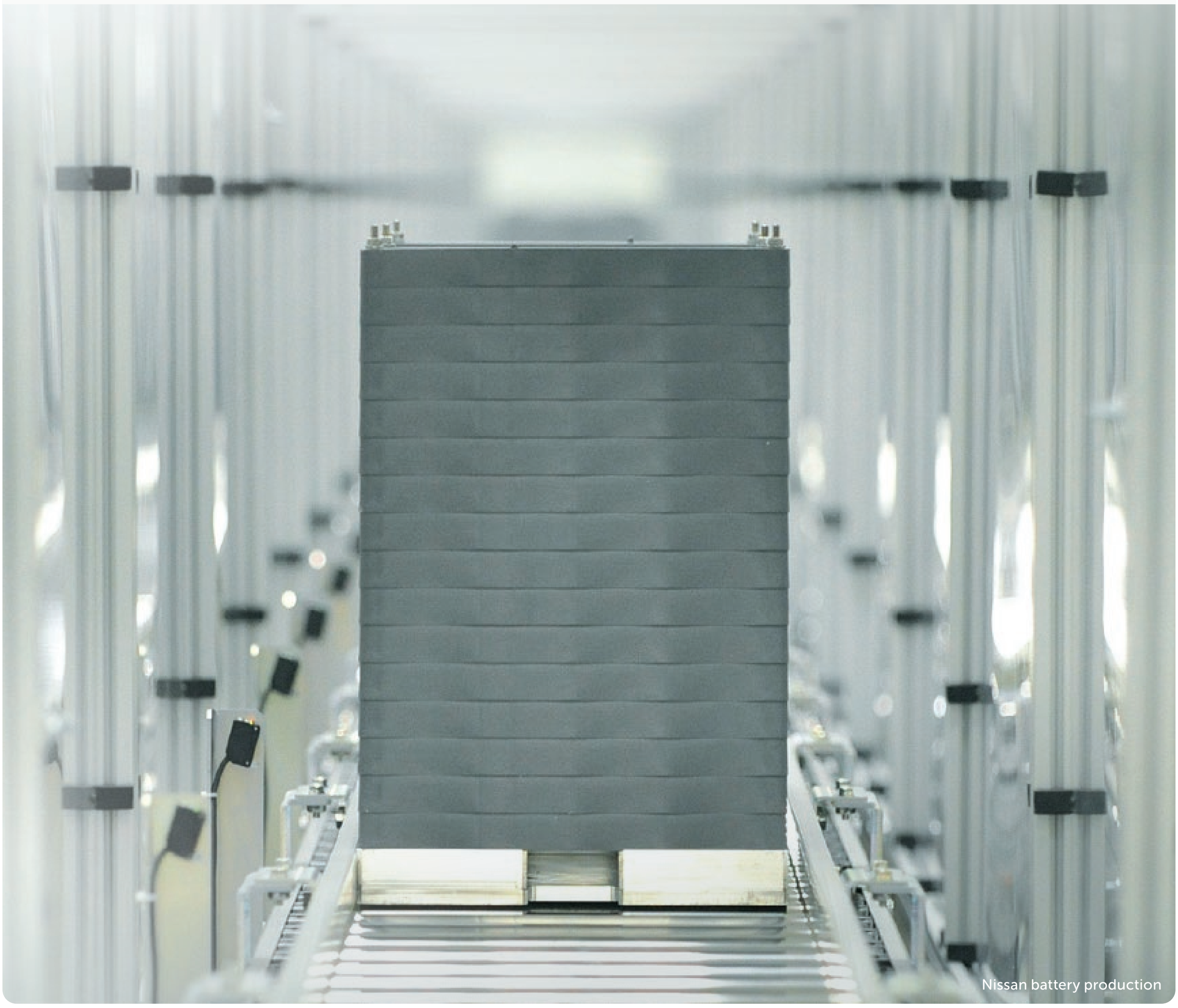
The use of ICE with sustainable liquid or gaseous fuels can provide significant WTW CO_2 reduction compared to fossil fuels. Currently, the compatibility of ICE with sustainable liquid fuels limits blending levels: for on road vehicles, biodiesel content is limited to 7% and bioethanol content to 5%. In the longer term, mass market production of fuels which are compatible at high blend levels can reduce GHG emissions further. Research and development is ongoing into the use of ICE with hydrogen and ammonia, which are zero carbon at the point of use. For all ICE, key R&D priorities are improving efficiency to minimise the use of scarce sustainable fuel, and to reduce harmful emissions to zero impact compared to ambient air.



New Holland Bio-methane engine

Evolving Supply Chain

As transport decarbonises, there will be an increasing element of electrification across all our modes making use of the batteries and power electronics, machines and drives (PEMD) technology. The UK's current R&D funding landscape of the Industrial Challenge Strategy Fund Challenges (ISCF) the Faraday Battery Challenge (FBC) and the Driving the Electric Revolution (DER) Challenge (Power electronics, E-Machines and Drives) are focussing on accelerating the development of technology and growing the UK supply chain. These technologies cut across all of our transport modes and will impact the entire supply chain from fundamental materials and components to complex systems. While electrification is not part of the near term solution for many of the modes considered within this report it acts is a supply chain disruptor and an opportunity for the UK. These changes are already occurring in automotive and aerospace markets which are important to the UK economy, sectors which also have added support through the funding platforms of the APC and the Aerospace Technologies Institute (ATI). The expertise and supply chains that are developed through these activities will grow the recognition of the UK as a destination for overseas investment supporting the development of UK industry.



Nissan battery production

Powertrains: Key findings and recommendations

A portfolio of options is needed to reach net zero transport GHG emissions by 2050. There are synergies across transport sectors, which can be united to help accelerate the development of the technology and growth within UK manufacturing. There is potential for shared learning across sectors at all TRL levels to accelerate the development of these powertrain solutions. Targeted collaboration across sectors could accelerate route to market, and reduce development and product costs

Recommendation for Government	Support for development and roll out of technologies to decarbonise transport should be technology agnostic, recognising the diversity of solutions that will be necessary to reach net zero for transport.
Recommendation for Industry	Continued development of low carbon vehicle technology, including propulsion systems, energy storage, and power electronics, machines and drives across all sizes and scales of vehicle.
Recommendation for TEN	Further investigation is required by TEN to identify where there is potential for common R&D activities and opportunity to support new collaborations, linking with APC roadmapping activities and government funded programmes including the APC, Aerospace Technology Institute, Mari-UK, Industrial Strategy Challenge Funds, Faraday Battery Challenge and Driving the Electric Revolution. This activity could lead to proposals for targeted funding to support common solutions across the transport modes to accelerate decarbonisation of the sector.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SYSTEMS

Scale up and commercialisation of low carbon sustainable fuels will be required

The scale-up of low carbon fuels will be vital to decarbonisation in the short, medium term and long term

It is widely recognised that low carbon sustainable fuels will be needed to decarbonise maritime and aviation sectors in the long term. However, work by the Tyndall Institute illustrates the importance of short term reductions in GHG emissions. Their analysis shows that taking into account the energy needs of developing and developed countries and assuming a carbon budget to provide a good chance of meeting targets for warming of between 1.5 and 2 degrees C, the UK needs to ramp up to GHG reductions of 13% per year in the near future[9]. Even in the passenger car sector where progress towards electrification is most advanced, the typical life of a passenger car means that it is expected that ICE based solutions will remain on our roads until well after 2035. Low carbon sustainable fuels are therefore essential to support rapid decarbonisation in this sector. In the heavy duty on and off road sectors, electrified and FC technologies are not currently mass market ready, so low carbon fuels will be vital to support decarbonisation in the short to medium term and potentially long term depending on the ultimate performance and acceptance of BEV and FC solutions.

Understanding changes in energy use by sector

This report shows the results of analysis that has been carried out to understand the potential split of transport energy by final energy vector. An estimate for energy use in 2050 was developed based on the roadmaps generated from TEN workshop output and sector-based work on pathways for decarbonisation. Key assumptions in the development of this analysis were:

2020 baseline (Figure 8)

- Energy use in 2020 is calculated based on statistics from BEIS and Sustainable Aviation
- Heavy Duty off highway energy is not included in 2020 or 2050 analysis due to poor aggregated data availability
- Electricity and biomethane provide energy for transport applications in 2020, however current use is several orders of magnitude lower than fossil fuels and so is not visible on this chart
- Energy use in the maritime and aviation sectors includes fuel supplied in the UK for both international and domestic use

2050 energy use estimate (Figure 9)

- All passenger cars are BEVs by 2050
- HD on road propulsion energy is split between sustainable diesel, electricity and hydrogen. Assumptions for this split follow analysis conducted by CCC[10] which assumes that smaller urban delivery vehicles electrify. Larger heavier vehicle propulsion is then split between sustainable diesel and hydrogen, as per TEN roadmaps. Future biomethane use is uncertain due to competition with use in power generation, so is not included in this 2050 analysis.
- Shipping propulsion energy is derived from recently published work on decarbonisation in this sector[11] and TEN roadmaps. Ammonia and hydrogen are the dominant energy vector in 2050 shipping although a small proportion of the 2050 shipping fleet is powered by sustainable diesel and fossil HFO.
- Aviation is assumed to be powered by sustainable aviation fuel. The degree to which propulsion might be electrified in this sector is currently unclear, so electricity is not included in the analysis at this stage

Figure 8: Baseline 2020 energy use – Total energy use 2207.72PJ

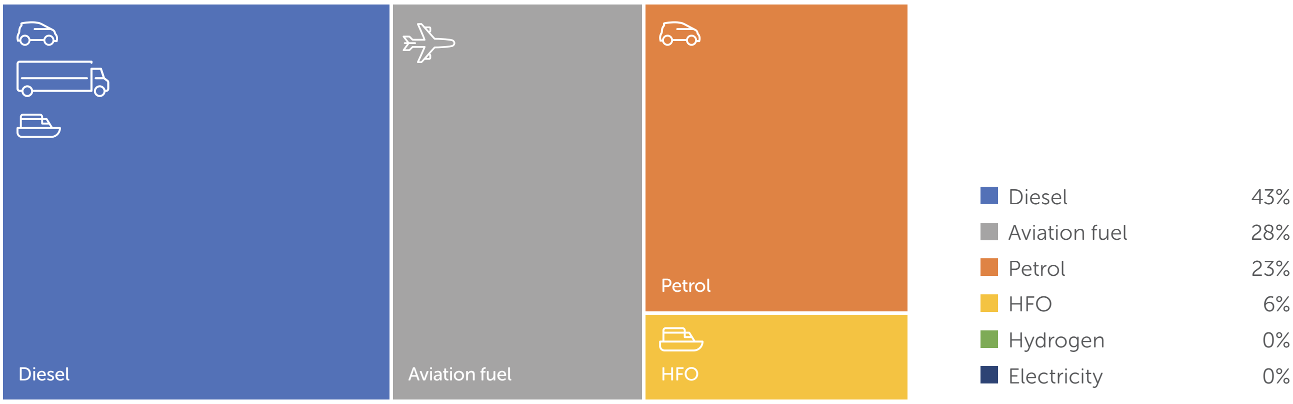
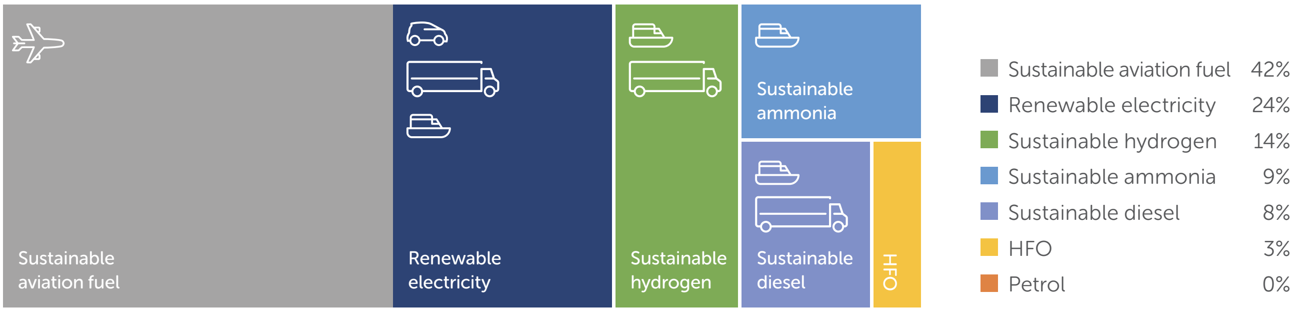


Figure 9: 2050 energy use estimate – Total energy use 1540.42PJ



The analysis shows a diversification of energy vectors between 2020 and 2050 to provide solutions for different sectors, with >75% of transport energy in 2050 potentially supplied by sustainable low carbon liquid and gaseous fuels. Progress towards net zero is supported by the growth of fuels with zero carbon at the point of use (sustainable hydrogen and ammonia) and sustainable replacements for fossil fuels. Further analysis is needed to understand feedstocks and production processes that could be used to provide this energy, and infrastructure needed to distribute the energy to relevant vehicles.

This work shows the potential to amalgamate demand across sectors to encourage investment and build production volumes, for example sustainable diesel may be in use across heavy duty on road and marine sectors, hydrogen could be used across shipping and heavy duty transport.

9 Kevin Anderson, 'Aligning UK car emissions with Paris, (1.5°-2°C), provisional analysis for Decarbon8', https://www.slideshare.net/DecarboN8/aligning-uk-car-emissions-with-the-paris-agreement-152c, accessed 25 August 2020

10 Committee on Climate Change, 'Net Zero Technical Report', May 2019

11 UMAS, E4tech, CE Delft, Frontier Economics, 'Reducing the maritime sector's contribution to climate change and air pollution – Scenario analysis: Take up of emissions reductions options and their impact on emissions and costs', July 2019

Low-carbon sustainable fuels and energy vectors

Low Carbon Hydrogen

Hydrogen presents an opportunity for zero carbon propulsion in combination with PEM FC or ICE. GHG emissions for hydrogen depend on the production method, Well to Tank (WTT) GHG emissions when using steam methane reforming of natural gas to produce the hydrogen are significantly greater than diesel or gasoline (containing 100-120 gCO_2e per MJ of fuel compared to 17-18 gCO_2e/MJ for UK pump diesel or gasoline) reducing with the use of CCS to ~40 gCO_2e/MJ[12]. Low carbon hydrogen can be produced from electrolysis powered by renewable energy or via gasification of biomass with WTT emissions of <12 gCOe/MJ. Scale up and cost reduction is needed to produce low carbon hydrogen competitively at mass market volumes, which will need to be coupled with access to renewable low cost electricity to power these processes. Demand for low carbon hydrogen for heat may reduce availability for transport use: in 2018, energy consumption for domestic use was 41,249Mtoe compared to transport use of 56,954Mtoe[13]. Additionally, investment is needed in the distribution and refuelling infrastructure. Depot fuelling for a limited number of back to base applications may provide a transitional solution, encouraging wider uptake.

Low Carbon Ammonia

Low carbon ammonia has potential for use in transport powering an ICE or FC. Large scale production and distribution of ammonia exists for use as a fertiliser, with current production using the Haber Bosch process and hydrogen produced by steam methane reforming. This energy intensive process requires around 27GJ of energy/tonne of ammonia and accounts for approximately 2% of annual global CO_2 emissions. The use of Carbon Capture and Storage (CCS) in the steam methane reforming process to produce blue ammonia can capture 90% of CO_2, with production GHG emissions reduction in the range 60-85% possible[14]. For green ammonia where hydrogen is produced via electrolysis of water using renewable electricity, cost is a key challenge with electricity costs making up 85% of the total. GHG emissions for blue and green ammonia are sensitive to the carbon intensity of the electricity used, varying from extremely low for green ammonia produced from renewable electricity to more than double a fossil fuelled comparator for green ammonia using electricity with the carbon intensity of the current EU grid mix[15]. Research is needed to reduce costs of green ammonia production, improve production plant operation at a smaller scale and improve tolerance to transient operation which may be necessary to operate on intermittent renewables. To support the use of ammonia in transport, it will be necessary to minimise other environmental impacts (reduction in biodiversity and air quality problems) and develop regulation and operating practises for safe refuelling and use.

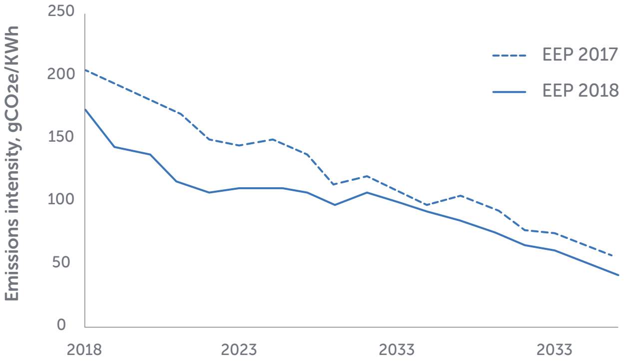
12 JEC Well to Wheels Report v5, 2020 https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/jec-well-wheels-report-v5 accessed 17 October 2020

13 Energy Consumption in the UK, BEIS, July 2019 https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/820843/Energy_Consumption_in_the_UK__ECUK__MASTER_COPY.pdf

14 The Royal Society, Policy briefing, 'Ammonia: Zero carbon fertilizer, fuel and energy store', February 2020

15 Dr Chris Malins, Cerulogy, 'What role for electromethane and electroammonia in European transport's low carbon future', June 2018

Figure 10:
Trajectory for UK power sector emissions intensity (source BEIS)



Low Carbon Electricity

WTW benefits of EVs depends significantly on the degree of grid decarbonisation. In the UK, BEIS 2019 projections show an anticipated steady reduction in carbon intensity to around 50 gCO_2e/kWh by 2035 (as shown in Figure 10).

The growth of electric vehicles and electrification of heat coupled with increases in distributed renewable generation will place additional pressures on the national electricity generation, transmission and distribution systems. National Grid Future Energy Scenario 2019[16] showed an increase in annual electricity demand to reach net zero across all sectors before 2050 from 346 TWh in 2019[17] to 491 TWh, with smart charging and appliances and vehicle-to-grid technology playing a key role in managing peak demand.

Recharging of high energy vehicles, such as HD trucks, or large numbers of passenger cars, can lead to increased pressure on the local electricity grid, necessitating local reinforcement. The Electric Vehicle Energy Task Force[18] recognised the need for the development of a smart grid which monitors and actively manages the electricity system to improve capability to support these requirements, alongside increases in low carbon generation capacity. The production of sustainable fuels like hydrogen, ammonia and electro fuels could be used as a mechanism to store intermittent renewable energy, supporting grid balancing.

Sustainable low carbon fossil fuel replacements

Sustainable fossil fuel replacements can provide significant decarbonisation compared to fossil diesel, gasoline and Compressed Natural Gas (CNG) when used in ICE, providing > 85% reductions in Well to Tank (WTT) GHG emissions. For some fuels, e.g. Fatty Acid Methyl Ester (FAME) or bioethanol, compatibility with the existing powertrains limit the maximum blend levels and therefore decarbonisation that may be achieved. Other fuels, for example HVO, electro fuels or biomethane, can be completely substituted for fossil fuels with no changes to the ICE, giving potential for very high reductions in GHG emissions. These drop in fuels can offer short term advantages as they make use of existing infrastructure, which means that they can help accelerate the UK towards meeting its decarbonisation targets across much of the vehicle parc in the near term, limited only by fuel production volumes.

A wide range of sustainable fuels are in development or production using a similarly wide range of feedstocks and manufacturing routes. Figure 11 shows Knowledge Transfer Network's analysis of sustainable fuel development and production in the UK[19], highlighting the current TRL of different fuel production processes, feedstocks and fuel types. For many options, R&D and supply chain development are needed to support mass market distribution.

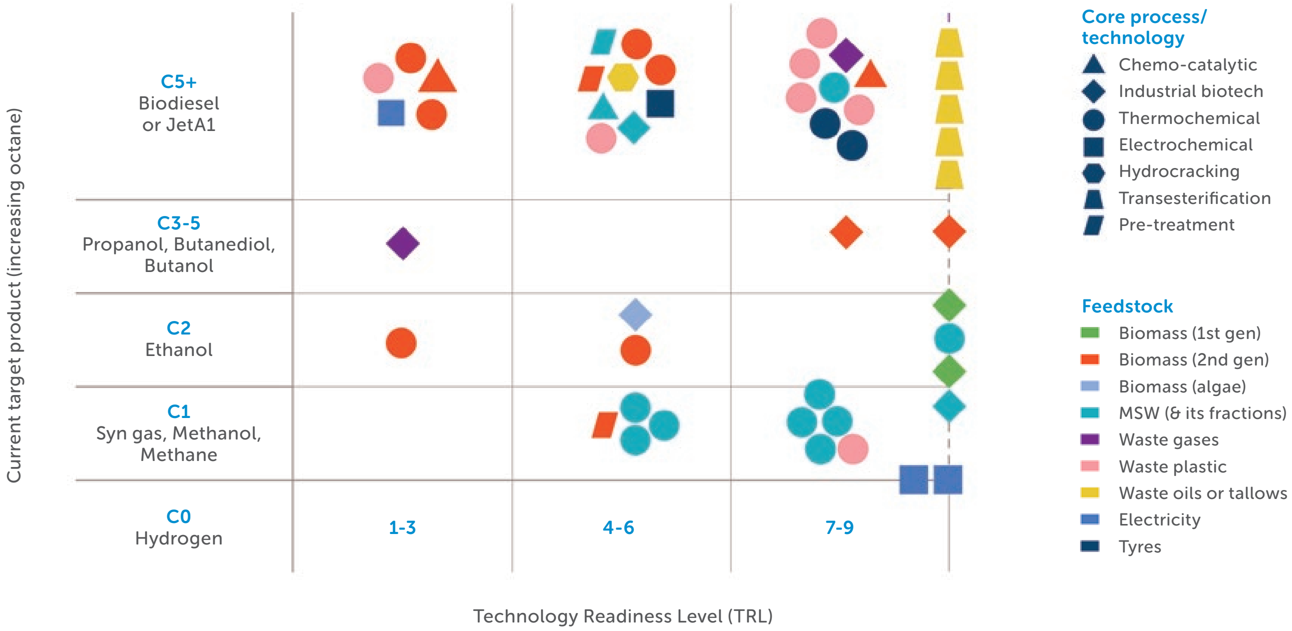
16 National Grid Future Energy Scenarios, 2019

17 UK government national statistics, energy trends : electricity, https://www.gov.uk/government/statistics/electricity-section-5-energy-trends, accessed 17 August 2020

18 Electric Vehicle Energy Task Force, 'Energising our Electric Vehicle Transition', 2020

19 Knowledge Transfer Network, Analysis of UK companies producing carbon molecules of potential value to a UK sustainable aviation fuel industry, 2019 https://ktn-uk.co.uk/news/analysis-of-uk-companies-producing-carbon-molecules-of-potential-value-to-a-uk-sustainable-aviation-fuel-industry accessed 17 August 2020

Figure 11: Sustainable fuel production by target fuel and TRL, source KTN



Gaining an improved understanding of the availability of feedstocks for these low carbon fuels along with the aggregated consumer demand is critical. In the UK, feedstock sources include around 6.2 million hectares of croppable land and 40 Mt of municipal solid waste (MSW) generated annually (50% of which is recycled). Given these relatively low volumes the UK could need to source further feedstocks from the international market. The UK also has access to renewable energy which could be used in power-to-liquids or manufacture of renewable hydrogen[20]. However, there is likely to be competition for scarce sustainable electricity and fuel resources across the UK energy system (heat, power, industry and transport) and between different fuel pathways (sustainable hydrogen is both a fuel in its own right and a feedstock for green ammonia or electro fuels, and can be used to decarbonise fossil fuel production, HVO can be used in diesel vehicles and also processed to provide sustainable kerosene). There is therefore a risk of double counting scarce sustainable energy resources.

Energy Systems Modelling is vital to support understanding of the implications of decisions surrounding different destinations of sustainable resources. The fidelity of this type of modelling is dependent on modelling assumptions and the quality of input data. Factors such as technology development timescales, manufacturing and supply chain challenges, vehicle fleet renewal rates are key to modelling scenarios for technology adoption. The stakeholders supporting TEN are well placed to contribute to this work, developing a consensus view of underlying modelling assumptions and building sectoral understanding of suitability and use profiles for low carbon energy vectors to mitigate against double counting.

20 UK PIA – Vision 2019 - https://www.ukpia.com/media/2230/ukpia-vision-july-2019.pdf

Low carbon sustainable fuels and energy vectors: Key findings and recommendations

Low carbon sustainable liquid and gaseous fuels are essential to long term decarbonisation in high energy sectors such as aviation, marine and some parts of the HD on and off road sectors, potentially making up >75% of transport energy demand in 2050. These fuels also offer an important route to decarbonisation in the short to medium term during the introduction of electrified and fuel cell technologies.

A whole systems approach is needed to consider the energy pathway through generation, transmission, delivery, storage and ultimately propulsion to ensure the optimum use of primary resources (renewable electricity or bio feedstocks) and overall efficiency. Additionally, there is potential to amalgamate demand for sustainable energy vectors across sectors to support investment in low carbon fuels and accelerate decarbonisation.

Recommendation for DfT and BEIS	Work together with stakeholders, such as TEN, to develop a clear strategy for the use of sustainable energy vectors that will be needed to ensure priorities across the energy system are met. Policy development should focus on supporting the quickest possible roll out of sustainable fuels to enable rapid decarbonisation.
Recommendation for Industry and TEN	Support urgent update of Automotive Council fuel and energy roadmap to grow understanding of expected technology development trajectories
Recommendation for TEN	Understand the sensitivity of final energy use to the developing technology landscape, and project the resource and infrastructure requirements for these sustainable energy vectors.

Hydrogen refuelling station

A lifecycle approach to emissions is vital

Policy needs to focus on genuine GHG savings

TEN stakeholders identified a lifecycle approach to the assessment of GHG emissions from transport as a key enabler for long term decarbonisation, avoiding a shift of emissions from one part of the vehicle lifecycle to another. Lifecycle emissions (see Figure 12) take into account emissions across vehicle and energy vector production and use:

- WTT – emissions from the production of feedstocks, fuel manufacture and distribution
- Tank To Wheels emissions (TTW) – in use emissions
- Vehicle production and disposal/recycling – taking into account energy use and materials

Figure 12: Lifecycle GHG emissions approach

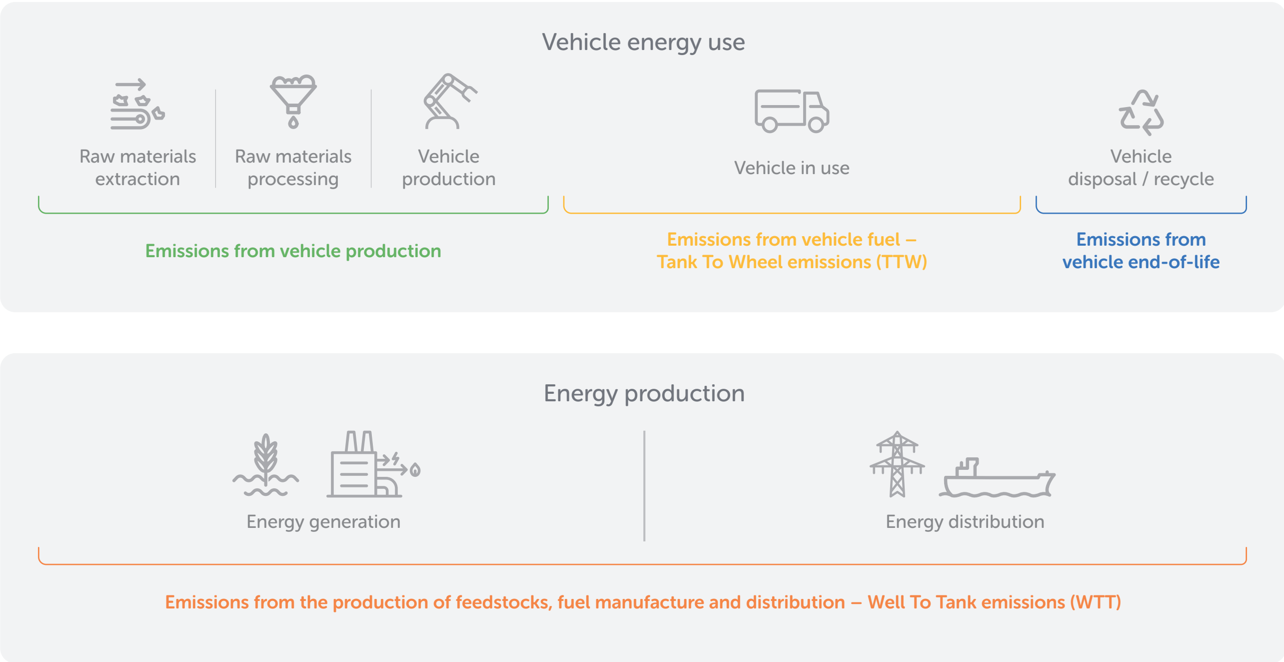
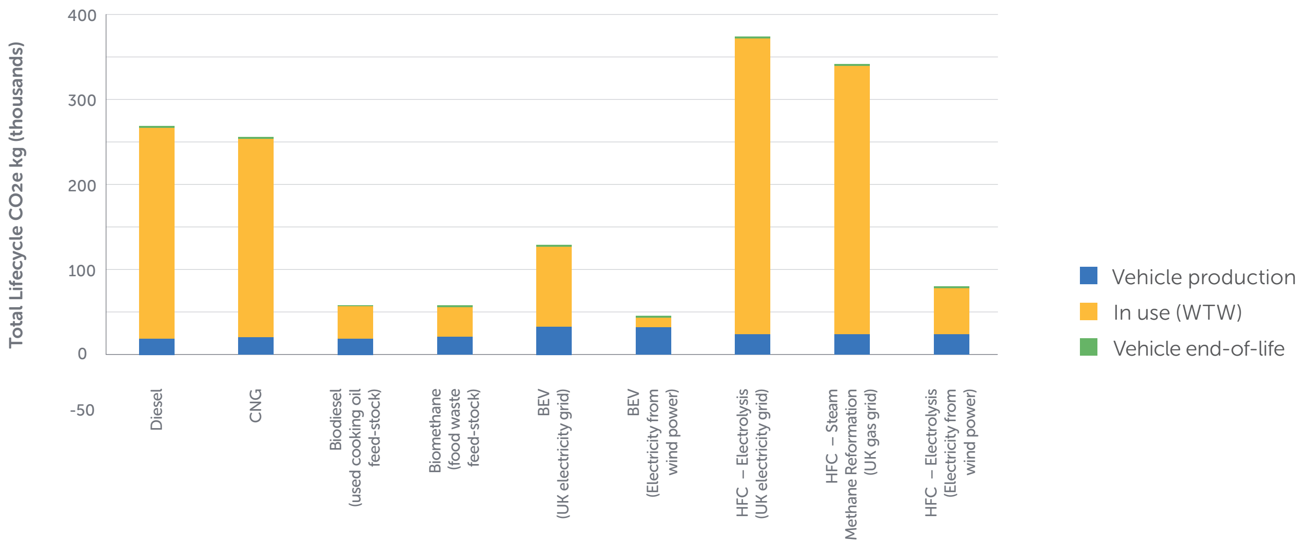


Figure 13: Lifecycle GHG emissions for a 7.5 tonne truck (source LowCVP)



Vehicle lifecycle CO_2e emissions for an urban truck across different powertrain technologies and low carbon fuels. Data supplied by LowCVP.

An example of lifecycle emissions for a 7.5 tonne truck using a range of energy vectors over a life of 500k km is shown in Figure 13.

The data shows the benefits in lifecycle GHG emissions that can be gained through the use of sustainable fuels for existing ICE based vehicles compared to the incumbent fossil fuels. The data also shows the relatively high levels of emissions for a BEV due to the UK grid carbon intensity. As grid carbon intensity reduces, lifecycle emissions for the BEV reduce but remain similar to emissions from biofuel powered ICE and renewable hydrogen vehicles on a lifecycle basis. The figure also shows the importance of hydrogen production method for GHG emissions from H2FC propulsion.

The production of low carbon energy vectors, in conjunction with vehicle manufacturing can give rise to unintended environmental impacts if not appropriately managed. This is most apparent through the use of natural resources, such as land to cultivate certain biofuels, mining of minerals for electric vehicle batteries and magnets, extraction of fossil fuels to generate power for manufacturing components for our transport systems and water use in the generation of hydrogen by electrolysis. Low carbon energy and transport supply chains must be sustainable to preserve terrestrial and aquatic ecosystems, protect air quality, conserve potable water and encourage resource efficiency and circularity.

It is essential that sustainability is embedded across different supply chains as early as possible. A first step is to identify key environmental risks in order to effectively negate these impacts and set appropriate sustainability criteria to support management to mitigate negative environmental impacts. This should include the raw materials used to produce components, energy required to manufacture components and vehicles as well as resources required for recycling at the end of vehicle life. Auditing and tracking of raw material supply chains will become increasingly important to demonstrate sound environmental practices.

The RTFO sets sustainability criteria for renewable fuels alongside lifecycle GHG emission thresholds. The regulations encourage the sustainable production of low carbon fuels from biomass waste and more recently non-biogenic resources such as water and CO_2 and applies to road transport, off road mobile machinery and aviation fuels. Taking into account the multi sector requirement for low carbon fuels, it is essential that these sustainability criteria are adopted across all sectors.

Lifecycle approach: Key findings and recommendations

A lifecycle approach to the assessment of GHG from transport is vital for long term decarbonisation to ensure emissions from one part of the vehicle lifecycle are not shifted to another. Low carbon fuel and transport supply chains must also be sustainable to preserve terrestrial and aquatic ecosystems, protect air quality, conserve potable water and encourage resource efficiency and circularity.

Recommendation for Government	Adoption and harmonisation of lifecycle analysis and sustainability criteria will become vital across different government departments and sectors to ensure net zero GHG emissions are achieved without wider negative environmental impacts. Vehicle emissions legislation must move away from current tailpipe based measures towards an LCA approach.
Recommendation for Industry	Develop lifecycle assessments of the GHG emissions and energy use for new transport solutions to support understanding of the implications of the adoption of different pathways.

Decarbonising transport requires a shared vision

Transport decarbonisation is a complex cross discipline challenge. Alongside discussions on technology pathways to net zero, TEN worked to understand enablers for the proposed pathways. Figure 14 illustrates the broad range of enablers recognised by this community.

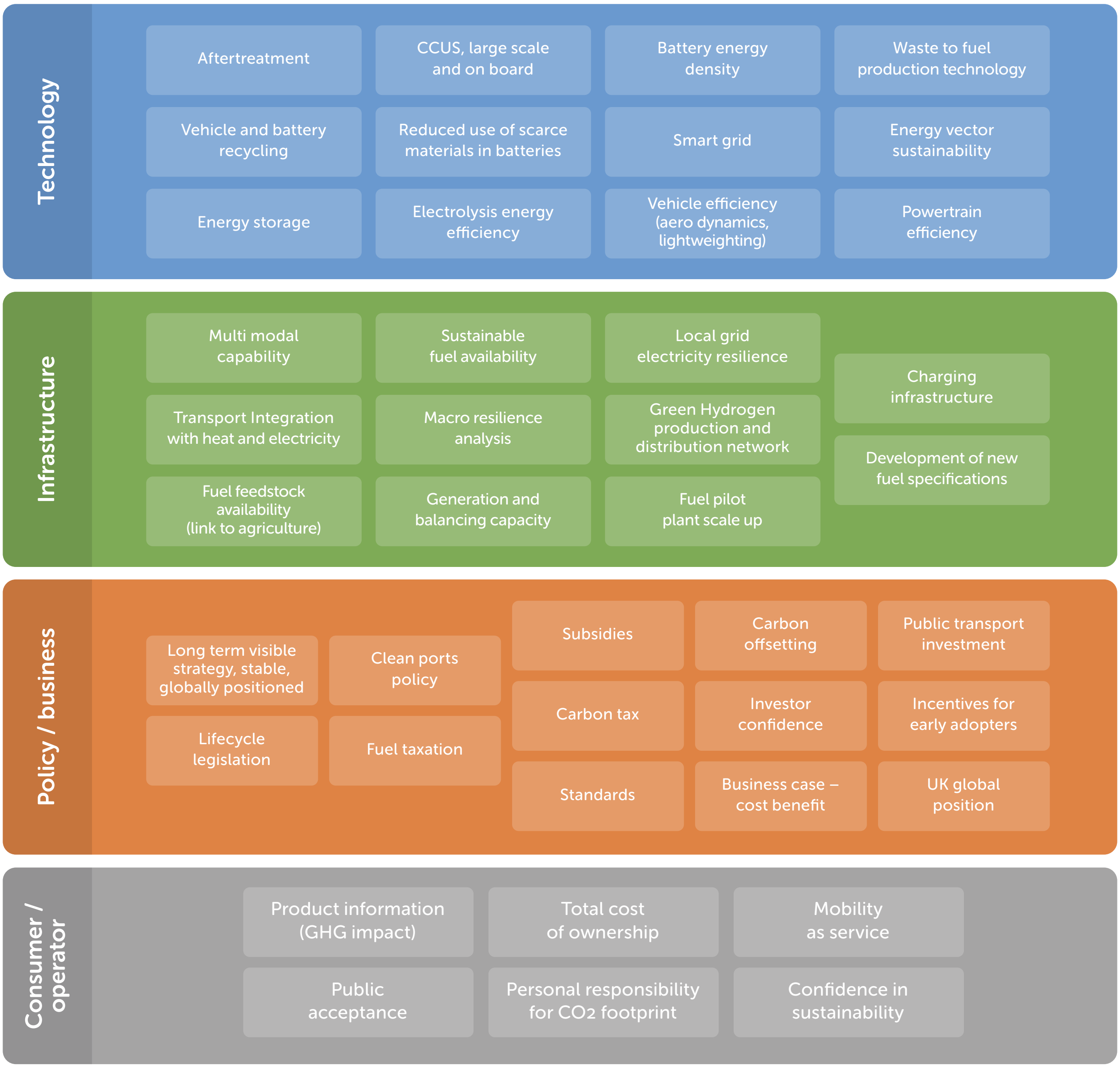
This wide range of enablers means that a correspondingly large number of stakeholders influence the success of low GHG transport: policymakers, industry associations, R&D organisations both in industry and academia, manufacturing supply chain, industrial standards bodies, agriculture, materials supply chain, Investors, public and operators. Policy and market drivers have a key influence on investment and destinations for sustainable energy.

An efficient transition to net zero transport will therefore require cooperation between these stakeholder groups based on a shared vision.

Internationally, policies on global emissions vary widely in terms of the metrics used, with some focussing on the reduction of GHG or CO_2, others focussed on improving fuel economy and others using a combination of the two. In practice, the different metrics are related as improvements in fuel economy reduce CO_2 emissions, and CO_2 emissions are a subset of GHG emissions[21]. However, for those modes that cross borders access to compatible fuel is paramount. This is particularly important in a post Brexit world to ensure that the UK does not isolate its technology development and access to transport solutions.

21 US Energy Information Administration – International Energy Outlook 2016 - https://www.eia.gov/outlooks/ieo/pdf/transportation.pdf

Figure 14: Selected enablers recognised by TEN stakeholders



As part of the Brexit process, the UK may need to revisit its main current carbon pricing mechanism, the EU Emissions Trading System (EU ETS), which covers about a quarter of UK emissions (currently covering only the aviation aspect of the transport sector). A carbon tax would be an effective way to price emissions not covered by the EU ETS. This topic is currently under review and was the subject of a Department for Transport consultation in 2020.

Organisations such as the Grantham Research Institute insist that having a meaningful price on carbon that covers all sectors is essential for the net zero target to have policy credibility, recommending that the UK should re-optimise its tax design, for example by expanding the proportion of emissions covered[22].

Sectoral Decarbonisation Actions

Setting the net zero target has led to each of the sectors working to address their own impacts.

In the heavy duty on road sector, EU legislation has been announced setting targets to reduce CO_2 emissions from these vehicles to 15% below 2019 values by 2025[23].

In the maritime sector, International Maritime Organisation (IMO) have made a commitment to improve energy efficiency of new ship designs, through the introduction in 2013 of the Energy Efficiency Design Index, which mandates an improvement in energy efficiency of 30% by 2025. This is important as the IMO suggest that whereas in 2015 emissions from maritime represented just 2.6% this could grow by between 50 – 250% by 2050. In January 2020, the maritime sector revised its IMO MARPOL Annex VI regulation to commit to the reduction in sulphur content of marine fuel oil.

In 2018 domestic and international aviation emitted 2.4% of global energy related CO_2 emissions and is experiencing rapid growth. The International Air Transport Association (IATA) is forecasting a doubling of global passenger numbers to 8.2bn by 2037. To tackle the carbon emissions of new aircraft, dramatic improvements in energy efficiency of between 16% and 40% have been achieved. A range of other advances are envisaged to achieve the target of 75% CO_2 reduction. This has led to IATA making a commitment to a reduction in net emissions of 50% by 2050 from their 2005 level across the sector, with the European Commission Flightpath 2050 project including a target of reducing emissions per passenger kilometre by 75% by 2050.

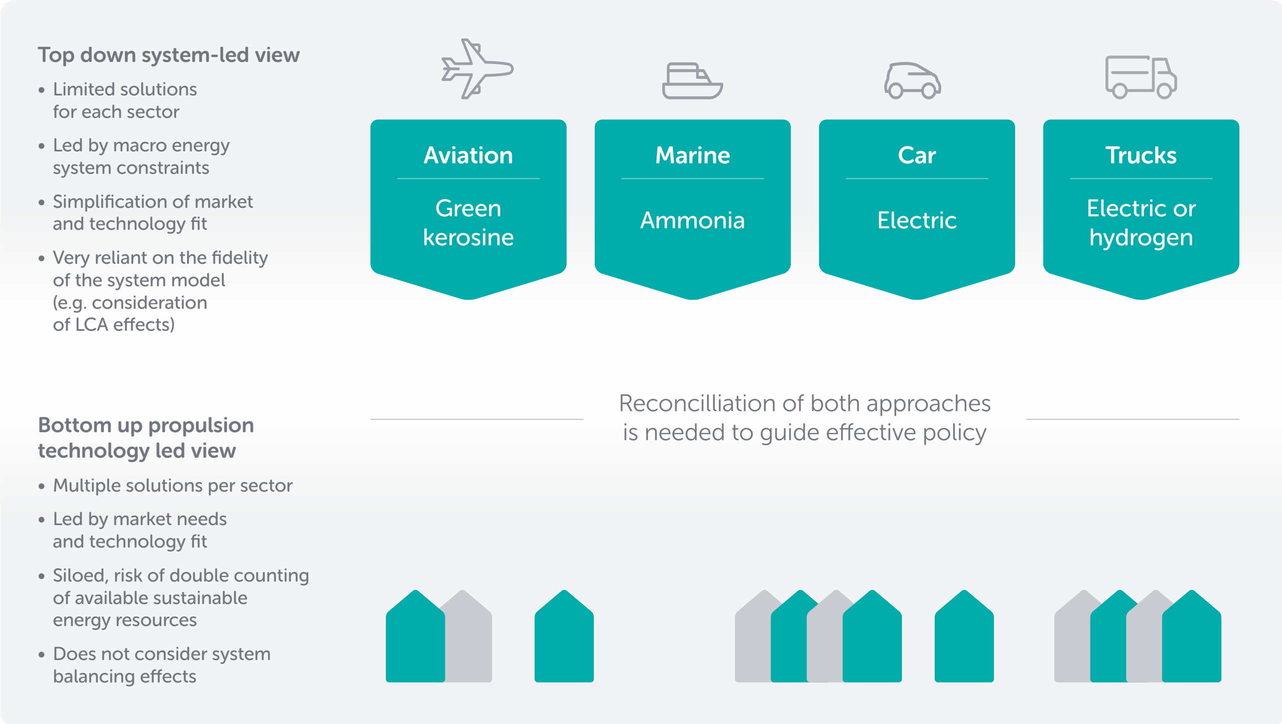
Closing the gap between policymakers and stakeholders

TEN workshops identified a disconnect between a top down, policy led approach and a bottom up R&D led view: the top down approach is led by macro energy systems constraints, to simplify market needs to identify one or two solutions per sector; whereas the bottom up approach was more led by market needs and technology fit, recognising multiple solutions per sector. There are risks with both approaches, the top down approach is led by macro energy system constraints, informed by a simplification of market and technology fit where understanding of outcomes is heavily influenced by the fidelity of the system model. The bottom up approach is led by market needs and technology fit, but risks double counting sustainable energy resources (see Figure 14). Consultation is therefore needed to support the development of a shared vision.

22 Grantham Research Institute on Climate Change and the Environment – Global Lessons for the UK in carbon taxes – http://www.lse.ac.uk/GranthamInstitute/publication/global-lessons-for-the-uk-in-carbon-taxes/

23 European Commission, Reducing emissions from heavy duty vehicles https://ec.europa.eu/clima/policies/transport/vehicles/heavy_en accessed September 28 2020

Figure 13: Disconnect identified by TEN stakeholders in UK Transport Decarbonisation Policy development



Shared vision – Key findings and recommendations

Policy and market drivers have a key influence on investment and destinations for sustainable energy. An efficient transition to net zero transport will therefore require cooperation between a wide range of stakeholder groups based on a shared vision (policymakers, industry associations, R&D organisations in industry and academia, manufacturing supply chain, industrial standards, agriculture, materials supply chain, investors, public and operators).

Recommendations for Government	Policy makers should work with the industrial stakeholders, such as TEN, to ensure that there is policy in place to develop the right solutions to support the UK's decarbonisation agenda, for both on vehicle technology and low carbon energy vectors.
Recommendations for TEN and Industry	Engage with government consultation activities to provide a holistic view of the transport sector.

Call for action

The key conclusions from TEN roadmapping were

- There is no 'silver bullet' technology to decarbonise transport.
- Scale up and commercialisation of low carbon sustainable fuels is essential to reach net zero GHG emissions.
- Adopting a lifecycle approach to emissions will have a bigger impact.
- Decarbonising transport cost-effectively requires a shared vision.

Action is needed from a range of stakeholders to accelerate transport decarbonisation

Government

- Support for development and roll out of technologies to decarbonise transport should be technology agnostic; recognising the diversity of solutions that will be necessary to reach net zero.
- Work together with stakeholders to develop a clear strategy for the use of sustainable energy vectors, with a particular focus on supporting the quickest possible roll out of sustainable fuels to enable rapid decarbonisation.
- Adoption and harmonisation of lifecycle analysis and sustainability criteria is necessary across different government departments and sectors to ensure net zero GHG emissions are achieved without wider negative environmental impacts.
- Work with stakeholders to ensure that policy is in place to enable solutions to meet the UK's decarbonisation agenda, for both on vehicle technology and low carbon energy vectors.

Industry

- Continue development of low carbon propulsion technology, including energy storage, and power electronics machines and drives across all sizes and scales of vehicle.
- Support the urgent revision of the Automotive Council energy and fuels roadmap.
- Develop lifecycle assessments of the GHG emissions and energy use for developing transport solutions to support understanding of the implications of the adoption of different pathways.

TEN

- Investigate potential for cross sector R&D activities and grow new collaborations.
- Understand the sensitivity of final energy use to the developing technology landscape, and project the resource and infrastructure requirements for these sustainable energy vectors.
- Work with APC to prioritise revision of the Automotive Council energy and fuels roadmap.

Next steps for Transport Energy Network

TEN will be undertaking a range of activities

- Support cross sector collaboration using workshops and focussed consultation to explore in detail the potential for cross sector collaboration to accelerate decarbonisation.
- Develop scenarios for resource usage and infrastructure development to support the technology pathways identified by these roadmaps.
- Work with APC to update the Automotive Council Energy and Fuel roadmap.

Biodiesel truck

Glossary

BEV – A battery electric vehicle (BEV), is a type of electric vehicle (EV) that exclusively uses chemical energy stored in rechargeable battery packs, with no secondary source of propulsion (e.g. hydrogen fuel cell, internal combustion engine, etc.).

Blue ammonia – Blue ammonia is produced from hydrogen derived from steam methane reforming with carbon capture and storage.

CNG – Compressed natural gas (CNG).

Diesel gate – The Volkswagen emissions scandal.

Electro fuels – Electro fuels are made by combining hydrogen (from for example the electrolysis of water) with carbon dioxide (from direct air capture or a point source).

Energy vectors – enable energy to be carried and can then be converted back into any other form of energy, for example, electricity, liquid and gaseous fuels.

FAME – Fatty acid methyl esters (FAME) are a type of fatty acid ester that are derived by transesterification of fats with methanol which is used to produce one form of biodiesel.

Geofencing – A geofence is a virtual perimeter for a real-world geographic area. A geo-fence could be dynamically generated – as in a radius around a point location, or a geo-fence can be a predefined set of boundaries.

GHG – A greenhouse has is a gas that absorbs and emits radiant energy within the thermal infrared range. Greenhouse gases cause the greenhouse effect on planets. The primary greenhouse gases in Earth's atmosphere are water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).

Green ammonia – ammonia production where the process of making ammonia is totally renewable and carbon free.

HEV – A hybrid electric vehicle (HEV) combines a conventional internal combustion engine (ICE) system with an electric propulsion system (hybrid vehicle drivetrain).

HFO – Heavy Fuel Oil (HFO) is a category of fuel oils of a tar-like consistency. Also known as bunker fuel, or residual fuel oil, HFO is the result or remnant from the distillation and cracking process of crude oil.

HVO – Hydrotreated Vegetable Oils (HVO) are produced via hydroprocessing of oils and fats. Hydroprocessing is an alternative process to esterification to produce diesel from biomass.

LCA – Life-cycle assessment is a methodology for assessing environmental impacts associated with all the stages of the life-cycle of a commercial product, process, or service.

LNG – Liquefied natural gas (LNG) is natural gas (predominantly methane) that has been cooled down to liquid form for ease and safety of non-pressurized storage or transport.

PEM FC – A proton exchange membrane (PEM) fuel cell uses hydrogen and oxygen gas as fuel to generate electricity using a proton exchange membrane electrolyte.

PHEV – A plug-in hybrid electric vehicle is a hybrid electric vehicle whose battery can be recharged by plugging it into an external source of electric power, as well as by its on-board engine and generator.

R&D – Research and development.

RTFO – The Renewable Transport Fuel Obligation (RTFO) in the United Kingdom is a requirement on transport fuel suppliers to ensure that a specified percentage of all fuel for on and off road vehicles is supplied from sustainable renewable sources.

SOFC – A solid oxide fuel cell (or SOFC) is an electrochemical conversion device that produces electricity directly from oxidizing a fuel using a solid oxide or ceramic electrolyte.

Tethered power – where electrical power to a vehicle is provided via a cable during operation.

Value chain – A value chain is a set of activities that a firm operating in a specific industry performs in order to deliver a valuable product (i.e., good and/or service) for the market.

Zero carbon fuels – Fuels which do not contain carbon within their chemical composition.

Cover images: Volvo FL Electric Truck | Ford Transit PHEV | JCB 19C-1E Mini Digger | New Holland T6 Methane Power Tractor | Volvo 7900 Electric Articulated Bus

About the authors

The Advanced Propulsion Centre (APC) was formed in 2013 as a collaboration initiated by the automotive sector and UK government to ensure that the UK remains competitive in the research, development and production of low carbon propulsion technologies. The APC spoke network aims to bring together specialist academic, technological and commercial expertise to share best practice and support the acceleration of development of these technologies.

LowCVP is a public private partnership with over 200 members focused on accelerating the sustainable transition to clean, low carbon vehicles and fuels. Their members cover a diverse range of stakeholders including automotive manufacturers, technological suppliers, renewable fuel suppliers, energy supply and distribution companies, infrastructure providers, academia, NGOs, policy makers and fleet operators. LowCVP has provided policy and technical support to Government for over fifteen years across light and heavy duty vehicle sectors and renewable fuels.

The Advanced Engineering Centre (AEC) at the University of Brighton is an internationally recognised centre of research excellence with an established track record of pioneering research in applied thermofluids, including automotive engineering, heat transfer, sprays and two-phase flows. We work alongside global academics, industry leaders and policymakers to significantly impact the transportation, aerospace and medical sectors. Our automotive research is focused on efficient, zero emission sustainable propulsion and sustainable fuels across different sectors. The University is the Thermal Efficiency Spoke for Thermal Propulsion Systems for the APC.

The Transport Energy Network was initiated to accelerate transport decarbonisation, supported by APC, LowCVP and the UK Automotive Council. Set up to address 2050 targets for Net-Zero GHG emissions, it considers different transport modes (on road, off highway, marine, rail and synergies with aerospace sector), looking at strengthening the UK supply chain. Network activities are designed to encourage collaboration between communities and provide evidence to support policy development in this area.

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