ACCELERATING ROAD TRANSPORT DECARBONISATION.

Institution of
MECHANICAL
ENGINEERS

A Complementary Approach Using
Sustainable and Low Carbon Fuels

Improving the world through engineering

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Sustainable and low carbon fuels offer us another option in the continuing challenge to reduce our impact on the planet. Road transport is one of the UK’s largest polluters, a sector where we can make a big impact through small changes and in parallel work on delivering a long-term solution.

Dr Jenifer Baxter
Chief Engineer
Institution of Mechanical Engineers

Cover image: Public access hydrogen refuelling station on the M4 corridor in Swindon. © Image courtesy of ITM Power.

This report has been produced in the context of the Institutions core strategic themes of Climate Change Mitigation and Adaptation, Decarbonisation: Delivering Net Zero, Future Transport Systems and Education and Diversity and its vision of ‘Improving the world through engineering’.

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EXECUTIVE SUMMARY

The decarbonising of our transport sector is increasingly urgent and important in the race to address climate change, with about 27%[1] of UK greenhouse gas (GHG) emissions currently coming from this sector. In addition, for the benefit of the population's health, there is a need to improve air quality in many of the UK's towns and cities, where road transport emissions are one of the biggest contributors to localised pollution.

The UK Government has already taken steps, with the launch of its 'Road to Zero' strategy: a long-term plan that will ultimately end the sale of new conventional petrol and diesel cars and vans by 2040.

The Institution of Mechanical Engineers believes sustainable and low carbon fuels offer an immediate opportunity to accelerate the decarbonisation of road transport, by employing existing technologies in a complementary approach to the long-term transition to fully electric vehicles.

Paul Jones
Chair, Automobile Division
Institution of Mechanical Engineers

Steve Sapsford
Chair, Powertrain Systems and Fuels Group
Institution of Mechanical Engineers

ACCELERATING ROAD TRANSPORT DECARBONISATION: A COMPLEMENTARY APPROACH USING SUSTAINABLE AND LOW CARBON FUELS

This short Technical Policy Paper from the Institution of Mechanical Engineers, provides an introduction to the life cycle of different fuels used in passenger vehicles. This includes the use of biofuels mixed with petrol, low-emission diesel and also hydrogen. Ultimately, the Institution of Mechanical Engineers would like to see a complete shift away from fossil fuel use for any part of our energy system. In the interim we must find near-term solutions that can make the biggest and fastest reductions in our CO_2 emissions and improvements in air quality.

This report aims to demonstrate how, by changing the fuels used in our passenger and commercial vehicles, we can move more rapidly towards the net zero future put forward by the Committee on Climate Change and ratified into UK law as the Climate Change Act 2008 (2050 Target Amendment)[2]. The goal is to implement our existing technologies now to decarbonise and clean up, and not wait until we are all agreed on a pathway for our low-carbon future transport system. Today, transport in the UK is responsible for approximately 27% of GHG emissions and has been experiencing a steady increase over the past three decades[3].

Although this report focuses on passenger and small commercial vehicles, it is important to draw attention to how options for alternative fuels could also have a major impact on reducing emissions from the heavy goods vehicle and aviation industries, with further potential in shipping.

Apart from just transport, we have seen a slowing of overall CO_2 emissions reduction recently, with the UK reducing by just 2% in 2018[4] and indeed global emissions increasing by 0.6% in 2019. A recent report from the Office for National Statistics, shows the UK to be the largest importer per capita of GHG emissions in the G7 from outsourced activities, such as manufacturing and food production[5]. This means that there is an imperative to act now and apply technologies that will reduce our impact on the environment and human health.

INTRODUCTION

POLICY BACKGROUND

Before moving forward with the technical information, it is important to understand the wider policy agenda, and why the Institution of Mechanical Engineers believes sustainable and low carbon fuels are an important area of GHG emissions reduction. Over the past year, there has been a rapidly growing interest throughout Government, industry, the media and the public in the impacts of climate change and what causes it. As sectors such as electricity reduce their carbon emissions through the addition of renewables, and switch to gas from coal, attention has turned to other parts of our energy system. The environmental impact of road vehicles is now under intense scrutiny, in terms of both GHG emissions and air quality. The range of propulsion system technologies available is greater and potentially more confusing than ever.

This paper aims to uncover solutions and debunk some myths about the potential for a variety of low-carbon vehicles in a net zero world. Other short reports produced by the Institution of Mechanical Engineers have covered the need for modal shift away from personal passenger vehicles[6]. However, with the urgent need to decarbonise our transport systems, this report provides quick solutions based on existing and implementable technologies.

The current Government policy, is to move away from fossil fuel-powered vehicles and electrify the powertrain (that is all the parts that, together, propel the vehicle, such as an internal combustion engine, electric motor, batteries and transmission system). This is designed to coincide as much as possible with a ban on the sale of new vehicles that use diesel or petrol engines as the sole source of propulsion in passenger vehicles and vans, as well as trains, from 2040. More recently, several political parties have begun looking into whether this is achievable earlier than 2040. Complete electrification of vehicles requires far fewer mechanical parts and can be achieved by battery electric vehicles (BEVs) or fuel cell electric vehicles (FCEVs). A shift towards all electric vehicles will create a very different sector for vehicles in terms of sale, maintenance, servicing and after-market.

Figure 1: The Transport Hierarchy[7]

MORE SUSTAINABLE

Priority 1	Minimise demand	Manage the reasons why transport is needed and the context in which transport demand is derived, to deliver the same access to services and activities with less powered/motorised transport.
Priority 2	Enable modal shift	Enable the choice of transport modes with the lowest environmental impacts, and enable easier changes between modes.
Priority 3	Optimise system efficiency	Increase all efficiency measures of transport modes and their use, particularly in terms of gCO_2/km for passengers and gCO_2/tkm for freight.
Priority 4	Increase capacity	After optimisation of the first three steps, any capacity increases that are required should be prioritised to the most efficient and sustainable modes.

LESS SUSTAINABLE

This has been a popular pathway for both politicians and the public, as the electric vehicles are low (zero) emissions at the point of use and play a key role in improving air quality, particularly in city centres. However, purely electric powertrains are unlikely to provide a complete solution for all vehicles, for instance heavy goods vehicles, or be the correct solution in all regions. As a consequence of the popularity of this pathway, research into improving the efficiency and emissions reduction of internal combustion engines (ICEs), their fuels and their associated mechanical systems, has reduced. This has been seen in the various funding calls for innovation and demonstration made available to the automotive industry. It also does not help that currently alternative fuels support falls across multiple smaller innovation funds, from heavy industry to low-carbon power, meaning there is no connection in infrastructure and technology developments. This is despite the use of low-carbon fuels and their associated technology being particularly relevant to the heavy goods vehicles, where all other alternatives are much more challenging.

This could result in unforeseen consequences, driven by how we 'measure' these vehicles. There is also a potential for missed opportunities in developing alternative and complementary technologies such as hydrogen and low carbon, renewable fuels that create a connected energy system, with production and pollution abatement being used to fuel our net zero future.

The options for reducing GHG emissions from cars with ICEs include:

- Improving the efficiency of the ICE
- Using alternative fuels that, from a life-cycle perspective reduce greenhouse gas emissions (GHGs)

TECHNICAL BACKGROUND

GHG emissions specific to the transport sector were responsible for about 27% of CO_2 emissions in 2018 in the UK[8]. Importantly, there are also three other emissions of concern:

1. Black carbon (particulates) produced by the combustion of diesel
2. Nitrogen oxides (NOx) produced by ICEs
3. Ground-level ozone produced by mixing with other emissions[9]

In 2018, the average new car CO_2 emissions at point of use (ie emitted while driving the car) rose 2.9% up to 124.5g/km; this rise is mostly attributed to the 29.6%[10] drop in diesel registrations (as petrol emits more CO_2), due to the concerns over oxides of nitrogen (NOx) emissions and association with poorer air quality. The particulate emissions from diesel vehicles have been almost eradicated by diesel particulate filters, which have been fitted since the Commission Regulation (EC) No 692/2008[11].

The very latest generation of diesel cars now have very low NOx emissions by virtue of advanced after treatment systems, and typically emit 15–20% lower CO_2 when compared like for like with petrol. In the short term, these vehicles provide a lower-carbon alternative to petrol in reducing GHG emissions[12].

There are two main pathways to reduce CO_2 emissions from vehicles at point of use:

1. Improve the overall vehicle efficiency
2. Reduce the amount of carbon in the fuel (**Figure 2**).

Figure 2: Pathways to reduced vehicle CO_2 emissions

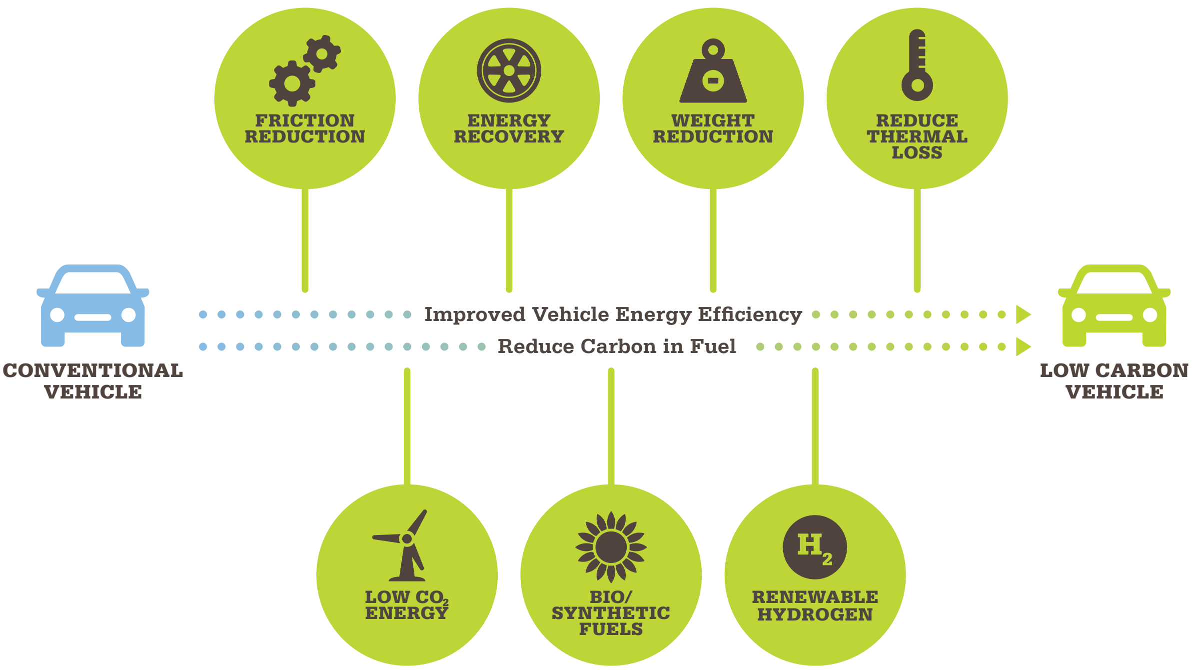


Figure 3 shows the huge strides that have been made in terms of improving passenger vehicle efficiency (ie fuel economy) over the last decade. It also shows the recent increase in CO_2 emissions, and why it is now becoming increasingly urgent to lower CO_2 emissions per km driven from our passenger vehicle and van fuels in the UK[13].

However, we cannot afford to consider GHG emissions only at point of use. While that might be where legislation has its current focus, we need to take into account all GHG emissions associated with the whole life cycle of a vehicle. Instead, we need to take a more holistic approach, including the GHGs associated with vehicle production, use and disposal/recycling (**Figure 4**).

Figure 3: Trends in carbon dioxide emissions per km driven from new passenger cars

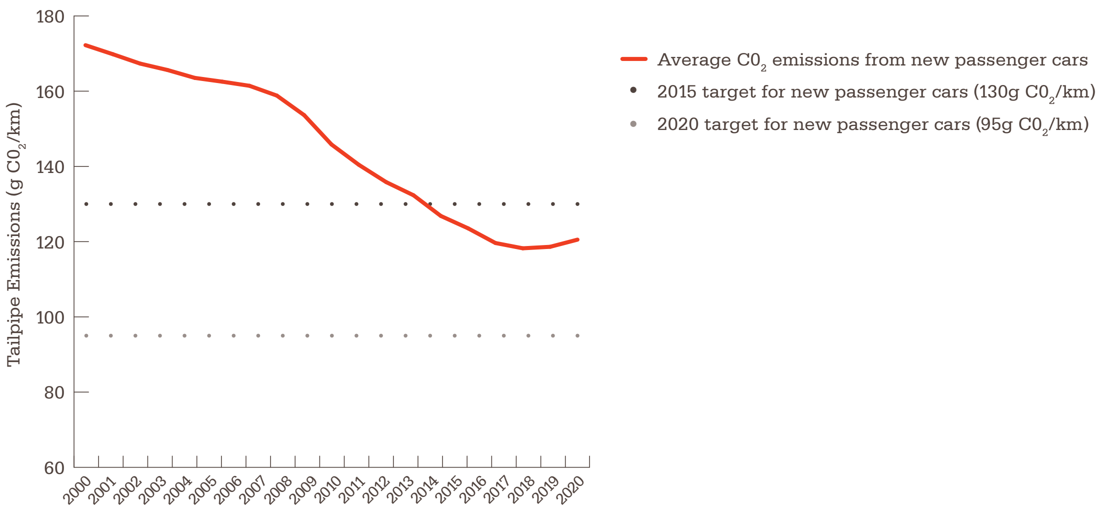
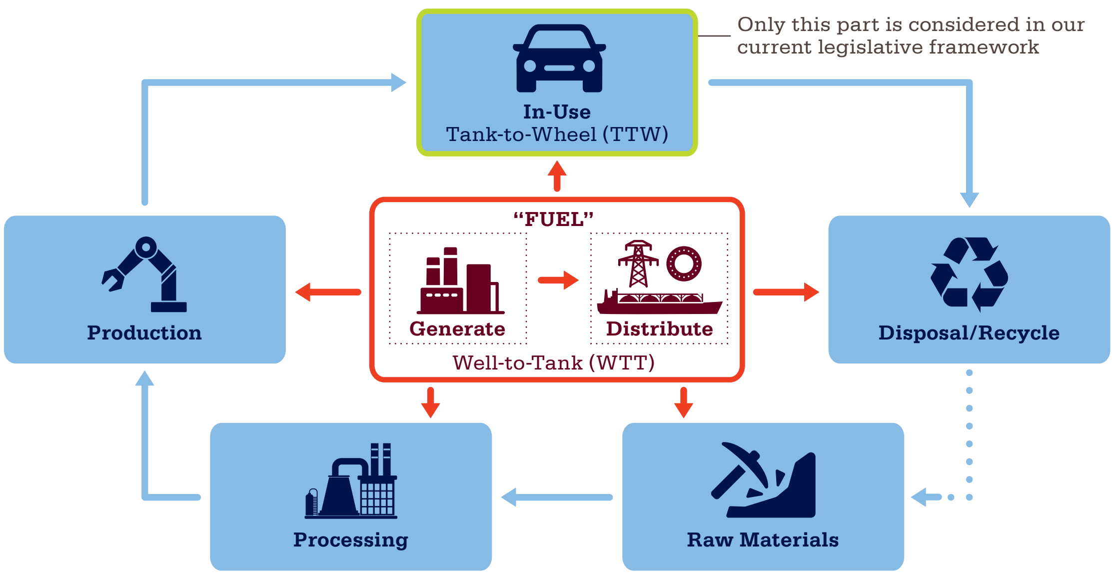


Figure 4: Automotive product lifecycle



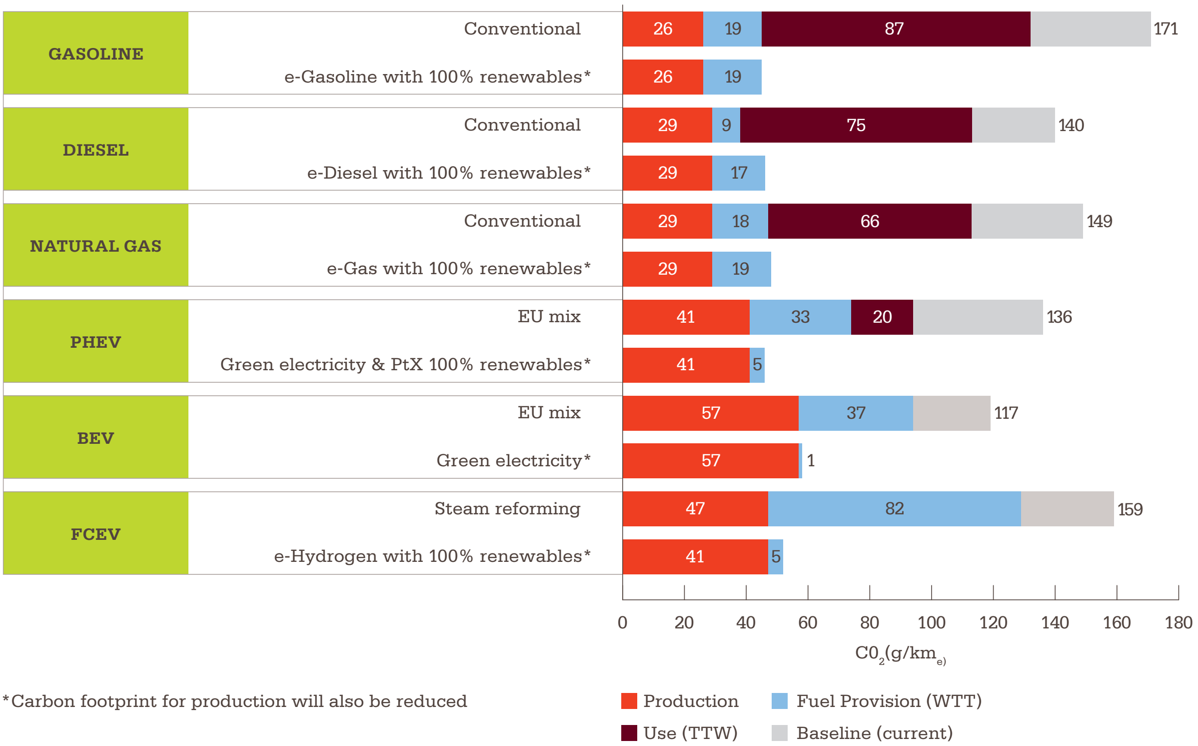
LIFE-CYCLE ANALYSIS AND HOW THIS CAN HELP WITH POLICY AND TECHNICAL DECISION MAKING

To deliver net zero in a timely manner, we need to be smarter about our technology choices, ensuring they achieve a rapid reduction, and either continue to do this, or lead to a situation where we are actively improving on the current infrastructure. Not simply replacing it with something that just has the appearance of being good in the short term.

Life cycle analysis is a technique for quantifying the environmental and human health impacts of a product over its lifespan and is often referred to as 'cradle-to-grave analysis', 'eco-balance' or 'environmental foot-printing'.

When applied in the automotive field, it can yield some interesting results, as shown in **Figure 5**. While pure electric vehicles offer a significant reduction in life cycle GHG emissions, they are far from zero emissions. This is driven primarily by the embedded emissions in the production of the vehicle (mainly the battery pack), and the type of generation used to make the power to charge the vehicle, neither of which is measured at point of use.

Figure 5: Life-cycle analysis of typical C-segment passenger vehicle in 2030 (sum of coloured bars) compared to current (grey bars) for different conventional and renewable fuels by life-cycle phase



*Carbon footprint for production will also be reduced

In a recent Science Briefing Paper[14] from the British Geological Survey, it was identified that the use and mining of metals for our emerging technologies will more than double by 2060. Considerable effort is being put into planning what can be mined from our seabed and elsewhere to meet this demand. This increasing demand means that more high-energy methods are used to extract metals and have a damaging environmental impact. For some primary metals, recycling can help reduce the environmental impact. However, for other metals, such as those used in batteries and communications, the extraction of these materials by recycling is difficult and complex, leading to yet more virgin extraction to meet demand.

FCEVs are similar to BEVs, in that electric motors propel the vehicle. Fuel cell vehicles offer a much-reduced life cycle CO_2 footprint, however only if the hydrogen that powers them comes from low-carbon sources, such as renewables or nuclear. **Figure 5** reminds us that the vehicles that can yield the lowest in lifetime CO_2 are those powered by a low-carbon fuel. Such conventional vehicles also benefit from the relatively low emissions associated with manufacturing an internal combustion engine vehicle and its end-of-life disposal. When in use, they operate in a carbon-neutral way (net zero), delivered because the CO_2 emitted from the tail pipe was itself absorbed from the atmosphere, either directly or indirectly in the production/growing of the fuel.

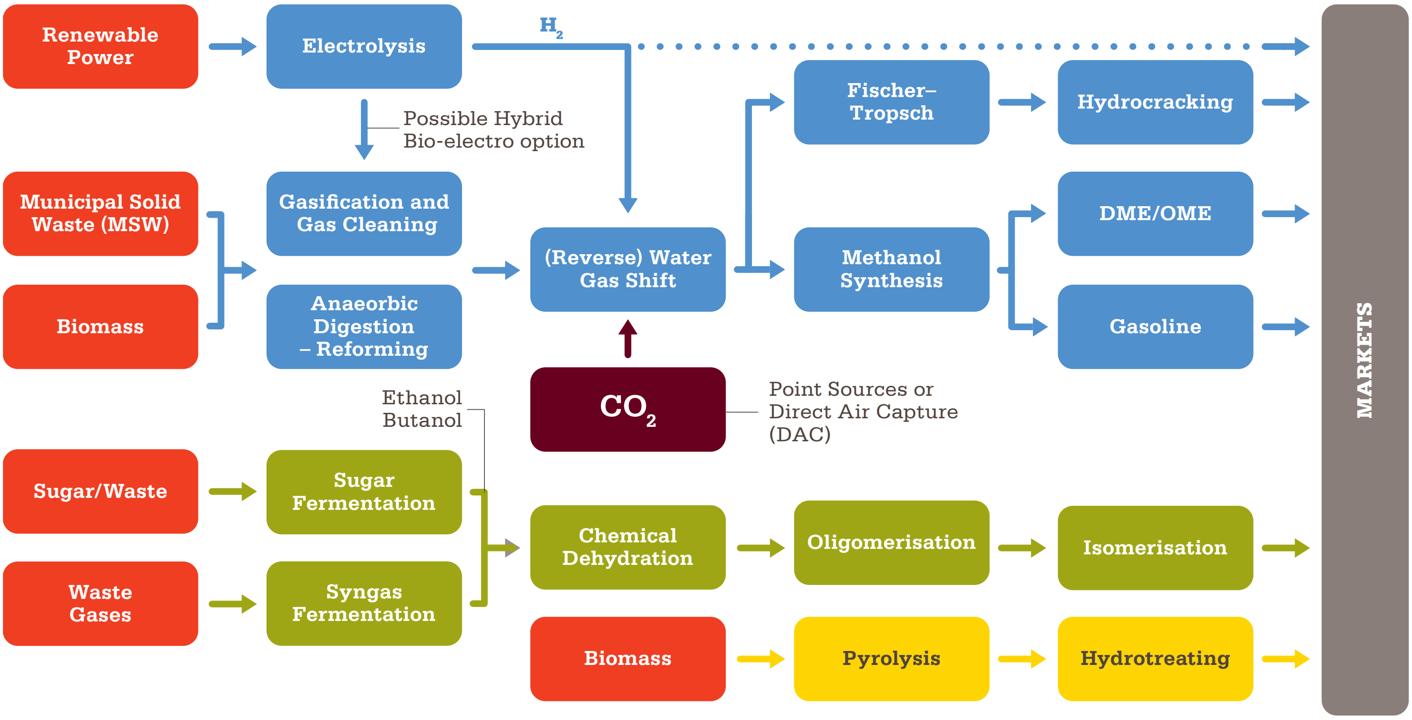
POTENTIAL FUEL SOLUTIONS

A low-carbon fuel is likely to be a hydrocarbon fuel much like we use today, except the carbon comes from biological, industrial or atmospheric sources rather than fossil-based deposits buried in the ground. **Figure 6** shows the typical range of routes for their production.

Low-carbon fuels fall into three categories:

- **Biofuel:** In the case of biofuels, such as biomethane and biogasoline, this carbon comes from sources such as agricultural waste, sewage wastes or municipal wastes, that can be processed via thermochemical or biochemical routes into fuels or fuel components.
- **Synthetic fuels:** The carbon (usually in the form of CO or CO_2) is combined with green or blue hydrogen, to create hydrocarbons or alcohols, which can then be further processed into diesel or petrol substitutes.
- **Hydrogen:** In addition to being used in the formation of bio- and synthetic fuels, hydrogen can be used directly in vehicles via a fuel cell. In this case the hydrogen is recombined with oxygen, to create electricity to power the vehicle.

Figure 6: Routes to production for bio-fuels



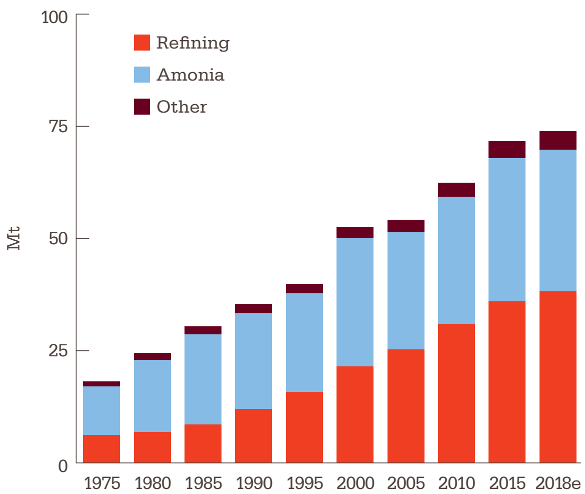
Demand for all has been growing and the data for hydrogen as an example is shown in **Figure 7**.

The benefits of hydrogen for new uses clearly come only from technologies that fall into the green or blue categories. These activities need to begin immediately to both replace brown hydrogen in use and create markets for the technologies and end uses, increasing research into more efficient production processes.

About 70Mt of dedicated hydrogen is produced globally today: 76% from natural gas and almost all the rest from coal and oil[16]. However, the majority of this is used in industrial processes, with a tiny amount available from current production for vehicle fuel. To put this level of global hydrogen into context, its energy content is equivalent to about 8,400PJ; global transport demand is 125,000PJ, meaning less than 7% of global transport energy demand could be met from current production.

The majority of energy needs in transport are delivered by oil. The development of purposeful infrastructure to deliver hydrogen for transport will take many years, and the use of alternative fuels provides us with a realistic opportunity to act more quickly to decarbonise. The Institution supports the continued development of hydrogen as a sustainable fuel, however with current production not yet able to support demand and the infrastructure needed some years away, this report has focused on near-term solutions.

Figure 7: Global demand for pure hydrogen[15]



SYSTEM EFFICIENCIES FOR THE VARIOUS ENERGY VECTORS

In order to understand the impact of the 'fuel' production on overall efficiency, we need also to look at the conversion efficiencies of the various processes associated with their manufacture (**Figure 8**). Clearly the most efficient use of primary energy in the form of renewable electricity, is to put it into electric vehicle batteries. Next comes hydrogen, the production and use of which can be a low carbon option that is continuing to improve in efficiency, followed by synthetic fuels. This relatively poor efficiency is dominated by the fuel production processes and the efficiency of the internal combustion engine.

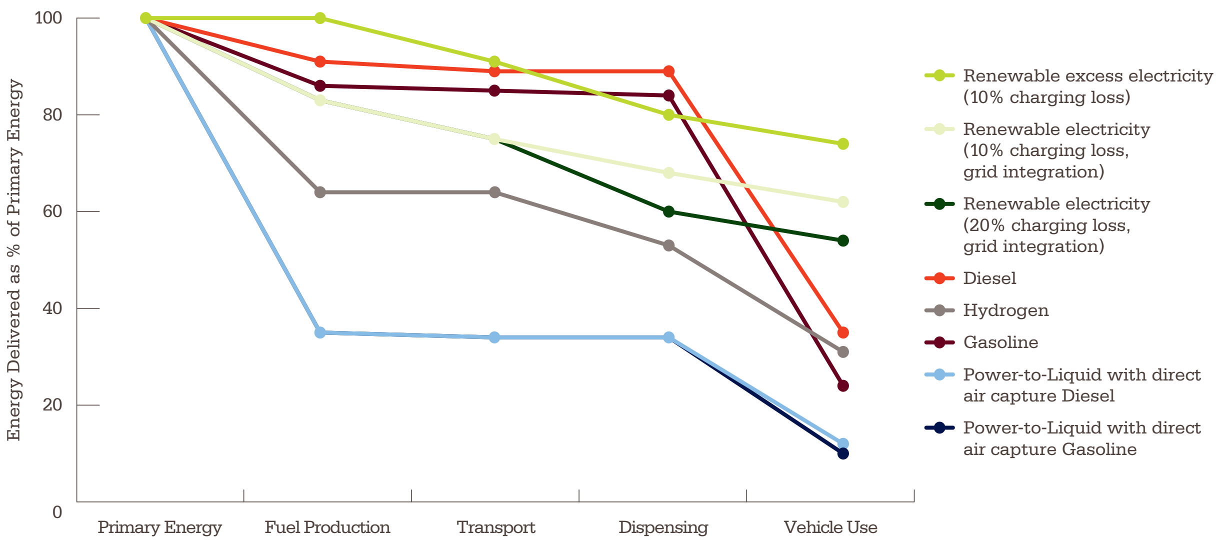
Based on the above, it would seem obvious that electric vehicles are the answer from a pure fuel production and use efficiency perspective, and we should focus all our efforts on accelerating their development and deployment.

However, when trying to consider all potential solutions, there are some other key facts that complicate the issue:

1. There are approximately 308.3 million passenger cars in circulation on European roads[17] and about 99% are powered by diesel or petrol.
2. Sales of electric vehicles and plug-in hybrid electric vehicles represented 2.5% of new passenger vehicle sales in Europe in 2018 (384,000 out of 15,624,000); over 97% of new vehicles are still powered by diesel or petrol.
3. Once a car enters the European 'parc' (the number of cars on and off the road in Europe), its average lifespan is ~12 years.

This means that we cannot rely on electric vehicles to make any meaningful impact in reducing GHG emissions fast enough and the internal combustion engine is likely to be with us for the foreseeable future.

Figure 8: Energy vector efficiencies



This system inertia is reinforced by data from National Grid, which produces a Future Energy Scenarios report each year. Its aim is not to predict the future of our energy system, but to lay out four plausible paths to 2050. It has two scenarios with aggressive emissions reduction ('Community Renewables' and '2 Degrees'), and two with slower progress ('Consumer Evolution' and 'Steady Progression'). Even in their most aggressive scenarios there will still be 27.6 million diesel/petrol vehicles on the road in 2030 (though the numbers fall rapidly in subsequent years), while the Consumer Evolution scenario assumes that there will still be 37.1 million vehicles with petrol or diesel engines on the road in 2030, and 22.5 million in 2040. HGVs are the most stubborn category of petrol/diesel vehicle category, with a reduction of just 9% by 2030 and 33% by 2040 in the most optimistic projections.

Figures 9 and **10** show the evolution of energy demand in the road transport sector for the most aggressive and least aggressive scenarios. Petrol/diesel is still the largest transport fuel in all scenarios until at least 2040.

When taken in combination, it is evident that there is not a 'one-size-fits-all' solution. We need to pursue all the potential powertrain solutions in parallel, because we simply do not have time to wait for the increasing share of electric vehicles to make a dent on the passenger car CO_2 footprint. Indeed, as we accelerate the adoption of electric vehicles, it is possible that we are accelerating the production of GHG emissions, unless battery manufacture and recycling improves from its current environmental footprint. While we pursue and invest in electric vehicles, we should also pursue and invest in hydrogen and renewable fuels, as these fuels from low-carbon sources can:

- Use the existing infrastructure
- Have zero consumer impact at the fuel pump (assuming cost parity with fossil fuels)
- Reduce/manage/avoid the cost associated with the overly-rapid investment in electrical infrastructure to support wide electric vehicle adoption
- Be increasingly blended with existing fuels (eg up to E10 and B7) as supply ramps up
- Help avoid fuel price volatility associated with global oil market shocks

Figure 9: Road transport energy demand in Community Renewables scenario

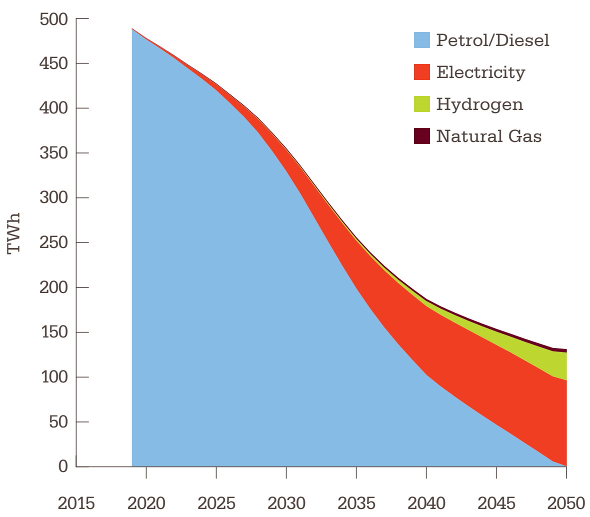
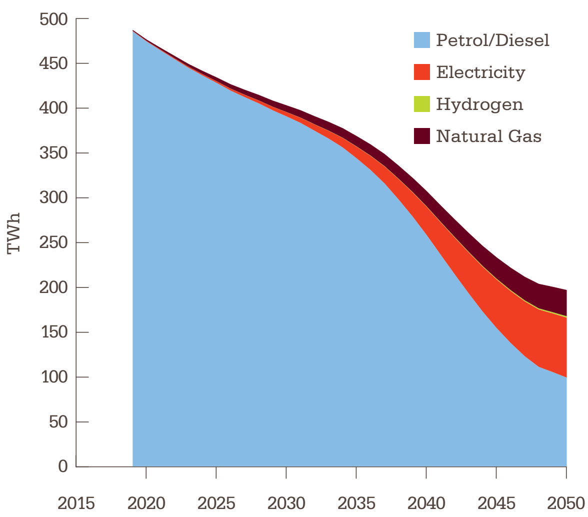


Figure 10: Road transport energy demand in Consumer Evolution scenario



RECOMMENDATIONS

The Institution of Mechanical Engineers recommends:

1. A move to E10 10% bioethanol in petrol pumps and B7 in diesel pumps, to help to rapidly decarbonise the many millions of internal combustion engines already running on conventional fossil fuels as soon as possible.
2. The adoption of a life cycle approach for all Government policy. This takes an holistic view of greenhouse gas emissions, and avoids the unforeseen consequences of backing particular technologies at the expense of exploring essential alternative and complementary approaches.
3. Substantial investment (similar to that provided for battery electric vehicles and charging infrastructure[i]) in sustainable and low-carbon fuel development and associated internal combustion engine technology levelling the playing field across low carbon technologies. This will enable both growth in EVs and further immediate reduction in vehicle CO_2 emissions with a managed transition to zero carbon.

[i] Equivalent to Electric Vehicle of 400 million in infrastructure[18] and 274 million Faraday Challenge[19]

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Institution of
Mechanical Engineers

1 Birdcage Walk
Westminster
London SW1H 9JJ

T +44 (0)20 7304 6862
F +44 (0)20 7222 8553

media@imeche.org
imeche.org