Driving Change

How Hydrogen Can Fuel A Transport Revolution

BY EAMONN IVES

Centre for Policy Studies

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I. Introduction

"Climate change knows no national boundaries, but I agree that the United Kingdom can lead the way, with punctilious and radical action."[1] The Prime Minister, writing in a recent letter to the Committee on Climate Change, was correct on both counts – that climate change is a truly international threat, but also that the UK can pioneer and deliver the necessary solutions to overcome it.

Since June 2019, the UK has been legally committed to the principle of 'Net Zero' domestic greenhouse gas emissions by 2050. This means that in three decades' time, no more greenhouse gases can be emitted in the UK than are removed from the atmosphere, for example via natural sequestration by trees, or by directly extracting offending gases from the air.

This objective cannot be met simply through fine words, noble ambition, and bold statements of intent. It will require changes to be made across the length and breadth of the economy, both at home and abroad. At the same time, for action to be not just meaningful but actually effective, it must work with the grain of the market – and of human behaviour. Successful climate policies need also to be a source of jobs, growth, and innovation, rather than an obstacle to them.

On this score, the UK already has a proud track record of reducing pollution without impacting growth. Across the 21st century, it can boast the highest average decarbonisation rate of any G20 nation.[2] Since 1990, it has cut domestic emissions by a third.[3]

Yet the burden of decarbonisation has not been equally shared. The bulk of the heavy lifting has been done by the energy sector, in particular the transition away from coal-fired power generation. Transport, a crucial sector in terms of emissions, has witnessed only fractional reductions in recent decades.[4]

With transport now the biggest contributor to overall greenhouse gas emissions – responsible for 28 per cent of the total – effectively decarbonising it will be critical to achieving the UK's 2050 Net Zero ambitions. This goes hand in hand with the equally pressing need to tackle the UK's dangerously polluted air – especially in urban areas.[5] Poor air quality is recognised as the number one threat to public health in the UK,[6] with estimates suggesting that ambient air pollution leads to the premature deaths of 40,000 people a year.[7] It also has significant economic and ecological consequences.[8] Despite this, the UK has consistently failed to meet its own standards with regards to certain toxic air pollutants, losing three court rulings on the matter in recent years.[9]

To their credit, successive Governments have had clear visions for cleaning up the transport sector. Yet the overwhelming focus has been on the personal car market, where decarbonisation efforts have been based principally on electrification.[10] The current administration, for example, has decided to ban the sale of new petrol- and diesel-powered cars and vans by 2040 – with a consultation currently underway to bring this forward to 2035,[11] and possibly even 2030.[12]

The problem is that the path to transport decarbonisation is not so much unclear as it is incomplete. In particular, heavier duty vehicles – such as buses, some light goods vehicles (LGVs), heavy goods vehicles (HGVs), and even shipping and parts of the railway network – are all likely to struggle to sufficiently reduce their gross emissions in line with Net Zero by 2050.

The key challenge is that while lighter vehicles like cars can easily take advantage of electrification and ever improving battery technologies, such solutions are less viable for heavier transport types – both in terms of charging times and the sheer weight and bulk of the batteries needed.[13] There are also question marks over whether or not the National Grid will be able to handle charging the entire UK vehicle fleet.[14]

Battery capacity is, of course, improving all the time. But in the absence of transformative breakthroughs in the fundamental technology, it will always have its limits – indeed, it is striking that the exponential growth in electric vehicle take-up in recent years has been overwhelmingly dominated by cars, with heavier vehicles remaining overwhelmingly dependent on fossil fuels.[15]

So, while the Government is right to focus on batteries as a key part of the solution, they cannot be depended on to fully decarbonise the transport sector.

If the UK is to succeed in complying with its ambitions for decarbonising transport, and cleaner air, another solution will be needed for heavier forms of transport. And the most obvious contender – indeed, the only realistic one – is hydrogen.[16]

This energy-dense fuel can be utilised in a fuel cell, which converts the hydrogen into water and an electric current via a reaction with oxygen taken from the air.

Often, fuel cell electric vehicles (FCEVs) and battery electric vehicles (BEVs) have been seen as in direct competition with each other. Yet in many ways, they are complementary.[17] Fuel cells have historically been more expensive than batteries, but innovation and deployment at scale have seen costs fall. The key advantages of fuel cells are that they are typically lighter than equivalently sized battery powertrains, and that they have much shorter refuelling times. Rather than waiting hours for a battery to recharge from the mains, one simply refills an FCEV's fuel tank with hydrogen at the pump just as one would do for petrol or diesel. Fuel cells are also much more energy-dense than batteries, and therefore take up less space on a vehicle.

In sum, hydrogen fuel cells can address the parts of the vehicle market that batteries cannot reach – those which require larger vehicles, with the ability to handle heavier loads, longer distances, faster refuelling times, and steeper hills. This makes FCEVs ideally suited to decarbonising HGVs, buses, shipping, trains (in the absence of full electrification), and potentially some parts of aviation.

Talking to policy specialists in this area, both within Government and outside it, there is a clear acceptance that FCEVs will need to play a role in the transport system in the coming decades, alongside BEVs. There is also a wider acceptance that hydrogen as a fuel will have a critical role to play in the wider decarbonisation agenda, for example via its use in domestic heating. But there is as yet no convincing roadmap for how that will happen.

The current risk, therefore, is that there will be some vehicles for which electrification cannot be relied upon, and the government will fail to meet its various climate and air quality objectives.

The UK has a clear strategy to deal with decarbonising the personal car market, but it needs to ensure that plans are in place for other vehicles – which are larger and typically make longer journeys, where constant recharging is not an option – to have a viable route to decarbonisation, such as through other clean fuels like hydrogen.

Battery technology is now also dominated by China – an economy many businesses might have apprehensions about fostering deeper trade links with as we emerge from the fallout of the COVID-19 crisis.[18] In early 2019, there were 316 gigawatt hours of global lithium cell manufacturing capacity, of which 73 per cent was in China.[19]

Hydrogen, however, is relatively unclaimed economic terrain. Certainly, some nations are starting to invest heavily in hydrogen, and it has been identified as an attractive industry to funnel money into as part of various COVID-19 economic recovery packages – recently evidenced by plans drawn up by the European Union.[20]

That said, there is still a window of opportunity for the UK to establish itself as a leading player in the global hydrogen economy – whether by producing the fuel itself, or the vehicles which will eventually make use of it. In fact, there are good reasons why the UK is especially well-positioned to capture the economic benefits of an expanded global hydrogen industry. For example, it has a mature renewable energy sector, which will be necessary to power the electrolysers to make green hydrogen, and vehicle manufacturers based in the UK are already producing hydrogen-powered FCEVs.

A home-grown hydrogen industry would be a significant source of green jobs and growth, especially in Britain's former industrial heartlands - which would no doubt help the Government make good on its desires to 'level up' the country.

The argument of this paper is therefore clear. Britain needs to decarbonise its transport network and clean up its air. But the longstanding battery-first, car-centric strategy risks leaving other parts of the transport sector behind. And since Britain will need hydrogen-powered vehicles and hydrogen infrastructure anyway, it makes sense to develop a clear strategy for FCEVs and the wider hydrogen sector at a point where Britain still has a realistic chance of capturing a significant slice of the global market.

Before the COVID-19 crisis began, the Government was working on a UK Transport Decarbonisation Plan, to be published later this year. A recent, and incredibly encouraging, positioning paper from the Department for Transport mapped out its anticipated programme of work, much of which would feed into the eventual plan.[21] It affirmed an ambition to oversee deep cuts to emissions in every class of transport – and was steeped in optimism about the role which scientific breakthroughs will play in delivering a more sustainable transport system.[22]

This report argues that the Transport Decarbonisation Plan, and the Government's wider strategy, should:

1 **Commit to ambitious targets for clean air, in order to incentivise cleaner travel and new technologies** – for example by confirming a ceiling for damaging particulate matter in line with World Health Organisation guidelines, and supporting local authorities to establish and expand Clean Air Zones.

2 **Introduce a target for a zero-emission bus fleet by 2038, accompanied by appropriate incentives** – both in order to drive decarbonisation and to help establish a test bed for zero-emission heavy vehicle technologies. Given the

absence of consumer pressure in the market, such a shift will have to be incentivised by Government. As part of this, the Bus Service Operators Grant should be reformed from a 'fuel used' model to a 'distance travelled' one, with incentives tilted towards low- or zero-carbon buses.

3 **Develop distinct strategies for decarbonising LGVs, HGVs, shipping, rail and aviation** – at the moment, the progress being made by the car sector is covering up more serious failures in the rest of the transport network. Strategies should be produced to evaluate not only how to transition the various forms of freight towards zero-emission vehicles, in particular those powered by hydrogen, but how to clean up existing fleets, for example via retrofitting or scrappage schemes.

4 **Ensure that Britain develops adequate hydrogen infrastructure and a comprehensive hydrogen strategy** – and that hydrogen technologies are included as part of the Conservative Party manifesto commitment towards investing in research and development and clean energy. As a starting point, the Renewable Transport Fuel Obligation should be amended in order to better support the production of hydrogen fuel, not least by phasing out support for those biofuels which may have little or even a negative impact on overall carbon emissions. We should also follow other countries by developing a proper UK hydrogen strategy and setting up a cross-departmental working group to coordinate policy.

The Conservative Party's 2019 manifesto correctly made the argument that free markets, innovation, and prosperity are not the enemies of the planet, but the best way to tackle the great environmental challenges we face.[23] Britain has decarbonised faster than its counterparts because the Government incentivised the transition from coal to renewables, but let the market decide how that transition would develop. The result of that was a process of scaling up and technological innovation that saw Britain lead the world in offshore wind – and the cost of the power generated fall beyond all expectations.

To reach Net Zero by 2050, the UK should not gamble everything on one technological solution. Battery electric vehicles, fuel cell electric vehicles, hydrogen for heating, heat pumps, insulation, and more will all have a part to play, in different ways, in decarbonising the economy.

If the Government can get it right, Britain can decarbonise in a way that not only protects jobs and growth, but leads the world in creating them.

II. Current issues with domestic transport

The 2050 target of 'Net Zero' means rapidly decarbonising transport

The impacts of global warming are well documented. In the UK, all ten of the hottest years on record have occurred since 2002,[24] while globally, 19 of the hottest 20 years have all occurred since 2001 – the single exception being 1998.[25]

As warmer air can hold more moisture than cooler air, climate scientists are observing a greater incidence of extreme weather phenomena – because evaporation and precipitation become more variable and pronounced.[26] Climate change is already manifesting itself in more frequent and extreme flooding events,[27] droughts,[28] and hurricanes,[29] alongside other phenomena such as forest fires and heatwaves.[30]

Last year, the Government signed into law a commitment to 'Net Zero' greenhouse gas emissions by 2050.[31] This means that the UK economy should not emit any more greenhouse gases than it sequesters, either via natural means like tree planting, or direct absorption of greenhouse gases from the atmosphere.[32]

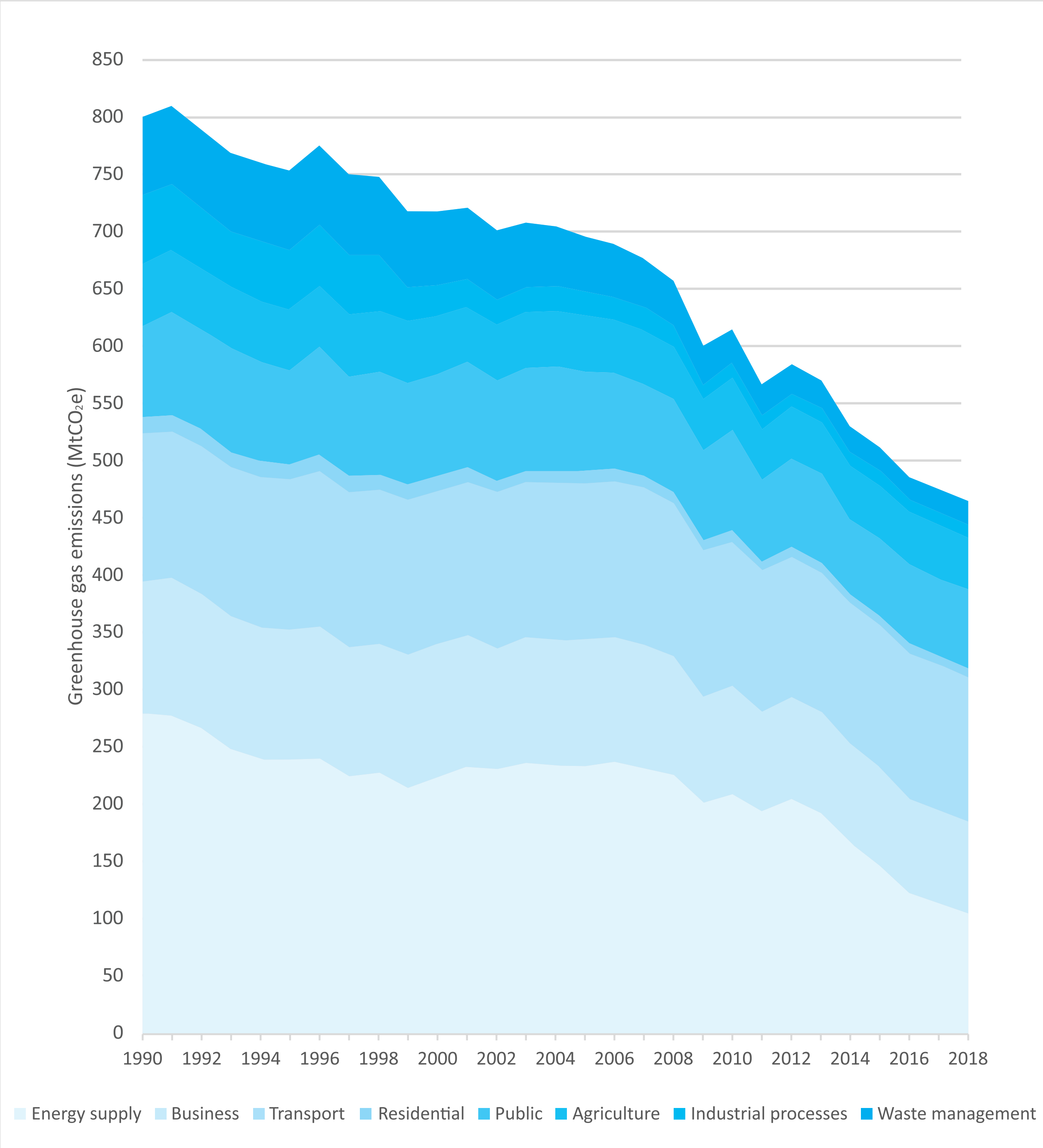
The move was a significant step up compared to the previous target of an 80 per cent reduction by 2050 compared to 1990 emission levels, as legislated for in the Climate Change Act 2008.[33] Yet getting to that target will take determined effort – especially if it is to be achieved in a way which promotes growth rather than curtailing it.

The sources and extent of greenhouse gas emissions

Just as there are many different forms of greenhouse gas emissions, so too are there many different contributing sources. In the UK, the leading source is now transport, which accounts for 28 per cent of all emissions.[34] This is followed by energy supply (23 per cent), emissions from businesses (18 per cent), residential emissions (15 per cent), and agriculture (10 per cent).[35] The remainder come from sectors like waste management, the public services, and industrial processes.[36]

As Chart 1 shows, the UK has managed to cut its domestic emissions dramatically in recent decades.[37]

Chart 1. UK domestic greenhouse gas emissions (1990-2018)



Source: Department for Business, Energy and Industrial Strategy, "2018 UK greenhouse gas emissions: final figures – data tables".

Yet such cuts have not been equally distributed. Greenhouse gas emissions in the energy supply, for instance, have fallen dramatically – from 278 million tonnes of carbon dioxide equivalent ($MtCO_2e$) in 1990 to 104.9 $MtCO_2e$ in 2018.[38] On the other hand, emissions from transport have barely changed at all – falling by just 3.8 $MtCO_2e$, from 128.1 $MtCO_2e$ to 124.4 $MtCO_2e$.[39]

In other words, since 1990, emissions from transport as a whole have declined by only 2.9 per cent.[40] And emissions from road transport specifically have actually increased, by around two per cent. In 2018, road transport in the UK emitted an additional 2.3 $MtCO_2e$ into the atmosphere, compared to 1990.

Table 1. Greenhouse gas emissions from selected transport types (1990 and 2018, in $MtCO_2e$)

Sector		1990	2018	Percentage change
Road	Passenger cars	72.3	68.5	-5.3
	Light duty vehicles	11.6	19.4	+67.2
	Buses	5.3	3.2	-39.6
	HGVs	20.5	20.7	+1
	Mopeds and motorcycles	0.8	0.5	-37.5
	Other	0.2	0.6	+200
Railways	Total	2.0	1.8	-10
Shipping	Total	8.5	5.9	-30.6
Aviation	Total	1.5	1.5	+/-0
Other mobile	Military aircraft and shipping	5.4	1.6	-70.4
	Aircraft support vehicles	0.2	0.6	+200

Source: Department for Business, Energy and Industrial Strategy, "2018 UK greenhouse gas emissions: final figures – data tables".

The Government is well aware that reducing emissions from domestic transport will be key to meeting its Net Zero target. And its current plan is geared heavily towards electrification as the means to do so.

Last year, the Transport Secretary announced that the Government would be developing the UK's first ever Transport Decarbonisation Strategy, to set out how Net Zero greenhouse gas emissions will be achieved across all modes of transport by 2050.[41] This plan is due to be completed and published later this year.

The Government has wisely made very clear that the plan will focus particularly on how new technologies and innovation can be used to reduce emissions, as well as looking at how individuals may need to make major changes to the way they travel (known as 'modal shift').[42]

Decarbonising transport has to be done in a sensitive way. Motorised transport is vital to our lives. Almost all of us are directly or indirectly dependent on the roads – and remained so even during the recent lockdown.

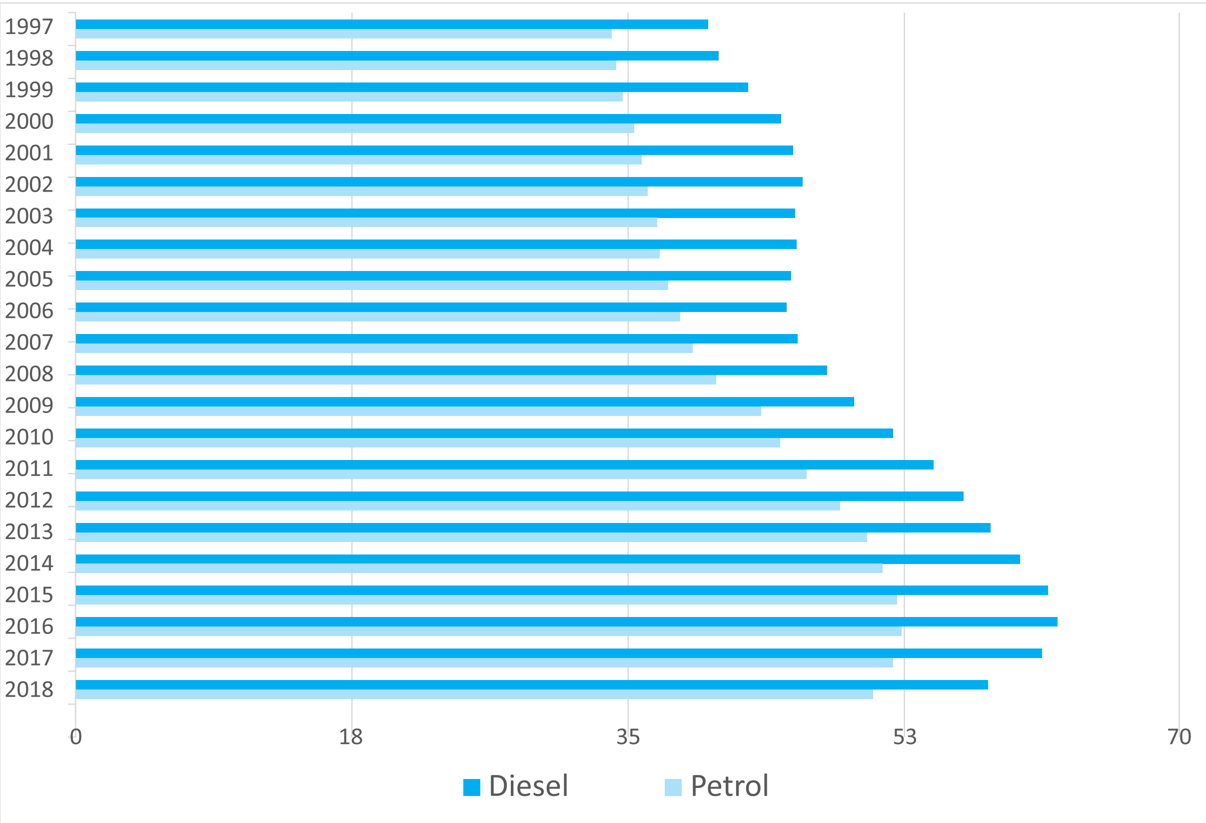
Nor does road travel show any signs of slowing down, at least in mileage terms. In 2018, 328.1 billion miles were travelled by road vehicles in Great Britain. This equates to nearly 5,000 miles per person, or about 14 miles each per day – and represents a 29 per cent increase compared to 1990. Since 2012, the distance travelled has increased every year.[43]

Delivering a sustainable and less polluting transport system will require a combination of targeted and appropriate government policies, in tandem with market-led technological advancements.

Already, progress has been made – and the UK now enjoys a slightly cleaner transport system than it once did,[44] especially considering growth in the population and the economy.[45]

This decarbonisation has been facilitated by ever more efficient engines, and the sorts of fuels which power them.[46] Chart 2 shows how many miles an average new car might be expected to drive on a gallon of either petrol or diesel.[47] Today, an average new petrol car should comfortably do at least 50 miles to the gallon – whereas in the late 1990s, an equivalent model might only have managed 34. Similarly, a new diesel car should be able to do around 60 miles to the gallon – whereas in the late 1990s, a figure closer to 40 would be more typical.[48]

Chart 2. Average fuel consumption of new cars (1997-2018)



Source: Department for Transport, "Energy and environment (TSGB03): TSGB0304 (ENV0103): Average new car fuel consumption".

However, as helpful as efficiency gains have been, it is clear they will prove nowhere near sufficient enough to get the UK to comply with its near-term air quality objectives, and will certainly be incompatible with Net Zero greenhouse gas emissions by 2050.

Case study. How the UK electricity grid has reduced its emissions.

Perhaps the greatest decarbonisation success story in Britain has been how emissions associated with the electricity grid have plummeted, even compared to just a few years ago. In 2008, each kilowatt hour of electricity generated in the UK added around 495 grammes of carbon dioxide to the atmosphere. A decade later, each megawatt was adding only 207 grammes of carbon dioxide – a reduction of nearly 60 per cent.

This was the result of a series of intelligent policy decisions made by governments over a prolonged period, twinned with technological innovation, which delivered in particular:

- **A cleaner energy mix**. Today, the UK is far less reliant on polluting fuels like coal to generate electricity, and ever more reliant on natural gas, nuclear and renewables. Low-carbon electricity sources now account for over half of all electricity generated in the UK, while pure renewables have gone from 2.7 per cent at the turn of the millennium to 33 per cent in 2018.
- **Reduced demand for electricity**. Despite economic growth of 12.4 per cent, and population growth of 10.1 per cent, demand for electricity actually peaked in the UK in 2005. Indeed, overall consumption is now comparable to levels observed in the mid-1990s. This has been facilitated by, among other things, homes and businesses becoming more efficient and using electricity more sparingly.

This approach required three key changes to be made:

- **A long-term policy horizon**, which ensured that while individual policies changed, there was no doubt of the ultimate goal in terms of reducing emissions in electricity generation;
- **Investing in and supporting new technologies**;
- **A flexible approach rather than seeking 'silver bullets'**, which set price signals while leaving it to the market to respond.

This shows that deep emissions reductions within sectors are eminently possible, and that impressive results can be delivered more quickly than many initially imagined. But in order to do so, a set of principles are prerequisite – including consistent signals from government, and a regulatory landscape which allows for technological learning and deployment to take place, and the market to operate.

The Government also needs to act to improve air quality

Another obvious environmental challenge which is exacerbated by transport is air pollution. The combustion of fossil fuels in vehicle engines spews out noxious gases and particulates, contributing to diminished air quality.[49] Less well-known, however, is the extent to which the wearing down of tyres, brakes, clutches and road surfaces also worsens air quality – with the Government estimating that as much as 60 per cent of the fine particulate pollution associated with transport coming as a result of the abrasion of vehicle parts and road surfaces.[50]

Air pollution is caused by a concentration of numerous harmful pollutants in localised atmospheres, and can become particularly acute in urban areas due to an increased density of economic activity and transport. The two pollutants which typically receive the most attention are oxides of nitrogen (NO_x) and particulate matter (PM).[51] PM refers to microscopic solid or liquid matter suspended in the air, and is categorised in terms of its size – with $PM_{2.5}$ (particulates measuring 2.5 microns or less in diameter) and PM_{10} (particulates measuring 10 microns or less in diameter) the two most common units of focus.[52] Other important pollutants include ammonia (NH_3), sulphur dioxide (SO_2), carbon monoxide, ozone (O_3), benzene, non-methane volatile organic compounds (NMVOCs), and heavy metals like lead, mercury, cadmium and nickel.[53]

The impacts of air pollution

A range of health impacts have been associated with exposure to air pollution, with respiratory and cardiovascular illnesses leading examples.[54] Increasingly, evidence has found that poor air quality can also lead to impaired cognitive ability,[55] mental health conditions like depression,[56] dementia,[57] stunted growth,[58] as well as various different cancers.[59]

As is the case with most air pollution, PM causes respiratory and cardiovascular conditions, and has also been linked to elevated risks of cancer and dementia.[60] Typically, the finer the PM, the more prejudicial it is to human health, as it means particulates can get deeper into the body, including the bloodstream, where they can damage tissues and internal organs like the heart, lungs, and brain.[61]

Some of the most common conditions linked to air pollution – such as respiratory diseases and cardiovascular diseases – have themselves been recognised as comorbidities with other serious conditions, not least COVID-19.[62] Air pollution might also be a vector for negative health impacts, with a group of scientists recently publishing a position paper – albeit non-peer reviewed – which hypothesises that high levels of particulate matter in Northern Italy helped carry the virus through the air, exacerbating the crisis.[63]

Ultimately, dirty air means people lead shorter and less healthy lives than the case would be otherwise. In 2016, a seminal report from the Royal College of Physicians and Royal College of Paediatrics and Child Health estimated that poor ambient air quality in the UK is responsible for 40,000 premature deaths each year.[64] In 2010, the Committee on the Medical Effects of Air Pollutants published a study which found that anthropogenic PM pollution is associated with a loss of 340,000 life-years each year – a figure one can safely assume to have increased since.[65]

The health impacts of air pollution, which impinge upon worker productivity and morbidity, also mean that dirty air poses a significant and growing economic cost.[66] Poor air quality can lower the productivity of capital equipment, and have other undesirable economic impacts – one recent paper, for instance, found that it can trigger company executives to migrate from areas with elevated air pollution to areas where it is lower.[67] Finally, air pollution can be detrimental to the natural environment – causing phenomena like acid rain,[68] the acidification of soils,[69] the eutrophication of watercourses,[70] biodiversity loss,[71] and lower crop yields.[72]

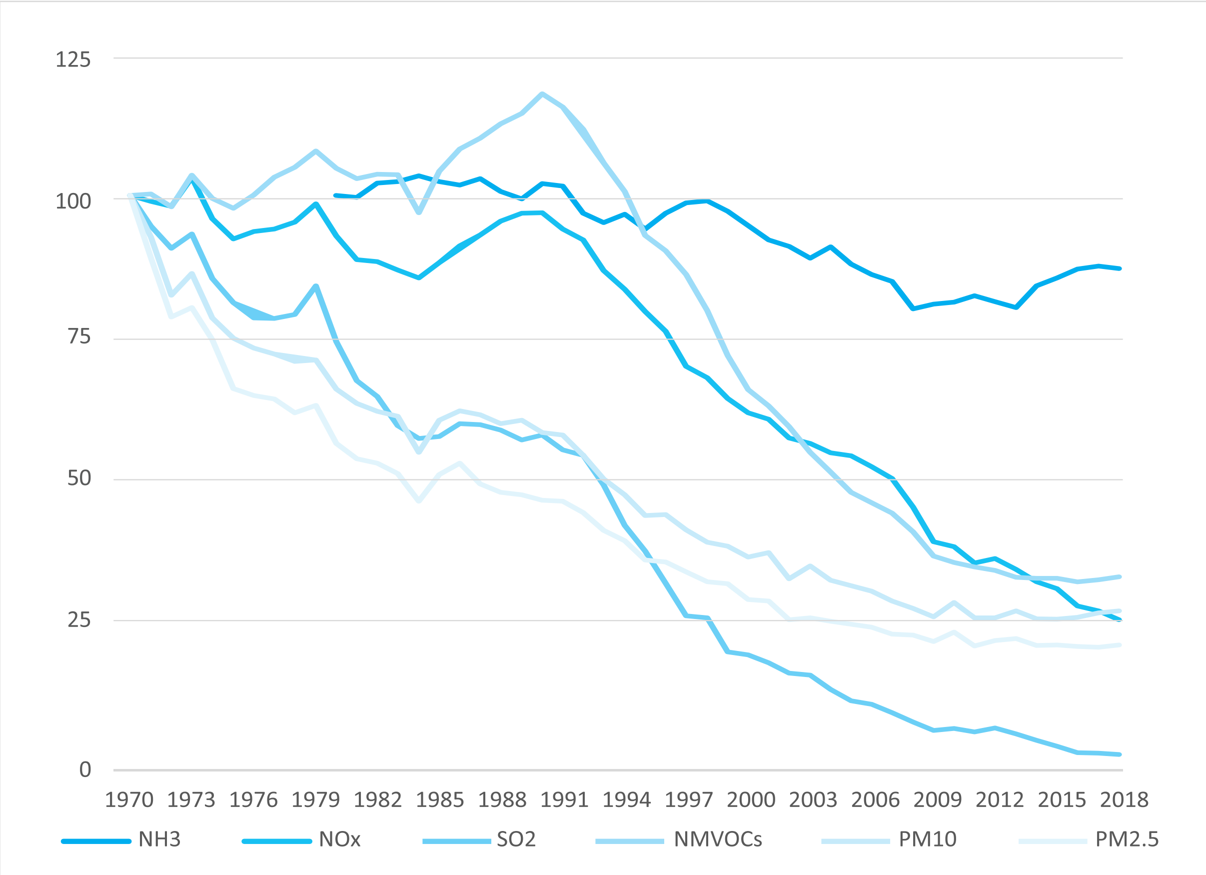
According to the OECD, the annual global welfare costs associated with the premature deaths from ambient air pollution alone stand at $3 trillion in 2015 prices.[73] At the UK level, the World Health Organisation estimated the cost of air pollution in 2010 at $83 billion, or 3.7 per cent of gross domestic product (GDP).[74] Transposing that crudely onto current GDP data would see the figure stand at £105.6 billion.[75]

Stagnation in air quality improvement

The UK now enjoys much cleaner air than was the case previously. Owing largely to technological advances – for example, cleaner energy production and cleaner vehicles – the air the British public breathes is of far better quality compared to that of even just a few decades ago.

However, improvements in air quality have, after decades of steady improvement, ground to a halt. Chart 3 shows how concentrations of PM have stopped falling, and the pace of reduction in SO_2 pollution has also slowed significantly. While NO_x pollution has been falling steadily, NH_3 pollution has remained stubbornly high, and has actually risen in recent years.

Chart 3. Levels of selected air pollutants (1970-2018)



Source: Department for Environment, Food and Rural Affairs, "Emissions of air pollutants: Trends in UK sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, ammonia, and particulate matter (PM10, PM2.5) emissions".[76]

In terms of the specifics, between 1970 and 2010, emissions of NO_x fell from 3.16 million tonnes to 1.22 million – a reduction of 61.4 per cent. While further reductions have been recorded in the years since 2011, the rate of has slowed – falling over that period by only 28.1 per cent. The rates for NMVOCs and SO_2 have followed a similar pattern – rapid falls from the late 20th century into the first decade of the 21st, followed by a slower rate of decline from around 2010 onwards.

A more troubling picture can be painted for both PM_{10} and $PM_{2.5}$. Between 1970 and 2010, emissions of these pollutants fell considerably – by 75.3 per cent and 77.8 per cent respectively. But since 2011, emissions have actually risen, by 4.7 per cent for PM_{10}, and 1.2 per cent for $PM_{2.5}$.

Emissions of NH_3 have only reduced by 12.8 per cent since 1980, increasing by 8.7 per cent between 2008 and 2018.

In other words, while the progress in terms of cleaning up the UK's air is commendable, it is clear that there is much more to do.

The sources and extent of UK air pollution

Table 2 displays data for NO_x and PM air pollution in the UK. In total, 873.4 kilotonnes of NO_x was emitted in 2017 – of which fractionally over 50 per cent came from transport.[77] PM emissions totalled 275 kilotonnes, roughly 60 per cent of which was PM_{10}, and 40 per cent of which was $PM_{2.5}$.[78]

Table 2. Particulate matter emissions (2017)

Pollutant	Total (kilotonnes)	Transport sector (kilotonnes)	Transport sector (percentage)
NO_x	873.4	437.4	50
PM_{10}	169	25	15
$PM_{2.5}$	106	13	12

Source: National Atmospheric Emissions Inventory, "About PM10 (Particulate Matter < 10·m)"; National Atmospheric Emissions Inventory, "About PM2.5 (Particulate Matter < 2.5·m)"; National Atmospheric Emissions Inventory, "About Nitrogen Oxides".

A troubling dynamic with NO_x pollution is that because so much of it is associated with transport, it is particularly problematic in urban areas – where volumes of transport are highly concentrated.[79] Road vehicles contribute an estimated 80 per cent of roadside nitrogen dioxide (NO_2, which is a primary form of NO_x), largely because of diesel-powered vehicles.[80] PM concentrations which are transport-generated are also higher in urban areas.[81]

Equally, however, this means that if transport can be effectively cleaned up in those urban areas, NO_x and PM concentrations could be expected to fall dramatically and in a relatively short time period.

To monitor air quality, the Department for Environment, Food and Rural Affairs maintains what is called the Daily Air Quality Index (DAQI). This records concentrations of five pollutants associated with air pollution: NO_2, SO_2, O_3, PM_{10} and $PM_{2.5}$.[82] Based upon these data, the DAQI assign ratings for specific localities, ranging from one (indicating good air quality) – to 10 (indicating poor air quality). The DAQI is also broken down into four bands – low, moderate, high, and very high.[83] Only low means that it is safe for those who are 'at risk' to go outside and enjoy their daily lives as normal.[84] 'High' and 'very high' mean it can be unsafe even for healthy adults to go outside and enjoy their daily lives.[85]

Table 3 shows how different places in the UK fare in terms of their DAQI rating. As can be seen, virtually all major urban areas in the UK frequently suffered from air quality rated moderate or worse. Several saw DAQI ratings of moderate or worse on a fortnightly basis, on average, while London had the dubious honour of experiencing, on average, moderate to very high air pollution once every nine days.[86]

Table 3. Air quality in selected UK locations (2019)

Location	Number of days rated moderate or worse
Greater London	40
West Midlands	27
Leicester	27
Tyneside	25
Nottingham	24
Cardiff	23
Greater Manchester	23
Sheffield	21
West Yorkshire	17
Bristol	16
Glasgow	15
Belfast	12
Edinburgh	8

Source: Department for Environment, Food and Rural Affairs, "DAQI regional data".

Political and legal pressures to reduce air pollution

Awareness of the dangers of air pollution among the public has steadily risen in recent years.[87] The clamour for cleaner air only appears to have grown in the wake of COVID-19, perhaps as people become increasingly aware of how polluted air can elevate health risks, but also as the other benefits of less dirty air become more apparent.

In opinion polling, large majorities express anxieties about the health impacts of poor air quality.[88] Importantly, such concern is shared reasonably equally among different groups – whether split by age, voting record, or location.[89] Moreover, data also suggest that air quality is increasingly becoming a politically sensitive issue – with people, especially younger voters, stating that they would be more likely to vote for a political party which would tackle the issue.[90]

Technological advances in transport, energy production, and industrial processes have certainly helped in ameliorating air quality in the UK over the past decades. But targets and accompanying regulations, deriving from national and international legislation, have undeniably been an important factor too, not least by prompting companies to innovate and bring to market less polluting technologies in order to comply with stricter standards.

The main current regulations on air quality stem from Britain's former membership of the European Union.[91] The UK has now incorporated the two key EU statutes on air quality: Directive 2004/107/EC – more commonly known as the 'Fourth Daughter Directive' – which sets limits for levels of heavy metals and polycyclic aromatic hydrocarbons;[92] and Directive 2008/50/EC, which sets legally binding limits for concentrations of several ambient air pollutants, including NO_2, $PM_{2.5}$, and PM_{10}.[93]

Under Directive 2008/50/EC, the UK is broken up into 43 areas or zones.[94] In 2018, NO_2 was the only pollutant which the UK failed to abide by limits for, in terms of mean average hourly and annual limits.[95] For NO_2 concentrations on a mean average hourly basis, two zones were not compliant – the Greater London Urban Area, and South Wales.[96] For NO_2 concentrations on a mean average annual basis, fully 36 zones were not compliant.[97]

In fact, excessive levels of NO_2 have blighted many parts of the UK for years – particularly in urban areas.[98] Since 2011, the Government has been taken to court – and lost – no fewer than three times by the environmental campaigning outfit ClientEarth, for failing to abide by obligations set out in Directive 2008/50/EC.[99] In the most recent court defeat, handed down in 2018, ministers were ordered to require local authorities to investigate and identify measures to tackle pollution in 33 towns and cities as soon as possible.[100]

Clearly, more progress must be made in terms of cleaning up Britain's air – not least because the Government has committed, in the wake of our departure from the EU, to retaining high standards on air quality.

III. The current plan for decarbonisation

The Government is focused on phasing out petrol and diesel cars

As shown in the previous section, the two pressing environmental policy challenges in terms of domestic transport are to reduce its contribution to greenhouse gas emissions and air pollution.

Much of the Government's current thinking on making transport more sustainable was detailed in its 'Road to Zero' strategy, released in 2018.[101] This contained a number of ambitious objectives – not least for all new cars and vans to be zero-emission by 2040.[102] Currently, the Government is consulting on bringing forward this target to 2035,[103] and potentially earlier, "if a faster transition is feasible".[104] It has even been reported that ministers are considering a 2030 target, as many environmental groups are campaigning for.[105]

As well as the target for a ban on the sale of new petrol and diesel cars and vans, the Road to Zero strategy set out a series of markers along the way, with the Government hoping to see at least 50 per cent of new car sales, and 40 per cent of new van sales, being ultra-low emission by 2030.[106]

The Road to Zero strategy also made some references to other elements of the transport system. On HGVs, for example, it detailed four policies:[107]

- Introducing a new voluntary industry-supported commitment to reduce HGV greenhouse gas emissions by 15 per cent by 2025, compared to 2015 levels;
- Launching a joint research project with Highways England to identify and assess zero-emission technologies suitable for HGV traffic on the UK road network;
- Working with industry to develop an ultra-low-emission standard for trucks;
- Undertaking further emissions testing of the latest natural gas HGVs to gather evidence that will inform decisions on future government policy and support for natural gas as a potential near-term, lower-emission fuel for HGVs.

Another important document pertaining to the cleaning up of domestic transport is the Government's Clean Air Strategy, released in 2019.[108] This contained a plethora of different policies which the Government would seek to introduce in order to drive down air pollution further, including an ambition to cut exposure to particulate matter to the levels recommended in World Health Organisation guidelines, which are stricter than those demanded by the two EU Directives now enshrined in UK law.[109] Swathes of the Clean Air Strategy were carried through in the Conservative Party's 2019 manifesto – including policies like establishing an independent Office for Environmental Protection and an intent to introduce "strict new laws on air quality".[110]

In many ways, the Government's overarching vision for reducing greenhouse gas emissions from transport is commendable – it is an approach which is perfectly comfortable with journeys continuing to rise as the economy and population grows, while still having mechanisms in place to act as a check on pollution, rather than imposing arbitrary costs and limitations on people's ability to travel.

It also treads a sensible path with regards to the balance between private and public transport. There is a renewed focus on increasing the share of journeys completed by public transport – but it is centred on making public transportation the "natural first choice",[111] which people actively want to opt for, as opposed simply consigning people to public transport systems irrespective of their quality or reliability.

At the same time, the approach recognises that while modal shifts will be critical in decarbonising some journeys, the main focus will need to be on cleaning up transport technologies.

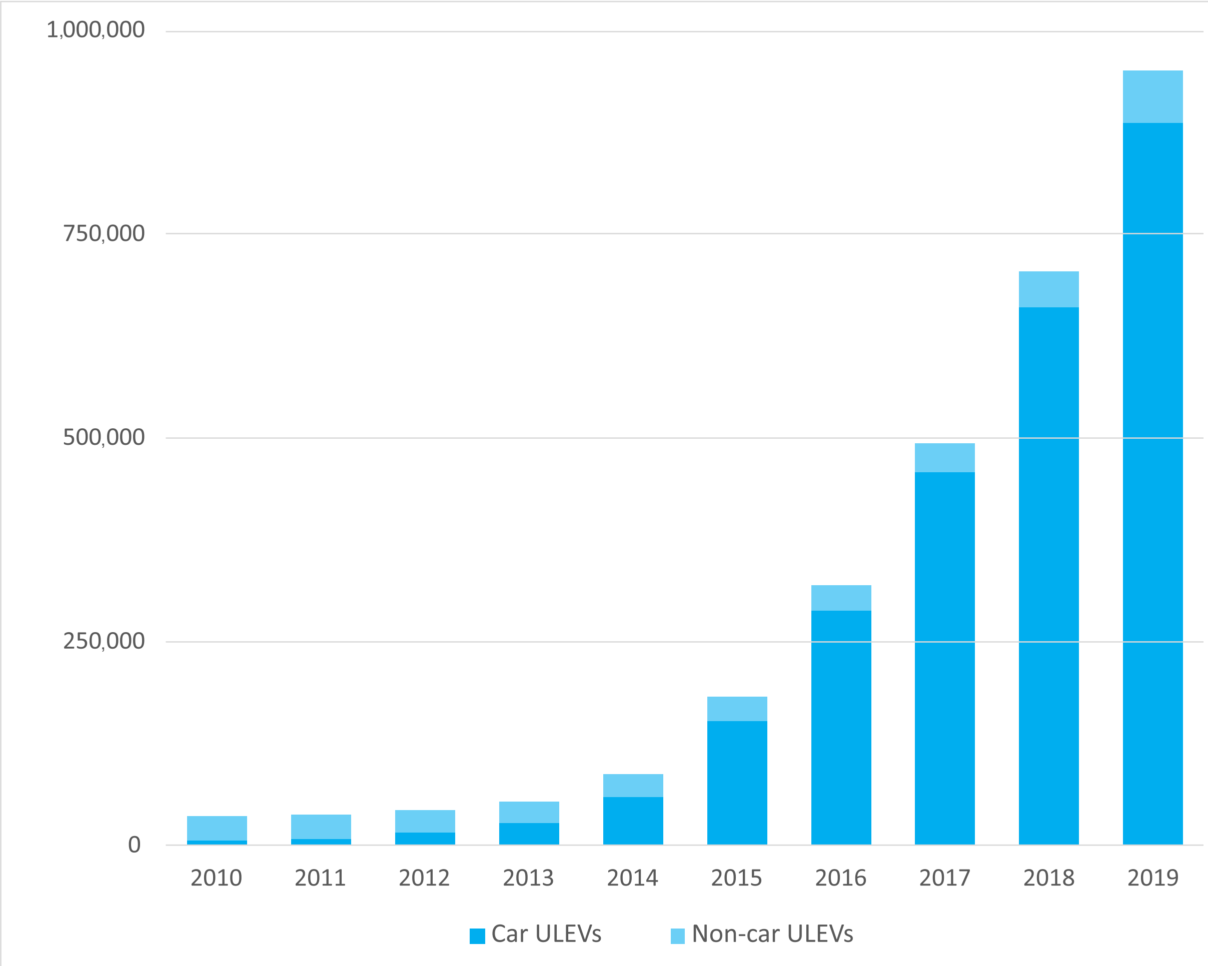
As the previous section showed, modern petrol and diesel passenger cars are much more fuel-efficient than their predecessors. But some cars – and, to a lesser degree, other vehicles – are doing without such fuels entirely. In recent years, more and more cars are making use of alternative fuels, and consequently lowering their carbon footprint and the extent to which they pollute the air.

Currently, zero-emission vehicles still represent a fraction of the total market.[112] At the end of 2019, there were over 19.2 million petrol cars and nearly 12.9 million diesel cars licensed in the UK – collectively occupying 97.6 per cent of the total car market of nearly 33 million vehicles.[113] A further 668,400 cars were hybrid electrics of some sort, while around 90,900 were fully electric – 0.3 per cent of all registrations.[114]

However, in large part this reflects the fact that fossil-fuelled vehicles have been so dominant in the personal car market for so many years. While the shift to ultra-low emission vehicles (ULEVs) – which is to say, vehicles with fully electric engines, plug-in hybrid engines, or tailpipe carbon dioxide emissions below 75 grammes per kilometre[115] – has been underway for a little while now, it will still take time to be completed. Encouragingly, the rate at which ULEVs are coming online is accelerating rapidly.

In 2010, there were fewer than 36,000 ULEVs licensed in the UK.[116] In 2015, there were nearly 183,000, a rise of over 408 per cent – in fact, more ULEVs were licensed in the first quarter of 2015 alone than were in the whole of 2010.[117] By 2019, over 951,000 ULEVs were licensed – a rise of 2,542 per cent compared to 2010.[118]

Chart 4. Ultra-low emission vehicle licences (2010-2019)



Source: Department for Transport, "Table VEH0103: Licensed ultra low emission vehicles (ULEVs) at the end of quarter by bodytype and plug-in grant (PiG) eligibility, including regional breakdown for the latest quarter, United Kingdom from 2010 Q1".

As shown by Chart 4 the ULEV revolution has been founded on the back of an exponential uptick in ULEV cars – with cars now representing nearly 93 per cent of all licensed ULEVs. Between 2010 and 2019, ULEV licenses for cars have gone from roughly 6,000 per year, to over 887,000 – a staggering increase of almost 14,700 per cent. Non-car ULEVs – which includes motorcycles, LGVs, HGVs, buses and coaches – have increased in licenses, but at a much slower rate. Compared to 2010, licenses in 2019 had grown by 114 per cent.

Table 4 breaks down the data further – this time per vehicle class. One can see how ULEV buses and coaches have increased by 513 per cent from 2010 to 2019, and LGVs by 148 per cent. Somewhat oddly, ULEV HGVs actually fell by 64 per cent.

Table 4. Ultra-low emission vehicle in the United Kingdom

Year	Cars (change since 2010)	Buses and coaches (change since 2010)	LGVs (change since 2010)	HGVs (change since 2010)
2010	6,012	291	15,304	4,090
2015	153,927 (+2,460 per cent)	718 (+147 per cent)	17,635 (+15 per cent)	1,797 (-56 per cent)
2019	887,122 (+14,656 per cent)	1,784 (+513 per cent)	37,887 (+148 per cent)	1,484 (-64 per cent)

Source: Department for Transport, "Table VEH0103: Licensed ultra low emission vehicles (ULEVs) at the end of quarter by bodytype and plug-in grant (PiG) eligibility, including regional breakdown for the latest quarter, United Kingdom from 2010 Q1".

It is clear from this not just that the shift away from fossil fuels has been overwhelmingly focused on cars, but that the markets for cars, LGVs, HGVs, and buses and coaches all behave in very different ways, and will therefore likely require different policy responses to decarbonise them.

From ultra-low to zero-emission vehicles

While the transition to ULEVs is a positive step, even some ULEVs emit greenhouse gases from their exhaust pipes. At sufficient scale, therefore, they will not be compatible with the UK's 2050 Net Zero greenhouse gas emissions target – and will limit progress on cleaner air.

Achieving these objectives will require a further shift, this time from ULEVs to fully zero-emission vehicles.

Currently, there are two broad types of zero-emission vehicles available on the market: those powered by conventional electric batteries – BEVs – and those powered by fuel cells – FCEVs.

BEVs run entirely on electricity discharged from an onboard battery, with the power initially being drawn from the grid. While BEVs produce no tailpipe emissions, it is important to note that they produce greenhouse gases indirectly, and will continue to for as long as fossil fuels make up some portion of the UK's electricity mix.[119] They also create air pollution by resuspension and tyre and break wear. Furthermore, some have questioned the environmental efficacy of mining the rare earth materials needed to produce batteries for electric vehicles,[120] while disposal of spent batteries can also be ecologically fraught.[121]

FCEVs generate electricity onboard via a clean fuel – hydrogen being the leading example. This means they too emit no greenhouse gas at the point of use. Similarly to BEVs, however, FCEVs still cause air pollution in various way, and are only truly zero-emission if their fuel cells run on fuel produced in a climate neutral manner – as we shall now explore.

The role of hydrogen in decarbonising transport

The most abundant element in the universe, hydrogen has long been regarded as an attractive means to generate useful energy.[122] Before the advent of fossil fuels, it was used to power embryonic internal combustion engines, and provided lift to aircraft.[123] Yet, clearly, it has not enjoyed the widespread adoption as an energy vector which many of its proponents would have liked – among zero-emission cars licensed in 2019, there were 90,858 BEVs, but just 1,830 FCEVs, of which one can assume a significant majority were powered by hydrogen.[124]

Hydrogen can be produced in many different ways. Importantly, it can be produced in ways which create greenhouse gases, and in ways which do not. When the production of hydrogen creates greenhouse gases, it is generally termed 'grey' hydrogen – and when it does not, it is referred to as 'green' hydrogen. A further category, 'blue' hydrogen, refers to when hydrogen is produced in a way which does create greenhouse gases, but which are captured and stored so as not to pollute the atmosphere.

The three main ways of producing grey hydrogen are as follows:

- Steam methane reformation (SMR) – accounting for half of all hydrogen produced in the UK;
- Partial oil oxidation (POX) – accounting for 29 per cent of hydrogen produced in the UK;
- Coal gasification (CG) – accounting for 18 per cent of hydrogen produced in the UK.

SMR works by reacting high-temperature steam (water heated to between 700°C and 1,000°C) with methane under pressure and in the presence of a catalyst to create carbon monoxide and hydrogen.[125] Subsequently, the carbon monoxide is reacted with water, with the help of a catalyst, to create more hydrogen molecules, plus carbon dioxide.[126] Estimates suggest that SMR produces around seven kilograms of carbon dioxide for every kilogram of hydrogen,[127] and the Committee on Climate Change works on an assumed emissions intensity of 285 grammes of carbon dioxide for each kilowatt hour of hydrogen produced via SMR.

Twenty-nine per cent of the UK's hydrogen production is made via POX.[128] Here, oil is gasified in the presence of oxygen under pressure and at temperatures of between 1,300°C and 1,500°C.[129] This creates carbon monoxide and hydrogen. As with SMR, the carbon monoxide is then reacted with water to produce more hydrogen, with a by-product of carbon dioxide.[130] However, POX is so carbon-intensive that the Committee on Climate Change did not consider it a viable potential means of producing hydrogen if climate objectives are to be met.[131]

Coal gasification accounts for 18 per cent of British produced hydrogen.[132] This process is similar to POX, where coal reacts with steam in the presence of oxygen under pressure and high temperatures, to create a gas of carbon monoxide and hydrogen.[133] The hydrogen is then stripped out of the synthesis gas, with the carbon monoxide being used (as above) to produce hydrogen molecules and carbon dioxide.[134] One paper, analysing the total carbon footprint associated with gasification of subbituminous coal and lignite – both types of coal – found that between 19.4 and 25.3 kilograms of carbon dioxide was emitted for every one kilogram of hydrogen produced via coal gasification.[135] The Committee on Climate Change works on an assumed emissions intensity of 675 grammes of carbon dioxide for each kilowatt hour of hydrogen produced via coal gasification.

Only around four per cent of all hydrogen is currently produced by a completely carbon neutral method, electrolysis via renewable electricity.[136] This is a process whereby an electric current is passed through two electrodes in a water solution, which breaks the chemical bonds of water molecules into hydrogen and oxygen.[137]

This disparity can be explained by a number of factors, but the most obvious is price. It has generally always been cheaper to produce hydrogen via fossil fuels rather than electrolysis due to the relatively higher cost of the electricity needed electrolyse water.[138] This may now be changing, as ever cheaper renewables come onto the grid, and the process of electrolysis undergoes refinement,[139] but the fact remains that the hydrogen economy has hitherto evolved around utilising fossil fuels as the primary feedstock.[140] The supply chains which have sprung up around this method also make electrolysis relatively more expensive, because it cannot benefit from the same economies of scale which grey hydrogen does.[141]

Once hydrogen has been produced – via whatever process – it can be fed into the economy. Indeed, there already a wide range of different applications for hydrogen, and it has been touted as a useful fuel for decarbonising other sectors too – from industrial processes, to cooking, and to heating.[142] For the purposes of this report, however, we will obviously focus on its potentially expanded role in powering transport.

Hydrogen-powered FCEVs and conventional BEVs are often pitted against each other as competing technologies. But in fact, they are better viewed as complementary. This is because the merits and demerits typically mirror each other, as Table 5 sets out.

Table 5. *Relative advantages and disadvantages of zero-emission fuel vehicle classes*

Vehicle type	Advantages	Disadvantages	Best suited for
Conventional BEV	• Slightly cheaper at present • More charging infrastructure at present	• Non-linear relationship between vehicle weight and battery weight • Longer charging times	• Smaller vehicles • Shorter journeys • Daily charging
Hydrogen-powered FCEV	• Shorter charging times • Linear relationship between vehicle weight and battery weight	• Slightly costlier at present • Less charging infrastructure at present	• Larger vehicles • Longer journeys • Irregular travel pattern

Source: Committee on Climate Change, "Hydrogen in a low-carbon economy".

This complementary nature of hydrogen-powered FCEVs and BEVs was clearly set out in a 2018 Committee on Climate Change report, which noted:

"While battery electric vehicles are now well placed to deliver the bulk of decarbonisation for cars and vans, hydrogen fuel cell vehicles could play an important role for heavy-duty vehicles (e.g. buses, trains and lorries) and potentially for longer-range journeys in lighter vehicles, where the need to store and carry large amounts of energy is greater."[143]

The key reasons for this are that while hydrogen tends to be more expensive, it has the following advantages:

- Greater energy density;
- Capacity for rapid refuelling;
- Seasonable durability.

Greater energy density. Hydrogen offers far greater energy density than other fuel types, including petrol and diesel. Compared to conventional batteries used in BEVs, hydrogen boasts higher specific energy – about 120 megajoules per kilogram, as opposed to about five megajoules per kilogram for present-day batteries.[144] This means that the engineers working on FCEVs do not need to adjust for a massively heavier power source, or indeed face the difficulties that BEV makers do in ensuring there is adequate space to store it onboard the vehicle.

At the higher end of the scale – principally HGVs, buses, and other heavy vehicle classes – this point becomes particularly pronounced, with battery packs accounting for perhaps two to three tonnes of weight per vehicle, or even more for trains or ships.

This greater energy density also means that hydrogen-powered FCEVs typically boast much greater ranges than BEVs, and are better at coping with more challenging terrain such as hills. Most FCEVs have ranges comparable to fossil-fuelled vehicles, with virtually all hydrogen FCEV cars able to comfortably do over 300 miles on a single tank, well ahead of comparable BEVs. In a submission to a House of Commons Science and Technology Select Committee inquiry into clean growth, the Royal Academy of Engineering and affiliated groups put it clearly: "As batteries have a relatively low power density and long charging time, battery electric heavy duty freight is unlikely to be feasible."[145]

Capacity for rapid refuelling. Hydrogen-powered FCEVs are remarkably similar to the conventional fossil-fuelled vehicles which most people will be familiar with. Hydrogen is pumped into the vehicle just as petrol or diesel would be, and stored onboard in pressurised tank. This tank connects to the fuel cell, in order to generate the electricity needed to provide propulsion and power to the vehicle. Refuelling at the pump can be done in minutes. Hydrogen is especially advantageous in terms of refuelling heavier vehicles, which if they had to rely on batteries could take several hours to go from flat to fully recharged. This facet of FCEVs means that they are extremely versatile, with owners seldom needing to consider whether or not they will have time in their schedule to recharge their vehicles between (or during) trips.

Seasonal durability. Anyone who has used a mobile phone in a cold climate will know that lower temperatures can impede battery performance. In the coldest weather, devices might not power up at all. BEVs are no exception to this phenomenon – their battery packs perform less well in low temperatures, with one paper showing that a drop in temperature from 5°C to -5°C can shave nearly 50 kilometres of range off one of the best-selling BEVs, the Renault ZOE.[146] Hydrogen-powered FCEVs are not impacted in the same way, and thus could be regarded as more reliable in countries which experience seasonal variability of this sort.

The obvious conclusion here is that if fossil-fuelled vehicles are to be replaced by zero-emission equivalents, the ideal technology will depend on what each individual vehicle is being used for.

For example, car journeys in England are on average only slightly more than eight miles. BEVs, therefore, should not struggle in handling the overwhelming majority of trips – especially when one takes into account the likely technological advances which will be made in terms of range and refuelling times.[147] A small family car driven by a suburban city-dweller who uses it to commute each day, or visit the supermarket at the weekend, living in a property that can accommodate the need for a regular overnight charge, would almost certainly be able to transition over to a conventional BEV – with only the occasional frustration over range and refuelling duration arising when heading to the countryside for a family holiday, for instance.

By contrast, battery power would be much less suitable for a lorry used as part of a small fleet to transport goods all across the country, including to rural areas, with no fixed pattern, by a medium-sized company which operates out of a small industrial estate with limited space on which to charge vehicles – and which wants to keep its vehicles on the road for as long as possible rather than having them spend hours charging in the depot. In such a case, an FCEV is probably going to be a far better option.

The current approach carries risks for certain vehicle classes

The official approach to decarbonising transport, pursued by successive administrations, has generally favoured electrification as the means to transition towards a zero-emission transport system.

There is good reason for this. Electrification, as has been explained, typically works well for personal cars and taxis. Given they are responsible for over three-fifths of greenhouse gas emissions associated with road transport,[148] it is perfectly reasonable that they command significant attention – and that, by extension, so too does electrification. In terms of air pollution, likewise, the problem is most acute in cities such as London, where shorter ranges are less of an issue.

As a result, many of the policies which have been relied upon to decarbonise road transport have taken electrification as the natural means to do so. The state, for instance, has long subsidised BEVs, through measures like the Plug-in Grant, which since 2011 has offered cash towards the cost of purchasing new models of fully or partly electric vehicles.[149] Table 6 gives an overview of the subsidies per vehicle class as of October 2018, when it was last updated.

Table 6. Plug-in Grant subsidies per vehicle class

Vehicle class	Carbon dioxide emissions	Zero-emission range	Grant	Maximum amount
Car	Less than 50 grammes per kilometre	70 miles	35 per cent	Up to £3,500
Motorcycle	No emissions	31 miles	20 per cent	Up to £1,500
Moped	No emissions	19 miles	20 per cent	Up to £1,500
Van	Less than 75 grammes per kilometre	10 miles	20 per cent	Up to £8,000
Taxi	Less than 50 grammes per kilometre	70 miles	20 per cent	Up to £7,500

Source: House of Commons Library, "Electric vehicles and infrastructure".

Other fiscal incentives, such as lower Vehicle Excise Duty payments for cleaner cars,[150] or Government-backed funds for installing charging points, also further subsidise BEVs,[151] as does the beneficial tax treatment of BEVs in various regards.[152]

Indeed, during our research, we came across a general acceptance that FCEVs had a part to play in the market, but also repeated anecdotal evidence of the Government implicitly favouring BEVs – even just in ministers' everyday rhetoric. Whether in speeches or statements to the House, there does seem to be a bias towards BEVs in official thinking. While the recent transport decarbonisation scoping paper contained much to admire, it was virtually silent on FCEVs, with hydrogen being referenced only a handful of times in the text.[153] If the new administration wants to distance itself from any allegations of 'picking winners' when it comes to industrial policy, giving technology pathways other than electrification a fairer hearing would be an obvious place to start.

As aforementioned, there is a reasonable degree of logic behind this implied 'bias'. The popularity of BEVs can be explained in large part because the technology they utilise was mature enough at the time it was needed, and works almost perfectly well for the hitherto fossil-fuelled journeys it has typically replaced – mostly short trips, made in personal cars.

While BEVs still account for a vanishingly small fraction of the overall national vehicle fleet, take-up is accelerating rapidly. The reasons why more people are shifting towards BEVs are multifarious. Certainly, steadily improving BEV technology has been a crucial variable. Each year, batteries enhance their capacity, and their ability to charge in ever shorter time periods, all the while becoming lighter and smaller. They are also now much cheaper – down 85 per cent compared to 2010, in terms of dollars per kilowatt hour. Owners, and prospective owners, of BEVs can now rely on over 31,000 connectors at over 11,000 charging point locations to refuel their vehicles – with the fastest types of charging points experiencing the largest share of growth in recent years.

It would be foolhardy not to expect further refinements in battery technology, and a greater proliferation of charging infrastructure going forward. This, doubtlessly, will only boost the attractiveness of BEVs.

However, the UK now finds itself at the stage where it must start to confront the issue of decarbonising all vehicle classes – including heavier duty vehicles like HGVs and buses. And there is a significant risk that relying on the electrification pathway which has broadly worked for personal cars may not be appropriate for those aforementioned heavier vehicles, or for other categories such as shipping and rail.

Even with profound technological advancements, BEVs cannot be relied upon to decarbonise every single vehicle which is currently powered by some sort of fossil fuel. As has already been discussed, batteries come up against certain limitations in certain vehicle classes – like buses and HGVs, not to mention trains and even shipping.

Weight is the primary barrier to using batteries to power the heaviest of vehicles, but other factors must be considered, too. HGVs and buses often work under tight time pressures and might not have the luxury to wait several hours after completing a long-distance journey, or even a medium-distance one, to recharge their batteries to full. FCEVs offer a particularly elegant solution here, as lorries and buses tend to operate on predictable routes which makes the coordination of refuelling infrastructure easier – simply by ensuring there is a supply of hydrogen fuel at the depots such vehicles make use of.[154] Even some vans might also do better to go down a hydrogen pathway as opposed to electrifying if they tend to be used for irregular or particularly challenging journeys – such as into rural areas with steeper terrain and where opportunities for charging are going to be diminished.

As should be fairly obvious, the issues around range, weight, durability, and refuelling are far less important for cars – particularly those which will be driven almost entirely on urban roads – than for an HGV or bus, which will generally be required to make long, near continuous journeys, with limited opportunities for refuelling stops.

Decarbonisation is not just about road transport

This report has principally looked at decarbonising road transport, on the grounds that this accounts for over nine-tenths of all greenhouse gas emissions in the sector.[155] That still, of course, leaves a small yet significant share of emissions stemming from other forms of transport – such as rail, shipping, and aviation. Moreover, this is, strictly speaking, an underestimate, since data on emissions seldom includes international transport – namely international aviation and shipping – because of difficulties in apportioning the emissions to any one country.

Relative to road transport, decarbonising these sectors is markedly more challenging. However, similarities also exist. Concerns about weight and refuelling times are as applicable for a cargo ship or an aeroplane as they are for a car, van, HGV or bus. Furthermore, companies are already beginning to test the viability of hydrogen fuel cells in such transport classes, akin to the work being done with hydrogen buses and other road vehicles.

Hydrogen trains

In 2017, rail contributed two million tonnes of carbon dioxide equivalent, an increase of three per cent on 1990 levels.[156] Rail in 2017 was also associated with 25,000 tonnes of NO_x emissions, 1,200 tonnes of PM_{10} emissions, and 1,200 tonnes of $PM_{2.5}$ emissions.[157]

Hydrogen fuel cells can also be used to power trains, with companies increasingly viewing hydrogen as an attractive way to decarbonise certain railway routes. The first commercial hydrogen-powered train began operations in 2018, in Germany.[158] Two trains, built by Alstom, run along a 62-mile route in northern Germany, and boast a range of about 600 miles.[159] Orders have been placed for 14 further trains for Lower Saxony by 2021, and 27 trains in Hessen shortly thereafter.[160]

Other countries are also preparing to welcome hydrogen trains to their railways. Alstom has completed testing of hydrogen trains in the Netherlands,[161] while other projects are in the pipeline in the United States, South Korea, France, and Japan.[162] In the UK, testing of hydrogen trains commenced in June 2019, as part of a collaboration between the University of Birmingham and Porterbrook, a rolling stock leasing company.[163]

The main benefit of hydrogen trains relative to electrified ones is that they do not require catenary power lines or electrified rails to operate, which can bring down infrastructure costs. It currently costs about £750,000 to £1 million to electrify a kilometre of track.[164]

On the busiest and fastest routes, where energy usage is highest and which can spread that cost out over a large number of passengers, electrification will probably make economic – and environmental – sense. But on quieter routes, such as rural stretches of rail, hydrogen trains might be the more cost-effective option.[165] Needless to say, hydrogen trains do still require some infrastructure of their own, namely a ready supply of hydrogen and refuelling infrastructure.

There may also be instances whereby hydrogen trains are the only possible means to decarbonise some routes. Certain lines might not have the space required to accommodate new overhead cables, thanks to tunnels or low bridges, rendering electrification an unviable option.

Alternatively, on routes which are already partially electrified, hydrogen could play a role on the railways by working in tandem with electrification on the same train. A 'bi-modal' train (one powered by both hydrogen and electricity) alternates between using power from the track or cables as a normal electric train would, but switches to drawing power from an onboard hydrogen fuel cell when required. Incidentally, the trains tested in the UK last year were bi-modal.

In February 2018, the then Transport Minister, Jo Johnson, called for the phasing out of all diesel-only trains by 2040.[166] This was followed by the convening of the Rail Industry Decarbonisation Taskforce, which in July 2019 presented a report which stated this ambition was perfectly feasible for passenger trains, although noted further work would be needed on freight.[167] For that to happen, however, hydrogen will need to play a role.

Hydrogen ships

Shipping is also a sector where hydrogen fuel cells could prove particularly helpful in terms of decarbonisation. In 2017, domestic shipping contributed 5.9 million tonnes of carbon dioxide equivalent to emissions, with international shipping contributing 7.8 million tonnes.[168] Combined, domestic and international shipping were responsible for 343,200 tonnes of NO_x emissions, 8,900 tonnes of PM_{10}, and 8,400 tonnes of $PM_{2.5}$.[169] Another air pollutant which is particularly pertinent to shipping is SO_2 – a toxic gas which causes numerous health conditions and other second-order environmental problems, like acid rain and biodiversity loss.[170] In 2017, shipping was responsible for 68,400 tonnes of SO_2 emissions, with domestic shipping alone accounting for 75 per cent of all transport-related SO_2 emissions.[171]

As with hydrogen-powered trains, hydrogen-powered ships are still in the early stages of their development. In December 2019, Japan launched the first ocean-going carrier ship powered by liquid hydrogen – albeit hydrogen produced from gasified brown coal in Australia.[172] In Norway, at least one company is piloting a hydrogen fuel system for large ships,[173] while the European Union is funding research into developing a hydrogen-powered 'utility vessel' to operate on the Rhône in France.[174]

Just as heavier road vehicles might not be able to transition quite so easily to electrification, so too will larger watercraft have significant problems. At the scale of a ferry or cargo ship, the weight of the batteries which would be needed to provide propulsion would be immense. This is because the energy density of batteries is so low relative to diesel fuel on a watt hours per kilogram basis. One rough estimate found that to electrify the heaviest of shipping vessels without any discernible addition of weight, batteries would need to increase their energy density tenfold compared to the current best examples.[175]

Hydrogen planes

At 918 million tonnes, aviation contributes about 2.4 per cent of global carbon dioxide emissions – more than most individual countries.[176] Planes also emit NO_x and soot, and create contrails, which as well as harming air quality, multiply the overall global warming effect of air travel.[177] As the world grows ever more prosperous, and international trade increases, aviation only looks set to increase its footprint – even with the disruption caused by the COVID-19 crisis.[178]

Aviation is perhaps the single most challenging sector to decarbonise, due to the sheer energy demands of launching an aircraft into the atmosphere (and then keeping it up there). But even here, innovative companies are pioneering solutions to reduce the environmental impact of flying. Throughout 2019, the UK and American start-up ZeroAvia successfully tested a hydrogen-fuelled powertrain in a six-seater light aircraft – and has designs on conducting a 300 nautical mile flight in Britain.[179]

IV. The economic implications – and opportunities

Hydrogen can help to decarbonise other elements of the economy

By using alternative fuels like hydrogen to clean up transport, the UK will ensure it is in better shape to meet its climate and air quality goals. Achieving these objectives will be hugely beneficial in their own right. But other environmental blessings could lie in wait if a flourishing hydrogen market for transport is created.

One of the key sectors where cuts to emissions need to be rapidly realised is heating, which accounted for an estimated 37 per cent of UK emissions in 2016.[180] As with transport, there is a debate as to whether sufficiently deep decarbonisation can be achieved via electrification alone.

Hydrogen, however, could play a role by replicating natural gas like for like – barring some infrastructure upgrades, not least the pipes which would need to be replaced in order to carry the gas.[181]

The main electricity-based technology to decarbonise heating is the air source heat pump, which may not always be suitable for the UK's particularly poor-quality housing stock, and also suffers from an unfamiliarity factor which could limit its acceptability among consumers.[182] As with electric vehicles, in other words, decarbonising heating will in all likelihood not be a case of Britain committing exclusively to one technology, but using both as appropriate.

Hydrogen can also be used to decarbonise industrial process which rely on high temperatures – like those which use furnaces or kilns.[183] Moreover, RenewableUK, a renewable energy trade association, note that hydrogen is regarded as one of the most economic ways to do so.[184] A recent paper from the Oxford Institute for Energy Studies explains how hydrogen furnaces could adeptly decarbonise processes like cement and steel making, which emit copious amounts of greenhouse gases per tonne of material they produce.[185] The same paper also notes how near-instant carbon savings could be achieved simply by using zero-carbon hydrogen, such as that which is produced via electrolysis, in the existing applications of industrial hydrogen use, which is generally derived from fossil fuels.[186]

Hydrogen could also bolster the case for the deployment of more renewables in the UK, such as new wind turbines or solar panels. When there is excess supply of electricity at any one time – perhaps due to unusually low demand, or unexpectedly high production – utilities sometimes instruct renewable generators to minimise power generation, or stop entirely.[187] This is to reduce what is known as 'transmission congestion' on the grid.[188] In the UK in 2017, curtailed power from wind production stood at around 1.5 terawatt hours – representing a sizeable wastage of electricity which otherwise could have gone to good use.[189] Electrolysers intuitively seem a good place to divert any renewably generated electricity, as hydrogen is a stable energy vector which can be stored and used later.[190]

However, these benefits can only be felt if there is an adequate infrastructure in the UK for producing, transporting and distributing hydrogen – as well as importing it from overseas if required. Currently, in contrast to BEVs, such an infrastructure is non-existent. Given the lead times involved, the groundwork needs to start being laid now in order to capture the benefits hydrogen offers in the future.

During our research, we heard repeatedly that the successful realisation of wider hydrogen deployment across the economy will be contingent to a large degree on hydrogen first being used in a select few sectors where it can be easily blended into current operations.

Transport is definitely one such sector, and discrete elements of it can be utilised as a 'bridgehead' for a hydrogen roll out at large. Buses and HGVs, for instance, could do a lot of the heavy lifting involved in bringing costs down, as those sectors scale-up demand for sustainable hydrogen, as well as providing parts of the infrastructure necessary to produce and supply it.

Hydrogen as an economic opportunity

Presently, the hydrogen economy is still comparatively very nascent. Worldwide demand for pure hydrogen stood at around 70 million tonnes in 2018,[191] which pales in comparison to demand for oil, which totalled around 4.6 billion tonnes.[192]

While some countries are definitely beginning to take a lead – such as Japan,[193] the United States,[194] Australia,[195] and the EU[196] – no single nation has a monopoly on hydrogen production, or the development and manufacture of vehicles or other equipment which will utilise it as a fuel source.

With swift and effective decision-making, the UK could easily stake out a strong position in supplying the global hydrogen market, or developing hydrogen-based technologies. This is not a case of 'picking winners' – it is very clear that this sector will be a major part of the British economy and others in the years to come. What is needed is for Government to act to bridge the gap between research and implementation, just as it did with other technologies such as wind turbines.

Indeed, the UK is blessed with favourable conditions to make truly sustainable hydrogen. Few other countries can rely on sites like the North Sea, which is not only very windy but is also relatively shallow.[197] This makes it easy to install the turbines which will eventually generate the electricity needed to electrolyse water into useful hydrogen.[198] As Britain necessarily reduces its reliance on the oil fields around its coast, offshore wind farms can be substituted in to deliver streams of zero-carbon electrons to either directly power homes and industry, or be put to use to produce hydrogen molecules to be fed into other applications.

It is also not completely irrelevant to note that by providing the conditions for a hydrogen industry to flourish in the UK, the country would be bolstering its energy sovereignty, too. Particularly from the perspective of fuelling transport, a portfolio of options – not simply relying entirely on batteries – could be especially wise. Home to 73 per cent of global lithium cell manufacturing capacity, China dominates battery manufacturing, and is also a leading producer of the elements commonly needed to make them.[199] As recent events with the COVID-19 crisis have only underscored, there is a sizeable risk in being overly dependent on an authoritarian superpower to provide critical parts for such an important sector as transport.

Capitalising on the economic opportunities which a thriving hydrogen sector offers would likely lead to an array of positive consequences for the nation. First and foremost, demand would be generated for high-skilled, high-paid jobs in the economy. Engineers would be needed to construct and maintain the necessary infrastructure to produce, transport, and store hydrogen, but employment opportunities would open up in numerous supply chains needed to support the sector – from providing raw materials, to service sector roles associated with distribution and administration.

One recent paper from the energy consultancy Element Energy estimated that using blue hydrogen to decarbonise British industry – covering sectors like steel and cement production, electrical equipment, textiles and other goods – could generate up to 42,800 jobs by 2050.[200] It is likely that demand for many of these jobs would still arise regardless of whether hydrogen is being produced in order to be used in domestic heating or transport, as well as industrial processes.

As the UK seeks to forge its own pathway in the international scene, hydrogen fuel and affiliated goods could be exported right across the world. While these might be regarded as desirable ends during normal times, the added impetus for a positive economic bounce-back is only heightened as the UK emerges from the COVID-19 lockdown.

And though the benefits of a growing market would be felt at a national level – and not least within the Treasury as tax revenues swell – there is good reason to think that such economic benefits would be particularly concentrated in areas of the country which have not shared in the prosperity seen in places like London and the South East in recent decades.

Much of what already exists of the hydrogen economy in the UK can be found in places the Government is now so keen to help 'level up'.[201] For instance, the HyDeploy project, which looks to seamlessly blend hydrogen into the existing gas network, is based in Keele, Staffordshire, and hopes to roll out further demonstrations in the North West and North East by the early 2020s.[202]

As mentioned, plenty of the renewable energy necessary to power the electrolysis to make green hydrogen could be captured off the coasts of Yorkshire, Lancashire, and North Wales[203] – while the manufacturing supply chains for the wind turbines needed to do so are already located in places like Hull.[204]

In terms of developing and assembling the vehicles which would ultimately consume the sustainably produced hydrogen, regions like the North East and West Midlands have a long-established pedigree in automotive manufacturing, and could doubtlessly transition to producing FCEVs just as adeptly as they have for BEVs.[205]

The benefits of cleaner air and fewer greenhouse gas emissions should be convincing enough justifications as any for a government to seek to foster a flourishing zero-emissions vehicle sector – underpinned by electrification and alternative fuels such as green hydrogen. But economic arguments cannot and should not be ignored either.

The Government ought to regard the transition to a sustainable transport system not as an economic burden but an economic opportunity. It should recognise that measures taken today could result in the UK being a market leader tomorrow – delivering jobs, exports, and growth. To its credit, the Government has stated formally that it has an aim "to put the UK at the forefront of the design and manufacturing of zero emission vehicles".[206]

As mentioned above, this is not to reheat the tired and fundamentally flawed argument for state planned industrial strategies – but rather to say that certain sectors will almost certainly be critical pillars of the future global economy, and that the UK Government should do what it can to help its own economy play a commanding role in them.

Zero-emissions vehicles, and the sustainable fuels which power them, will unquestionably fall into that category. As a matter of urgency, the Government should map out how, while still remaining faithful to free market orthodoxies, it can help UK business capitalise on those opportunities which lie in wait.

How scale and innovation can cut the costs of hydrogen

The main reason why we have not witnessed a wider roll out of FCEVs is that they have typically been more expensive to manufacture than fossil fuelled vehicles. Yet, to presume this will persist in perpetuity is blind to reality, and the experience of other green innovations of late.

Within the bus market, costs are already tumbling at a rapid rate. In 2019, for instance, the manufacturer Wrightbus sold 15 hydrogen-powered double decker buses at around £500,000 apiece to First Aberdeen – yet new cost figures which we have seen indicate they could now sell similar buses for around ten per cent less, and less still with additional volume.[207] For single decker models, the price is naturally even lower – which compares favourably to equivalent battery electric buses.[208]

It is not just about vehicles and the fuel cells which will power them, however, but fuel costs too. A report in January 2020 from McKinsey predicted that the cost of low-carbon and or renewable hydrogen production will fall by up to 60 per cent over the coming decade.[209]

This is not a new problem. Renewables have long been seen as expensive additions in the energy system – as things which we pay a premium for in order to avoid the negative externalities associated with fossil-fuelled power generation. But that is no longer necessarily the case. Costs for different renewables have plummeted around the world – with solar photovoltaics (solar PV) being a particularly good example. According to the International Renewable Energy Agency (IRENA), the global weighted average levelized cost of energy from solar PV has fell by 77 per cent between 2010 and 2018.

This fall in cost can be explained by many things. Firstly, and perhaps most obviously, is how the price per individual module of solar PV has plummeted. Since the end of 2009, IRENA estimate that module prices have fallen by 90 per cent – with the pace of reductions rapidly increasing in recent years. Secondly, the costs associated with installing solar PV have also fallen, owing to industry learning, as have those with operation and maintenance.

These cost reductions in themselves can be explained by a number of causal variables. But two reasons stand out in particular. First, the enormous and growing scale at which solar PV modules are deployed at each year mean that fixed costs can be spread over a greater amount of energy produced. This phenomenon – 'economies of scale' – is nothing new, and holds true in many facts of business and indeed life. When factories are churning out more and more modules, the average marginal cost per module decreases. Similarly, installation costs fall when spread out over more units, as has been the case recently – in 2000, there were 1.8 gigawatts of installed solar PV in the world, while in 2018 alone, 94 gigawatts of additional solar PV were installed.

Second, solar PV is itself getting better. A module installed today will likely produce more useful electrical energy per meter squared than, say, one installed ten years ago. This stems from the cumulative learning which goes on in terms of research and development (R&D) carried out each year in corporations and research institutes involved in developing solar PV. That gradual technological refinement quickly adds up. In the world of solar PV, for instance, it is not uncommon to talk about first, second, and now third generation technologies, the latest of which are epitomised by highly productive solar cells which could deliver efficiencies twice or thrice that of existing modules.

Of course, learning is not just contained to the production of the solar PV modules. Understanding of, for instance, where best to site modules to ensure they capture as much solar radiation is equally getting better, as are techniques in installing and maintaining them.

As noted, such falls in costs have been observed in other renewable forms of energy generation as they too have scaled up in terms of gigawatts of energy generated. The global weighted average levelized cost of energy of onshore wind projects commissioned in 2018 was 35 per cent lower than those in 2010, while costs of offshore wind fell by 20 per cent fall over the same time frame.

There should be few reasons to believe that sustainably produced hydrogen will not witness the same falls in price if it is able to occupy a larger share of the UK's – and indeed world's – energy needs.

First of all, green hydrogen is produced via renewably sourced electricity – like that generated by solar PV or wind turbines – which, as evidenced above, are already tumbling in price. These cost reductions will naturally make electrolysis less expensive as time goes by.

Moreover, much as how solar PV technology has been refined over the years, moving from first to third generation solar cells, so too has electrolysis. Scientists have experimented with electrolysers to improve them in various ways, such as coating the electrodes with new elements like copper to aid efficiency.

Lastly, the deployment of hydrogen at scale should bring down other costs which are incurred with its supply – be that in the form of refuelling stations or other associated infrastructure and equipment needed to get the hydrogen produced in an electrolyser into a bus or HGV.

In short, the price gap between hydrogen and other options is set to narrow in the coming years, and to do so dramatically if solar photovoltaics, offshore wind and other technologies offer any precedent. In doing so, it will open up a substantial global market – one in which Britain ought to be a major player.

IV. Policy recommendations

Tackling the twin threats of climate change and air pollution, and meeting the Government's legal commitments in both areas, requires a shift toward cleaner vehicles. Barring a series of miraculous technological breakthroughs – admittedly not impossible, but unlikely at the speed required, and certainly too risky a chance to bet on – government at all levels will need to facilitate and incentivise that shift by setting and enforcing sufficiently ambitious targets and regulations.

Fundamentally, both climate change and poor air quality are market failures writ large. Polluters do not have to bear the full costs of their actions, yet they can still reap the full rewards. As such, a greater quantity of greenhouse gases and air pollutants are released into the atmosphere than is socially optimal. It is therefore legitimate for government to step in and intervene in such instances, caveated with the provisos that it does so in a proportional and considered manner – and with an acute regard to the economic costs it is imposing on businesses and consumers alike.

In the case of decarbonising transport in the UK, this means not only continuing to focus on the technological solutions that are currently on offer, but also introducing judicious policy changes. In particular, there is a need for greater focus on areas where technological solutions are struggling – which is evidently the case for large, heavier vehicles, as opposed to the personal car market, where advances have been, and look set to be, relatively quickly forthcoming.

With that in mind, we argue that the imminent Transport Decarbonisation Plan, and the Government's wider strategy, should follow four key principles:

- **Commit to ambitious targets for clean air, in order to incentivise cleaner travel and new technologies** – for example by confirming a ceiling for damaging particulate matter in line with World Health Organisation guidelines, and supporting local authorities to establish and expand Clean Air Zones.
- **Introduce a target for a zero-emission bus fleet by 2038, accompanied by appropriate incentives** – both in order to drive decarbonisation and to help establish a test bed for zero-emission heavy vehicle technologies. Given the absence of consumer pressure in the market, such a shift will have to be incentivised by Government. As part of this, the Bus Service Operators Grant should be reformed from a 'fuel used' model to a 'distance travelled' one, with incentives tilted towards low- or zero-carbon buses.
- **Develop distinct strategies for decarbonising LGVs, HGVs, shipping, rail and aviation** – at the moment, the progress being made by the car sector is covering up more serious failures in the rest of the transport network. Strategies should be produced to evaluate not only how to transition the various forms of freight towards zero-emission vehicles, in particular those powered by hydrogen, but how to clean up existing fleets, for example via retrofitting or scrappage schemes.

- **Ensure that Britain develops adequate hydrogen infrastructure and a comprehensive hydrogen strategy** – and that hydrogen technologies are included as part of the Conservative Party manifesto commitment towards investing in research and development and clean energy. As a starting point, the Renewable Transport Fuel Obligation should be amended in order to better support the production of hydrogen fuel, not least by phasing out support for those biofuels which may have little or even a negative impact on overall carbon emissions. The Government should also establish a proper UK-wide hydrogen strategy and a cross-departmental working group on the issue, as other countries have done.

In the rest of this section, we will examine some specific policy measures which would help meet those goals.

1. **Confirm a sufficiently ambitious target for $PM_{2.5}$ in line with World Health Organisation guidelines.**

The Environment Bill was introduced to Parliament in October 2019, and was reintroduced in January 2020, following the Conservative Party's general election victory.[210] It is a wide-ranging piece of legislation, covering as diverse a set of issues as resource and waste management, nature restoration, chemicals regulations, and, importantly for the purposes of this report, air quality.[211] Critically, a lot of what it handles relates to responsibilities which have been repatriated to the UK since the country's formal departure from the EU earlier this year.[212]

As it currently stands, the Environment Bill commits the Government to the establishment of a binding ceiling target for $PM_{2.5}$.[213] However, it does not state at what level that target should be.[214] Prior to the publication of the Environment Bill, there was a widespread hope among many environmental and health groups that a firm target would be set as part of the draft legislation – as opposed to simply a requirement to set a target (as is presently the case).[215] Indeed, in a speech made last year, the then Environment Secretary, Michael Gove, asserted that "[w]e have got to ensure our Environment Bill includes a legally binding commitment on particulate matter".[216]

$PM_{2.5}$, as has already been discussed, is particularly prejudicial to human health. The Environment Bill should therefore be amended to ensure that a target for $PM_{2.5}$ is included in the Bill when it receives Royal assent. Failure to do so would lead to uncertainty for businesses, while also potentially increasing public exposure to $PM_{2.5}$ for many years longer than necessary. Given Michael Gove's speech argued that the legally binding commitment should ensure "that no part of the country exceeds the levels recommended by the World Health Organisation (WHO)", adopting the WHO guidelines would be an obvious starting point – while representing a significant toughening of the rules compared to current EU policy.[217]

Alongside a target for $PM_{2.5}$, the Government will need to select a date by which is should be met. This can be set via secondary legislation, and should be designed to be stretching, achievable, but not overly economically damaging. In July 2019, the Department for Environment, Food and Rural Affairs published a document which found that achieving the WHO target for $PM_{2.5}$ would be technically feasible, but that further analysis would be required to determine appropriate timescales and economic impacts.[218] Such analysis should be brought forward, based on comprehensive expert advice.

To ensure that this new target is taken seriously, the Environment Secretary of the day should be accountable to Parliament for explaining how the country is meeting its air quality objectives, or what plans it has to improve if performance is lagging. The soon to be established Office for Environmental Protection should be afforded the requisite powers and independence to monitor any plans to achieve compliance with a new target for $PM_{2.5}$ – and indeed any other air pollutant – in the same way that the Committee on Climate Change scrutinises decarbonisation efforts.[219] Needless to say, this would require the new Office for Environmental Protection to be up and running by the time the Brexit transition period ends.

Prima facie, the setting of a new, and indeed stricter, regulation might contradict our laissez faire instincts. Yet not all regulations are created equal, and in the case of many environmental regulations – where there is a clear and apparent justification for action on the grounds of public health – those in the classical liberal tradition should welcome proportionate regulation to combat genuine instances of public goods violations. As Murray Rothbard wrote on the subject of air pollution:

> "[D]enial of the very existence of the problem is to deny science itself and to give a vital hostage to the leftist charge that defenders of capitalism 'place property rights above human rights'. Moreover, a defence of air pollution does not even defend property rights; on the contrary it puts [a] stamp of approval on those industrialists who are trampling upon the property rights of the mass of citizenry."[220]

In the case of emissions regulations, they are clearly justifiable on a public goods rationale so long as they are proportionate and evidence-based, as these would be.

2 Support local authorities to establish and expand Clean Air Zones to improve air quality in their jurisdictions.

Clean Air Zones (CAZs) are legal or voluntary frameworks which seek to improve air quality in a given area.[221] CAZs fall into two categories – charging and non-charging, which stipulate whether or not a CAZ will charge certain motorists a fee for driving into a CAZ or not.[222] For charging CAZs, further sub-categorisation applies, based upon what types of vehicle fall in scope of its charges.[223] These range from Class A zones (which cover buses, coaches, taxis and private hire vehicles) to Class D zones (which cover all of the aforementioned vehicles, plus HGVs, LGVs and ordinary passenger cars).[224]

One CAZ already exists in England, in the form of London's Ultra Low Emission Zone (ULEZ). Introduced in 2019, London's ULEZ currently covers much of the centre of the capital, and will extend to the North and South Circular by October 25, 2021.[225] Cars, motorcycles and vans which are not compliant with the ULEZ's minimum emissions standards will be charged £12.50 per day to drive in the ULEZ (on top of the existing Congestion Charge), while heavier vehicles like buses and lorries will be liable for a £100 daily charge.[226]

Other areas were due to introduce CAZs either this year, however owing to the COVID-19 pandemic these will, understandably, now be postponed until 2021 or later.[227] When they do come into force, they will be a mixture of charging and non-charging CAZs. Cities including Birmingham, Bristol, and Greater Manchester will introduce charging CAZs,[228] while Southampton will introduce a non-charging CAZ.[229]

According to the Government's own advice, CAZs are the most effective lever to drive compliance on existing air quality targets.[230] In London, evidence suggests the ULEZ has been remarkably successful – cutting roadside NO_2 concentrations by over a third and reducing the number of highly polluting vehicles driving into the ULEZ each day by 13,500.[231]

CAZs – especially the charging variety – help address not only dangerously high levels of air pollution and excessive greenhouse gas emissions, but other social problems, such as noise pollution and congestion. Proponents of free market economics ought not have any problem with the 'polluter pays' principle, which charging CAZs embody, using the price system to allocate scarce resources, or the notion of essentially privatising state owned assets.[232] Charging CAZs could even be used as the kernel of a system of full-blooded road pricing, the quid pro quo for which would be the abolition of other motoring taxes, such as fuel duty. This method of taxation would be more environmentally friendly, economically rational, socially equitable, and ensure that the Treasury generates the revenues necessary for maintaining existing road infrastructure.

For the purpose of this report, however, the importance of CAZs is that they incentivise the decarbonisation of transport, as those vehicles that have to enter city centres will need to be cleaner to avoid paying costly charges. However, during our research, we heard that local authorities often struggle to understand how best to implement CAZs, or run into difficulties when trying do so.

Historically, central government has delegated considerable responsibility to local authorities with regards to establishing CAZs, without simultaneously providing adequate support structures – such as legal advice or technical know-how. During our research, we found there was a general feeling of central government playing a rather inconspicuous, or even at times obstinate role in introducing CAZs. Going forward, a more cooperative relationship needs to be struck between central government and any local authorities who are implementing, or wish to implement, CAZs.

Establishing CAZs may require central government to provide upfront funding for the required infrastructure (cameras, signage and road markings), plus other costs associated with their introduction, such as public awareness campaigns. Preferably, this could be found by rationalising any current schemes or subsidies aimed at ameliorating air quality which the CAZs should render unnecessary – or, at least, less necessary. Or the Government may just accept that paying some money now could be prudent in the long run if it means tackling a genuine public bad.

To bolster the case for local authorities to implement expanded CAZs, the Government could tie various funding streams to their adoption – such as the Air Quality Grant, which since 1997 has disbursed over £64 million to local councils for air quality improvement measures.[233] Targeting the existing funding for low- and zero-carbon transport infrastructure, which allows individuals to switch away from high-carbon transport, would likely neuter much opposition to CAZs, which is often based upon arguments around lack of alternative transport provision. Of course, other funding arrangements could also be explored, such as central government providing loans to local and combined authorities, which are then paid back over time via the proceeds of revenues generated by charging CAZs.

3 Set a target for a zero-emission bus fleet by 2038.

To help realise the achievement of WHO standards for $PM_{2.5}$, and the implementation of enhanced CAZs, the

Government needs to support the shift toward a zero-emissions bus fleet.

According to the Department for Environment, Food and Rural Affairs, emissions from buses are proportionally higher in many urban areas – typically because so many still run on polluting diesel fuel.[234] The Government has currently proposed that by 2035 there will be no new cars and vans sold that are not zero-emission vehicles. This shift is already underway in the UK car market, but it has not really begun for larger vehicles like buses.

If the Government is going to impose such bans, there is actually a stronger case for doing so with buses than cars. That is because the state is much more heavily involved in dictating the composition of the market: the tool of 'consumer pressure' cannot be relied upon to the same degree to help nudge bus markets towards more sustainable outcomes. While many consumers are signalling through the price mechanism that they have less desire to purchase fossil-fuelled cars, it is not the passengers who make decisions about the kind of buses they are using. The idea, for instance, that someone would refuse to board a bus because it still ran on diesel fuel is preposterous.

We therefore propose that the Government should set out annual targets for a market share of buses to be zero-emission, whereby 100 per cent of buses driving on British roads are zero-emission by 2038. In terms of what would be feasible yet demanding interim targets, this is something which the Government should explore in more depth working along bus operators who will have the best understanding of their vehicle stock, among other things. However, a starting point would be to aim for 50 per cent of buses being zero-emission by 2030.

It is important to note that when setting these targets, the Government should be agnostic in terms of what fuels those zero-emission buses will eventually make use of. Whether the pathway is electrification or hydrogen should be of secondary concern: the operative focus should be to get buses down to zero-emissions.

But when should the cut-off date be, if reaching Net Zero by 2050 is the aim?

Already, bus operators represented by the Confederation for Passenger Transport – whose members account for 95 per cent of the British bus fleet – have pledged to purchase only zero-emission or next generation ultra-low emission buses from 2025 (and 2023 in some urban areas). This gives us a good starting point and the confidence that a potentially early target could be set.

Currently, most buses are removed from service after around 12 to 14 years. Data from Transport for London, where roughly a quarter of buses in Great Britain can be found, show that of buses registered prior to 2019, less than two per cent have been in operation for over 12 years, and just 0.3 per cent for over 15 years.

In theory, therefore, a date to have zero-emissions buses could be set as early as 2032 without artificially retiring many buses much earlier than they otherwise would have been. However, this would assume that bus lifespans will mirror those which went before, and this is unlikely. For myriad factors, more modern vehicles tend to last longer, and this increases the average retirement age. Moreover, BEVs and FCEVs, which do without complicated and error-prone internal combustion engines, typically require less maintenance, and so that too could boost average lifespans.

In addition, bus manufacturers and operators will doubtlessly need time to readjust production lines among other things in order to respond to the new regulatory landscape. Some technological refinement may also need to happen to ensure zero-emission buses can tackle virtually all existing routes – and not leave, for instance, rural communities isolated. It is only right that these concerns are taken into consideration when setting a phase out date.

We suggest setting a target date of 2038 for the phasing out of petrol and diesel buses. Under this timeframe, a bus which rolled off a production line today would have around 18 years before being required to be retired. We are confident that the cut-off date we propose is a sensible compromise between requiring action to be taken for environmental reasons, while remaining cognisant of average expected bus lifespans, and the needs of bus operators and manufacturers. It also fits with the existing voluntary commitments made by bus manufacturers.

This target is also both achievable and affordable. In 2018/19, there were 33,900 buses in operation in England.[235] If the transition to zero-emission buses commenced immediately, that would mean switching an average of 1,883 buses to zero-emission models each year for 18 years. In fact, the number would actually be less, given some zero-emission buses are already in operation, and it should be noted that in any case, zero-emission buses will quite organically occupy a larger share of the national bus fleet as operators purchase them at increasing scale.

By setting out a position with a fixed overall date for the phase out of fossil-fuelled buses, and sub-targets acting as progress staging posts, the Government will provide certainty and clarity for what the bus sector can expect in the future. It will provide impetus for zero-emission buses to be built by manufacturers, and to be bought by operators. It should also incentivise investment in research on zero-emission technologies. Indeed, the positive effects of having a clear idea of what the regulatory landscape will look like in the near- to medium-term have certainly been seen in the personal car market, as well as other sectors of the sustainable economy, such as wind turbines and solar photovoltaics.

Such policy assurances will help to stimulate the market and drive costs down further, as zero-emission buses and associated infrastructure are developed at scale – spreading electric vehicle adoption not just for buses, but for other heavyweight transport classes.

4 Reform the Bus Service Operators Grant from a 'fuel used' model to a 'distance travelled' one.

To accompany the target of having only zero-emission buses on British roads by 2038, the Government should also consider how it can better support the adoption such vehicles. Even small tweaks to existing policies could tip the balance in favour of zero-emission vehicles – incentivising operators to invest in them.

The Bus Service Operators Grant (BSOG) is a government subsidy to make bus travel cheaper than it would be under true market conditions. Each year, the Department for Transport gives approximately £251 million to local authorities and bus service operators in grants.[236] BSOG payments are based on the volume of fuel consumed by bus operators – allocating 34.57 pence per litre of diesel or biofuel fuel consumed,[237] 32.66 pence per litre of unleaded petrol, and 18.8 pence per kilogram of natural gas or other road fuel gas.[238] Certified low-carbon operators can also claim an additional six pence per kilometre travelled.[239]

Doubtlessly, the BSOG helps in incentivising bus travel, and lowers carbon emissions and air pollution by reducing the necessity for private car travel, all other things being equal. However, there is good reason to believe a reformed BSOG could deliver better value for money, and be a more effective tool in decarbonising bus fleets.

As the BSOG is largely paid in accordance with the amount of fuel a bus uses, it fundamentally incentivises fuel consumption before all else. However, if the purpose of the BSOG is to increase bus services above what they would be under actual market conditions, there are surely better variables to try and incentivise. A BSOG which incentivises distance travelled would be a much more sensible end to encourage.

If the Government is to continue subsiding bus travel through the BSOG, officials within the Department for Transport should model changing from a consumption-based subsidy to a distance-based subsidy. They would need to calculate at what level that should be set (on a per kilometre measure), so as not to lead to a reduction in the current provision of bus services.

In addition, civil servants should look to reform how the BSOG rewards low-carbon buses. As mentioned, low-carbon buses can currently claim six pence per kilometre driven. There could be an argument to increase this, so as to further incentivise the uptake of cleaner buses. In order to limit the costs of doing so, this could be funded by better apportioning the overall envelope of BSOG support – with a higher proportion going towards rewarding distance travelled by low-carbon buses, and a lower proportion towards the quantity of fuel consumed by all buses (which, of course, we would hope to see changed to a distance-based model itself).

Other reforms could include reviewing what qualifies as a low-emissions bus which is liable for the additional payment, potentially moving one day towards a system which only subsidises zero-emission buses rather than ULEVs. To its credit, the Government did in 2018 state that it "remain[s] committed to reforming BSOG, to bring it up to date".[240] The ideas outlined here could help the Government make good on that commitment.

5. **Reform the RTFO rules to better support the production of hydrogen gas.**

The Renewable Transport Fuel Obligation (RFTO) mandates that significant suppliers of transport and non-road mobile machinery fuel (those dispensing more than 450,000 litres a year or equivalent) must ensure a certain proportion comes from renewable or sustainable sources.[241]

Under the RTFO, companies which supply qualifying renewable fuels receive Renewable Transport Fuel Certificates (RTFCs).[242] Fuel suppliers which are subject to the RTFO are accordingly required to redeem a certain number of RTFCs in proportion to the volume of non-renewable fuels they supply.[243] The RTFO is a key plank of the Government's overall strategy for transport decarbonisation, with the current objective for the proportion of fuel to reach 12.4 per cent by 2032.[244]

From January 1, 2019, the Government has had a target for 'development fuels' under the RTFO.[245] These development fuels are fuels made from either certain sustainable waste products or residues, or a renewable fuel of non-biological origin (RFNBO).[246] According the Government itself, the simplest RFNBO is renewable hydrogen, for example hydrogen which is made from wind or solar powered electrolysis.[247] The Government wishes to incentivise the production of development fuels because they deem them to be part of "the UK's long term strategic needs".[248] Accordingly, development fuels attract double the number of RTFCs per unit supplied.

Just as the Government has targets for increasing the supply of renewable transport fuels altogether, it also has specific sub-targets for the share of which the total fuel supply comprises of development fuels. For 2020, this stands at 0.075 per cent, with an intention for supply to gradually increase year on year, until it stands at 1.4 per cent of total supply in 2032.[249]

The Government should closely monitor progress towards the achievement of these targets, and not be afraid to amend regulations which support the supply of development fuels if it appears that a target will not be hit. An obvious starting point, for instance, would be to increase the multiplier awarded for the production of development fuels above its current rate of two.

Other modifications could also be made to current RTFO rules which ensure that it is as sustainable as possible, while also supporting genuinely environmentally friendly methods of renewable energy generation. A perennially contentious issue with biofuels is that some of them deliver only marginal environmental benefits, and may even increase net greenhouse gas emissions.[250] So called ‘first generation’ biofuels – such as bioethanol made from cereals or root crops – have been criticised on the basis that they compete with food production.[251] Biofuels of this sort, therefore, necessitate more agriculture than the case was previously, which can harm the environment.[252] This can be particularly unhelpful with regards to greenhouse gas emissions when it leads to the conversion of previously uncultivated carbon sinks like woodlands or grasslands.[253]

There are already some limitations around how biofuels are treated under the RTFO. In 2017, the Government introduced a ‘crop cap’, which curbs the amount of renewable fuel which can come from crop-based sources.[254] This was initially set at four per cent, and under current plans will slowly fall to two per cent by 2032.[255]

Owing to the potentially damaging consequences of first-generation biofuels, the Government should also consider setting a future target to eliminate their contribution to the RTFO entirely. This would signal to current biofuel producers that they cannot rely on them being a permanent feature of the transport fuel market, as well as incentivising production of second and third generation biofuels which are demonstrably better for the environment.

In doing so, the Government should acknowledge that biofuel producers have invested considerable sums of money in plants and machinery which use crop feedstocks, and also that first-generation biofuels serve as a necessary stepping stone towards developing more advanced biofuels. The Government should therefore work with the biofuel industry on mapping out a sensible schedule for the phasing out of first-generation biofuels from the RTFO – ensuring that the RTFO only supports truly sustainable fuel sources which make a meaningful and positive impact on reducing greenhouse gas emissions.

6 **Establish a cross-departmental Hydrogen Working Group and produce a UK-wide hydrogen strategy for the UK ahead of COP26.**

This report has largely limited its focus to the role of hydrogen in the transport system, especially in terms of the decarbonisation of heavy transport. But that is not to say that hydrogen will not be useful in other sectors. We have already touched upon how hydrogen could replace natural gas for domestic heating and cooking, or decarbonise various industrial processes. Moreover, this report has also illuminated how hydrogen offers not only savings in greenhouse gas emissions, but could improve air quality, too.

Yet precisely by virtue of being a technology with such a wide range of potential applications and benefits, hydrogen does not have a natural department to champion its cause. One could reasonably argue that any of the Department for Transport, the Department for Business, Energy and Industrial Strategy, the Ministry for Housing, Communities and Local Government, or the Department for Environment, Food and Rural Affairs could or should take the lead on hydrogen policy in the UK.

In truth, it is perhaps most prudent for all of the above to play a role. To ensure that the UK has a joined-up policy on hydrogen, the Government should establish a civil service working group drawn from all of the aforementioned departments. If any department were needed to head the working group, the Department of Business, Energy and Industrial Strategy would likely be the best candidate, overseen by the Minister of State for Business, Energy and Clean Growth.

Once the working group is convened, it should set about producing a hydrogen strategy which identifies policy obstacles to wider hydrogen proliferation – be that planning or health and safety regulations, or how hydrogen is treated relative to other zero-carbon fuels in government decision making – and make recommendations on how best to eliminate these where it may be judicious to do so. It should aim to ensure not that hydrogen is privileged above other alternatives, but that sustainable hydrogen is given a fair hearing where relevant in policymaking going forward. It was striking, for example, that the recent proposal to create Britain's first all-electric bus town was restricted solely to BEVs. Here, a robust hydrogen working group might have advocated instead for a 'zero-emission bus town', which could draw upon the advantages of both hydrogen and electric buses, and would surely have been a more rational way to model the scheme. It could also contribute to the thinking around the idea of piloting a zero-emission city, in which the costs and challenges of moving the entire local transport network to zero emissions could be evaluated.

A key area which the strategy should also examine is around where hydrogen applications in industry can be tied to a further roll out in transport, and vice versa as the technology naturally scales up. One of the biggest challenges with hydrogen, and one which adds significantly to its cost, is the infrastructure needed in storage and supply – so if some degree of coordination could be achieved between domestic, industrial and transport uses of hydrogen, it could deliver a significant spur to hydrogen deployment.

Prior to the COVID-19 outbreak, the UK was due to co-host the 26th United Nations Climate Change Conference – COP26 – in November 2020.[256] The summit will now take place in 2021, and will draw the attention of diplomats, heads of state, key private sector decision makers, civil society. The run-up to COP26 should therefore serve as the ideal time to publish the findings of the hydrogen strategy, as well as showcase British hydrogen technologies and manufacturing skills to global companies and governments that are seeking practical solutions for their own decarbonisation goals.

The policy of having a hydrogen strategy, and accompanying units within government to advance it, is nothing novel. Other countries around the world already have hydrogen strategies of their own, many of which aim at exactly what has been stated above – namely, the coordination of hydrogen deployment across various different, and not necessarily always obviously connected, parts of the economy.

In Australia, for instance, there is the Hydrogen Working Group, chaired by the chief scientist. Convened in December 2018, it has an explicit objective of focusing "on actions that remove market barriers, efficiently build supply and demand, and accelerate [Australian hydrogen's] global cost-competitiveness".[257] Moreover, a "key element" of the Australian strategy is to understand how geographical hydrogen hubs or clusters could "promote synergies from sector coupling", whereby applications like hydrogen in transport, heating and industry are made easier by a unified approach to hydrogen deployment.[258]

The Australian government, however, is not alone in taking a forward-thinking approach. Other countries, like South Korea,[259] China,[260] Japan,[261] and Germany have published similar strategies or statements of intent about how they plan to integrate hydrogen into their future economies.[262] The Scottish Government has similarly made hydrogen a focus of its industrial and environmental thinking. The wider UK should follow their lead to ensure it is equally well-placed to capture the economic and environmental benefits of green hydrogen, by removing barriers to facilitate its wider deployment in the economy.

7. **Develop a distinct strategy for cleaning up HGVs and LGVs, as well as other sectors such as rail and shipping.**

Part of the reason that we have argued strongly for a rejuvenated strategy for decarbonising buses, as set out above, is that bus decarbonisation can be what spurs the market for zero-emission HGVs and LGVs – markets which are far from maturation at present.

Using buses as a test bed will help in not only refining zero-emissions technologies involved in powering heavier vehicles in the first place, but also in terms of installing (and further refining) the necessary infrastructure associated with zero-emissions vehicles – whether that be new electric charge points, or hydrogen refuelling stations.

But the Government must also act to improve the long-term take up of zero-emission HGVs and LGVs, as well as other transport classes discussed above – as well as making existing models cleaner.

The Government should start by having the Department for Transport consult on the drafting of a distinct HGV and LGV strategy, given the current failure to move away from conventional internal combustion engines for these vehicle classes, with separate projects examining rail, shipping and aviation to follow later.

At present, the reasonable progress being made by the car sector toward low- and zero-emission vehicles is covering up a much more serious failure around the rest of the transport network – something clearly evidenced by Chart 4. A thorough and comprehensive strategy for decarbonising HGVs and LGVs will should also help to focus minds in the sector about getting to a situation where such vehicle classes are fully decarbonised by the date of the Net Zero target.

A good place to start here would be to issue a green paper and launch a public consultation specifically on how to shift freight vehicles towards Net Zero greenhouse gas emissions by 2050. It should make suggestions around target dates for fossil fuel phase-outs of HGVs and LGVs, as well as on other relevant issues – like how to fund the infrastructure which will likely be necessary to facilitate the transition towards zero-emission vehicles. As before, it should be acutely sensitive to the economic costs being imposed, and to ensuring that the roadmap it sets out is affordable as well as achievable.

The green paper should also consult on how best to clean up the existing HGV and LGV fleet of nearly 4.8 million vehicles – surveying opinions on measures which could be introduced to reduce the pollution emitted by HGVs and LGVs immediately, such as through retrofitting programmes or scrappage schemes.[263]

Part of the reason why uptake of zero-emission HGVs and LGVs has been so slow to date is because of the limited range of models on the market, especially for the heaviest vehicle classes. In light of this, the Government should consider how the regulatory landscape for R&D can be amended to stimulate research into innovative solutions to help address key hurdles in decarbonising HGVs and LGVs.

R&D on improving zero-emission powertrains should be prioritised – whether that is those based upon electrification or via alternatives like hydrogen fuel cells – but other technologies should not be overlooked, like integrating smart telematics,[264] electronic driver aids and automation,[265] aerodynamics,[266] or other inventions which may come to fruition which cut vehicle emissions overall.[267]

Already, the new Government has put a renewed focus on boosting the UK's investment into R&D – not least by setting out plans in the recent Budget to raise public R&D investment to £22 billion per annum by 2024-25, increasing the rate of the Research and Development Expenditure Credit from 12 per cent to 13 per cent, and scoping out an ultimate target of increasing R&D spend as a percentage of GDP to 2.4 per cent by 2027.[268]

This redoubling of attention on innovation is certainly welcome, and should help drive genuine long-term growth in the economy.[269] As part of this expansion in public investment into R&D, the Government should ensure projects which seek to deliver pure public goods, like cleaner air or a more stable climate, are given their due recognition – as indeed R&D into decarbonising hard-to-reach elements of the transport system might be regarded.

V. Conclusion

In recent years, concern for environmental issues has been growing – both among conservatives and the wider general public.[270]

In the current Government, we have an administration devoted to seeing the UK reduce its greenhouse gas emissions to Net Zero by 2050, while also being committed to taking immediate action to improve air quality to ever safer levels, and using environmental policy as a lever to deliver the jobs and economic opportunities of the future.[271]

Importantly, this Government wants to achieve these ends with an approach underpinned by faith in markets and technology, which goes with the grain of established patterns of behaviour.[272] It is wise to do so. Others in the environmental movement – perhaps harbouring ulterior motives – might wish for altogether more radical tactics.[273] But the end point of such an approach is to shut down some or all of the modern economy, causing enormous damage to lives and livelihoods.

Already, the UK has excelled in taking meaningful action in the climate debate. It has cut greenhouse gas emissions dramatically, while concomitantly growing its economy and population.[274] In the business world, British companies and research institutes have designed, engineered, and installed some of the vital technologies which allow us all to live more sustainably. In the political sphere, British prime ministers have also demonstrated leadership which has reverberated around the world – from Margaret Thatcher's 1989 speech on the floor on the United Nations General Assembly calling for global climate action,[275] to Boris Johnson making the 2050 Net Zero pledge a key plank of his recent general election victory.[276]

On air pollution, too, Britain has witnessed significant success – with emissions of some forms of harmful pollutants down to mere fractions of what they once were.[277] Again, a combination of sensible and appropriate regulation, twinned with entrepreneurial ingenuity, has meant that the British public now breathes markedly cleaner air than the case was even just a few decades ago.[278]

But past triumphs are not sufficient in these debates. There is still more to do – in some cases, much more. Commitments to meeting Net Zero greenhouse gases by 2050, and delivering cleaner air as soon as possible, are just that – commitments. What now needs to follow are a set of actionable and effective policies to ensure that the objectives of such ambitions are realised.

Some of these policies are already in place, and have given the UK a head-start in terms of getting to where it ideally wants to be. But others still can help, just as those which are currently in law could be tweaked and amended to ensure they are as efficacious as they possibly can be.

Transport is now the single biggest emitter of greenhouse gases in the UK, and a primary cause of the most harmful instances of air pollution. The report shows why the current strategy of transport decarbonisation, while effective for some classes of vehicle, is not be suitable for all. It makes the case for examining the potential role which alternative fuels, such as sustainably produced hydrogen, could play in ensuring that the UK can meet its climate and air quality objectives. It outlines the potential advantages to Britain of being an early mover in this technology, and using the heavy transport sector, and in particular the bus network, as a test bed for innovation. And it outlines how the UK can meet its Net Zero targets in the sector without excessive taxation or regulation, while delivering cleaner air, cleaner engines, and cleaner roads.

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