

# A BREATH OF FRESH AIR: NEW SOLUTIONS TO REDUCE TRANSPORT EMISSIONS.

Institution of  
**MECHANICAL  
ENGINEERS**



Improving the world through engineering

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The UK needs to create a new Clean Air Act which takes a more holistic approach and encourages everyone to play a role in reducing emissions.

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**Philippa Oldham CEng MIMechE**  
Lead Author and Member of the  
Institution of Mechanical Engineers

This report focuses on emissions from the UK's transport sector. The Institution acknowledges that greenhouse gases and emissions that result in poor air quality come from a number of other sectors, including the energy supply, domestic gas combustion, agriculture, business and residential.

This report has been produced in the context of the Institution's strategic themes of Energy, Environment, Education, Healthcare, Manufacturing and Transport and its vision of 'Improving the world through engineering'.



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# EXECUTIVE SUMMARY

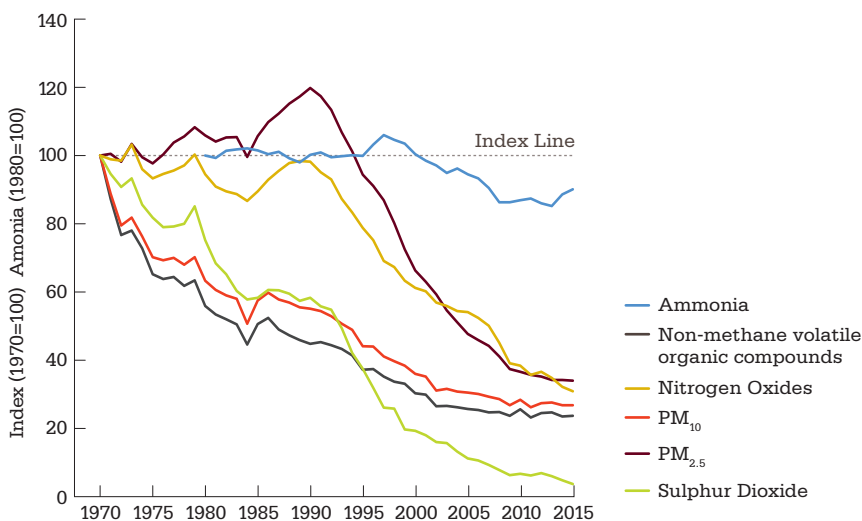
Air pollution has always been a topic on the Government's agenda, but one where the focus has changed over the years. Back in the 1950s, pollution reached a peak with the Great Smog. At the time this five-day event was directly linked to the deaths of more than 4,000 Londoners and led to the 1956 Clean Air Act which focused on tackling smoke and sulphur dioxide. The Act required everyone to do their bit: factories had to make their chimneys higher, householders had to burn smokeless fuels, and Government moved some power stations out of cities<sup>[1]</sup>.

Today, London is ranked 15<sup>th</sup> out of 36 major global cities in terms of overall air quality, lagging behind other European cities such as Berlin and Vienna<sup>[2]</sup>. The UK needs to prioritise this issue and create a modern Clean Air Act that takes a holistic approach; it must not just target individual sectors, but encourage everyone to play a role in reducing emissions.

Part of the problem is that climate change and air pollution are not talked about in the same circles. However, they are both challenges that the UK needs to overcome, as they are both damaging to our health and the environment. It is important that we calculate and monitor all our emissions, recording those responsible for climate change, eg greenhouse gases (GHG), and air quality, eg particulate matter (PM) and nitrogen dioxide (NO<sub>2</sub>)<sup>[1]</sup>.

As is evident from **Figure 1**, over the past 45 years there has been a long-term decrease in emissions of all the air pollutants. However, of note is that PM<sub>10</sub> and PM<sub>2.5</sub> emissions have remained relatively static over the past five years<sup>[3]</sup>.

**Figure 1:** Trends in UK sulphur dioxide(SO<sub>2</sub>), nitrogen oxides(NO<sub>x</sub>), non-methane volatile organic compounds, Ammonia and particulate matter(PM<sub>10</sub>, PM<sub>2.5</sub>) emissions 1970–2015.<sup>[3]</sup>



**Figure 2** shows how GHG emissions have changed since 1990, with transport now being the largest contributor in the UK. These emissions have risen for three years in a row to their highest level since 2009. This reflects rising demand for travel, potentially a slowing of progress in improving the efficiency of new vehicles, and an ineffectiveness to remove those older, more polluting vehicles. If we are to meet the Fifth Carbon Budget our transport emissions need to reduce by an average of 4% per year to 2030<sup>[7]</sup>.

The transport sector has significant opportunities to reduce emissions, but requires stronger policies and signals over the long-term to provide incentives for efficiency improvements in conventional vehicles, switching to ultra-low emissions vehicles and changing travel behaviour.

Both challenges need to be tackled, remembering that climate change with its associated GHG is a global issue, whereas having clean air within our local environments is much more about reducing pollution, thereby addressing the domestic agenda.

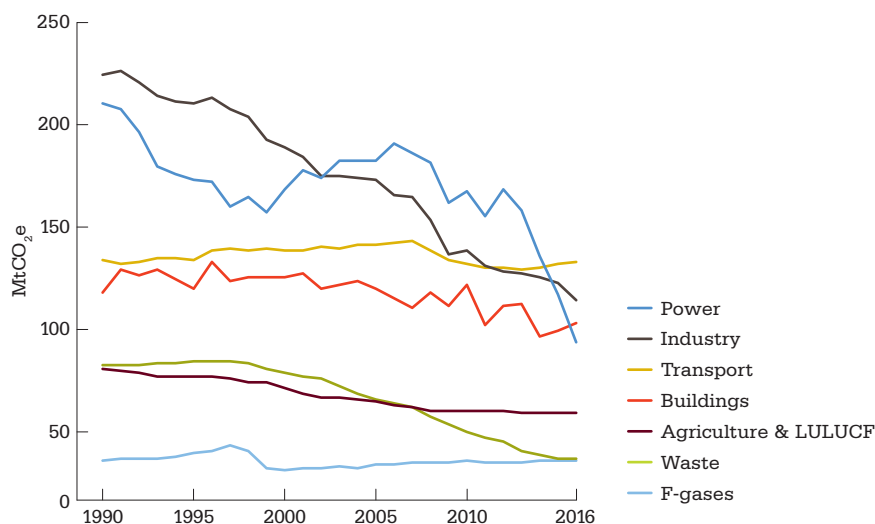
Current transport air quality policy is too short-term, focused on individual modes of transport, rather than looking holistically at the big picture. To have a true impact, a Clean Air Act is needed with a much broader scope; addressing all emissions from across our transport modes, it needs to be strategically robust and long-term.

Currently UK cities use air quality monitoring data, which in London's case is from the London Air Quality Network (LAQN). This is a collection of over 100 monitoring sites located around the city. However, this measures ambient pollution and has no ability to apportion to source, basing its analysis on historical data looking at the total concentration of pollution at the sites, rather than emissions from original sources<sup>[8]</sup>. Emissions monitoring, analysis and modelling have improved significantly over recent years and continue to evolve. We must ensure that we are making decisions that are evidence-based rather than knee-jerk, seemingly policy-winning solutions.

While much of the media focus is on our capital, it is worth noting that this is a serious problem that affects us all. Government statistics show a total of 278 of the 391 local authorities (71%) missed their air quality targets last year, up from 258 in 2010<sup>[9]</sup>.

Whatever our Government policies are, they must be coherent. They need to offer a joined-up strategy to achieve both improved air quality and a reduction in GHG. While investments in our public transport network are helping to reduce emissions, we must address how to encourage individuals to switch to low-carbon emission vehicles, potentially making use of scrappage schemes or retrofitting grants, or alternatively shifting modes to public transport and changing their travel patterns, thereby reducing demand. Another option is to encourage non-motor alternatives such as walking or cycling, further enhanced by the creation of dedicated cycle lanes and better workplace storage and shower facilities etc.

**Figure 2:** UK GHG emissions by sector (1990–2010)<sup>[4,5,6]</sup>



The Institution recognises that the challenges of air pollution and climate change are tough for Government, as they cross five central departments as well as needing to align with regional and local government initiatives. We are pleased to see the joint inquiry on air quality that has been launched, with four of the select committees combining forces. The Department for Environment, Food & Rural Affairs must develop policies that support technological developments and acceleration to implementation to reduce all of our harmful emissions. Our policies and regulations need to reflect emerging scientific evidence on pollution from the wear and tear of the build, operation and disposal of all our transport vehicles<sup>[10]</sup>.

The UK needs a holistic lifecycle approach, particularly recognising that some of our new technologies eg electric vehicles, have challenges from the start of production of their battery cells and at the end of life, with issues such as battery recycling being currently uneconomically viable, but accepting they are much lower emission at the point of use. The Department for Business, Energy & Industrial Strategy has recently launched its Clean Growth Strategy which the Institution welcomes, however, while this certainly talks about the move to electric vehicles, there are only acknowledgements of the need for improving the other modes. In 2018, the Institution would hope to see more emphasis on the other modes from the Department for Transport's strategy for zero-emission transport.

With the introduction of Clean Air Zones (CAZs) and Ultra Low Emission Zones (ULEZs) in cities, we must focus on the ease of access to public transport. There have been notable improvements happening within our bus sector, with the nitrogen oxide (NO<sub>x</sub>) emissions from London's bus fleet having halved in 2016 compared to 2008 levels<sup>[11]</sup>. This means a journey by a Euro 6 diesel car now emits ten times the per passenger NO<sub>x</sub> of a comparable journey by the latest Euro VI diesel bus<sup>[12]</sup>. This example is something we need to learn from and introduce elsewhere within the transport sector.

We have become a society that demands everything now. The UK needs reliable and robust infrastructure to move goods and services in and out of our cities, towns and villages. Addressing this 'Just in Time' philosophy may need to be revisited and re-addressed, encouraging consumers to group their deliveries so that emissions are reduced and air quality improved. This is already offered by some online food delivery companies. The UK logistics organisations must have a supportive environment, ensuring they meet necessary measures to protect citizens, such as Clear Air Zones, but that these are implemented in a way that is not damaging to business<sup>[13]</sup>. The development of better freight networks and platforms to help business to collaborate needs to be reviewed.

Individuals breathe in 20kg of air every day and because we can't see it, we don't know what's in it<sup>[14]</sup>. Our decisions on what vehicle we travel in or how we deliver our goods are having an impact on those around us. The engineering community needs to develop new technology to help solve this issue, but in order to do this we need to properly understand it. We need more accurate information about what real-world emissions are and the harm that they are causing us.

In 2017, Government published its Air Quality Plan; however, it has only addressed the challenges of nitrogen dioxide (NO<sub>2</sub>), with little mention of other harmful pollutants, eg particulate matter (PM). If we are encouraged to make our choices and policies based only on this single pollutant, then we will make overall improvements but not a full comprehensive one to the air we breathe or to climate change<sup>[15]</sup> and in the long term will only shift the problem elsewhere.

There is no silver bullet, no one solution to solve this crisis. Different communities will require their own solutions; for example, in cities outside London the proportion of public transport is lower, so the proportion of emissions from diesel and petrol cars is greater. In Manchester, 43% of emissions come from cars and just 11% from buses<sup>[12]</sup>. Technology will play a part in addressing this problem, but there is a role and responsibility for individuals too. Back in the 1950s, doctors kick-started a national movement on the risks of smoking; maybe there is a need to start doing the same with air quality, to encourage people to drive less and use public transport, walk and cycle more<sup>[15]</sup>.

## RECOMMENDATIONS

The Institution of Mechanical Engineers recommends that:

1. The Department for Environment, Food & Rural Affairs (Defra) work with the Department for Transport (DfT) to introduce emission monitoring equipment across our transport network (eg in streets, underground stations, enclosed railway stations, ports, airports) along with real-time on-vehicle monitoring.

This will provide us with a complete picture of our baseline pollutants, which would enable us to monitor peaks throughout the day. These monitors will need to record all types of pollution including oxides of nitrogen (NO<sub>x</sub>), particulate matter (PM) and ultra fine particles (UFP). This data will help to baseline our emissions and then prioritise investment schemes to tackle pollutants in a logical, evidence-based way.

This may result in financial incentives that support vehicle retrofit or scrappage programmes. The data could be used to create a traffic-light pollution index system. This could then be displayed in public locations, particularly near schools, hospitals, large shopping centres to help raise awareness and encourage public behaviour change.

2. DfT and the Department for Communities and Local Government (DCLG) work with surface transport operators (buses, rail, and freight), addressing how to maximise the reduction of pollutants through incentivising the right actions. This needs to include the reduction of legacy vehicles with poor emissions across the network, including cars, taxis, vans, buses, trains and HGVs.
3. DfT and DCLG work alongside freight and logistics operators, to help address the efficiency of the network, and to consider incentivising when deliveries take place.

This would help reduce the concentration of pollutants during the morning peak which in London were found to be 13–43% higher than during the afternoon or evening peak<sup>[8]</sup>. However, such an approach on reducing congestion must also address passenger transport efficiency, which could additionally have a large impact on reducing emissions at these peaks.

4. DfT conduct a series of trials on existing diesel railway rolling stock, the new bi-mode trains and in major stations, to understand the level and effect exposure of pollutants has on commuters and railway workers.

Some rolling stock diesel vehicles still have many years left in service, so it may be appropriate to retrofit technology, for example stop-start functionality to reduce emissions while trains are standing at platforms. The key to this is understanding the exposure that individuals are susceptible to over an average day, addressing the maximum limits and then aiming to reduce these.

5. DfT conduct a series of trials to understand individual exposure from our overground and underground railway stations, ports, airports and bus stations. We need to monitor emissions within our major transport terminals as well as on the network itself. Currently, occupational health standards are not suitable for enclosed railway stations, as there are no workplace exposure limits (WELs) for employees who work within station environments for emissions, eg NO<sub>x</sub>, SO<sub>x</sub> and PM<sup>[14]</sup>.
6. DfT and the Department of Health (DH) need to work together, to create a campaign that informs people of the health benefits of switching to lower-emission modes of transport, for example a switch from car to bus, or even non-motored travel (cycle, walk etc). However, for such a campaign to be a success, individuals would need to have confidence in the frequency, reliability and cost of their new mode.
7. DfT instruct Network Rail to develop an appropriate specification for railway electrification that will achieve an affordable business case for a rolling programme to complete the electrification of the main lines between Britain's principal cities and ports, and of the urban rail networks through our major city centres.
8. The Department for Business, Energy & Industrial Strategy (BEIS) work with DfT to fund research through the Clean Air Fund and Innovate UK to create programmes to clean up various transport modes.

One challenge may include research into how to clean up the particulate matter (PM) and ultra fine particle (UFP) emissions from our congested streets, underground platforms and rail track beds, removing particulates and preventing recirculation. These new funding calls could be focused on reducing overall emissions, reducing congestion or improving mobility rather than the traditional calls that are focused on individual modes of transport.



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Globally, air pollution is responsible for one in ten of all deaths.





## UNDERSTANDING THE DAMAGE THESE EMISSIONS CAUSE

Globally, air pollution causes one in ten deaths, with an expectation that if nothing is done this number will continue to rise<sup>[16]</sup>. In July 2017 the Department for Environment, Food & Rural Affairs (Defra) and Department for Transport (DfT) published the UK plan for tackling roadside nitrogen dioxide (NO<sub>2</sub>) concentrations<sup>[17]</sup>. The overall target is for a full shift to ultra-low and zero (tailpipe) emissions, eliminating sales of traditional internal combustion engine (ICE) vehicles by 2040<sup>[17]</sup>. However, while a diesel phase-out would trigger a 45% drop in NO<sub>x</sub> emissions, our particulate matter (PM) emissions would see only a 2% reduction. The PM emissions created by road transport are predominantly being caused by brake and tyre wear<sup>[8]</sup>. Greater attention must be given to these PM emission, which are known to be especially harmful as they are absorbed into the bloodstream and deep into the lungs<sup>[11]</sup> – see **Table 1**.

It has become evident that London has a particularly bad NO<sub>2</sub> problem, with levels similar to such cities as Shanghai and Beijing. This puts it among the worst cities globally in terms of overall air quality<sup>[2]</sup>.

In addition to NO<sub>2</sub>, health professionals believe PM to be a big concern. PM, particularly those categorised as PM<sub>2.5</sub> or Ultra Fine Particles (UFP) (particles with a diameter of less than 2.5µm – 1/400 of a millimetre – or 50 times smaller than the width of a human hair). These small particles can be absorbed deep into lungs, where our bodies have few defenses to break them down or remove them. They may be able to make their way into the bloodstream and these particulates have been linked to illnesses such as dementia. In 2010, a study by the Committee on the Medical Effects of Air Pollutants (COMEAP) estimated that PM<sub>2.5</sub> pollution had an effect on mortality of 340,000 life years lost, equivalent to nearly 29,000 premature deaths across the UK in 2008<sup>[16]</sup>.

Air pollution affects everyone, but some are more vulnerable than others. Children are at particular risk from poor air quality. Professor Frank Kelly from King's College London has repeatedly raised awareness of studies carried out in the US, China and the UK. These have shown that air pollution can slow the development of children's lungs. This is important, as our lungs continue to grow until we are about 18, and anything that impedes that growth is irreversible. California takes this risk seriously and has laws dictating that schools should be built a certain distance away from main roads<sup>[10]</sup>. While this may not be possible in some parts of the UK, it should be a mandatory consideration when building new schools.

Initiatives such as encouraging parents not to leave their car engines idling when picking up children from school, or encouraging them to use public transport, walk or cycle to school instead, are options that should be promoted. In addition to this there are plants that absorb pollution, such as bamboo palms, peace lilies and rubber plants that could be introduced into classrooms. Planting trees and hedges between roads and schools to absorb and disperse pollution can also help.

However, it is not just our young who are affected by these emissions. We have an ageing population that is ever more at risk. Elderly individuals who suffer with respiratory and cardiovascular issues are in danger, and should consider taking extra precautions when pollution levels are high<sup>[10]</sup>.

As a result of climate change, heat-related premature deaths are forecast to increase steeply in the UK, with the elderly population particularly vulnerable. Levels of ozone, which is a respiratory irritant, are predicted to increase, and changes in the seasons, temperature and weather patterns will have an impact on exposure to pollen, increasing allergies<sup>[18]</sup>.

Further information is required to understand the relative impact of different emissions. This needs to include analysis of pollution decomposition and an understanding of how pollution dissipates across its geographical location. This will give us more of an understanding of how we should rank our vehicle usage within particular pinch points.

**Table 1** provides more detailed information about the pollutants and the effects that they have on our health.

**Table 1:** Pollutants, their sources and impacts <sup>[2,20,9]</sup>

Pollutant	Key sources of emissions	Health/environmental effects
<b>Particulate matter (PM) and black carbon (BC)</b> Particles under 10µm in diameter (PM <sub>10</sub> ) and fine particles less than 2.5µm in diameter (PM <sub>2.5</sub> )	Transport (exhaust, tyre and brake wear, wheel and rail interface, pantograph, industrial processes, construction and demolition, natural sources)  Also created by interaction of other pollutants	Linked to asthma, lung cancer, respiratory and cardiovascular diseases, infant mortality and low birth weight  The smallest particles are of greatest concern (PM <sub>2.5</sub> )  Black carbon (a component of PM) second biggest (after CO <sub>2</sub> ) driver of climate change, contributes to global warming – approximately 50% of Arctic warming is attributed to BC <sup>[19]</sup>
<b>Oxides of nitrogen (NO<sub>x</sub>)</b> Including nitrogen oxide (NO) and nitrogen dioxide (NO <sub>2</sub> )	Combustion: – Internal combustion engines (transport) – Domestic heating – Power generation: gas, oil, coal, biomass  Lightning	Exposure to NO <sub>2</sub> can cause lung irritation, decrease lung function and increase chance of respiratory infections; long-term exposure is associated with low birth weights in babies and excess deaths  NO and NO <sub>2</sub> are precursors to formation of ozone and acid rain  NO <sub>2</sub> can be deposited into fresh water and land, harming biodiversity in sensitive sites  NO <sub>x</sub> is a precursor to ground-level Ozone(O <sub>3</sub> ) (see opposite)
<b>Sulphur dioxide (SO<sub>2</sub>)</b>	The largest UK source is currently power generation  Combustion (particularly coal)  Shipping – currently the use of fuel oil generates significant quantities of SO <sub>2</sub>	Causes irritation of lungs, nose and throat, and exacerbates asthma  Health effects can occur very rapidly, making short-term exposure to peak concentrations important.  Precursor to formation of smog  Forms acid rain, which damages freshwater environments, soils and vegetation

Pollutant	Key sources of emissions	Health/environmental effects
<b>Ozone (O<sub>3</sub>)</b>	A secondary pollutant produced by reaction of hydrocarbons, NO <sub>2</sub> and volatile organic compounds (VOCs) in sunlight	Harms lung function and irritates respiratory system; can increase incidence and severity of asthma and bronchitis  Long term exposure can lead to cardiorespiratory mortality; acts as a powerful greenhouse gas; stunts plant growth  High concentrations can irritate eyes/nose/throat and can cause breathing difficulties  It is not good for anyone to perform rigorous exercise in an area of high levels of ozone
<b>Carbon monoxide (CO)</b>	Road transport (particularly petrol), combustion industry  CO arises from incomplete combustion	Headaches, nausea, dizziness, affects lung performance  Precursor to the formation of ozone
<b>Benzene (C<sub>6</sub>H<sub>6</sub>)</b>	Evaporation and combustion of petroleum products  Ambient benzene combustion processes, in addition to road transport	Cancer, leukemia  Acute exposure to high concentrations affects the central nervous systems  Can pollute soil and water
<b>Heavy metals</b> (eg arsenic (As), cadmium (Cd), lead (Pb), mercury (Hg) and nickel (Ni))	Combustion, industrial processes  Combustion of heavy fuel oil (HFO)	Nausea, diarrhoea, abdominal pain, irritation of eyes, nose, throat and lungs; brain and kidney damage, asthma, respiratory diseases, lung cancer  Can pollute soil and surface waters
<b>Polycyclic aromatic hydrocarbons</b> eg benzo(a)pyrene (BaP)	Combustion  Residential wood burning  Burning organic material as well as from diesel engines	Maternal exposure has been linked to mental health problems and neurocognitive delay in children  Lung cancer



This is not a new problem, and there are already recommended 'safe' limits in place developed by the EU and World Health Organization limits, see **Table 2**<sup>[46]</sup>.

**Table 2** indicates that a true understanding of the harm has not yet been reached there as according to the EU's data only 8% of the population are overexposed to the PM<sub>2.5</sub> limit of 25 µg/m<sup>3</sup> a year, whereas this increases significantly to 85% when we take the WHO annual limit of 10 µg/m<sup>3</sup><sup>[21]</sup>.

**Table 2:** Suggested exposure limits to pollutants <sup>[21]</sup>

Pollutant	EU limit	Proportion of urban EU population exceeding EU limit (%)	WHO limit	Proportion of urban WHO population exceeding WHO limit (%)
PM <sub>10</sub>	40µg/m <sup>3</sup> annual mean	16–21	20µg/m <sup>3</sup> annual mean	50–63
PM <sub>2.5</sub>	25µg/m <sup>3</sup> annual mean	8–12	10µg/m <sup>3</sup> annual year	85–91
BaP	1ng/m <sup>3</sup> annual year	20–24	0.12ng/m <sup>3</sup> annual year	88–91
NO <sub>2</sub>	40µg/m <sup>3</sup> annual year	7–9	40µg/m <sup>3</sup> annual year	7–9
SO <sub>2</sub>	125µg/m <sup>3</sup> in 24h	<1	20µg/m <sup>3</sup> in 24h	35–49
O <sub>3</sub>	120µg/m <sup>3</sup> in 8h	8–17	100µg/m <sup>3</sup> in 8h	96–98

**BaP** Benzo(a)pyrene  
**NO<sub>2</sub>** Nitrogen Dioxide  
**O<sub>3</sub>** Ozone

**PM<sub>2.5</sub>** Particulate Matter ≤2.5µm  
**PM<sub>10</sub>** Particulate Matter ≤10µm  
**SO<sub>2</sub>** Sulphur dioxide

## BASELINE OUR EMISSIONS

This data indicates that the problem is bigger than just addressing emissions from NO<sub>2</sub> as current UK policy intends to do. With any engineering problem, it is important that we understand the starting position and the size of the challenge, so we can gauge the effectiveness of trials and potential solutions. To achieve this initial understanding, we need to have better monitoring in place, collecting information in real-time.

This baseline data will provide the complete picture of where our air pollution is coming from. Monitors need to record all types of pollution including NO<sub>x</sub>, SO<sub>x</sub>, PM and UFP. In addition to exhaust emissions, it is important to consider non-exhaust particulate emissions – brake and tyre wear and road abrasion. Currently there is very little data available on non-exhaust emissions compared to data on exhaust emissions.

Improved monitoring in this area will provide better understanding of non-exhaust emissions, with information on usage as well as the combustion type enabling the future possibility to rank vehicles, which would help with future legislation. Monitors range from simple, cheap NO<sub>x</sub>/NO<sub>2</sub> diffusion tubes to more sophisticated ones recording real-time NO<sub>x</sub> and PM emissions. The cheaper, low-precision devices could be used to check for any problems across an area and then, when hot spots are identified, a more in-depth analysis could be conducted of those specific areas.

### **The Institution of Mechanical Engineers recommends:**

Defra work with DfT to introduce emission-monitoring equipment across our transport network (eg in streets, underground stations, enclosed railway stations, ports, airports) along with real-time on-vehicle monitoring. This will provide us with a complete picture of our baseline pollutants, which would enable us to monitor peaks throughout the day. These monitors will need to record all types of pollution including oxides of Nitrogen (NO<sub>x</sub>), particulate matter (PM) and ultra-fine particles (UFP). This data will help to baseline our emissions and then prioritise investment schemes to tackle pollutants in a logical, evidence-based way. This may result in financial incentives that support vehicle retrofit or scrappage programmes. The data could be used to create a traffic-light pollution index system. This could then be displayed in public locations, particularly near schools, hospitals, large shopping centres to help raise awareness and encourage public behaviour change.

DfT and DCLG work with surface transport operators (buses, rail, and freight), addressing how to maximise the reduction of pollutants through incentivising the right actions. This needs to include the reduction of legacy vehicles with poor emissions across the network, including cars, taxis, vans, buses, trains and HGVs.

DfT and DH work together, to create a campaign that informs people of the health benefits of switching to lower-emission modes of transport for example a switch from car to bus, or even non-motored travel (cycle, walk etc) However, for such a campaign to be a success individuals would need to have confidence in the frequency, reliability and cost of their new mode.



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In 2016, there were 793 billion passenger kilometres travelled by road in the UK.





# CURRENT STATUS

To achieve a reduction in emissions, all sources must be targeted. Transport is a significant contributor, with stakeholders including mode operators and manufacturers, fuel manufacturers and suppliers, Government and policy makers, media and consumers<sup>[22]</sup>. To achieve the right outcome we must address the whole challenge. Failure to do so will not solve the emission problem in the long term<sup>[18]</sup>.

Road transport is flexible and convenient, making this the most popular way of moving ourselves and our goods. However, increased vehicle movements bring problems of congestion and pollution. All internal combustion engines (ICEs), whether fuelled by petrol or diesel, emit pollutants into the atmosphere. These impact on our health and environment; the greater vehicle use, the more the damaging the effects. Current data suggests that demand is not going to decrease any time soon. In 2016 there were 793 billion passenger kilometres travelled. This was the highest volume ever recorded in the UK, indicating our insatiable appetite to keep travelling by car<sup>[4]</sup>. This is an example of why we need to be re-addressing both air quality and climate change.

GHG emissions from the transport sector are similar to 1990 levels, with road transport remaining the most significant source of emissions in this sector. However, emissions from passenger cars have decreased since the early 2000s, due to the lower petrol consumption outweighing an increase in diesel consumption and, more recently, improvements in the fuel efficiency of both petrol and diesel cars. However, this decrease has been partially offset by an increase in emissions from light goods vehicles<sup>[6]</sup>.

## **The Institution of Mechanical Engineers recommends:**

Defra work with DfT to introduce emission monitoring equipment across our transport network (eg in streets, underground stations, enclosed railway stations, ports, airports) along with real-time on-vehicle monitoring. This will provide us with a complete picture of our baseline pollutants, which would enable us to monitor peaks throughout the day. These monitors will need to record all types of pollution including oxides of nitrogen (NO<sub>x</sub>), particulate matter (PM) and ultra-fine particles (UFP). This data will help to baseline our emissions and then prioritise investment schemes to tackle pollutants in a logical, evidence-based way. This may result in financial incentives that support vehicle retrofit or scrappage programmes. The data could be used to create a traffic-light pollution index system. This could then be displayed in public locations, particularly near schools, hospitals, large shopping centres, to help raise awareness and encourage public behaviour change.

DfT and DCLG work with surface transport operators (buses, rail and freight), addressing how to maximise the reduction of pollutants through incentivising the right actions. This needs to include the reduction of legacy vehicles with poor emissions across the network including cars, taxis, vans, buses, trains and HGVs.

## ROAD VEHICLES

Assessing the whole transport emission picture is essential, as is learning from our past errors. For example, from the turn of the century we pushed consumers towards diesel-fuelled vehicles due to their lower CO<sub>2</sub> emissions. This has led to a failure to manage emissions, such as NO<sub>x</sub>, which are far higher from diesel vehicles compared to those using petrol<sup>[8]</sup>. Diesel penetration in new car sales rose rapidly between 2000 and 2011, from 14% to 50.6%. Between 2011 and 2014 diesel share was higher than petrol, as consumers switched to get the benefits of the lower CO<sub>2</sub> performance and increased fuel economy<sup>[23]</sup>. This push has led to there being 10.7 million diesels on the road, making up 36% of the total fleet. This growth has been replicated with the growth in diesel vans and light goods vehicles from 51% of the total fleet in 1994, to 96% in 2014<sup>[8]</sup>.

Government is now implementing incentives to shift the consumers to ultra-low and zero tailpipe emission vehicles. It is expected that this will continue to gather pace over the coming years as we move towards 2040, which is when Government plans to end the sale of all new conventional petrol and diesel cars and vans. It is presumed that this shift will resolve our air quality problem as combustion engines gradually disappear from the streets of our towns and cities, some as soon as the early 2020s<sup>[17]</sup>. However, new cars less than one year old represent only about 8% of all cars in use, these emit about 20% less CO<sub>2</sub> than the average car on the road<sup>[24]</sup>. Due to their limited numbers in the fleet they have a comparatively small impact on total road transport emissions, so emissions must be tackled by other vehicles on our roads, including vans, HGVs, buses and coaches. Reducing total emissions relies on more than just the vehicle itself, with improved infrastructure to help with efficiency, access to low-carbon fuels and a change in driver behaviour all important considerations<sup>[22]</sup>.

### Road: Cars

The UK automotive sector is currently one of our thriving sectors. In 2015 annual UK automotive turnover was £71.6bn which added £18.9bn in value to the UK economy<sup>[25]</sup>. Automotive engineers have a history of developing vehicle systems which reduce tailpipe emissions. The average new car in the UK now produces 33% less CO<sub>2</sub> than in 2000, with NO<sub>x</sub> emissions down by 84% over the same period, and soot particulates almost eliminated<sup>[26]</sup>. However, these results are obtained from the test cycle data and have been proved not to be representative of the real world.

Figures show that in Greater London more than half of NO<sub>x</sub> is emitted by road transport with 24% of this from diesel cars, 12% from petrol cars, 21% from heavy goods vehicles, 12% from vans and mini-buses, 20% from Transport for London (TfL) buses, 6% non-TfL buses and coaches, and 4% from taxis<sup>[12]</sup>. This shows that all our road vehicles are part of this pollution challenge.

One issue that needs to be overcome is the average age of vehicles on the road. In 2015 the average age of a car at scrappage reached 13.9 years. The lowest scrappage age, 13 years, was recorded in 2009, a result of Government's scrappage scheme. Over the years the average age of a vehicle on the road has increased, from 6.8 years in 2003 to 7.8 recorded in 2015. This reflects both slower fleet renewal and the increased longevity of vehicles. This trend works against the uptake of new vehicles, which would bring greater environmental benefits<sup>[26]</sup>.

In September 2017 the European Commission introduced a new on-road Real Driving Emissions (RDE) test, which new vehicles have to pass in addition to laboratory tests (this standard is referred to as Euro 6c). The RDE test is used for new models in Europe from 1 September 2017, and for all new vehicles sold from September 2019<sup>[16]</sup>. This test should help negate the impact that flawed emissions tests have shown over recent years, giving reliable real-world vehicle data. Following these recent failures, Government must work with the manufacturers to look at how they are able to conform to satisfactory operation of pollution control equipment. This would address some of the challenges within the aftermarket potential of remapping engines or removing or interfering with pollution reduction devices.

## Road: Buses

In the UK, 5.2 billion passenger journeys take place on 88,683 buses and coaches amounting to 18.1 billion passenger miles each year<sup>[27]</sup>. Journeys by bus in Great Britain represent 62% of all journeys by public transport and 28% of total passenger miles travelled in 2014/15. Of these journeys, bus use is highest among those aged 17–20 and 60+ years, and decreases as household income increases. It remains the most used transport mode for secondary school children travelling over two miles<sup>[11]</sup>. These figures demonstrate how crucial the role of the bus is within our communities. It provides transport options for those at either end of the age spectrum, and can help provide a sense of community.

However, buses and taxis are a significant source of NO<sub>x</sub> emissions, particularly in Central London where, together, they make up 30% of total road transport emissions<sup>[16]</sup>. TfL has recognised this and made significant investment in low-emission buses, with over 1,500 low-emission hybrid buses already in service (representing 20% of the total fleet)<sup>[16]</sup>.

The bus sector has made dramatic improvements to its fleet, with clean diesel bus technology exceeding that used in car manufacturing. Since 2004, NO<sub>x</sub> emissions from diesel buses have been reduced by a factor of 20, compared to emissions for diesel cars reducing by less than a third<sup>[12]</sup>. In 2009 the Low Carbon Vehicle Partnership (Low CVP) worked with the industry and Government to devise two incentive mechanisms: the Bus Service Operators Grant (BSOG) Low Carbon Emission Bus Incentive, and the Green Bus Fund. These were adopted by DfT and embedded into national transport policy<sup>[11]</sup>.

These incentive programmes have successfully cleaned up vehicles and fleets. Such an initiative would benefit the other modes of transport, from the freight and logistic operators to the rolling stock rail operators.

However, while the uptake of cleaner new technologies has been impressive within the bus fleet, this has meant high capital cost. Buses are part of the solution and Government needs to continue to support these initiatives.

## Road: HGVs/Vans

Freight is essential for our cities and economies to function. HGVs represent 21% of surface transport CO<sub>2</sub> emissions. These vehicles have struggled to decarbonize, due to powertrain requirements and limited scope for electrification. Many businesses have called for support from Government to switch to greener technologies to help meet emission targets as well as improve air quality<sup>[13]</sup>.

The scale of potential air quality controls on HGVs and vans presents significant cost implications for businesses of all sizes. Euro VI HGVs have been tested and are meeting their real-world emissions limits. Analysis by TfL shows that Euro VI trucks are achieving a 77% reduction in real world NO<sub>x</sub> emissions compared to Euro V trucks – a step in the right direction<sup>[8]</sup>.

Getting a better understanding of the mix of fleet vehicles that make up our freight operators is imperative. For example, London freight traffic is almost one third of all morning peak traffic, of which about 80% is van traffic. The market for commercial vans has doubled in volume since 2009, to 374,093 units. The total vehicle fleet has grown from 3.5 million units in 2007 to over 4 million in 2016. Similarly, vehicle use has increased, rising by 47.2% between 2000 and 2015. Within this same period CO<sub>2</sub> emissions from commercial vans rose by 26.2%, including growth in each of the past five years to 2015, reflecting the rapid growth in van use<sup>[23]</sup>.

Vans are bought by businesses to do a job and are specified based on size and load capacity. Operating costs over a vehicle's working life are minimised, with running costs such as fuel efficiency being important. Currently most vans are diesel-fuelled, with just a handful of alternatively fuelled vehicles. Generally, the larger the van, the higher the CO<sub>2</sub> emissions per mile, although on a 'per tonne transported' basis the performance may be very different<sup>[23]</sup>. Vans are the last road sector to be fully cleaned up with RDE legislation – this implies that there is a large air quality concern over the next three years.



“““

In the past 20 years, there has been a 106% increase in passenger-km travelled on the UK national railway network.





## RAIL: OVERGROUND

There has also been significant growth in refrigerated units, which are estimated to emit up to six times as much NO<sub>x</sub> as a Euro VI truck, and up to 29 times as much PM. The Greater London Assembly (GLA) has suggested that 5–25% of heavy goods vehicles in Central London are refrigerated. The emissions associated with these vehicles are not currently included in emissions models<sup>[8]</sup>.

There are concerns for the financial burdens that Ultra Low Emission Zones (ULEZs) will have on logistic operators and small businesses. Government must offer support to logistics operators (both road and rail), whether that is through help with purchasing cleaner vehicles more quickly, or through supporting and encouraging the retrofit of proven technologies to help clean up the existing fleet.

### The Institution of Mechanical Engineers recommends:

DfT and DCLG work with surface transport operators (buses, rail and freight) addressing how to maximise the reduction of pollutants through incentivising the right actions. This needs to include the reduction of legacy vehicles with poor emissions across the network including cars, taxis, vans, buses, trains and HGVs.

DfT and DCLG work alongside freight and logistics operators, to help address the efficiency of the network, and to consider incentivising when deliveries take place.

### National Rail passenger services

National Rail Passenger Services in the last 20 years, railway passenger numbers have dramatically increased. Passenger-km on the UK national network have risen by 106% between 1996/7 and 2016/7, outperforming other modes in the UK and all other railways in Europe.

The railway sector now faces the challenge of dealing with ageing diesel-powered (or diesel-hauled) passenger vehicles. As of March 2017, there were 3,924 diesel-powered or diesel-hauled vehicles, 29% of the present national fleet. This comprised 1,057 shorter-distance vehicles, generally with 75mph maximum speed, 1,367 middle distance vehicles with a 90–100mph capability, and 1,500 long-distance vehicles mainly with 125mph capability<sup>[28]</sup>.

Of these 3,924 vehicles, 1,005 entered service in the 1970s, 876 in the 1980's, 687 in 1990-93, and the remaining 1,356 after 1997, ie post-privatisation. The design life of these vehicles is 30–35 years, but more than 1,000 of these are older than this and with Government's cut backs to the planned programmes of electrification in England and Wales (see Railway Electrification, page 19), it is now expected many of the diesel vehicles built before 1993 will remain in service for a further ten years or more<sup>[28]</sup>.

As regards the compliance of these vehicles with EU emissions legislation, the rail industry's Long Term Passenger Rolling Stock Strategy<sup>[28]</sup> states that:

- None of these present diesel fleets (as listed above) has an engine that is compliant with EU legislation regarding emissions from diesel engines for new rail vehicles, known as Stage IIIB.
- Existing EU and UK legislation does not prevent the continued operation of any of the present vehicles, thanks to an amendment agreed in 2011. (Legislation prevents any more engines of the present types being manufactured for these fleets, but engine components can be manufactured).
- It is unlikely that a business case can be made at present to retrofit a Stage IIIB compliant diesel engine (or engines) to any of the existing British diesel-powered passenger vehicles.

Currently 71% of the national passenger fleet is electrically powered, and this will rise to 77% by March 2019<sup>[28]</sup>. This percentage includes bi-mode vehicles: electrically powered vehicles that also have diesel engines for operation away from the core electrified network. More than 1,000 such vehicles are now on order. Their diesel engines comply with Stage IIIB legislation.

Bi-mode trains can enable the cost of electrification to be reduced or eliminated. They provide operational flexibility during the roll-out of electrification, and enable trains to serve communities beyond the electrified routes. However, their emissions are increased when operating in diesel mode. These trains have higher capital and maintenance costs than pure electric trains, and are less powerful when working in diesel mode than when operating on the electrified network. This investment in diesel engine equipment having been made undermines the business case for future electrification, for example on key parts of the Great Western and Midland Main Lines<sup>[28]</sup>.

#### **The Institution of Mechanical Engineers recommends:**

DfT conduct a series of trials on our existing diesel railway rolling stock, the new bi-mode trains and in major stations, to understand the level and effect exposure of pollutants has on our commuters and railway workers. Some of our rolling stock diesel vehicles still have many years left in service, so it may be appropriate to retrofit technology, for example stop-start functionality to reduce emissions while trains are standing at platforms. The key to this is understanding the exposure that individuals are susceptible to over an average day, addressing the maximum limits, and then aiming to reduce these.

#### **National Rail freight services**

Increasing the volume of freight that is transported by rail remains high among Government's objectives being highlighted in the recent Clean Growth Strategy. It is estimated that every tonne of freight transported by rail produces about 80% less CO<sub>2</sub> than that same amount moved by road. Each year, rail freight is currently estimated to save about 1 million tonnes of CO<sub>2</sub> by taking the place of about 7 million HGV journeys and saving 1.6 billion HGV kilometres in the UK<sup>[29]</sup>.

However, even if we manage to achieve a 50% additional shift from our roads to railways by 2030 (the equivalent of 2.4 billion vehicle kilometres), this will deliver only about a 0.5% reduction in the whole transport sector's emissions. The current market price of commodities does not reflect their true environmental cost. This will change as global resources become more stretched and the environment more stressed, pushing up prices on food, energy and rare metals<sup>[30]</sup>.

Rail freight customers such as Drax already add a specific clause into their road haulage contracts to drive the adoption of best practice in terms of environmental standards. However, this does not guarantee the same demand flows down through the supply chain into ancillary contracts. By adopting a national freight strategy, Government could further incentivise take-up of technology that would help reduce pollution, future proofing air quality and GHG emissions<sup>[31]</sup>.

The UK rail freight fleet has fewer than 1,000 locomotives, of which approximately half are of a single type (Class 66) and use an American two-stroke engine with a long development history. This one class probably moves over 80% or even 90% of rail freight tonnage. These locomotives are approaching half-life refurbishment, which presents an opportunity to re-engine, possibly with multiple smaller engines in line with emerging practice elsewhere. In addition, such new smaller engines comply with current Euro IIIB emissions standards. The limited market for large rail diesel engines is currently limiting development of a suitable engine for diesel freight locomotives, which is further restricted by restrictive UK loading gauge. Upgrading with stop/start technology typical of road vehicles, however, will not happen without some encouragement. A further factor which will affect such investment decisions is the extent to which the UK's strategic freight network (and diversionary routes) is to be electrified over the next ten to 15 years<sup>[31]</sup>.



Even though the transition to rail freight is championed within the Clean Growth Strategy, there is very little on how we expect to achieve this. There is the need to have better comparative air quality data between HGVs and rail locomotives across a range of freight types and using comparable vehicles. More research is needed to look at how and where freight operations can be shifted to rail for the majority of the journey, when large distances and heavy loads need to be transported. This needs to be combined with work looking at better integration with low-emission first/last mile delivery operations. As with our overground rolling stock, there needs to be targeted investment to improve emissions performance of the rail freight sector, including retrofitting existing diesel freight engines. In addition to this, there is the opportunity to look at how the existing electric freight network could be expanded, with the potential of using bi-mode freight traction<sup>[32]</sup>.

### **Railway electrification**

As of March 2017, 42% of the total track mileage of the national rail network is electrified<sup>[28]</sup>. This figure is significantly lower than on the other principal railways of Western Europe. It had been planned to increase this proportion to 51%, with projects committed for completion by March 2019, enabling 75% of passenger traffic to be electrically operated<sup>[28]</sup>, but Network Rail has experienced problems with delivering these commitments on time and on budget. This led to some elements of the programme being cancelled, and the concept of an ongoing rolling programme of electrification has been abandoned except in Scotland (see below).

Electrification offers major opportunities to reduce the unit costs of train operation and maintenance, and to provide improved capacity, journey times and reliability while also producing significant environmental benefits. Britain has a long record since the 1950s of repeatedly showing enthusiasm for railway electrification, only to follow this with long periods with no new electrification, this cycle causing great problems for the supply chain. Transport Scotland is to be congratulated for insisting in its High Level Output Statement, published in July 2017, that Network Rail should work with its industry partners to develop “an efficient electrification technical specification optimised for Scotland that... can deliver an efficient and affordable rolling programme of electrification with appropriate plant, staff and resources based in Scotland to deliver the outputs and maximise the benefits to Scotland, including through the supply chain”.

In contrast with this, Government Ministers and Network Rail are now repeatedly stating that physically continuous railway electrification is not necessary in England and Wales (beyond the presently committed projects), arguing that the technology of bi-mode trains can produce the same benefits for passengers without the cost and disruption of electrification works. The Institution of Mechanical Engineers refutes this argument. Bi-mode trains have had to be ordered in the large quantities stated above only because of the failure of Network Rail to develop and deliver its electrification programme on time and on budget. A bi-mode intercity train is effectively a more expensive, heavier and less reliable electric train, or a more expensive, under-powered diesel train.

#### **The Institution of Mechanical Engineers recommends:**

DfT instruct Network Rail to develop an appropriate specification for railway electrification, that will achieve an affordable business case for a rolling programme to complete the electrification of the main lines between Britain's principal cities and ports, and of the urban rail networks through our major city centres.

### National Rail passenger stations

Despite growing rail passenger demand there is limited information on pollutants that commuters may be being exposed to. This monitoring needs in particular to address occupational and public health for those who work in, and travel through, railway stations where train services include high numbers of diesel-operated services<sup>[14]</sup>. Currently UK railway stations are not required to comply with air quality standards imposed by the EU, despite the fact that eight million passengers pass through them every day<sup>[27]</sup>. **Figure 3** provides data from the DfT that informs us of modal choice. The graph shows all modes have mixed purpose of use; however over half (56%) of all trips by rail are for commuting and business purposes<sup>[4]</sup>, so it is important to know what emissions these commuters in particular are being exposed to.

Major railway stations with high numbers of diesel-operated trains include London Marylebone, Birmingham (New Street and Snow Hill), Manchester (Piccadilly and Victoria), Liverpool Lime Street, Sheffield, Leeds, Newcastle, Bristol Temple Meads and Cardiff (Central and Queen Street). Being to a large extent an enclosed environment, such stations have relatively high levels of air pollution from diesel vehicles<sup>[14]</sup>. Regular commuters encounter this air pollution twice a day up to 250 days a year. Thus these travelers may experience short-term (acute eg asthma) and long-term (chronic eg bronchitis) health problems<sup>[14]</sup>.

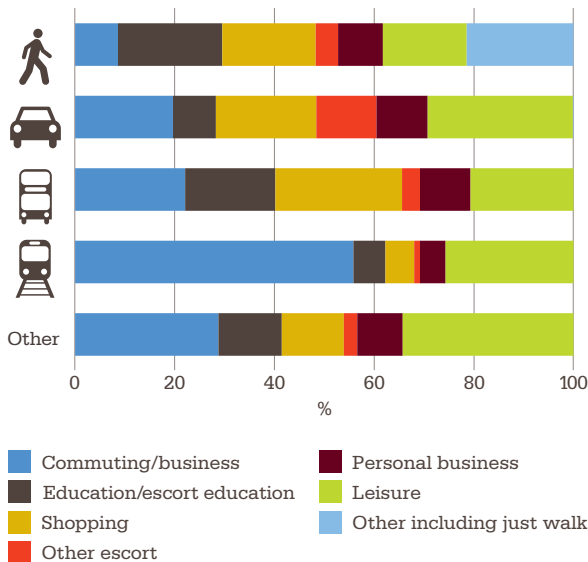
Paddington Station serves 38 million passengers annually, making it the seventh busiest station in the UK. Up to 70% of trains passing through the station are at present powered by diesel engines that are exempt from regulations for modern diesel trains<sup>[27]</sup>. In 2012, a University of Cambridge report found the NO<sub>x</sub> levels at Paddington were equal or in excess of those on the surrounding roads. Researchers evaluated the air quality levels over a period of five days and each time found them to be in breach of European limits regarding NO<sub>2</sub> for outdoor air quality. However, London Paddington, Glasgow Queen Street and Edinburgh Waverley are major stations whose passengers and staff will soon benefit from the current committed electrification programmes.

#### The Institution of Mechanical Engineers recommends:

Defra work with DfT to introduce emission monitoring equipment across our transport network (eg in streets, underground stations, enclosed railway stations, ports, airports) along with real-time on-vehicle monitoring. This will provide us with a complete picture of our baseline pollutants, which would enable us to monitor peaks throughout the day. These monitors will need to record all types of pollution including oxides of nitrogen (NO<sub>x</sub>), particulate matter (PM) and ultra fine particles (UFP). This data will help to baseline our emissions and then prioritise investment schemes to tackle pollutants in a logical, evidence-based way. This may result in financial incentives that support vehicle retrofit or scrappage programmes. The data could be used to create a traffic-light pollution index system. This could then be displayed in public locations, particularly near schools, hospitals, large shopping centres to help raise awareness and encourage public behaviour change.

DfT conduct a series of trials on existing diesel railway rolling stock, the new bi-mode trains and in major stations, to understand the level and effect exposure of pollutants has on commuters and railway workers. Some rolling stock diesel vehicles still have many years left in service, so it may be appropriate to retrofit technology, for example stop-start functionality to reduce emissions while trains are standing at platforms. The key to this is understanding the exposure that individuals are susceptible to over an average day, addressing the maximum limits and then aiming to reduce these.

**Figure 3:** Trips by main mode and purpose: England 2015<sup>[40]</sup>



## RAIL: LONDON UNDERGROUND

With five million people using the London Underground a day, we need better data on their exposure to emissions<sup>[33]</sup>. We recognise that road transportation accounts for a vast majority of pollution, but this does not relieve the rail industry of its responsibilities. While London Underground makes use of electric trains, these can cause pollution with damaging implications for health – for example metal-rich UFP from brake linings and friction between wheel and rail.

In 2017, research from the University of Surrey found concentrations of PM became much higher from the moment that the commuter gets inside the underground station<sup>[34]</sup>. Underground platforms have much higher concentrations than the platforms above ground for all pollutants, owing to a lack of dispersion in a more confined underground environment<sup>[34]</sup>.

The same study found that air quality inside underground trains was affected by the ventilation setting in the train. Concentrations were found to be higher in the tunnel sections with very high levels of PM found onboard the Northern and Victoria lines.

The majority of PM – about 90% of the dust found underground – is made up of iron oxide<sup>[35]</sup>. In 2004, a report published by the Institute of Occupational Medicine (IOM) found that London Underground (LU) workers may accumulate this iron dust in their lungs but in a concentration and form that would not cause fibrosis, emphysema, cancer, asthma, or bronchitis. It was believed that it would not accumulate in any tissues other than the lungs, and therefore not lead to haemochromatosis.

In 2016, 4-RAIL analysts carried out research to review the levels of airborne respirable dust; personal samples taken on train operators and passenger journeys travelling on the following lines: District, Jubilee, Piccadilly, Victoria Bakerloo, Central, Northern, Circle and Hammersmith & City, were all below the workplace exposure limit of 4mg/m<sup>3</sup> for respirable dust (long-term eight hour, time-weighted average – less than a shift lasts for)<sup>[35]</sup>.

The highest readings obtained from a train operator was on the Bakerloo Line, and the lowest results from train operators on the District, Hammersmith & City and Circle lines. For passengers, the highest levels were found on the Bakerloo and Victoria lines. Using Grimm laser scatter data results showed that the Piccadilly, Northern and Central Lines presented higher dust concentration than the other lines<sup>[35]</sup>.

In addition to this, the findings showed that the samples from Tottenham Court Road station's platforms – Central and Northern Lines – were significantly higher (between 0.79 and 1.15mg/m<sup>3</sup>) than the previous round of monitoring carried out in 2014 (<0.02 and 0.52mg/m<sup>3</sup>)<sup>[35]</sup>. This requires further investigation to discover why it should be so.

Currently, no limit exists for short-term exposure, but typically, short-term exposure limits are taken as three times the limit for long-term exposure, ie 12mg/m<sup>3</sup> over a 15 minute period. Therefore, the levels recorded for the train operators, 4-RAIL passengers and station personnel were significantly below the short-term exposure limit<sup>[35]</sup>.

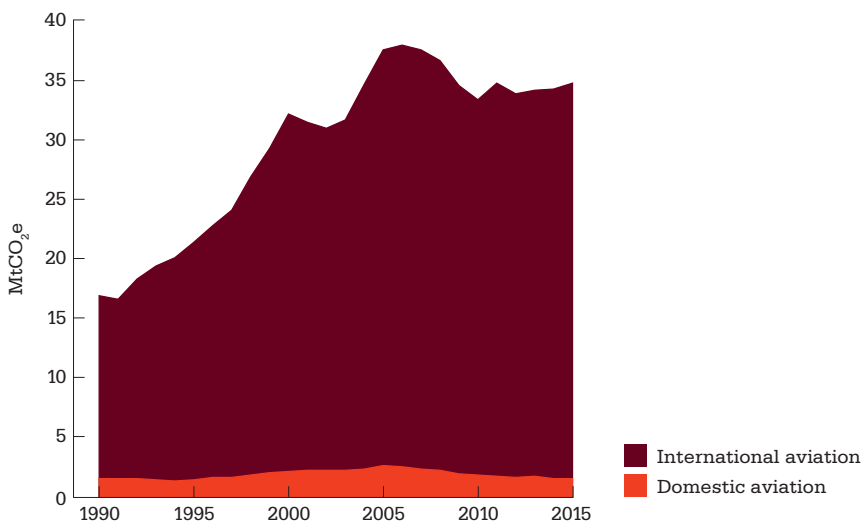
TfL has acknowledge the results produced raise concerns about the PM and UFP within the LU. To address this, it is now working closely with COMEAP (the Committee on the Medical Effects of Air Pollutants) to ensure that it is doing all it can following the latest data, to minimise the health implications that LU has for its workers and passengers.

## AVIATION

Total domestic and international aviation emissions increased by 1% in 2015, to 34.8 MtCO<sub>2</sub>e (Figure 4). A large proportion of this increase came from international emissions, which represent the vast majority of aviation emissions. International aviation emissions are currently not formally included in carbon budgets. In 2015, passenger demand rose by 5.5% and the number of flights increased by 2.5%. As emissions rose only 1% it would suggest a range of efficiency improvements have limited the increase in emissions. These could include higher load factors (eg the number of passengers per flight increased by 3% in 2015 and is now 20% higher than in 2005), improved fuel efficiency of new aircraft entering the UK fleet, and/or changes in the route mix<sup>[7]</sup>.

However, to reduce the emission impact of our aviation industry, we need to think of the aircraft and the supporting functions of the airport as one system. Low-emission surface access to our airports is fundamental; this includes good rail access to help reduce the number of road vehicles accessing these airports<sup>[36]</sup>.

Figure 4: UK aviation emissions (1990–2015)



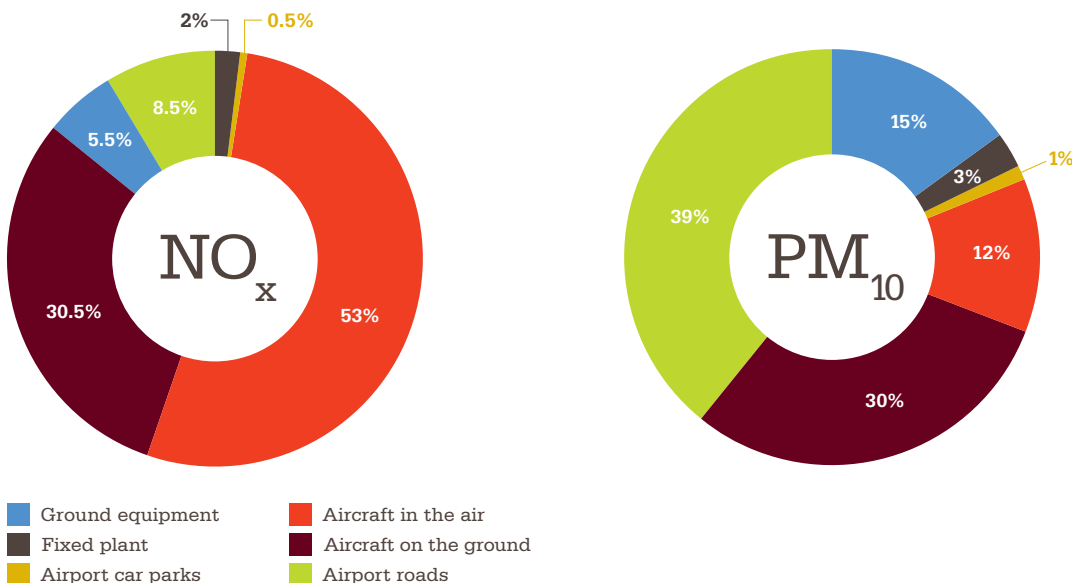


**Figure 5** shows the principal sources of airport-related emissions; the largest share of total emissions is from aircraft operations on the ground (such as on-stand power, taxiing and take-off) and in the air below 3,000 feet (1,000m)<sup>[36]</sup>.

Since July 2014, demand has been incredibly robust. Passenger traffic has risen at an average of more than 6% on a compound annual growth rate (CAGR) basis. That is well above the long-term average and a continuation of the trend enjoyed since recovery from the last demand downturn began in 2009<sup>[37]</sup>. The Advisory Council for Aviation Research and Innovation in Europe (ACARE) has a target of a 90% reduction in NO<sub>x</sub> emissions from new aircraft by 2050. The aviation sector is working to use UK airspace more efficiently, with a wide range of real-time flight information to minimise delays, improve passenger experience and reduce emissions<sup>[36]</sup>. To help meet these ambitious targets there must be policy certainty, so that the private sector will invest in alternative aviation fuels (including the extension of the Renewable Transport Fuel Obligation to jet fuel)<sup>[36]</sup>.

With seven consecutive years of growth and recent low fuel prices, there has been increasing demand for commercial passenger jet aircraft, with the in-service fleet growing by more than 3,000 aircraft in three years. This has led to the fleet age profile altering significantly. In particular, when considering the fleet age on a cumulative service profile, the proportion of 15+ year old aircraft in service today has risen globally by about 3.5% from 2013, increasing its share to 24.5% of the fleet.<sup>[38]</sup> The global commercial aircraft fleet in service is expected to increase by 81% to 49,940 aircraft in 2035. By then, 41% of the fleet is expected to be operating in Asia Pacific and China, where continued higher-than-average passenger traffic growth rates (of 5% and 8% respectively) will see those regions remain the key drivers for growth and new aircraft demand in the next 20 years<sup>[39]</sup>. It is estimated that emissions can be reduced by 1.5% annually, through improved fuel efficiency of new aircraft, aircraft modifications, airport restructuring and optimised navigational systems. However, for significant reductions long term, more renewable and sustainable biofuels (known as biojet) need to be developed for our airlines<sup>[40]</sup>. In 2012, it was estimated that the aviation sector used 310 x 10<sup>9</sup> litres (billion litres) of jet fuel, equal to 12% of global consumption of transport fuels. This is expected to increase to between 710 x 10<sup>9</sup> litres and 1,065 x 10<sup>9</sup> litres by 2050<sup>[40]</sup>. Current production levels of biojet suggest that the US could produce 3.8 x 10<sup>9</sup> litres by 2018.

**Figure 5:** On-airport emission sources for oxides of nitrogen (NO<sub>x</sub> left) and particulate matter (PM<sub>10</sub>), based on emission inventories for Gatwick (2010) and Heathrow (2013) airports.



## MARITIME

The International Maritime Organisation (IMO) is the United Nations body responsible for shipping standards. The IMO has responsibility for global standard-setting for safety, security and environmental performance of international shipping<sup>[41]</sup>.

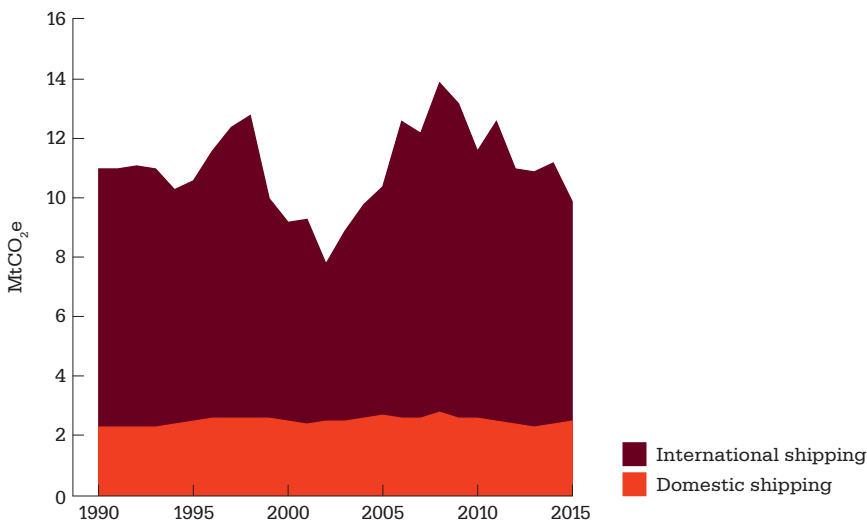
The prevention of pollution of the marine environment by ships from operational or accidental causes is covered by the MARPOL treaty. Annex VI of the treaty was adopted in 1997 to limit the main air pollutants contained in ships' exhaust gas. This includes SO<sub>x</sub> NO<sub>x</sub> and prohibits deliberate emissions of ozone-depleting substances (ODS), volatile organic compounds (VOC) and shipboard incineration<sup>[41,42]</sup>.

Total domestic and international shipping emissions fell 12% in 2015, to 9.9 MtCO<sub>2</sub>e. This continues the reduction seen in recent years, as demonstrated in **Figure 6**: emissions are now 29% below 2008 levels. International emissions fell by 16%, whereas domestic emissions rose by 5%. These could include falling ship speeds, improvements in fuel efficiency of ships, or changes in bunkering patterns (eg taking on more fuel at ports outside the UK, which would therefore not be counted towards UK emissions).

Shipping is responsible for producing only a small proportion of domestic GHG emissions (0.5%), but in pollution hot spots, such as London, action is needed to tackle emissions from all sources. Local authorities must calculate their additional impact of all new developments within built-up environments, with planning permissions for new shipping facilities requiring appropriate mitigation measures from developers. This should include, where practicable, a requirement to provide infrastructure to supply electricity to ships at berth<sup>[10]</sup>.

On the open seas, bunker oil is used almost exclusively. This is a residual refinery product, heavy fuel oil (HFO), which by comparison to fuel used in our road vehicles contain high amounts of sulphur, ashes, heavy metals and other toxic residues and sediments. Where areas are not within Emission Control Areas (ECAs), the sulphur content of marine fuels is currently capped at a maximum of 3.5%. This is 3,500 times more than is permitted in the diesel fuel used in HGVs. Cleaner exhaust gas technology has been a legal requirement for land-based freight for some time, but this is not reciprocated within our maritime sector<sup>[19]</sup>. Today about 80% of the fuel that the world's shipping fleet burns is high-sulphur (3.5%) HFO<sup>[41]</sup>.

**Figure 6:** UK shipping emissions (1990–2015)



In 2010, the IMO adopted a revised MARPOL Annex VI with the aim of significantly strengthening the emission limits. It is thought that post 1 January 2020 this will produce a significant reduction in the emissions from international shipping to the world's air pollution, from about 5% to 1.5%.

The UK is dependent on its maritime sector, as 95% of our imports and exports by volume are transported by water. Each year UK ports handle over 500 million tonnes of freight. About 80% is international traffic, but 15% is domestic cargo travelling around the coast. Water freight can offer substantial advantages over other modes: there are barges on the Thames that are capable of carrying up to 1,000 tonnes, while one HGV can typically carry just 20 tonnes and a van can carry about 1.5 tonnes. This means water freight offers important advantages for some applications, for example movement of construction materials and waste. The challenges to increased usage, where suitable, include planning, national policy and governance issues<sup>[25]</sup>.

However, freight is not the only bulk movement on our seas. Despite the economic crisis, the cruise sector has been growing rapidly. In Europe, no other tourism sector is growing as fast as cruise tourism. In 2014, 22 million passengers worldwide went on an ocean cruise<sup>[43]</sup>. There are more than 35 new cruise ships with a total capacity of about 100,000 passengers that will be introduced to the European market by 2020<sup>[43]</sup>.

### **Emission Control Areas (ECAs)**

As of 1 January 2015, a cap of 0.1% m/m (mass by mass) of sulphur content of shipping emissions came into effect. The ECAs established under MARPOL Annex VI are: the Baltic Sea area; the North Sea area; the North American area (covering designated coastal areas off the United States and Canada); and the United States Caribbean Sea area (around Puerto Rico and the United States Virgin Islands). On 1<sup>st</sup> January 2020 there will be an international reduction in sulphur emissions from 3.5% m/m to 0.5% m/m will come into effect for all international shipping outside ECAs<sup>[41,42]</sup>.

In October 2016, the IMO adopted mandatory requirements for large ships to record and report data on their fuel consumption. This broadly aligns the IMO with the EU's approach, which is also to introduce a monitoring and reporting system for CO<sub>2</sub> emissions. The IMO has approved a roadmap for developing a strategy to reduce emissions from ships. The aim is for this to be adopted in 2018, followed by a planned revised version in 2023, which will take into account the new available data from reported fuel consumption, and further consideration of measures required<sup>[7]</sup>.

### **The Institution of Mechanical Engineers recommends:**

DfT conduct a series of trials to understand individual exposure from our overground and underground railway stations, ports, airports and bus stations. We need to monitor emissions within our major transport terminals as well as on the network itself. Currently, occupational health standards are not suitable for enclosed railway stations, as there are no workplace exposure limits (WELs) for employees who work within station environments for emissions, eg NO<sub>x</sub>, SO<sub>x</sub> and PM<sup>[14]</sup>.

Defra work with DfT to introduce emission monitoring equipment across our transport network (eg in streets, underground stations, enclosed railway stations, ports, airports) along with real-time on-vehicle monitoring. This will provide us with a complete picture of our baseline pollutants which would enable us to monitor peaks throughout the day. These monitors will need to record all types of pollution including oxides of nitrogen (NO<sub>x</sub>), particulate matter (PM) and ultra fine particles (UFP). This data will help to baseline our emissions and then prioritise investment schemes to tackle pollutants in a logical evidence based way. This may result in financial incentives that support vehicle retrofit or scrappage programmes. The data could be used to create a traffic light pollution index system. This could then be displayed in public locations, particularly near schools, hospitals, large shopping centres to help raise awareness and encourage public behaviour change.

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The benefits of electric vehicles are that they produce zero air pollution emissions from their exhaust when in use and are much quieter.





## RETROFIT

We have entered the next generation of vehicle technology, but this does not necessarily mean that we should reject those vehicles that use traditional fuels and ICE. Robust solutions are needed for the existing fleet, introducing technologies and alternative fuels that can achieve an immediate impact in reducing emissions. Vehicles that make use of traditional combustion methods can now be fitted with after treatment solutions that offer emission reduction<sup>[44]</sup>. In this chapter we highlight solutions trialed in one mode that can be implemented across other transport modes, in order to reduce overall emissions.

Retrofitting refers to updating legacy vehicles by fitting a new system to clean up emissions and improve running performance. For buses, retrofits have already proved to deliver Euro VI emission performance and are reliable, with direct monitoring already in place. If a scrappage scheme is justified for diesel cars the case is even more compelling for diesel buses. Work done by the Low CVP found that Government financial support for bus retrofitting provides more than 15 times as much value as scrappage allowances for diesel cars to convert to Euro 6 or electric, and 11 times as much value from a bus scrappage scheme, compared with diesel car scrappage<sup>[12]</sup>.

The taxi market has had access to an incentive scheme to retrofit the black cab market. With the long-term move to Zero Emission Capable (ZEC) taxis, there is a complementary short- to medium-term option to retrofit existing taxis. For example, taxis can be retrofitted to run on LPG, which significantly reduces their NO<sub>x</sub> emissions compared to diesel taxis, as well as reducing their running costs. Test results for a Euro 4 London taxi converted to run on LPG show an 80% reduction in NO<sub>x</sub> emissions, 99% reduction in PM emissions and 7% reduction in CO<sub>2</sub> emissions, compared to a diesel equivalent<sup>[16]</sup>. A project from DfT is providing a grant to convert 80 black cabs to LPG in Birmingham at a cost of £500,000. In theory, this is a cost-effective solution, with an LPG conversion costing about £8,000 per taxi and paying for itself within about 70,000 miles through lower running costs (or two to three years at an average of 30,000 miles per year)<sup>[16]</sup>. This solution would also be suitable for both passenger cars and vans.

Vehicle and engine manufacturers have made significant progress over the years in reducing emissions from their engines, but legislated limits mean that exhaust after-treatments are also required. Exhaust after-treatment technology has been successfully fitted to older, heavy-duty diesel vehicles since the mid-1990s. This has enabled cities in particular to reduce their ambient pollution levels. After-treatment takes the form of one or more catalysts (including selective catalytic reduction systems (SCRs)), which convert the gaseous pollutants to harmless gases and/or a diesel particulate filter (DPF) to trap the PM. Many catalyst systems require particularly high temperatures to operate, which will be reached by larger vehicles, eg HGVs that have engines that run at a higher temperature; however this is a challenge with private passenger vehicles as they are used for shorter periods and tend to run cooler<sup>[44]</sup>. Operators that have gone down this route, have found that the additional costs incurred for fitting this technology can be recovered over an extended life cycle.

In 2014, the Euro VI standard for buses was introduced. These vehicles make use of advanced technologies such as SCR and DPFs, and deliver benefits in fuel efficiency and emissions for fleets across the UK. Results from these Euro VI buses have found a 95% reduction in NO<sub>x</sub> compared with their Euro V counterparts<sup>[11]</sup>.

Effective emission abatement technologies are currently not typically fitted to ships today, but if adopted they could have a big impact. Currently there are about 600 ocean-going vessels that have SCR systems fitted, and results show that these can eliminate most of the NO<sub>x</sub> from ships exhaust fumes. However, there has been little evidence that cruise operators (despite their responsibility to protect the health of passengers and the environment) are taking this approach<sup>[43]</sup>. An SCR system and a DPF for a large container ship cost about €500,000 each. The building cost for a ship with a loading capacity of 10,000 to 12,000 standard containers is about €100m. This would increase by a mere 1% if these technologies were fitted. If new vessels switched to a lower-sulphur diesel fuel (50ppm) and fitted DPF and SCR systems it would reduce black carbon (BC) emissions by 99%, NO<sub>x</sub> emissions by 97% and emissions of other toxic substances such as toxic metal oxides by more than 99%<sup>[19]</sup>.

The minimum operating temperature of an SCR system depends on the sulphur content of the fuel: the lower the sulphur content, the lower the operating temperature. The sulphur content of marine fuel should therefore be as low as possible. In 2013, the difference in price of marine diesel oil (MDO) with 0.1% sulphur content and diesel fuel with 0.005% sulphur content was just US\$11 a tonne in Rotterdam. The use of diesel fuel is therefore justifiable. In addition, using appropriate diesel fuel would further reduce a ship's sulphur dioxide emissions by a factor of 20.

Retrofit solutions are extremely effective for PM<sub>10</sub> and PM<sub>2.5</sub> so need to be more widely adopted across the modes. Retrofit for NO<sub>x</sub> has more recently becoming a key technology with the benefit of Euro VI in trucks and on buses as detailed above, this offers a real solution that can dramatically improve the existing vehicle parc.

### Selective Catalytic Reduction (SCR)

This is an exhaust after-treatment emission control technology. The system injects a reductant agent, typically ammonia, through a special catalyst into the exhaust stream of a diesel engine. The ammonia initiates a chemical reaction that converts nitrogen oxides into nitrogen, water vapour and carbon dioxide, which are then expelled through the vehicle tail-pipe<sup>[9]</sup>.

## ENGINE MANAGEMENT

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Engine management refers to altering the engine's performance requirements for particular scenarios. This can help with emission reduction and fuel optimisation. The aviation sector is benefiting from sophisticated engine management tools. Aircraft engines are designed to provide the high levels of thrust required for power-intensive stages of flight, such as take-off and climb. This means that not all engines need to be running to taxi on the ground. Depending on the aircraft type, either one or two engines can be shut down for taxiing before take-off and after landing. Not only does this save fuel, but it reduces emissions at the airport<sup>[36]</sup>; however, it can reduce engine life.

## SENSORS

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We are moving into a time of mass digitisation and big data. The transport market has an opportunity to use this evolution, to improve the efficiency and the design of future vehicles. Sensors have the potential not only to map pollution, but to monitor real-time emissions from our vehicles. They can integrate with schemes such as ULEZs. But for them to have a real impact, sensors have to be reliable as well as affordable<sup>[44]</sup>.

Improvements in low-cost sensors provide an opportunity to drive infrastructural and behavioural change based on real-time data. This implies they can generate information that can inform both Government and industry on where changes need to be made. To get more accurate information from these sensors, more work is needed to ensure that the data is calibrated to provide accurate information.



## LIGHTWEIGHTING AND MATERIALS

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The sector that has the biggest impact on reducing emissions through material selection and lightweighting, is the aviation sector. Weight reduction is a big contributor to fuel savings and reductions of CO<sub>2</sub>, NO<sub>x</sub> and PM for this sector. The Airbus A350 XWB is made of 70% advanced materials including titanium alloys and over 50% lightweight carbon fibre, with some parts made by additive layer manufacturing (ALM) or 3D printing. Airbus is using this technology to shape the future of aircraft component manufacture for its jetliners. Benefits of ALM include lighter parts, shorter lead times and fewer materials used during production, so there is a significant reduction in the manufacturing process' environmental footprint. For the A350 XWB, Airbus has produced a variety of plastic and metal brackets, whose material and structural properties have been tested and validated<sup>[36]</sup>.

## EMISSION CONTROL AREAS

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Today, local authorities are introducing Clean Air Zones (CAZs) and Ultra Low Emission Zones (ULEZs) within our cities. These interventions can be an effective way to persuade people to travel more sustainably and help reduce air pollution<sup>[18]</sup>.

The maritime sector has also implemented ECAs that allows only a maximum permissible value for sulphur content of 0.1% m/m of the fuel to be used in these regions<sup>[43]</sup>. Ships that use these areas need to be equipped with a (TIER III) modern engine, or one that is fitted with an SCR system that cleans exhaust emissions<sup>[43]</sup>. Tier III vessels offer a reduction of 80% NO<sub>x</sub> emissions compared to Tier I engines. There are more than 500 ships today that have SCR already built in<sup>[43]</sup>. The US environmental agency EPA, estimates that the introduction of the ECAs will save about 320000 tonnes NO<sub>x</sub> emissions (23%), 90,000 tonnes PM<sub>2.5</sub> emissions (74%) and about 920,000 tonnes SO<sub>x</sub> emissions (86%) a year. It is forecast that these reductions could prevent approximately 14,000 premature deaths and alleviate respiratory diseases and symptoms of about 5 million people<sup>[43]</sup>.

## TRANSPORT ALTERNATIVE ENERGY OPTIONS

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### Electric vehicles (EVs)

The benefits of EVs are that they produce zero air pollution emissions from their tailpipe when in use and are much quieter. While our grid is not completely green, the well-to-wheel GHG emissions of an electric bus when charged using the UK electricity grid are more than 60% lower than a typical diesel bus, and the increasing use of renewable electricity will further reduce the carbon footprint of electric buses<sup>[45]</sup>.

Much of the investment and focus when looking at low-emission vehicles points consumers in the direction of EVs, from incentives to buy such cars, to mass investment in charging stations. However, there still remain key bottlenecks with the requirement for long lasting, lightweight (high energy density) and low-cost batteries<sup>[44]</sup>.

There is also the question of the sustainability of these batteries. Many still use rare earth materials, which are sometimes extracted using unethical methods, and it largely remains economically unviable to recycle and breakdown the batteries in terms of re-use of materials. It is of the utmost importance that lifecycle analysis remains at the forefront of our discussions, so that we don't leave future generations with significant problems.

Our national rail passenger service is also adopting electrification as a solution. In January 2015, the first modern British electric train with supplementary traction batteries (the so called Independently Powered Electric Multiple Unit (IPEMU)), operated service trials on the route between Harwich and Manningtree in Essex. This was the result of a partnership between train manufacturer Bombardier, train operator Abellio Greater Anglia and Network Rail<sup>[27]</sup>. The trials were a technical success and provided practical data on the required battery capacity and potential duty cycles for such a train. The train has now been restored to standard configuration. Some routes have been suggested where an IPEMU could operate to fill present or future gaps in the electrified network, but no orders have yet been placed for such a train in Britain.

In addition, light rail vehicles with supplementary batteries or super capacitors can operate in town centres without overhead electrification where this would be obtrusive. This will be demonstrated on the Edgbaston extension of the Midland Metro in the near future.

### Plug-in hybrid vehicles

Plug-in hybrid technology offers a stepping-stone to full electrification for vehicles. For example, plug-in hybrid buses can give the zero-emission benefits of an electric bus in the city centre combined with the range and flexibility of a diesel vehicle for sections of the route that are less emissions-sensitive or beyond the reach of EVs. Manufacturers can control and force the electric mode of a plug-in hybrid bus using GPS, known as 'geofencing', in defined geographical zones. Geofencing has the ability to take into account time of day, so a route connecting a residential area to a city centre could deploy EV mode in the city during the day, or during the night to reduce both noise and emissions<sup>[45]</sup>. However, with hybrid vehicles it must be noted that as these vehicles have both powertrain systems there is an increase in weight of the vehicles which leads to an increase in the energy consumption required to run them.

Plug-in hybrids offer many opportunities as they can be matched to the usage profile of a user; meaning that using a plug in vehicle for lots of long motorway journeys is a bad idea but for multiple short journeys and an occasional long journey is an ideal profile, and obviates the restriction of public infrastructure. Plug-in vehicles allow users to more rapidly electrify the mileage that is most important to air quality, without compromising the overall flexibility of a vehicle.

### Hybrid vehicles

A hybrid electric vehicle combines an ICE or hydrogen fuel cell with an electric propulsion system and associated batteries. This works by using regenerative braking, when the driver brakes, kinetic energy is captured in a battery or a flywheel and stored for use later, when it is required for propulsion. The next time the vehicle accelerates, the stored energy is fed back to the driving wheels, reducing the load on the engine, saving fuel and reducing CO<sub>2</sub>, and other emissions. Hybrid buses have been found to save 30% or more in fuel consumption compared to conventional diesel vehicles. The latest Euro VI hybrid buses can achieve very low levels of emissions, offering benefits in cities with poor air quality while helping to cut CO<sub>2</sub> emissions significantly<sup>[45]</sup>.

A key message here (and particularly relevant in commercial vehicles), is to encourage a spectrum of electrification technologies, properly matched to usage profiles to maximize each technology and to make the biggest overall impact. This applies to both passenger and freight vehicles. We need to get away from the 'one vehicle for all tasks' and towards a more 'right tool for the job' approach.

## Hydrogen

This technology is at a less advanced stage than electric batteries and faces significant difficulties with storage, durability, reliability and safety, in addition to cost and supply chain considerations<sup>[44]</sup>. The hydrogen transport sector is in the early stages of commercialisation, with only a small number of vehicles currently on the roads in the UK. Hydrogen fuel cell buses have been given particular attention, with several large demonstration projects to explore the practical, economic and environmental case for city operation<sup>[45]</sup>. For the bus sector, hydrogen buses offer zero tailpipe emissions and longer range than electric models, though costs are higher. They use a hydrogen fuel cell to power an electric motor, which provides propulsion. The fuel cell converts chemical energy from hydrogen reacting with oxygen into electrical energy, producing only water vapour as a waste product<sup>[45]</sup>.

Hydrogen production methods vary significantly in carbon intensity. In the UK it is produced industrially, through steam reforming of natural gas, compressed and transported by road to a fleet operator's refuelling station. Steam reforming of natural gas is an energy-intensive process and has a high carbon footprint. A lower-carbon method of generating hydrogen is via the electrolysis of water. This involves running an electrical current through water in an electrolyser, to split the water into hydrogen and oxygen. By using electricity from renewable sources in this process, the hydrogen can be produced with very low carbon emissions<sup>[45]</sup>.

In June 2016, in its report Meeting the Carbon Budget, the Committee on Climate Change, said that hydrogen could play a major role in reducing carbon emissions from transport, especially for HGVs from 2030. It expects that due to advances in technology and investment in the required infrastructure, by that time hydrogen-fuelled HGVs will be a realistic and competitive option for fleet operators. However, there is no hydrogen technology available and viable for use in heavy trucks at this stage, and most vehicle manufacturers do not see hydrogen playing any significant role in powering heavier HGV duty cycles before 2050<sup>[13]</sup>. This needs to be adopted if we expect to see a change in the future.

One mode of transport that will soon be demonstrating H<sub>2</sub> as an energy alternative is rail. A new fleet of Alstom's Coradia iLint hydrogen fuel-cell powered trains are expected to enter service next year on regional services in northern Germany, replacing diesel-powered trains. The infrastructure for production of hydrogen already exists in this region. Trains have inherently long service life, so if these vehicles can evolve flexibly and utilise these new technologies, there is the potential to significantly change plans for the replacement of existing diesel trains and for the electrification of some secondary routes by using electricity to generate hydrogen and then using this hydrogen to power the train<sup>[28]</sup>.

## LPG vehicles

Well-to-wheel analysis suggests LPG-fuelled vehicles generate 14% fewer CO<sub>2</sub> emissions than petrol cars and 10% fewer than diesel vehicles. LPG is particularly clean-burning and produces less PM. LPG cars produce 50% fewer nitrogen oxides than petrol, and 20 times fewer than diesel.

The UK has adopted some LPG infrastructure with over 1,400 filling stations. However, despite the economic and environmental benefits of LPG, it remains a niche transport fuel, with only about 43,000 LPG cars on the road in Great Britain (0.1% of the total fleet) and 10,000 LPG vans (0.3% of the fleet). In Europe LPG is far more common: 46,436 filling stations and 8 million LPG vehicles across Europe as a whole, representing about 3% of the car fleet<sup>[16]</sup>.

## LNG vehicles

This is a solution that the maritime sector is considering, however, LNG will not be available at scale for 2020, due to the high cost of retro-fitting a vessel to use it, a lack of infrastructure to support refueling ships and no existing regulations on how LNG must be handled. The use of LNG as a marine fuel has been limited to date, but an increasing number of vessel owners are now exploring its use. LNG exceeds all IMO emission standards and could be significantly cheaper than HFO. However, the cost of retro-fitting a vessel with LNG is in the tens of millions of dollars. It is therefore, more likely to be seen as an alternative fuel for new ships. Finally, in order to be scalable, there needs to be considerable investment in purpose-built infrastructure as well as a new set of guidelines and regulations for the handling of LNG<sup>[41]</sup>.

## Biofuels

Biofuels, which include bioethanol, biodiesel and biogas, can help reduce CO<sub>2</sub> by replacing fossil fuels with those derived directly from plants, or indirectly from agricultural, commercial, domestic, and/or industrial waste. Biofuels can have an impact on reducing PM. Petrol and diesel sold in the UK already contain biofuels; E5 allows for up to 5% of petrol to be made up of ethanol and B7 allows for up to 7% of diesel fuel to be biodiesel. This is driven by the UK's Renewable Transport Fuel Obligation (RTFO). The adoption of road transport biofuels is one of a package of measures Government has introduced to reduce road transport CO<sub>2</sub> emissions. The UK is looking to introduce E10 (10% bioethanol blended with petrol) in the near future. It is estimated that in 2015 more than 92% of petrol cars were suitable to use E10 petrol<sup>[46]</sup>. It is important that the fuel quality is correct to avoid any issues which impede the normal operation of the vehicle and tarnish the image of biofuels. The higher use of biofuels could help reduce emissions from the vehicle fleet. However, the source of the biofuel is important to sustainability and broader environmental issue<sup>[22]</sup>. Based on current carbon savings from bioethanol and the carbon intensity of electricity generation in the UK, the introduction of 95 E10 with 85% take-up would reduce Carbon Dioxide emissions by 0.76mt per year (0.61mt applying EU ILUC factors), which is the equivalent of replacing 2.17 million petrol cars with Nissan Leaf models<sup>[46]</sup>.

Globally, about 4% of transport fuels are now biofuels, with about 0.8% of the world's total energy supply coming from biofuels in 2015<sup>[47]</sup>. The US and Brazil dominate the world's production of biofuels, together producing almost three quarters of the global total in 2015, largely from corn and sugarcane with the expectation that production will continue to increase in the foreseeable years. Note: hydro-treated vegetable oil (HVO) is a form of biodiesel produced from vegetable oils and fats by treating them with hydrogen, rather than methanol as for other biodiesels<sup>[47]</sup>.

The UK produces less than 2% of the world's biofuel. About three quarters of the biofuel used in the UK is imported, so it is important to recognise that the feedstocks can add significantly to their carbon footprint. Shipping adds between 7% and 38% to the total carbon footprint of biofuels transported over 10,000km<sup>[47]</sup>.



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Globally, about 4% of transport fuels and 0.8% of the world's total energy supply come from biofuels.





## Synthetic/paraffinic fuels

These are synthetically manufactured and can be used as a drop-in (substitute) fuel for diesel engines. Because the fuels are synthetic the manufacturing process produces more consistent and uniform molecules compared to conventional crude oil refining. This improves their combustion properties and therefore can reduce air pollutants when used in a standard diesel engine. They are also free of unwanted components such as sulphur, metals and aromatics. This makes them nontoxic and less harmful to the environment.

## Gas to liquid (GTL)

This is a drop-in fuel created by Shell. It is easy to integrate with new and older on-road diesel engines and requires no infrastructure investment. It offers lower emissions of PM, NO<sub>x</sub>, hydrocarbons (HC) and carbon monoxide (CO) and has been found to reduce engine noise by 1–4dB. It is classified as nontoxic and readily biodegradable, it is likely to be more benign, biodegradable and pose fewer environmental hazards than conventional diesel. There is less smell and some customers have said it was odourless. As there is no bio component, GTL offers good oxidation stability. Shell worked alongside Deutsche Bahn (DB), the German rail company, to see what performance benefits the fuel offered.

Tests demonstrated emission reductions (under loading) of 6% in NO<sub>x</sub>, 28% in PM, 14% in CO and 11% in HC. However, when idling, performance was even better: 22% in NO<sub>x</sub>, 54% in PM, 32% in CO and 21% in HC. It seems that this fuel may provide a viable solution to help with the reduction of emissions from diesel-powered rail vehicles on non-electrified routes, as well as an alternative for our HGVs<sup>[48]</sup>. In 2014, trials were conducted by Dutch not-for-profit company TNO, addressing the opportunity for GTL within marine applications. It was found GTL could reduce NO<sub>x</sub> emissions in the range of 8–13% and, 15–60% for PM<sup>[48]</sup>, however, the processing increases costs by about 10%.

## Low-sulphur fuels

The use of low-sulphur fuels would have an immediate effect on the emissions produced by our marine sector. This reduces both sulphur oxides and heavy metal emissions (above all lead and tin) without necessitating technical conversions.

Transportation costs account for an average of 2–3% of a product's total costs. A standard 20-foot container (TEU) can be shipped from Shanghai to Hamburg profitably for about €1,000 (£900). The capacity of containers this size is about 28,000 T-shirts or just under 3,500 shoe boxes. This equates to about 2p and 30p per unit respectively<sup>[19]</sup>.

In comparison to HFO, the additional costs for lower-sulphur fuel (0.005% m/m) amounted to approximately 45% in the second half of 2013. Fuel costs account for about 26% of freight costs. This means the shipping costs increase by only 12% if the diesel fuel is used instead of HFO. These costs could be offset by means of 'slow steaming' when a vessel slows down to reduce its engine output and to save fuel. Even if it were not possible to offset this additional cost anywhere, it could be added to the end product – adding just 0.2p or 3p more respectively to the T-shirts or shoes<sup>[19]</sup>.

### **With the solutions available the Institution of Mechanical Engineers believe that it is important for:**

BEIS to work with DfT to fund research through the Clean Air Fund and Innovate UK to create programmes to clean up various transport modes. One challenge may include research into how to clean up the particulate matter (PM) and ultra fine particles (UFP) emissions from our congested streets, underground platforms and rail track beds removing particulates and preventing recirculation. These new funding calls could be focused on reducing overall emissions, reducing congestion or improving mobility rather than the traditional calls that are focused on individual modes of transport.

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In 2015, only 2% of trips in England were made by bicycle, despite the average length of all trips being seven miles.





# BEHAVIOURAL CHANGES/INDUSTRY CULTURAL CHANGE

Future hopes are for towns and city centres to be pleasant places to shop, work and socialize in, with clean air, safe streets, and fast, efficient, affordable public transport. To create this environment, there needs to be a modal shift away from the car to sustainable forms of transport: walking, cycling and public transport. Cars are inefficient in comparison to other modes of transport, limiting the number of people moving around. Cities that have a higher percentage of people travelling by sustainable modes are generally more vibrant, healthy and prosperous. This would create a virtuous circle of falling costs, higher bus frequencies, lower fares and higher patronage<sup>[12]</sup>.

In 2013 the Institution of Mechanical Engineers published its Transport Hierarchy policy paper. This hierarchy (**Figure 7**) aimed to get individuals to think more intelligently about how to travel. By reducing journey demand through initiatives such as flexible home-working solutions, it could help ease congestion and reduce emissions. Sustainable business travel modes, for example cycle commuting, public transport for business travel or encouraging lift sharing for commuter travel, could all have a positive impact<sup>[49]</sup>.

Our infrastructure planning needs to incorporate this approach into its implementation. For example, the introduction of cycle highways in UK cities is welcome; the fact that we have built them by congested roads suggests the decision on location was not well thought through. As individuals cycle on busy roads they are using more energy and therefore breathing deeper so while they may believe they are improving their fitness and wellbeing they might actually be causing themselves more damage, as the pollutants are inhaled deeper into their lungs.

In 2015, only 2% of trips in England were made by bicycle, despite the average length of all trips being only seven miles. Switching from cars to bikes would not only reduce air pollution, but solve many of the biggest issues facing our cities and towns. Congestion is estimated to cost the UK economy £11bn a year and is getting worse. While a 3.5 metre-wide single lane can transport 2,000 people an hour in cars, the same lane can be used to transport 14,000 people on bicycles. Mixing human-powered transport with efficient, green public transport is something we need to strive towards.

Figure 7: IMechE Transport Hierarchy<sup>[49]</sup>

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

## TRAFFIC MANAGEMENT AND CONGESTION

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Air quality discussions often fail to address traffic congestion. In nose-to-tail traffic, tailpipe emissions are four times greater than they are in free-flowing traffic. Over the past decade we have seen congestion steadily increasing in all our major cities. Tackling air quality is not just about getting rid of older, more polluting vehicles; it is about reducing the number of vehicles in congested urban areas where the air quality problem is most acute.<sup>[12]</sup>

Congestion does not affect just our health, it has an impact on our businesses. The cost of congestion for an HGV is calculated by Freight Transport Association (FTA) at £1 a minute, meaning that congestion is a costly factor in servicing urban areas; adding to the cost of road freight and increasing the cost of living or operating a business. Stop-start traffic also has a negative impact on fuel consumption, emissions and air quality. According to information supplied to FTA by manufacturers, a comparison of an HGV travelling at 30mph that stops three times in a mile and then gets back up to speed, and one that cruises at 30mph, shows a tripling of emissions<sup>[25]</sup>.

As consumers, our insatiable demand for online shopping continues. Online sales accounted for approximately 14.6% of all retail spending in 2016. 'Click & Collect' has become increasingly popular, allowing consumers the flexibility of collecting their goods when convenient and reducing the number of failed deliveries. It was expected that this 'Click & Collect' service would reduce traffic but this remains debatable, especially if it results in an increase in demand for same-day delivery<sup>[25]</sup>.

So how do we rectify this? During the 2012 Olympic Games, TfL adopted an approach to minimising the impact of freight on businesses operating in London, based on '4 Rs': reduce, re-time, re-route and re-mode<sup>[16]</sup>. We need to consider a similar system for London and other major UK cities. In some areas it already applies, as the London Boroughs Consolidation Centre was initiated by Camden Council, in partnership with Enfield, Waltham Forest and Islington Councils. These councils now use a single consolidation centre for all council deliveries. The project has led to a 46% reduction in the number of vehicles delivering to council sites and a 45% reduction in the total distance travelled by these vehicles. As a result, the project achieved a 41% reduction in CO<sub>2</sub> emissions, a 51% reduction in NO<sub>x</sub> emissions and 61% reduction in PM compared with previous delivery systems<sup>[16]</sup>.

Modal switch is another approach that would help reduce congestion. Our bus network effectively tackles congestion, with one bus moving ten times as many people as a car (based on average vehicle occupancy for both). A fully loaded double-decker bus could take up to 75 cars off the road. So more discussions over bus priority measures could enable more effective management of road space and speed up journeys, offering high value for the taxpayer. Effective investment in bus infrastructure can generate up to £7 of net economic benefit for every £1 invested<sup>[12]</sup>. However, one of the challenges that we face is changing behaviours. More needs to be done to encourage people to get out of their cars and on the bus. Currently drivers do not want to give up their freedom to be in control of their own travel.

## WEARABLES

It is not just the ground that gets congested; our airspace is also being affected. Through more sophisticated electronic data systems, there are a number of emerging opportunities to improve the efficiency of how aircraft traffic flows are managed, both in the air and on the ground, to avoid aircraft queueing, minimise delays and prevent unnecessary emissions. National Air Traffic Services (NATS) has been working with airport air traffic controllers and airlines, to promote smooth taxiing and avoid unnecessary stop/starts. By providing early information so that pilots plan for expected ground routings, air traffic controllers help avoid unnecessary stops at taxiway junctions and as a result reduce fuel burn and emissions. Putting this in context, a Boeing 737-300 burns about 13kg of fuel per minute during ground taxiing – the cost of a taxiway stop/start is about £50 in fuel. Taxiway stop/start for a long-haul aircraft can cost £200 in fuel compared to a smooth continuous taxi operation<sup>[36]</sup>.

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We are in a time that is ever increasingly digital, with the cost of electronic systems diminishing. Open and big data are enabling quality information to be gathered and used to inform decisions. Through the use of low-cost air quality monitoring sensors, we can obtain evidence about the pollution to which we are being exposed.

As our cities become smarter, linking sensors and data to the management of urban infrastructure will allow us to predict air pollution. This will enable real-time reactions to manage traffic flows and public transport, with the aim to reduce pollution on our infrastructure. Data and analysis should be used to influence urban planning and design decisions. In order to provide reliable data, low-cost and miniature sensors will require a greater degree of reliability and robustness. These sensors and emissions data will help inform and develop legislation and regulation<sup>[44]</sup>.

An example of a wearable air quality tracker, the Flow, was launched in January 2017 by Plume Labs. The device essentially sucks air into a valve from its surroundings. It then uses internal sensors to scan this air for particulate matter, nitrogen dioxide, ozone, volatile organic compounds (VOCs), temperature and relative humidity. The user can then see the air quality rating, scored on a range from 'fresh' to 'extremely polluted' via 12 LED lights (the more polluted the air, the redder the lights) or view a 12-hour historical exposure set<sup>[14]</sup>. This is a connected device, so the information captured by each of the monitors will help feed the data of various geographical locations to help inform the 'Plume reports' giving real-time data to consumers about the air quality within their cities.

## TAKING CONTROL

Amid all the doom and gloom portrayed by the national media, there is the positive news that general awareness of the challenges we face with both air quality and climate change has increased<sup>[10]</sup>. The work being championed by Government in switching from ICE to EVs will help reduce early deaths associated with air pollution, but it will do little to encourage greater physical activity. In England in 2012, only 67% of men and 55% of women met physical activity recommendations, with a similar picture in Scotland, Wales and Northern Ireland. Research from the University of Glasgow recently found cycling regularly reduced the incidence of cancer by 45%, heart disease by 46%, and death by any cause by 41%. TfL has also run its own calculations and found that if all Londoners walked or cycled for 20 minutes a day, this would save £1.7bn in NHS treatment costs over 25 years in the capital alone.

Citymapper is a leading application, which provides an integrated set of information on public transport, walking, cycling and even Uber private hire vehicles in London, but it does not currently provide information on car club locations. TfL and other local transport providers need to work alongside car clubs to produce a consolidated feed of data on car-sharing locations and availability to integrate into navigation applications allowing user choice<sup>[16]</sup>.

Sustrans (a charity making it easier for people to walk and cycle), in partnership with Living Streets (a charity for everyday walking) and TAS Partnership (TAS is a transport consultancy that provides research, advice and data analysis across all modes of ground passenger transport service), has created an active travel toolbox to make the case for improved walking and cycling schemes. The toolbox is designed to link issues and people working on them – for example, bringing transport planners, health practitioners and spatial planners together. It includes guidance, tools and case studies to make the economic case for walking and cycling to decision-makers and funders, and ensure plans for local housing growth will align with sustainable transport modes, rather than encouraging more car journeys.

### **The Institution of Mechanical Engineers recommends that:**

DfT and DH work together to create a campaign that informs people of the health benefits of switching to lower-emission modes of transport, for example a switch from car to bus. However, for such a campaign to be a success, individuals would need to have confidence in the frequency, reliability and cost of their new mode.



**In addition to this toolkit there are general best practice advice pointers that people can adapt their travel to fit around:<sup>[50]</sup>**

- Transport does not always have to be powered; walking, cycling, rollerblading, skateboarding and using a scooter are viable alternatives.
- When using non-powered options try to use alternative routes away from busy roads, as this will reduce your exposure to pollutants
- Try to avoid travelling at the busiest times.
- If there are trees, try to keep them between you and the road, as they can capture some of the fine particles and act as a shield.
- When walking on a hill, stay on the side of the road where traffic is driving downhill – vehicles use less fuel to drive down hill and will be causing less pollution.

**When in a car:<sup>[50]</sup>**

- Close windows and vents when stuck in traffic. The same applies for tunnels.
- If you can, try driving at less busy times to reduce your exposure.
- Consider electric or hybrid vehicles and avoid diesel where possible.
- Avoid leaving the car idling or “ticking over”, especially near schools.

**At home:<sup>[50]</sup>**

- If you live on a busy road keep windows closed at peak times, or open windows facing away from the road.
- Avoid burning solid fuel (wood and coal) if you live in a densely populated area.
- Open your windows and use your extractor fan when cooking with gas and oil, as this also contributes to air pollution.
- If you live in a rural area, keep windows closed during pesticide spraying season.

## BUSINESSES BEING PROACTIVE

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Much of what is discussed requires businesses to take the initiative and adopt the hierarchical approach. It is important to acknowledge that some of the solutions presented require large capital expenditure, but not all do. For example, Bristol Airport's driver training has reduced emissions from airport buses by 12%, with alternatively fuelled vehicles eliminating even more.

Companies that use seagoing vessels to import or export their components and products need to actively demand the use of lower-carbon and lower-sulphur fuels from the ships owners and logistic companies<sup>[19]</sup>.

Businesses must review their car use policies and reward schemes (for example companies give car allowances but do not always offer rail season ticket loans). Organising car clubs for employees, or providing a cost-effective solution for businesses in place of private pool car fleets, could reduce the overall environmental impact of commuting. Such an approach could lead to a reduction in emissions, and the space required for car parking too. This initiative has been adopted by Jaguar Land-Rover: the company has modified its corporate travel policy encouraging sustainable travel, which has enabled it to remove one car park entirely and expand its manufacturing facilities<sup>[49]</sup>.

## POLICY

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Government is investing over £900m in clean transport via the Office of Low Emissions Vehicles (OLEV), including rolling out electric vehicle charging infrastructure and providing grants for purchasing ultra-low emissions vehicles (ULEVs). It is also supporting research into clean engine technologies in collaboration with industry through the Advanced Propulsion Centre. While these initiatives are making some progress, in order to see the major advances we need, it is vital to consider our transport network as a whole system providing mobility for all. This means that we must not leave certain parts of our transport network behind in terms of cleaning up their emissions; this starts with monitoring and understand just how damaging they are.

We must to start taking ownership for our actions; while sometimes it can be difficult to see the impact that we have as individuals, we need to think that every little helps and demonstrate good practice to those around us. There is hope that the Clean Air Strategy that is to be launched by BEIS in 2018 will look at both national and international commitments to help reach emission reduction targets for the five key air pollutants. This needs to focus on how we can reduce usage, through improving the energy efficiency of buildings, maximising opportunities for renewable energy, changing lifestyles, patterns of production and consumption, and using energy and resources more efficiently in the production of goods and services.

In addition to this BEIS has stated that it will be producing a strategy that shows how it expects to achieve zero emissions for road vehicles. This needs to look across all our modes, to ensure that we are looking at the complete picture and not just targeting individual transport types.

Local government needs to demonstrate integration, showing how the region understands that there are links between our transport behaviours and infrastructure developments, and the impact that this will have on our environment. This joined-up thinking and the approach need to be adapted to suit all UK regions. This must include addressing procurement contracts for our transport providers, specifying the minimum standards for vehicles that are used on local government contracts. This approach is currently used by Transport for Greater Manchester. Local authorities need to work in coherence and alignment with legislation put in place by Government, to ensure that we have a consistent approach to reducing emissions and improving air quality across the country. It will be down to the local authorities to then identify cost-effective ways of accelerating the replacement of pre-Euro VI vehicles.

The key to success with behaviour change is collaboration; between companies for goods and people for shared mobility solutions. A critical enabler for these is big data. Data driven mobility could efficiently unlock significant improvements. However, we cannot offer a mobility solution that is a backward step from where we are now. The solution has to be, for example, one that encourages someone to park their car outside town and take a bus into the town centre. However, this must offer benefits in access to the option of taking the car all the way into the town centre. We need our policies to work out how to create and encourage these “no brainer” behaviour changes. Fiscal measures can play a big part in this process.

**The Institution of Mechanical Engineers recommends that:**

DfT and DCLG work with surface transport operators (buses, rail and freight), addressing how to maximise the reduction of pollutants through incentivising the right actions. This needs to include the reduction of legacy vehicles with poor emissions across the network, including cars, taxis, vans, buses, trains and HGVs.

DfT and DCLG work alongside freight and logistics operators, to help address the efficiency of the network, and to consider incentivising when deliveries take place. This would help reduce the concentration of pollutants during the morning peak which in London were found to be 13–43% higher than during the afternoon or evening peak<sup>[8]</sup>. However, such an approach on reducing congestion must also address passenger transport efficiency, which could additionally have a large impact on reducing emissions at these peaks.

BEIS to work with th DfT to fund research through the Clean Air Fund and Innovate UK, to create programmes to clean up transport modes. One challenge may include research into how to clean up the particulate matter (PM) and ultra fine particles (UFP) emissions from our congested streets, underground platforms and rail track beds, removing particulates and preventing recirculation. These new funding calls could be focused on reducing overall emissions, reducing congestion or improving mobility, rather than the traditional calls that are focused on individual modes of transport.

# CONTRIBUTORS

## Lead author

- Philippa Oldham CEng MIMechE

## Contributors

- John Bickerton CEng MIMechE
- Andrew Bradley CEng FRAeS FIMechE
- Dr Colin Brown CEng FIMechE
- Malcolm Dobell CEng FIMechE
- Eur Ing Richard East CEng FIMechE
- Andy Eastlake CEng FIMechE
- Bridget Eickhoff CEng FIMechE
- Professor Richard Folkson CEng FIMechE
- Andrew Fraser CEng FIMechE
- Eur Ing Daniel Kenning
- Stephen Kent CEng MIMechE FHA
- Chris Kinchin-Smith CEng FIMechE
- James Lyon
- Richard McClean CEng FIMechE
- Mark Munday CEng FIMechE
- Graham Neil CEng FIET FIMechE
- Cliff Perry CEng FIMechE
- John Phillips CEng FIMechE
- Stephen Phillips CEng MIMechE
- Brian Robinson CEng MIMechE

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**Institution of  
Mechanical Engineers**

1 Birdcage Walk  
Westminster  
London SW1H 9JJ

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

[transport@imeche.org](mailto:transport@imeche.org)  
[imeche.org](http://imeche.org)