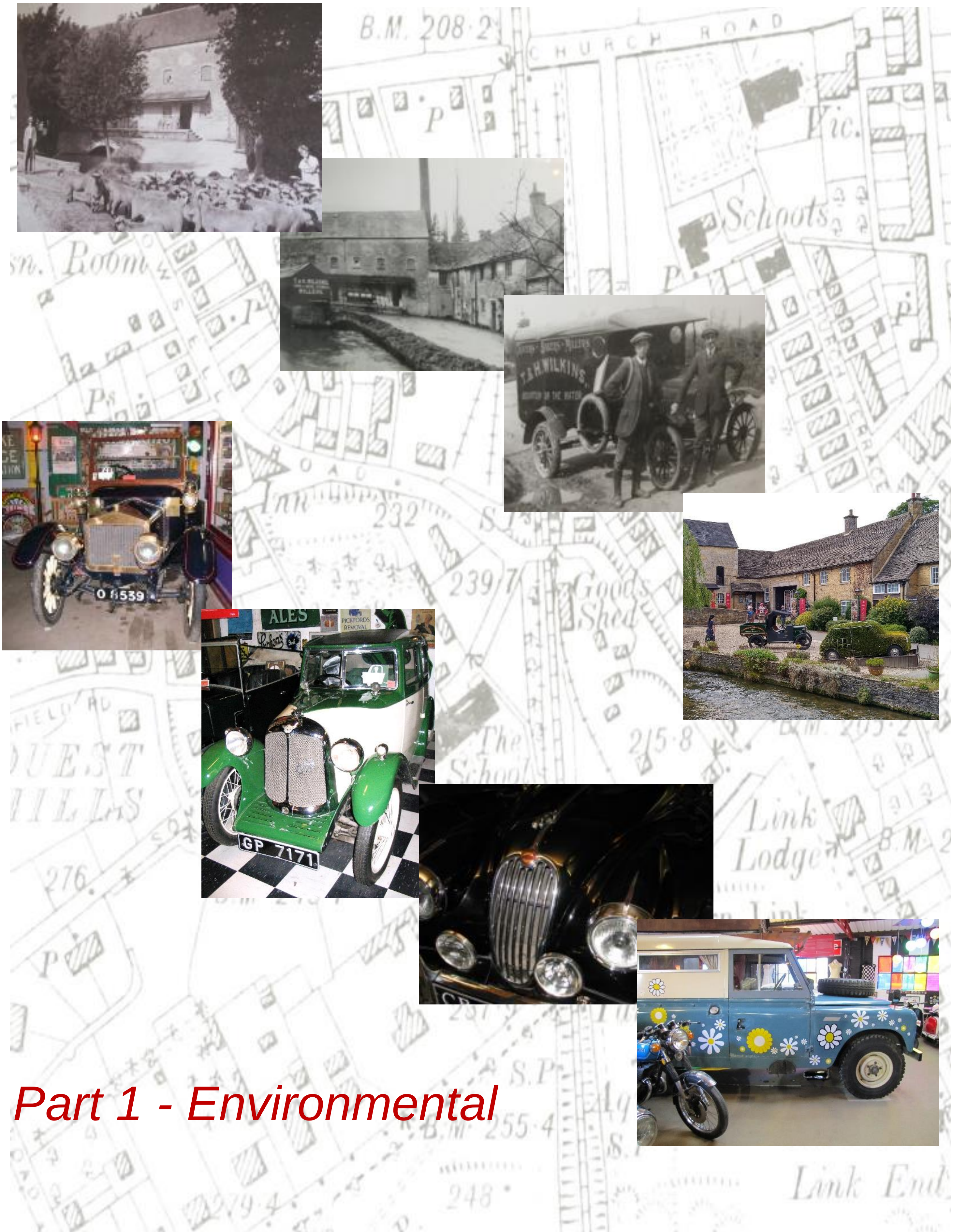
The Direction of Travel:
Motoring from The Past to The Future



Part 1 - Environmental

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Source of right-hand image above: Metropolia University of Applied Sciences, Helsinki, Finland.

Contents of Part 1 – Environmental

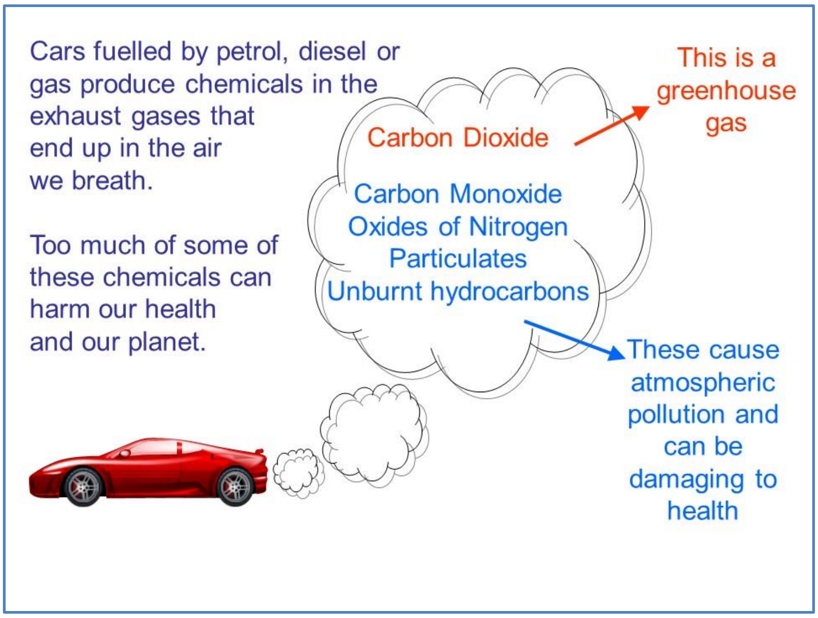
Part 1 - Environmental | Introduction

The change to our environment over the last 130 years as a consequence of motoring is clearly vast and in some areas changes have crept up on us almost subliminally.

A time-traveller from the early days of motoring, parachuted into the 21st century, would be astounded at the incessant noise levels around our main roads, the high level of artificial light, much of which is for the benefit of the motorist and the sophistication of the supply and maintenance infrastructure developed to support our motoring, all of which we largely accept as just part of modern life.

Equal astonishment would likely be aroused by the way in which the car and commercial vehicles have revolutionised what we today call our supply chain. Fresh produce to shops across the country within hours of being gathered or off-loaded at the ports provides choice and health benefits unavailable at the dawn of the motoring age, the car providing that final link to home in the chain.

As little as ten years ago, the diminishing supply of affordable oil to power our automotive-centred lifestyle was a major concern: had we reached or even passed peak oil production? Today, with greater awareness of the consequences of burning the products of fossil fuels, our concerns are around the effect, on our health and on our planet, posed by the gases and particulates pumped into the atmosphere by our cars and commercial vehicles.



Part One of this book summarises some of the latest research into the effect on our health and on the well-being of our planet which can be directly related to our dependency on a means of transport powered by the internal combustion engine. It is not just the ***usage*** of the car however that has environmental implications; is it better to retain an older, less, environmentally- friendly car or to incur the one-off environmental cost of new car production and end of-life scrappage? Retain or replace? In addition, are there things we can do to reduce our usage of the car and avoid congestion? Lots of questions, and there will be more as we investigate further.

Will the plastic dinosaur soon become extinct – how the debate has changed?

Less than a decade ago, most main-stream predictions on the future of motoring were concerned with the availability of oil. We may not have asked specifically about plastic dinosaurs but there was concern that we were burning a finite resource which fulfilled so many other roles in our domestic and industrial lives. We were asking:

- How much oil do we have left and how long will it last?
- With an increasing global population and industrialisation in India, China, and African and South American countries, would there be enough oil to last beyond 2050?
- As readily accessible oil was becoming scarcer, previously uneconomic and technically challenging reserves would have to be exploited. Had the peak of oil production already passed?

Extraction of oil from sources previously technically too difficult and / or economically unviable sources featured highly in the thinking of those closest to the issue. Included in these resources were the 'tar sands', a mixture of sandy clay and black viscous bitumen, predominantly found in Canada and Venezuela, shale oil, a sedimentary rock containing kerogen and liquid fuels produced from coal or liquefied gas.

Biofuels, made from crops such as corn, soya beans, palm oil and sugar beet were seen as key in reducing reliance on fossil fuels. However, there are problems with biofuels made from crops. These include the displacement of food crops, consequent rising food costs, environmental damage as large areas of Amazonia, Malaysia and Indonesia are cleared to grow biofuel, and the volume of crops needed to produce a gallon of oil. Consequently, the UK agreed to cap its use of food-based biofuels at 4% of UK road fuel by 2018, dropping to 2% by 2032.

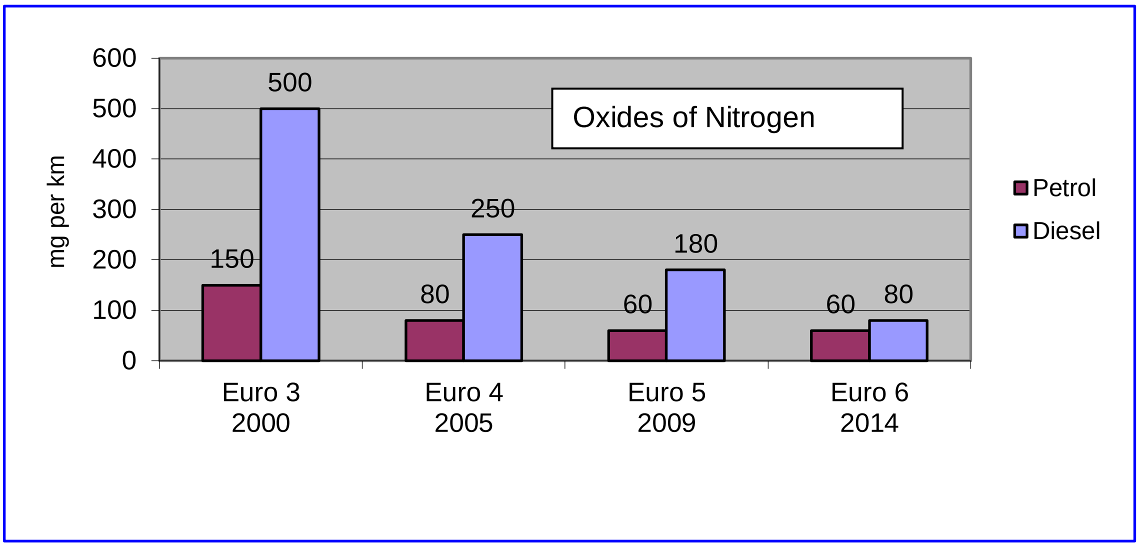
Articles on biofuel produced from algae were published in the scientific and industry-focused press with the technique seen by conservationists as a more reliable and safer source of energy that is both renewable and easy to attain. The US Department of Energy reported that algae can give up to 30 times more energy per acre than land crops such as soya beans. The action of sunlight on algae, in the presence of water and carbon dioxide, produces lipids or oils from which fuel can be processed.

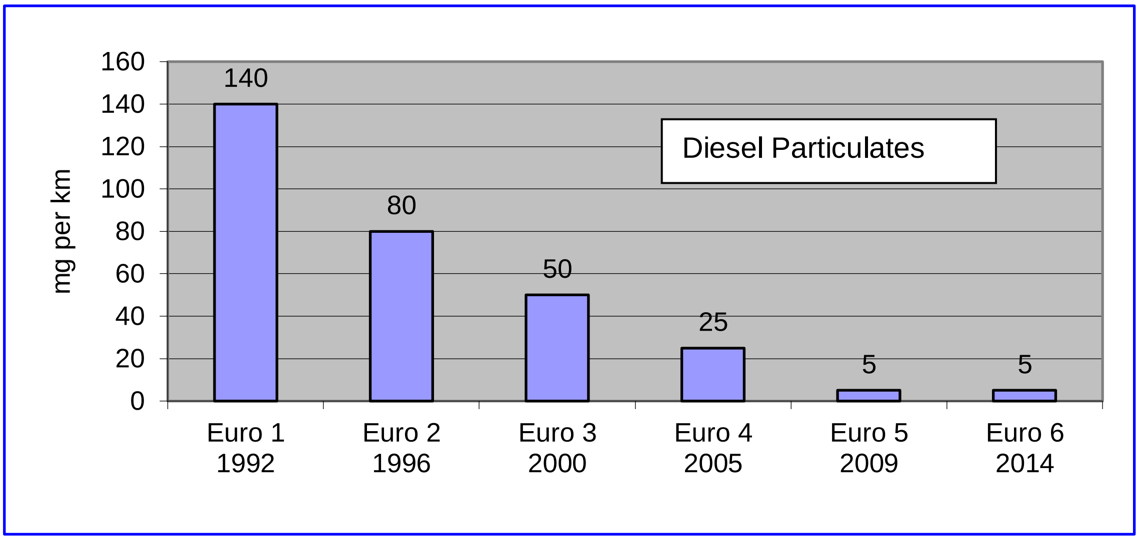
Whilst the production of biofuels does release carbon dioxide into the atmosphere[1], albeit usually less than burning fossil fuels, nowadays, the debate has moved on. There is an unacceptable risk to our environment and our personal health through burning even those reserves of fossil fuels that are currently known and accessible. As we will see shortly, the day when the internal combustion engine will cease to be our main source of motive power (certainly in most industrial countries of the world) can now be confidently predicted.

[1] New Scientist 27 July 2019

Air pollution has been linked to respiratory and cardiovascular disease, diabetes and cancer. It may also harm foetuses and cause long and short-term cognitive problems in children and adults. In 2014, the World Health Organisation estimated that air pollution was a factor in ***7 million*** premature deaths worldwide each year. The corresponding annual figure for the UK is ***40,000***, of which nearly half are due to nitrogen dioxide[2]. A report from King's College London claims that, in 2015, there were ***9,500*** premature deaths in London, due to air pollution: specifically, particulate matter and nitrogen dioxide. For comparison, the number of fatalities through road traffic accidents in Great Britain during 2017 was 1793 (131 in London).

What steps are being taken to reduce harmful emissions from road transport?
Since 2000, European legislation, for both diesel and petrol cars offered for sale within the EU, has sought to legislate ever lower levels of harmful gases and fuel-derived particulates. (Particulates produced by wear from tyres and brakes are excluded from these figures).





[2] Death certificates do not currently bear the words "Air Pollution" as a cause of death. It is the mixture of particulate and gaseous vehicle emissions from which expert bodies, such as the UK Committee of the Medical Effects of Air Pollutants, assess the shortening effect on lifespan to be equivalent to tens of thousands of deaths per year.

Two examples of the Euro 5 and 6 levels, along with earlier limits, expressed as milligrams (mg) per kilometre driven, are shown in the graphs above.

Surely, cars are getting cleaner, things are getting better?

Well, there are several reasons why we should be wary of graphs such as those above.

Firstly, a demonstration of compliance with the legally required standards shown in the graphs must be reproduceable from manufacturer to manufacturer and laboratory to laboratory across the globe. Consequently, the legislation defines a driving cycle against which emissions are measured and this driving cycle, known as the New European Drive Cycle (NEDC), ensures consistency across all laboratory testing.

It is however, widely recognised that this testing cycle is not representative of real-world driving. Consumer groups and others have shown that under real-world driving conditions, some new diesel-powered vehicles, compliant with Euro 6 under NEDC testing, can emit up to 20 to 25 times the Euro 6 limits of nitrogen dioxide.

Consequently, new diesel-powered cars are now required to comply with Real Driving Emissions (RDE) testing, which is being introduced in two phases: RDE1 and RDE2.The graphic on the following page adds some figures and dates to this new testing regime.

There are further reasons why the earlier graphs, which suggest we should be seeing a significant improvement in air quality, should be treated with caution. Since 1994, when compliance with the Euro 1 standard became mandatory:

- the number of vehicles on the UK roads has increased from around 25 million (of which 21 million were cars) to 38.4 million at the end of 2018. Of these 31.5 million were cars.

- The fastest growing category of vehicle is the van (Light Commercial Vehicle – LCV), growing in number by 29% over the decade 2002 to 2012, compared with just 11% for the number of cars. Delivering our internet shopping means that the average LCV typically covers 60% more miles per year than the average car. (As from September 2016, all new LCVs also had to comply with Euro 6).

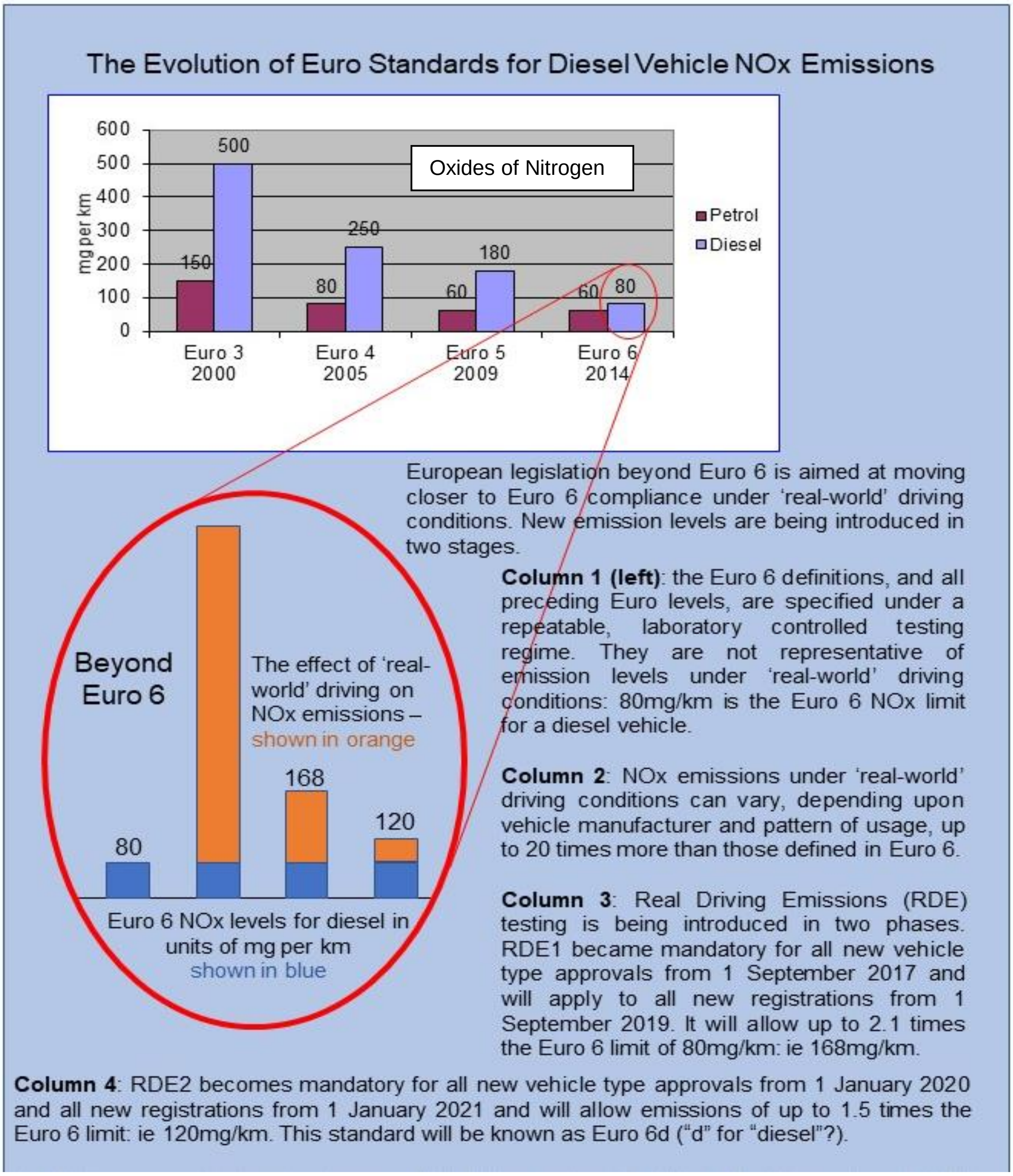
- the proportion of diesel cars, of all ages on UK roads, has increased from 7.4% in 1994 to 40.1% in 2017.

So, in summary:

- particulate matter and nitrogen dioxide in car exhaust emissions adversely affect human health[3]
- both are emitted in greater quantities from diesel engines than petrol
- the legislated emissions levels are far exceeded in real-world driving conditions
- the number of vehicles on the road has increased year on year since WW2
- the mix of vehicles has changed (more diesel, more LCV)

all hindering efforts to improve air quality in our urban areas.

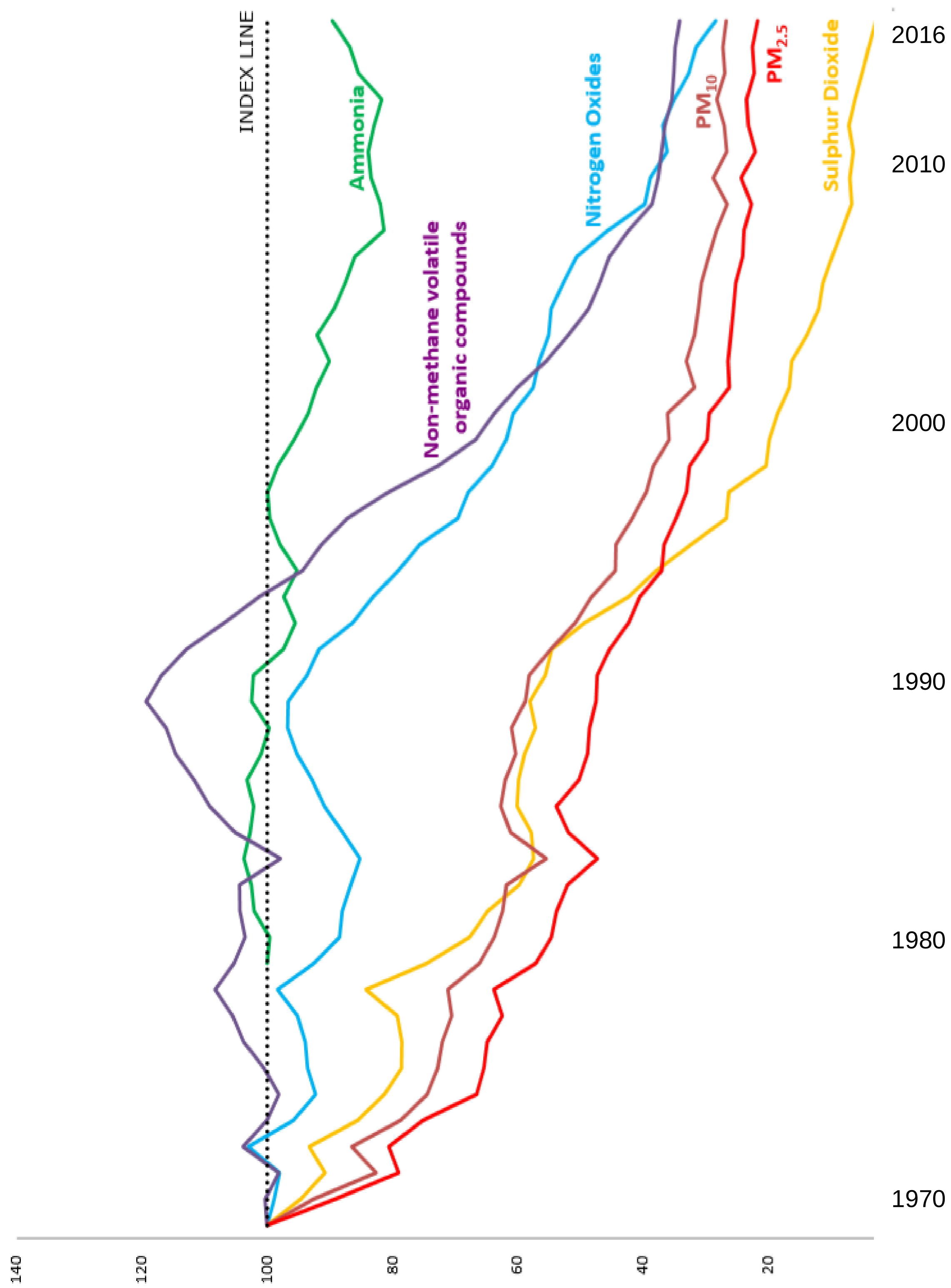
[3] As mentioned, European legislation covers particulate matter (PM) emitted from a car's exhaust system. PM from tyres, brakes and the road surface is typically just a few percent of that from a car's exhaust. Paradoxically, for a battery powered car, PM generated by tyres and brakes is typically 15% to 25% higher than for the corresponding petrol or diesel model: a consequence of the greater weight.



But, across the UK, EU, US, Australia and New Zealand, ***air pollution levels overall (ie not just related to transport) are falling***. For example, figures for particulate matter (soot) less than 2.5microns (ie 2½ thousandths of a millimetre), denoted as $PM_{2.5}$ in the figures below, have fallen steadily since 1970. DEFRA (Department for Environment, Food and Rural Affairs) figures for the UK are shown in the following chart. They have not however, fallen fast enough to meet World Health Organisation guidelines and, globally, the figures are dwarfed by the increases from developing countries such as Nigeria, Bangladesh, India and China[4]: countries to which many European nations and the USA have 'outsourced' much of their heavy industry.

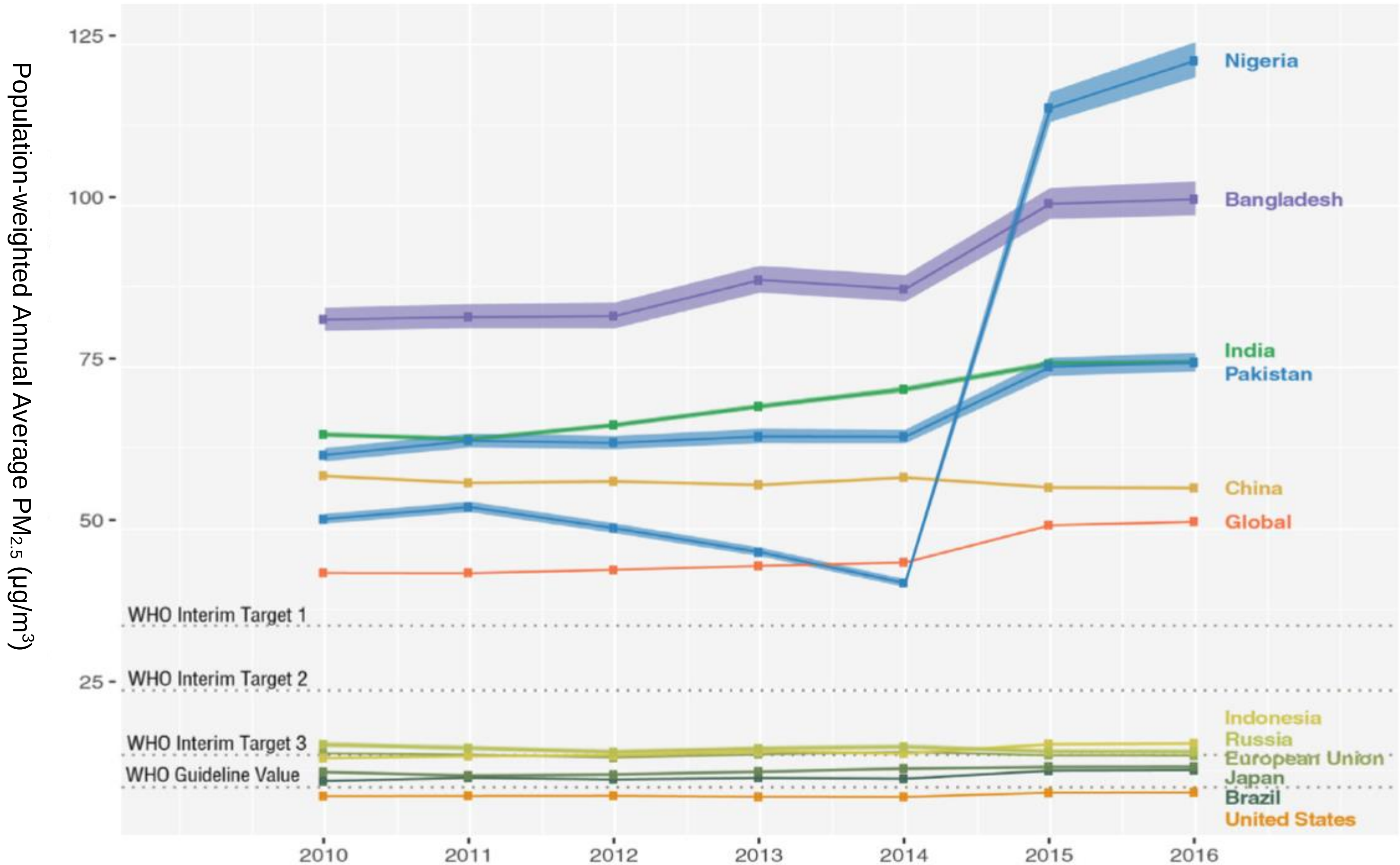
[4] See both New Scientist, 6 May 2017 and "DEFRA STATISTICAL RELEASE: 15 FEBRUARY 2018 EMISSIONS OF AIR POLLUTANTS IN THE UK, 1970 TO 2016" and "The State of Global Air 2018" from which the following two graphs are reproduced.

Trends in UK sulphur dioxide, nitrogen oxides, non-methane volatile organic compounds, ammonia and particulate matter (PM_{10}, $PM_{2.5}$) emissions 1970 – 2016



Figures relative to 100 in 1970
(1980 for ammonia)
DEFRA National Statistics Release: Emissions of air pollutants in the UK 1970 to 2016

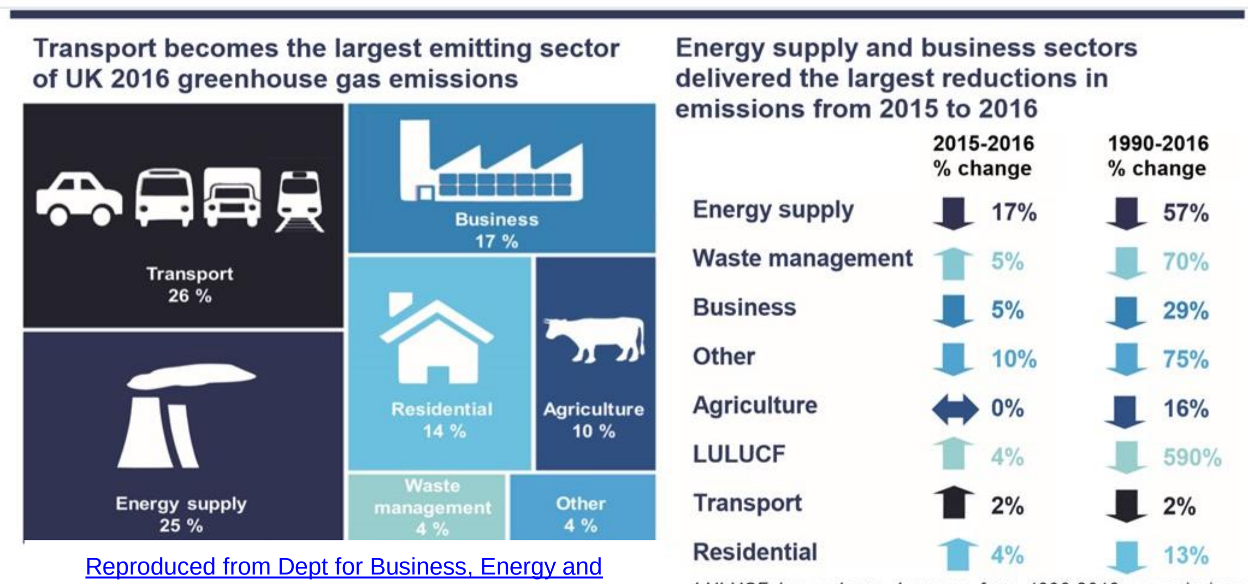
Trends in population-weighted annual average $PM_{2.5}$ concentrations in the 10 most populous countries plus the European Union, 2010–2016.



The human influence on atmospheric carbon dioxide

Carbon dioxide (CO_2), methane, nitrous oxide and other so-called greenhouse gases in the Earth's atmosphere have increased steadily since the time of the industrial revolution. Many graphs can be found that show pre-industrial levels of CO_2 averaging around 200 parts per million (ppm) while today, that level exceeds 400ppm: a level not seen for over 400,000 years[5]. Initially, the main contributors to the increase came from the new 19th century industrial economies of Europe, subsequently the US, and are now dominated by China, India and newer, developing economies whilst the EU and US emissions are in decline.

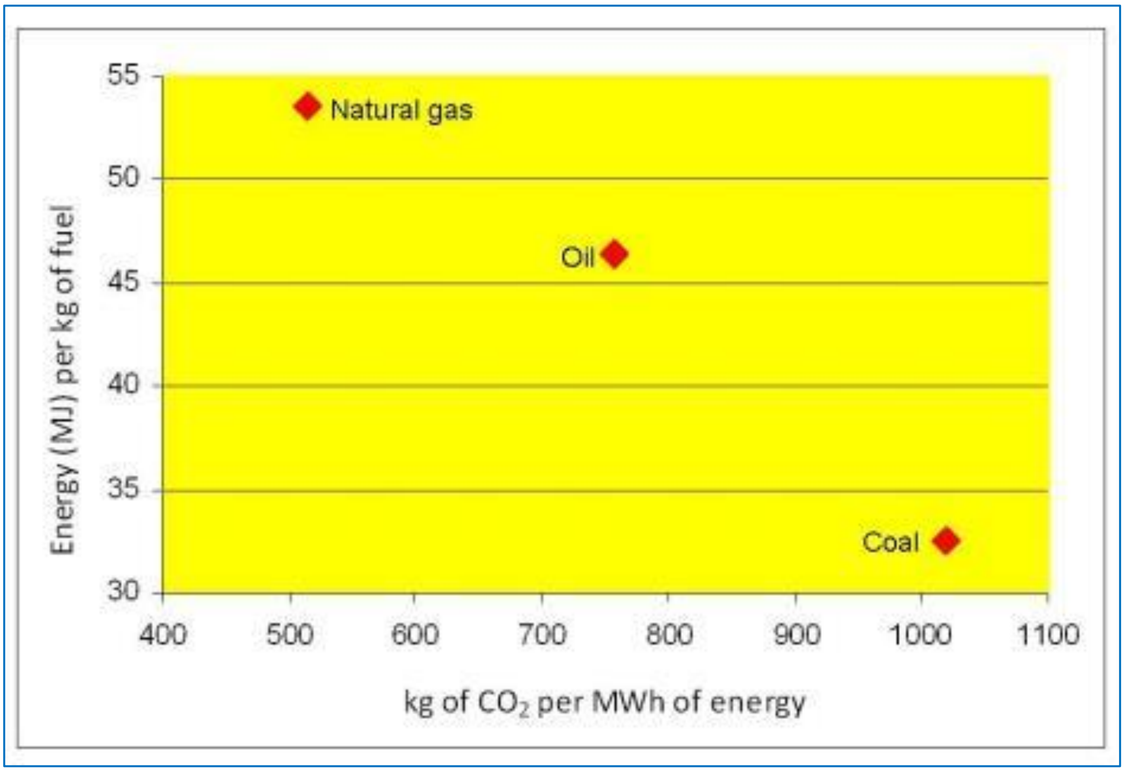
Globally and closer to home across the 28 (27?) nations of the EU, power generation, with its heavy dependence on coal, has been the largest single source of CO_2 emissions: larger than the transport sector. However, in the UK in 2016, for the first time, greenhouse gas emissions from transport (26%) exceeded those from energy supply (25%). This trend is continuing in provisional figures for 2017 and is due to the reduction in the use of coal for power generation whilst the transport figures remain largely constant since 1990.



Reproduced from Dept for Business, Energy and Industrial Strategy

The dramatic shift away from coal and oil for power generation is not entirely based on environmental arguments. As can be seen from the following graph, the energy released in burning 1 kg of natural gas is around 65% higher than that released by burning the same mass of coal whilst the CO_2 generated per kilowatt of energy released is less than half that for coal.

[5] Air bubbles trapped in ancient ice in case you were wondering.



The contribution of transport

Returning to the Department for Business, Energy and Industrial Strategy graphic on the previous page, the main contributors to the transport figures are petrol and diesel vehicles.

Historically, CO_2 emissions from road vehicles were not covered by EU legislation. With the increasing evidence that rising CO_2 levels are having a role in global warming, this changed in 2007. As a first step, EU legislation required the CO_2 emissions to be achieved by 65% of new cars registered in the EU from 2012, from each manufacturer, not to exceed 130 grams per kilometre (g/km). A sliding scale of limits applied from 2012 to 2015 at which time 100% had to meet the 130 g/km value.

In practice, by 2017, the average for all new cars was 118.5g/km.

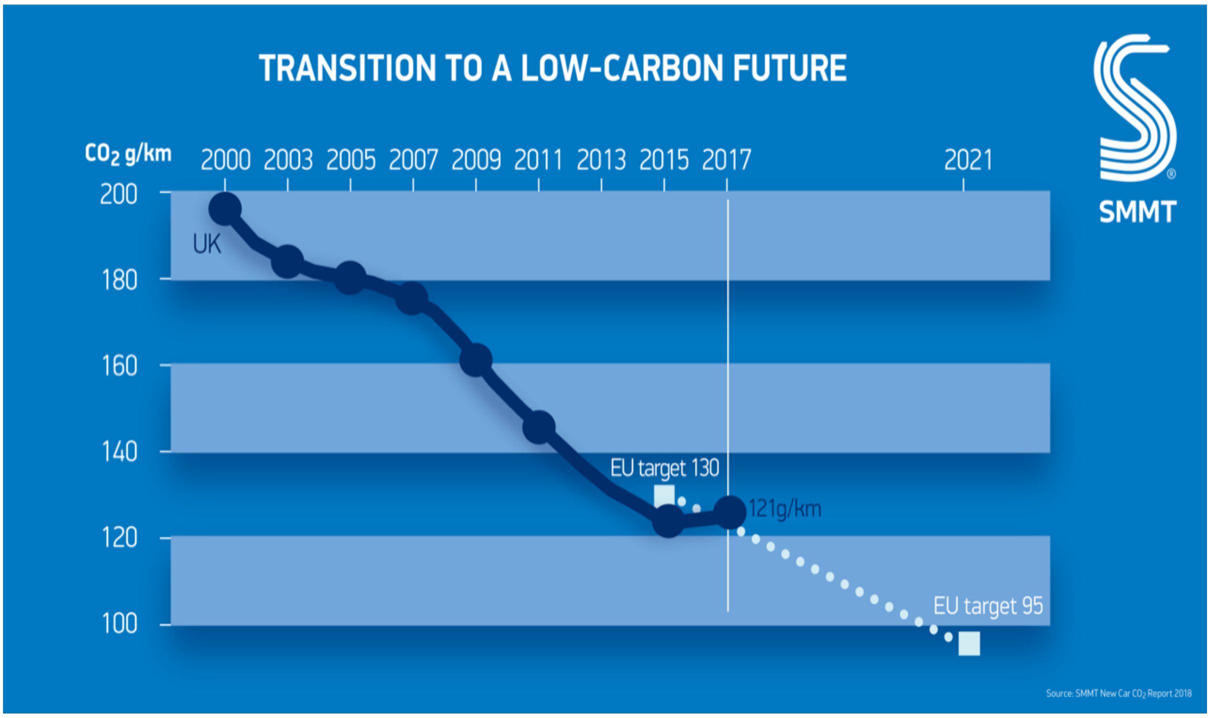
European legislation now requires a 95g/km limit for cars to be achieved by 2021 and 147g/km for LCVs. Beyond 2021, the targets are a 15% reduction on the 2021 figures for both cars and LCVs by 2025 and a 30% reduction by 2030.

From September 2017 the EU introduced a new test procedure, known as the Worldwide Harmonized Light Vehicles Test Cycle (WLTC), it covers fuel consumption and CO_2 emissions and, although still a laboratory test, it reflects a 'real-world' driving profile and is the method by which compliance with the above limits will be determined.

The amount of CO_2 present in vehicle exhaust gases is very dependent on the fuel efficiency of the engine. It is for this reason that diesel fuel became the preferred choice for high-mileage drivers throughout Europe: like-for-like performance engines being generally more efficient when burning diesel than petrol. In the UK, this switch to diesel was encouraged by road and fuel tax incentives[6].

In the UK, the benefit of these incentives in reducing CO_2 can be seen in the SMMT (Society of Motor Manufacturers and Traders) graph below. This shows the year-on-year average CO_2 emissions for all ***new*** cars produced in that year.

For comparision, the average of ***all*** cars on the roads of GB in 2017 was 144.3g/km.



The year-on-year downward trend in CO_2 emissions, which has been steady since 1980, when the average was typically around 250g/km, has recently reversed and this is due to the increased awareness amongst the vehicle-buying public of the adverse health implications of the emissions from the diesel engine. In 2017 petrol engine cars – with their higher CO_2 output - outsold diesel (53% to 42%) reversing the pattern from earlier years.

No matter how efficient the design, cars propelled just by petrol or diesel will struggle to achieve levels of CO_2 much below about 80-90 g/km. Moves to reduce CO_2 emissions from cars below this figure have seen the increasing use of electric power: either stand-alone electric or as a hybrid with internal combustion.

[6] https://www.greenncap.com/ is a European consumer-focused group, independent of the motor manufacturers, which is building a database of cars and their environmental performance based on real-world testing. They are finding that although a car may be efficient (ie good miles per gallon figures), it is not necessarily good on emissions that are harmful to health. They plan to expand their analysis to include the lifetime efficiency of cars through inclusion of the environmental impact of production and disposal.

So, in summary:

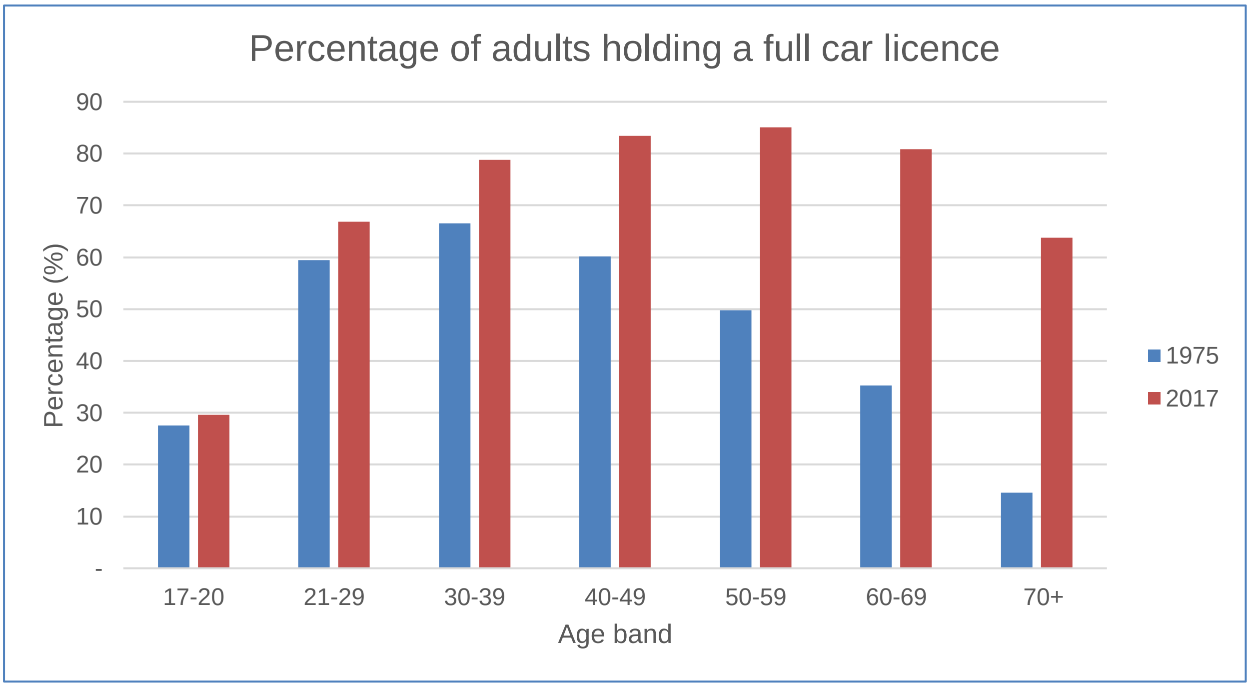
- in the UK, transport is now the largest contributor to greenhouse gas emissions
- CO_2 emissions from vehicle exhausts dominates this mixture of greenhouse gases
- across Europe, 72% of vehicle emissions are generated by cars and LCVs
- EU legislation has driven down the average new car CO_2 emissions from around 250g/km in 1980 towards a target of 95g/km in 2021
- in 2017, the average UK new car CO_2 emissions rose for the first time since the 1980s to 121g/km because of both the switch away from new diesel car registrations in favour of petrol and increased mileage[7].

[7] Although the average annual mileage per car in the UK is decreasing, because there are more vehicles, the number of miles travelled per year is increasing.

Part 1 - Environmental | Cars of the Future

Throughout the 20th century, as cars became 'easier' to own and drive, the number on the roads of developed countries soared. How have cars become 'easier' to own and drive? Consider: the advent of the electric starter motor, avoiding the need for hand cranking an engine, pneumatic tyres, improving ride comfort, power assistance for steering and brakes, plus the elimination of driver controls ranging from ignition timing to choke control to automated lights and wipers, not to mention adaptive cruise control, lane keeping and collision avoidance. Couple this with the real terms decreasing cost of purchasing a car, and it is easy to see why the number of cars on UK roads has grown from 14 or 15 in 1895 to 9.97 million in 1970 to 31.5 million today.

In addition, people's life-expectancy is growing and car manufacturers are focusing on the older driver with higher seating, easier access and moves towards autonomous cars: it doesn't look as if the number of cars on the road is about to decline for at least the next decade.



The performance of the internal combustion engine has changed beyond recognition during the 130 years that it has come to dominate our lives. Driven by market competition and global legislation, environmental performance continues to improve and that seems likely to continue with incremental improvements in the efficiency over the first few decades of the 21st century. Techniques such as automatic stop-start, turbocharging and cylinder deactivation are now in widespread use by many manufacturers. All help to improve fuel consumption, and hence reduce CO_2 emissions, with turbocharging allowing smaller, lighter engines of equivalent power output to their larger, heavier predecessors. Also, thanks to lower weight materials plus electric rather than hydraulic actuators and improved combustion, the fuel consumption and CO_2 emission figures of the average family saloon from even 10 years ago look very poor when compared with today's figures.

Even with these improvements to the environmental performance of the internal combustion engine however, legislation within many countries is aiming to move it from the pedestal of prime motive power well before the middle of this century. It will be banned!

Globally, a special report by the UN's Intergovernmental Panel on Climate Change has warned that:

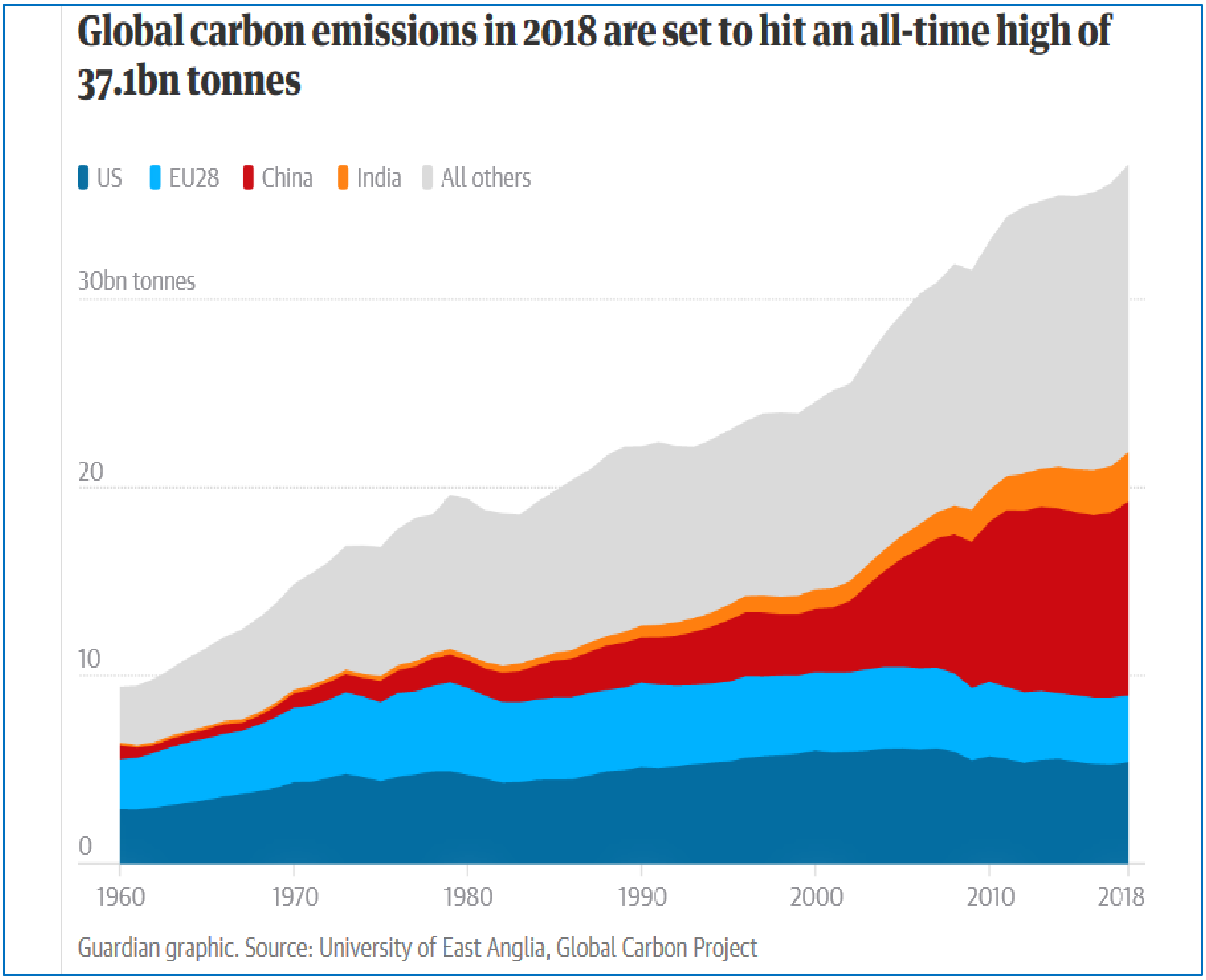
> ***"… keeping to the preferred target [of global warming] of 1.5ºC above pre-industrial levels will mean rapid, far-reaching and unprecedented changes in all aspects of society are needed***".

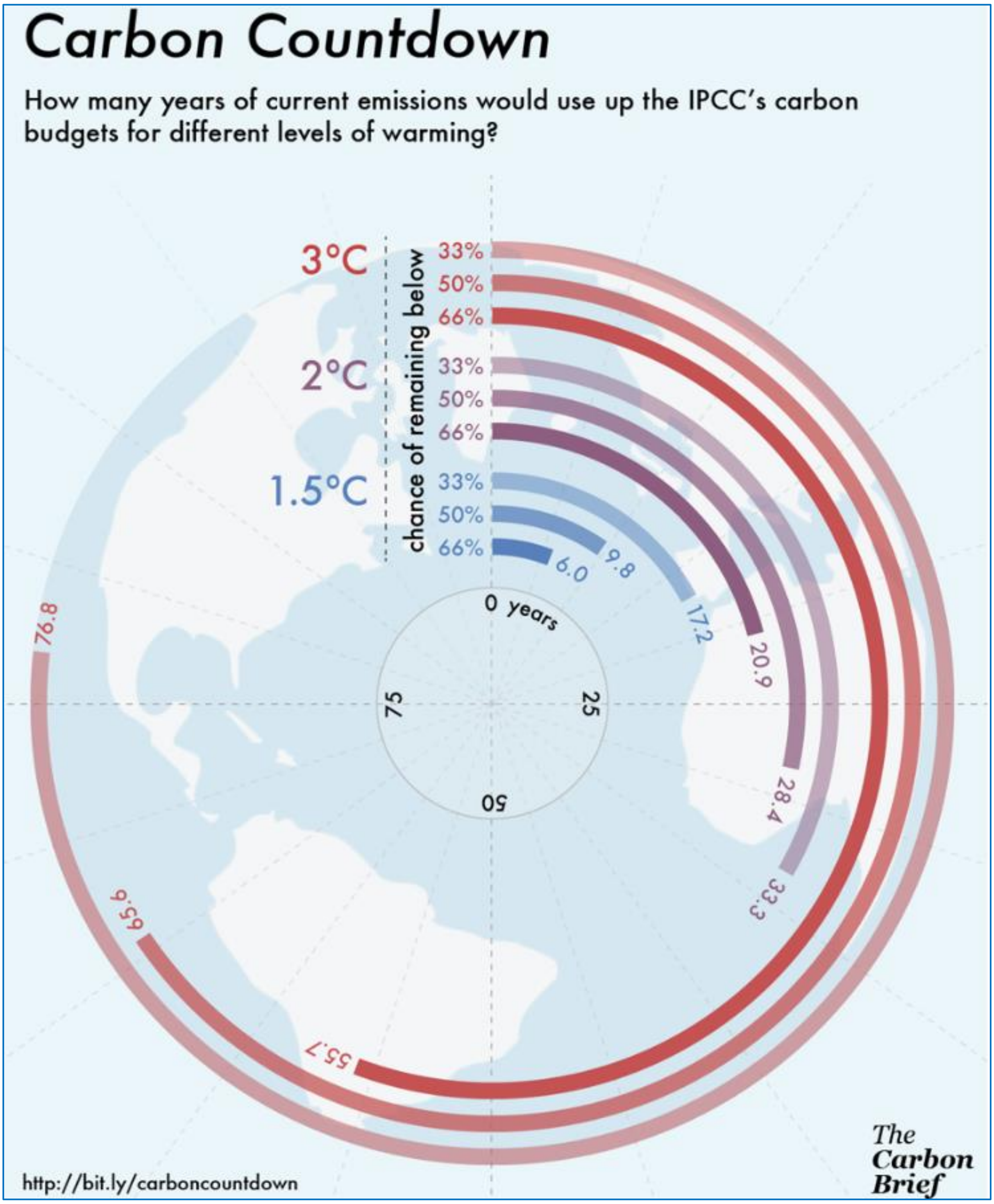
In the UK, the future ban on the sale of cars and vans, powered solely by petrol and diesel, is also partly a consequence of legal challenges to the government. The date currently set for the UK ban is 2040 although there is pressure to bring this forward to 2032. From China (2040) to Norway (2025) and many jurisdictions in between, similar dates have been passed into national law and some cities, which suffer particularly bad pollution, have earlier dates. In most countries, cars that use the internal combustion engine as part of a hybrid power train, will initially be exempt.

Is the ban on petrol and diesel consistent with the best estimates of global warming?

Well, looking at the 2016 chart on page 18, the answer to that question seems to be "barely"! To keep global warming below 1.5ºC, with a 66% level of confidence, climate scientists tell us that we can only continue to emit CO_2 at the current level until 2022. (ie 6 years beyond the date of the 2016 data). 2036 would be the equivalent date for a 2ºC increase.

The global forecast for 2018, shows CO_2 emissions are likely to be an all-time high – see page 17 - and the forecast of world oil production shows no decline until at least the end of 2020 – top of page 19. There is not a lot of scope for optimism!


Global carbon emissions in 2018 are set to hit an all-time high of 37.1bn tonnes
US
EU28
China
India
All others
30bn tonnes
20
10
0
1960
1970
1980
1990
2000
2010
2018
Guardian graphic. Source: University of East Anglia, Global Carbon Project


Carbon Countdown
How many years of current emissions would use up the IPCC's carbon budgets for different levels of warming?
3°C
2°C
1.5°C
chance of remaining below
33%
50%
66%
33%
50%
66%
33%
50%
66%
0 years
25
50
75
6.0
9.8
17.2
20.9
28.4
33.3
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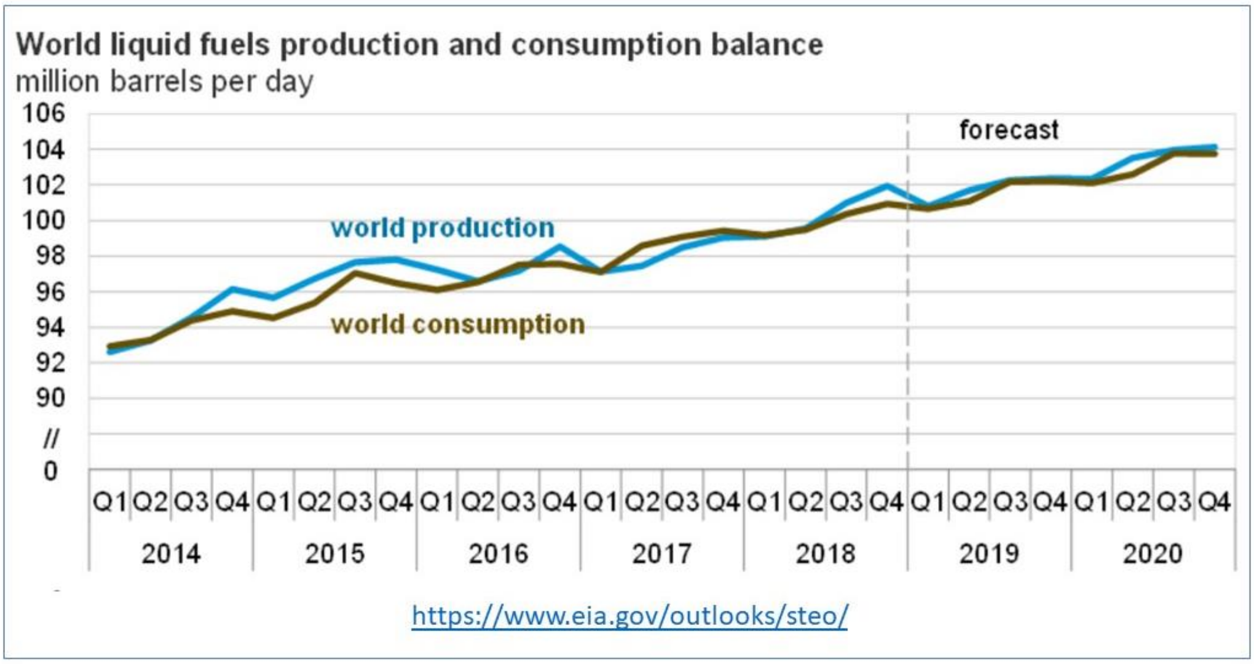
http://bit.ly/carboncountdown
The Carbon Brief



Battery powered electric vehicles and hybrids of internal combustion engine and battery electric are envisaged to be the immediate future, displacing the cars and vans powered solely by petrol or diesel. Purely electric vehicles do not come without some well-known limitations such as range anxiety and limited charging infrastructure, not to mention concern over adequate capacity within the UK generation network. Furthermore, the CO_2 displacement only occurs if the recharging infrastructure is based on renewable energy: nuclear, wind, solar, tidal, wave, hydro or biomass, albeit displacing the location of the pollution from city centre to the site of generation.

It is difficult to see the hybrid vehicle – either plug-in or range-extended - as anything but a stop-gap measure. The weight penalty associated with carrying two power sources, electric motor(s) and internal combustion engine, on a single vehicle seems far from ideal.

What lies beyond the battery electric and hybrid era?

The hydrogen fuel cell was invented in 1842 by William Grove and over the last few decades has been the focus of development as a future power source for electric vehicles. The fuel cell is an electrochemical, energy conversion device. It converts the chemicals hydrogen and oxygen into water, and in the process, it produces electricity. Electricity can be produced constantly if the flow of hydrogen and oxygen (from the air) continues.

Hydrogen production, for example through electrolysis of water, requires energy and unless this is derived from renewable sources, the overall CO_2 production associated with hydrogen propulsion may not be as little as first appears. Two fuel cell powered electric cars are currently available in UK showrooms: the Toyota Mirai and the Hyundai Nexo. Both can be refuelled in around 5 minutes and the Nexo has been tested with a range of 336 miles[8].

[8] Which?, February 2019

Challenges to the widespread adoption of hydrogen power include:

- provision of an adequate infrastructure for hydrogen production, distribution, storage and retail. Hydrogen produced from natural gas is neither renewable nor clean.
- overcoming perceived safety issues: compressed hydrogen gas – at typically 700 bar - rather than liquid hydrogen, is stored in carbon-fibre reinforced tanks. The Nexo, however, achieved the highest Euro NCAP rating for any large SUV in 2018
- reduction in cost through minimising the use of the expensive platinum catalyst in the fuel cell. Cobalt may be one feasible alternative.

Non-technical, societal changes may also provide part of the solution to the negative impact of internal combustion engines. Driven by cost of ownership and increased congestion, even of electric and hybrid vehicles with partial or complete autonomy, the perception of a car as a status symbol may wither. Less personal ownership and more rent-on-demand services from fleets of battery or fuel cell electric vehicles, with the vehicle chosen to suit the journey and planned use, may become the norm, especially in busy cities.

So, in summary:

- the sale of new cars and LCVs powered solely by petrol or diesel engines will be banned in most developed countries before 2040
- by that time, most new cars and LCVs will use battery electric or hybrid power sources
- the internal combustion engine will have been relegated to a diminishing support role in hybrid vehicles: its 150-year history will be coming to an end
- hydrogen fuel cells to power electric cars, LCVs and public transport are likely to be the first choice in urban areas
- reduced dependency on fossil fuels, specifically oil, will ensure that those reserves that are extracted are used for the medicinal, industrial and domestic uses for which there are few alternatives – rather than being burnt.

A glimpse into the near future? This battery electric, 11-seater, autonomous bus started a regular service in the Swiss town of Neuhausen Rheinfall during 2018 and is fully integrated with the town's public transport network.

https://www.intelligenttransport.com/transport-articles/70339/autonomous-shuttle-regular-public-transport/

So far in this book, only the CO_2 produced during vehicle use has been considered. When looking at the CO_2 emissions over the lifetime of a vehicle, it is also legitimate to consider the CO_2 emitted during the manufacture of raw materials from which the vehicle is built, the vehicle production itself, fuel production and energy expended when the vehicle is scrapped.

Work by the University of Technology, Finland in 2006 quantified the CO_2 emissions for an average 2004 European light vehicle[9] over its life. The CO_2 attributable to production and disposal, expressed as a percentage of the lifetime emissions (ie production, use and disposal), amounted to 41%, reducing to 34% if the vehicle remained on the road for 20 years.

The same university used data from nearly 5000 cars from the European and US markets and concluded that taking account of emissions of CO_2 during vehicle and fuel production, distribution and vehicle scrappage added, on average, 54.7% to the usage figure. Restricting the analysis to just 2006 model year European cars, resulted in a one-off production and disposal contribution of around 35% of the lifetime average CO_2 figure[10].

An SMMT (Society of Motor Manufacturers and Traders) figure, quoted just 15%: 10% in manufacture and 5% in disposal. A higher figure is quoted by ERTICO[11] who state, "Fuel consumption during vehicle operation, for example, contributes around 60% of the life-cycle greenhouse gas emissions of a passenger car", leaving 40% for production and disposal.

Finally, a 2017 report from the European Environment Agency attributes a CO_2 contribution, arising from production and disposal, of 30% to the lifetime figure for a petrol car and 36% for a diesel (production and disposal are the same for petrol and diesel cars but lifetime emissions during use are lower for the diesel).

The difference between these sets of figures is not surprising since a lot will depend on the assumptions made. For example:

- was the energy used in the steel and other raw material production taken into account?
- did this come from coal-burning power stations or from renewable energy sources?
- how consistent is the vehicle mix between the various studies?
- how old is the data? The figures above span an 11-year period and production techniques have become more efficient over that time.

The percentage of CO_2 generated during production and disposal of a battery electric car is around 20% more than a corresponding petrol or diesel car whilst the lifetime average CO_2 depends heavily on the mixture of power generation used to recharge the batteries.

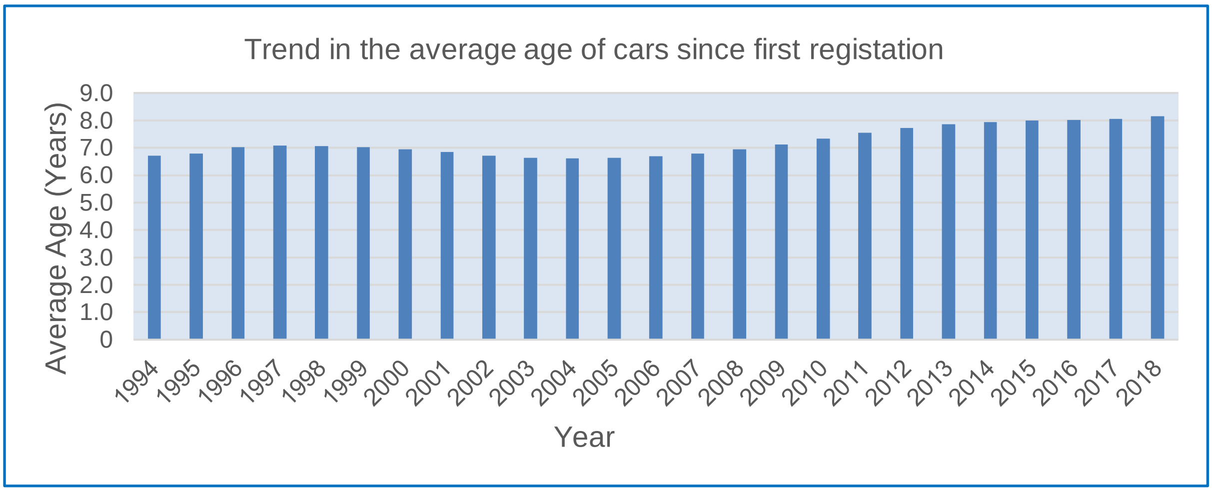
It is clear is that the energy used, and CO_2 released in the manufacture of the vehicle, is significant in comparison with the CO_2 emissions throughout its life but becomes a diminishing

[9] Assumptions: kerb weight 1290kg, travelling 8440 miles per year, 10-year life, fuel consumption of 38.7mpg. Data used is an average for new vehicles sold in 2004 and is based on >14 million cars and 1.8 million vans and pick-ups
[10] Assuming a vehicle lifetime of 14.4 years and annual mileage of 8420 miles
[11] An EU organisation devoted to Intelligent Transport Systems

proportion if that life is extended. Hence, from an environmental point of view, there appears to be a strong argument for maintaining a car well beyond the average life of 13.9 years after which a car is scrapped. The economics of modern vehicle ownership and maintenance, however, do not necessarily encourage this approach.

Age mix

During the period 1994 to 2018, data on the age of cars on the road is available from the Department for Transport website. The graph below shows that in the mid-1990s, and again since 2004, there has been an increase in the average age of cars on the road: including the 2009/10 period of the UK government scrappage scheme when over 400,000 cars over 10 years old were replaced.



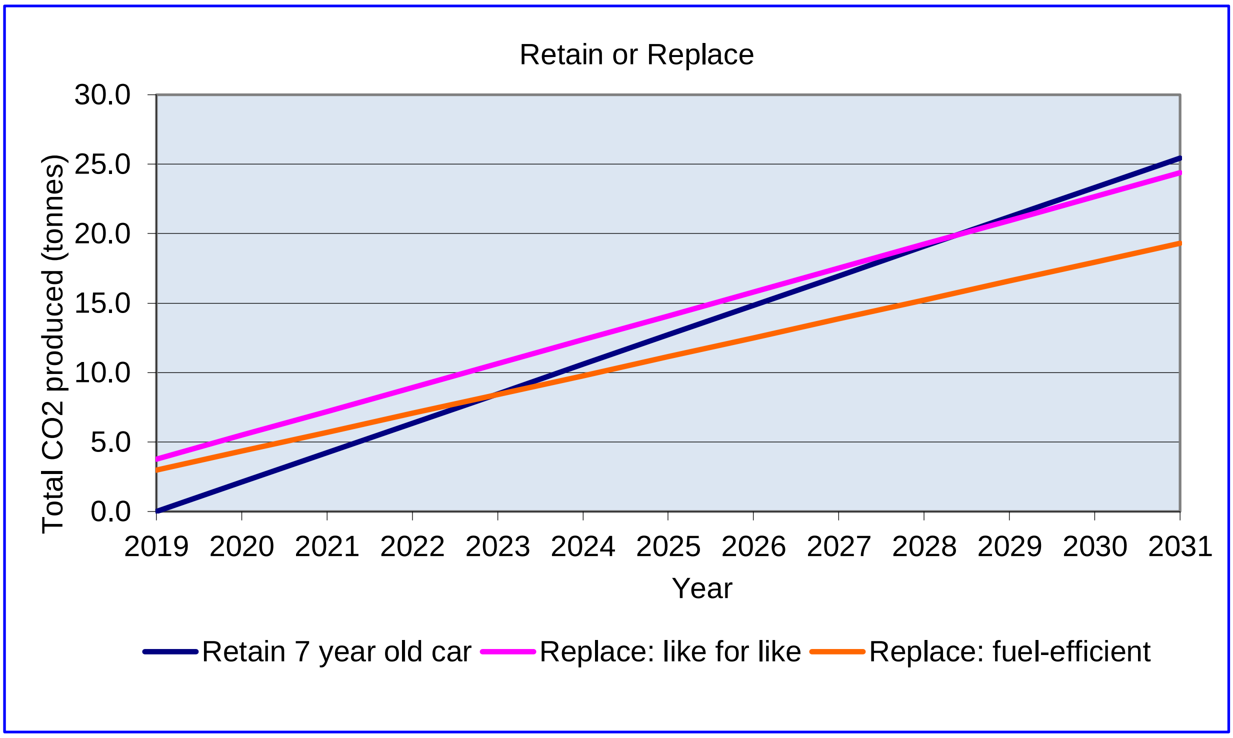
To clarify why this is not the same as the 13.9 years quoted above as the average age at which a car is scrapped, consider the 31.5 million cars on the UK roads at the end of 2018, some will have only been registered for a few months, others may have been registered since 1994; the average period for all 31.5 million was 8.2 years.

This increase in average age coincides with an increase in multiple car ownership within households (hence lower mileage per car) and improvements in build quality for the low and mid-range makes within the mass car market.

Replace or retain

To quantify the benefit of retaining rather than replacing our car, consider the example of an driver who is torn between replacing their car with an equivalent, modern model or going for a more environmentally friendly alternative. Let us assume that the owner of a 2012 car is contemplating replacing that car with a similar 2019 model and consider that decision to be made solely from a CO_2 emission point of view.

Assume the owner travels 7,800 miles each year and both the old car and potential replacement have typical CO_2 for the year in which they were registered: namely, 148g/km for 2012 and 120g/km for 2019. For the older car, the one-off energy associated with manufacture and distribution is now irrelevant but for the replacement, represents 25% of the lifetime CO_2 production. How do the CO_2 budgets compare?



The graph above illustrates, for three examples, the effect that the customer's choice can have on their CO_2 motoring emissions. It is just under 9 years before the like for-like replacement is showing a CO_2 advantage and 4 years before the fuel-efficient model has produced less CO_2 than the, by then, 11-year-old model. Food for thought for those that advocate vehicle scrappage schemes!

Where retaining a car is not a possibility as it really has reached the end of its economic life, then reuse and recycling are areas where the automotive industry has developed considerable expertise. Within Europe, the End of Life Vehicle Directive was adopted in 2000 and the EU have legislated that 95% by weight of material must be reused and recovered. Not all states of the EU have achieved that figure.

But are energy use and CO_2 emissions the whole story? Availability of raw materials is becoming an increasingly significant factor, especially as the value of electronic components in a modern car continues to increase.

An ACEA report draws attention to the future limited availability of lithium if the projected global increase in electric vehicle numbers materialises. Lithium is a key component of modern batteries in the consumer electronics, power generation and automotive sectors.

Powerful magnets used in the traction motors of electric vehicles, make use of neodymium, one of the rare earth elements in the periodic table. Currently 97% of rare earth elements are sourced from within China which presents a possible geopolitical issue around availability, especially since recycling of these materials is not yet a common practice.

So, in summary
Apportioning the up-front energy used in vehicle production and distribution, plus the energy used during scrapping the vehicle, over as long a life as possible, especially for low mileage, well-maintained cars, can make good environmental sense. On the other hand, a small, efficient modern vehicle replacing one of average emissions performance from 7 years ago, covering high annual mileage, can provide an emissions benefit within the following few years.

Maximising the useful life of a vehicle can also make sense from the perspective of material wastage as, in the case of rare earth elements, these are usually mixed with other metals and contaminants making recovery both difficult and energy intensive.

The earlier forecast of the effect of increasing CO_2, at current levels of release, shows that global warming of over 1.5ºC or 2ºC could occur within a decade or two. Waiting for the ultimate, large-scale replacement of the internal combustion engine by less harmful methods of propulsion may not be acceptable given the on-going risk to our health, particularly in congested urban areas. This therefore begs the question, what steps can be taken, at an individual level, today, to mitigate the worsening air quality and associated risks? A couple of the most basic steps are:

- reduce usage
- whenever possible, avoid congestion

Reducing Usage

In some parts of the world, it has proved necessary to legislate to allow only multiple occupancy cars in dedicated lanes on the highway; enforced by video surveillance. Some Asian cities allow alternate day car travel at times when peak congestion coincides with unfavourable weather conditions.

All of the main motoring organisations in the UK have advice to offer on voluntarily reducing usage and the following summary has been compiled from the websites of AA and RAC:

- where possible plan to combine multiple trips into one journey
- for the daily commute, consider car sharing
- consider alternative modes of transport
- can some journeys be avoided altogether? eg work from home some days, use video or audio conferencing

Incurring additional miles through becoming lost on our journey can be both frustrating, wasteful of our time and environmentally unfriendly. Just how much such unintended D-tours add to the national annual mileage total is not a figure produced by the Department for Transport and, even if such a figure was published, would we believe it? Who of us would honestly admit to missing signposts, taking wrong turnings or arguing with our satnav? In an attempt to quantify the cost of becoming lost, a very approximate, 'ball-park' figure is calcuated in the spreadsheet attached as Annex A to this document and summarised below.

Making what appear to be 'reasonable' assumptions about the frequency and impact of drivers departing by accident from their planned route, the annual, avoidable increased fuel cost, for cars alone, is around £38 million whilst the increase in CO_2 (for cars, LCVs and HGVs) is over 70,000 tonnes or around 0.06% of the 124 million tonnes of CO_2 (or equivalent) generated annually by all road transport in the UK.

For comparison, 70,000 tonnes is of the same order of magnitude as the CO_2 output of between 8000 and 9000 UK family homes in one year.

Again, advice from the websites of the AA and RAC, suggest the following:

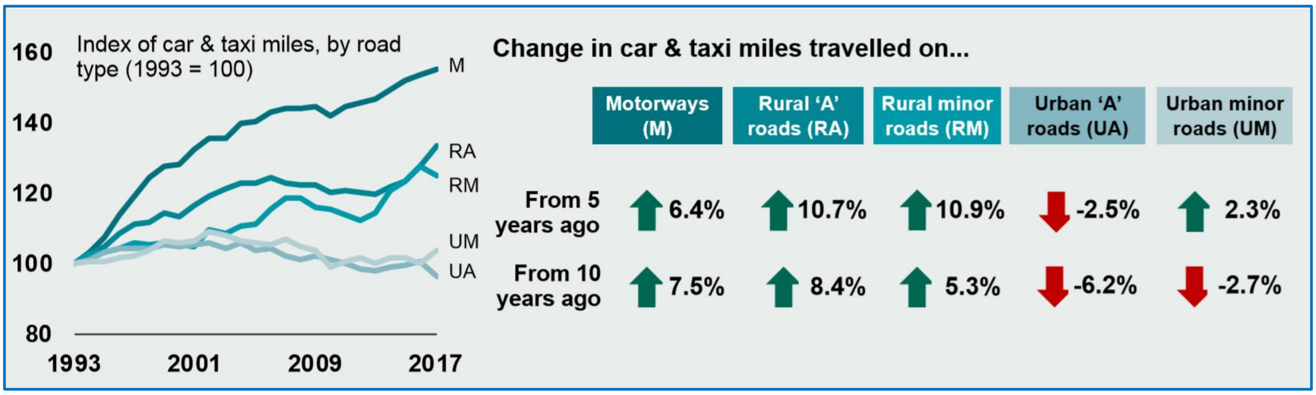
- journey preparation is crucial. Use either up-to-date paper or website maps
- ensure the satnav maps are up-to-date
- if using a portable in-car satnav or smartphone, ensure batteries are charged and that the charger is available and working
- don’t assume the satnav knows best. Even if using an updated satnav, be careful not to follow it blindly. Use common sense, and if in doubt about the route being offered, turn around and try another one
- keep an up-to-date map in the car as back-up, just in case

Congestion

Many of the roads on which we travel today owe their origins to some of the early animal tracks. They were later used by drovers and then developed for wheeled, animal drawn carts and marching Roman legions[12]. In the UK, some of the earliest roads are based on Ridgeways dating from between 5000BC and 2000BC. Those that survive include the Hogs Back in Surrey and parts of the Pilgrims Way over the North Downs. Trade routes developed on these Ridgeways: one example being the old salt road from Droitwich to the River Severn cutting through the Malvern Hills at the Wyche Cutting[13]. (Wyche or Wich – as in Nantwich and Droitwich - meaning salt in old English).

Today, there are over 31,900 miles of motorways, trunk roads and other primary ‘A’ roads and, in total, over 246,700 miles of driveable roads of all categories in Great Britain. This sounds plenty to avoid ever seeing another vehicle! However, given that, at the end of 2018, there were approximately 31.5 million cars and 6.8 million other licensed (and license exempt) vehicles in Great Britain, the trend in traffic volumes on virtually all types of road is quite clear from the Department for Transport graph below. Car and taxi traffic in 2017 amounted to 254.4 billion vehicle miles on all road types; an increase of 1.1% over 2016.

Confirming our everyday suspicion: congestion is increasing!



12 “Roads and Tracks of Britain” by Christopher Taylor

13 “Ways of the World – A History of the World’s Roads and of the Vehicles That Used Them” by M G Lay

As one measure to alleviate congestion, or at least to prevent it becoming worse, the road network is continuously being expanded, with the associated issues that brings around the loss of amenities and quality of life for those nearby. Re-design and re-layout of the of the road network may help as do the programmes to 'smarten' our motorways and provide information and advice to the driver either before or during the journey.

As a car driver, there are some steps we can take to minimise the risk of congestion but the random nature of traffic accidents and other incidents causing a tail back means that avoidance of congestion includes a strong element of luck. However, some mitigation steps are possible, for example:

- travel outside of peak times if possible. This can help to reduce the stress of the journey as well as the risk of delays
- check for traffic information on the intended route using local radio, websites such as Highways England or via relevant smartphone applications
- check the traffic information features of the satnav - if included
- for regular routes such as commuting, rehearse alternative routes and diversions for the day when the main route is closed or congested
- consider splitting the journey before congestion starts: use Park and Ride
- when in heavy traffic, drive smoothly: avoid acceleration and sudden braking, not only does this reduce fuel consumption it helps towards a steady flow of the traffic

The final bullet point, as well as being intuitively self-evident, has been supported by a number of studies that have demonstrated that a smooth, safe driving style is one that results in good fuel efficiency and hence minimises harmful emissions. To encourage such behaviour in fleet drivers, some organisations are fitting driver monitoring equipment to fleets of vehicles. This monitors, location, harsh acceleration and deceleration and other business-specific parameters. Used constructively, so that they are not perceived as a 'big brother', these measures can help to encourage fleet drivers to adopt an economical driving style.

Humans in general are very tolerant. We largely accept the inconvenience, delay and frustration that accompany traffic congestion as an inevitable part of life. Such acceptance, however, is likely to have its limits. The improvement of fixed and mobile broadband and the beneficial economics of 'hot-desking' in the office have helped to bring about a change in working practices over the last decade. It is now easier to work from home, to videoconference ('Skype'), to arrange meetings at motorway service areas, conference centres and other out-of-town locations whilst still having secure access to corporate IT systems and the internet. A consequence of this is going to be less traffic on the busiest roads at peak times. Are we saying, "enough is enough" and taking a solution to congestion into our own hands?

Part 1 - Environmental | Conclusion

The development of the internal combustion engine, and the road vehicles powered by this most disruptive of 20th century technologies, has brought immeasurable benefits to the health, prosperity and social well-being of populations across vast swathes of the planet. In addition, the cumulative, adverse effects of those vehicles on the health of the planet and large parts of the population are now better understood than at any time in history.

The urban smog and 'pea-souper' fogs of the 1950s and earlier - a consequence of the coal that we burnt on our domestic coal fires and our industrial dependence upon coal – have, in some global cities, been replaced with the emissions from nose-to-tail traffic jams at certain times of the day.

Changes are necessary, and in a timescale measured in years, not decades, if those adverse effects are not to prove to be irreversible.

Annex A – The Cost of Lost – an intelligent (?) guess

Estimate of the cost, both financial and environmental, of getting lost

Reliable input data and its source:

Number of registered cars in UK (End of 2018)	31,500,000	
Proportion of all registered cars that are company cars (%)	8.9	https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/716075/vehicle-licensing-statistics-2017-revised.pdf
Hence number of company cars on UK roads	2,803,500	
Hence number of private cars on UK roads	28,696,500	
Average annual mileage for a private car in England in 2017	7,800	https://www.racfoundation.org/motoring-faqs/mobility#a24
Average annual car mileage for a company car	11,700	Estimate based on historical DfT data

Now use this data along with reasonable estimates (guesses) of the probability and severity of taking a less than optimal route:

		Company Cars (Type of Journey)			Private Cars (Type of Journey)		
		Business	Commuting	Private	Business	Commuting	Private
Average annual mileage (2017) split based on historical DfT data		4170	3730	3800	610	2360	4830
Probability of becoming lost / enforced detour		1.5%	0.4%	2.0%	2.0%	0.4%	2.0%
Effect on journey length of becoming lost - incremental journey distance		5.0%	5.0%	5.0%	5.0%	5.0%	5.0%
Company cars on UK roads in 2018	2,803,500						
Privately owned cars on UK roads in 2018	28,696,500						
Annual incremental mileages when lost (millions of miles)		8.77	2.09	10.65	17.50	13.54	138.60
Average CO_2 in g/km for company cars (2017)	118.5						
Average CO_2 in g/km for private cars (2017)	144.3						
Annual incremental CO_2 as a consequence of becoming lost (tonnes)		1,672	399	2,032	4,065	3,145	32,188

Annual Total from cars 43,501 tonnes

Now include other forms of road transport and assume that the propensity to get lost is the same as for car drivers:

Proportion of total transport sector CO_2 emmisions in the EU from HGVs (%)	15	https://ec.europa.eu/clima/policies/transport/vehicles_en
Proportion of total transport sector CO_2 emmisions in the EU from LCVs (%)	25	

Fuel cost (pence per litre)	130
Average miles per gallon (cars)	30

Annual Total from HGVs 10,875 tonnes

Annual Total from LCVs 18,125 tonnes

NB:
DfT = Department for Transport

Annual CO_2 cost (all vehicles)	72,502	tonnes
Annual financial cost (cars only)	£38	million pounds

The Cotswold Motoring Museum and Toy Collection is not just about cars. Toys that our parents and grandparents played with as children, everyday artefacts from the Victorian and Edwardian era plus an insight into the social history of the village of Bourton-on-the-Water and much more can be found in the Old Mill, alongside the River Windrush.