Powering Ahead

The future of low-carbon cars and fuels

Viewpoint and Executive Summary

Duncan Kay, Nikolas Hill and Dan Newman
Ricardo-AEA
April 2013

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The UK Petroleum Industry Association (UKPIA) represents the interests of nine member companies engaged in the UK oil refining and downstream industry on a range of common issues relating to refining, distribution and marketing of oil products, in non-competitive areas.

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Viewpoint

In 2007, HM Treasury published the seminal *King Review of low-carbon cars*.[1] Its aim was to “undertake an independent review to examine the vehicle and fuel technologies which over the next 25 years could help to decarbonise road transport, particularly cars”.

Much has happened in the low-carbon vehicle sphere in the six years that have now passed: conventional new car carbon dioxide (CO_2) emissions have decreased by almost 20%, from 164.9 g/km in 2007 to 133.1 g/km in 2012; vehicle manufacturers are now offering an increasing range of electric vehicles, into which the government is pouring money; and, more recently, the government launched a ‘UKH2 Mobility’ platform setting out a plan for the roll-out of hydrogen vehicles from 2015 onwards.

To understand where expert thinking has got to, we commissioned environment and energy consultancy Ricardo-AEA to examine the relative merits of the major fuels and powertrains in delivering the UK’s greenhouse gas reduction targets over the coming decades. We also wanted to know what each technology’s market potential was. To achieve these research goals, the authors reviewed a wide range of market take-up scenarios from leading consultancies and other stakeholders around the world. While the average of expert opinion can be a pretty good estimate of what may happen, any market projection, of course, only paints a picture of what *could* happen. No one can predict with certainty what *will* happen: all forecasts have to make assumptions about what the world may look like in the future.

This report suggests that there will be a multitude of options for consumers to choose between, both in terms of fuels and powertrains: petrol, diesel, natural gas, plug-in hybrids, fuel cell vehicles – and others besides. Each has its own strengths and weaknesses, and will be used in a different application. The report also demonstrates that this range of fuels and powertrains can be used in various combinations, which is good news because it means that the transport system will be more resilient – for example, in terms of oil price shocks – and that there are many benefits to be realised across different technologies, such as making vehicles lighter and more aerodynamic.

The most important finding is that conventionally powered petrol and diesel cars will remain with us for a long time yet, and that the lion’s share of emissions reductions in the short to medium term will come from their improvement through, for example, engine downsizing with turbocharging. All the signs are that they will continue to be the dominant form of powertrain

1 The King Review was published in two parts: the first was published in 2007 and examined the potential for CO_2 reduction in all the main fuels and powertrains; the second, published in 2008, made a series of (policy) recommendations for achieving the UK’s carbon reduction targets for road transport over the long term.

until at least 2030: according to the average market projections, about 60% of vehicles in 2030 are likely to be powered, either in part or in full, by internal-combustion engines. Even in the 2050 scenarios the report anticipates that some cars will still feature an internal-combustion engine, although these are expected to be almost exclusively full hybrids, plug-in hybrids and range-extended electric vehicles driven mainly in electric mode.

Electric vehicles remain a controversial subject. Advocates will say that their market share has increased by hundreds of percentage points over the last years, and that this trend will continue. Critics will reply that this still only represents a small fraction of the market. But what do we actually mean by 'electric vehicles' anyway? The term is most often loosely applied to mean plug-in hybrid electric vehicles, range-extended electric vehicles and pure/battery electric vehicles. However, these technologies are quite different in their degree of electrification, and these differences lead to significant implications for their optimal application, costs of ownership and operation, as well as overall usefulness. Thus, while plug-in and range-extended hybrids could be described as 'the best of both worlds' and seem to make more sense as a mass-market proposition, pure electric vehicles appear to be less promising. Whatever people's feelings about all these plug-in vehicles, the projections reviewed in this report show that by 2020 they are likely to account for anything between 5% and 15% of new car sales, and for between 20% and 50% by 2030.

Much of the limited utility of pure electric vehicles today comes down to simple physics: in terms of energy density, liquid fuels are still dozens of times better than electricity stored in batteries. Even though electric vehicles are now a practical proposition – evidenced by the fact that some people, albeit few, *are* buying and using them – big question marks still remain over how they will perform after several years in terms of day-to-day wear and battery rundown.

Central to all of this is battery technology. The future mass-market success of electric vehicles is highly dependent on breakthroughs in this field, both to increase energy density and to reduce cost, which are essentially two sides of the same coin. While there may be innovative ways of avoiding merely increasing battery size – battery swapping, more frequent trickle charging, rapid charging – all of these come with their own problems.

And then there is their future greenhouse gas reduction potential, which relies largely on decarbonisation of the grid. Although this is strongly implied by the Climate Change Act 2008, it cannot be accepted as a given because of the vast investment required and the potential competition for low-carbon electricity from other sectors like heating homes. There are ongoing discussions in the context of the UK Energy Bill – a proposed legislative framework for delivering secure, affordable and low-carbon energy, which at the time of writing is at report stage prior to its third reading – as to whether it should include a decarbonisation target for power generation by 2030. Whether such a target will be set, and if so at what level, is yet to be determined.

Similar arguments apply to hydrogen fuel cell vehicles, which are not only costly but require both expensive infrastructure for market adoption and 'clean' hydrogen to realise greenhouse gas savings. While the recently launched UKH2 Mobility platform does not guarantee any take-up by the market, it does show that the government is interested in these vehicles.

There appears to be a false perception that investment in electric vehicles comes at the expense of encouraging improvements to the internal-combustion engine. However, the two technologies are at quite different stages of market development: while conventional vehicles are very well established, electric vehicles are only at their infancy. They therefore require different types of government policy. Conventional vehicles need strict but achievable environmental standards while, in theory at least, electric vehicles need supply-push (subsidies for the industry) and demand-pull (consumer incentives such as purchase grants) policies. However, whether the degree of public investment in electric vehicles is appropriate, given their current prospects as a viable form of transport for ordinary people, is another matter, and the subject of considerable debate. If there is any kind of trade-off, it could be said to lie between electric vehicles, particularly pure electrics, and hydrogen fuel cell vehicles. But even here the two technologies are at different market stages – compared to electric vehicles, hydrogen vehicles are far from being a mass-market proposition.

Ultimately, it is not clear which technology will 'win' in the long term. The common consensus in the industry, supported by the market projections reviewed in this report, is that there will not be a single, dominant technology or fuel in the way that there has been over the last century with the monopoly of the internal-combustion engine, but that there will be a range of solutions for different transport applications.

For policymakers this presents a challenge, as it will be difficult for them to decide what policies they should adopt, let alone when and in what form. The case of biofuels shows that decision-makers sometimes get it wrong. In October 2012, the European Commission published proposals to amend the Renewable Energy Directive[2] by capping the share of 'first-generation' biofuels – that is, those derived from food crops – to half of the possible 10% by energy to meet the EU's 2020 targets for renewable road transport fuels. This change of policy caused outrage among the biofuels industry, since these biofuels already account for 4.7% of total fuels, and the industry has huge sunk investments which, effectively, would be wasted if the amending Directive were passed. This example clearly illustrates the need for decision-makers to keep policies under review in the light of new technology and other developments.

It is very clear to us that government policies should be technology-neutral; the emphasis should be on using fiscal and regulatory levers, and other policies,

2 Directive 2009/28/EC: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=Oj:L:2009:140:0016:0062:en:PDF

to incentivise both the demand and the supply of low-carbon vehicles in the market place. The record so far has demonstrated how effective this can be. The automotive industry, with the associated huge research and development effort going on, should lead the evolution and the bringing to market of the different technologies, to which consumers will respond. However, we do recognise that government has a role in supporting fledgling research (through, for example, the successful programmes of the Technology Strategy Board). And from time to time there are consequential policy issues (as in the case of biofuels) which cannot be avoided.

Overall, we believe that this report has made a valuable contribution to the discussion on the road ahead for all types of low-carbon vehicles. Only time will tell what exactly we will be driving in the next couple of decades. Whatever it is, it will be low-carbon and very efficient. And, it is to be hoped, also exciting.

On the basis of the evidence in this report, we make the following recommendations:

- Regulation based on tailpipe emissions is increasingly no longer fit for purpose and must be changed to be based on well-to-wheel, and ultimately even life cycle, emissions.
- Government should push strongly for a move away from the current ‘New European Drive Cycle’ (NEDC) test cycle, towards the ‘Worldwide harmonized Light vehicles Test Procedure’ (WLTP) cycle to capture tailpipe emissions and fuel consumption more accurately, as the discrepancy between stated and real-world performance is wide, and confusing for consumers. This must be introduced in tandem with tightening the entire vehicle type approval test.
- The 2025 new car CO_2 target should be set at a maximum of 70 g/km from the tailpipe, with a preferred target of 60 g/km. Regulation must be carefully designed to capture well-to-wheel (or even life cycle) emissions, whilst spreading the burden on vehicle manufacturers in an equitable manner.
- Government should take a technology-neutral approach to the encouragement of low-carbon vehicles. It should focus on the use of fiscal, regulatory and other policy levers to drive both the demand and supply of such vehicles, leaving the automotive industry to lead the evolution, and the bringing to market, of the various technologies.
- Government must deal with the ‘ILUC issue’ – indirect land-use change, in other words secondary and often unanticipated negative environmental impacts – if it wants to seriously consider biofuels and avoid any potential negative indirect consequences.

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Executive summary

Introduction

This report examines how the challenge of achieving the UK's legally binding commitment to a substantial reduction in greenhouse gas (GHG) emissions by 2050 is likely to affect the cars and fuels we will use over the next 20 years.

It is now six years since Professor Dame Julia King set out her recommendations for action to reduce carbon dioxide (CO_2) emissions from the passenger car sector in the *King Review of low-carbon cars*. Over this period, policies and initiatives to promote the uptake of lower-carbon cars have been introduced at both European and national levels, and manufacturers and fuel suppliers have worked to develop lower-carbon options for consumers.

Policy context

In 2008, the UK became the first country in the world to introduce a law committing the government to cut GHG emissions: the Climate Change Act 2008. This requires an 80% reduction in GHG emissions by 2050 relative to a baseline of 1990.

Transport is responsible for 21% of UK GHG emissions by source, with cars accounting for 55% of that share or 12% of the total.

Later this year the European Commission is expected to confirm that new cars sold in Europe should emit an average of 95 gCO_2/km or less by 2020. Consultation will also be held until 2014 regarding a new target for 2025.

Alongside this, the Commission has introduced directives governing renewable energy and vehicle fuels, which require that at least 10% of transport fuels by volume (excluding aviation fuels) must originate from renewable sources by 2020. It had been expected that the vast majority of this would be met through the use of biofuels. However, there are continuing concerns about true level of biofuel GHG savings, particularly for first-generation biofuels, once 'indirect land-use changes' (ILUCs) have been taken into account. As a result, in October 2012, the Commission announced proposals to amend the Renewable Energy Directive so that no more than half of the 10%-by-energy target can be met through the use of first-generation crop-based biofuels. Given that current production volumes of alternative next-generation biofuels are relatively small, and that uptake levels of plug-in electric vehicles using renewable electricity may well provide only a limited contribution, it is not clear how this target will be reached by 2020.

The UK has introduced a range of policies to encourage uptake of lower-emission vehicles. Vehicle Excise Duty (VED) and company car tax have been progressively revised to strengthen incentives to choose low-CO_2 options. The UK's colour-coded vehicle fuel economy labelling system is designed to make it easier for consumers to choose more fuel-efficient models. In 2010, a new 'first-year rate' of VED was introduced to provide a stronger signal at the point of purchase, with rates for the highest-CO_2 vehicles now set at £1,030.

The Plug-in Car Grant scheme provides 25% (capped at £5,000) towards the cost of eligible plug-in cars (and 20% – capped at £8,000 – for plug-in vans). The Plugged-in Places scheme has seen over 2,800 charging points installed, in eight areas of the country.

Together these policies appear to be having the desired effect. According to the SMMT (Society of Motor Manufacturers and Traders), the average tailpipe CO_2 emission figure for cars sold in the UK in 2012 was 133.1 g/km, representing a fall of almost 23% over the last decade.

Maintaining this good rate of progress in the reduction of carbon emissions from cars will require that future policies continue to drive technological progress. Perhaps the most important decision facing policymakers is what level to set as the target for CO_2 emissions in 2025. The European Commission has announced that it will explore a level of 70 g/km, and is expected to seek stakeholders' views on both this and a target for vans sometime in 2013. Some environmental groups feel that the 2020 target of 95 g/km lacks ambition, and are already pushing for 60 g/km by 2025.

Alongside this is the problem of a growing gap between the type-approval fuel economy figures obtained using the official test cycle (the NEDC – New European Drive Cycle) and those that drivers achieve in the real world. It has been noted that some of the largest differences are for the vehicles with the lowest official CO_2 figures, meaning that consumers who choose the most 'environmentally friendly' option may be the most disappointed by their vehicle's actual fuel economy.

The Commission aims to address this by introducing the new 'Worldwide harmonized Light duty vehicles Test Procedure' (WLTP), which is considered to be more representative of real-world driving conditions. The WLTP is being developed under the UNECE (UN Economic Commission for Europe) for global application. Alongside this, changes are also planned to the way that emissions tests are conducted.

In the longer term there is an increasing need to consider not merely the CO_2 emissions from vehicle exhausts, but the whole life cycle environmental impacts of vehicles. For pure electric vehicles, referred to here as battery electric vehicles (BEVs), it does not make sense for legislation to relate solely to tailpipe emissions, since there are none. However, there are certainly emissions associated with the production of the electricity needed to power the vehicle. Equally, BEVs' manufacturing emissions are currently significantly higher than those of a comparable conventional vehicle (owing primarily to the batteries).

Future fuels and vehicle technologies

In the past, conventional petrol- and diesel-fuelled internal-combustion engines (ICEs) were the dominant technology. But a much wider range of technologies and fuels is already becoming available, and these will become ever more common in the coming years.

Chapters 3 and 4 of this report investigate, respectively, the future potential of a range of fuels and of powertrain technologies and other aspects of vehicle technology that improve efficiency. For each option the chapters set out, and where possible quantify, their characteristics in terms of GHG reductions, advantages and disadvantages, infrastructure requirements, availability, and cost. A high-level summary of the findings is presented here:

Petrol and diesel: Conventional petrol- and diesel-powered cars accounted for virtually all (99%) of all new cars sold in the UK in 2012. The diesel engine's higher efficiency offers a reduction in life cycle GHG emissions per km of about 14% compared to an equivalent petrol vehicle, although technologies such as petrol direct-injection in combination with downsizing and turbocharging might reduce this advantage. Petrol engines produce lower NO_x and particulate emissions, although the Euro standards on air pollutants will narrow the gap between petrol and diesel vehicles. However, the additional exhaust aftertreatment needed for diesel vehicles to meet these standards may further erode their fuel economy advantage.

LPG (liquefied petroleum gas) / CNG (compressed natural gas): Gas-powered vehicles account for only a tiny fraction of new car sales in the UK. Many manufacturers offer natural gas vehicles in other countries, and aftermarket conversions are available here. Life cycle CO_2 emissions for CNG are up to 24% lower than for a comparable petrol car. For LPG the figure is about 14%. LPG- and CNG-powered vehicles also produce lower NO_x emissions and very low particulate emissions. However, the lack of refuelling infrastructure, and the reduced range compared to petrol or diesel, continue to constitute barriers to their uptake.

First-generation biofuels: There is a range of first-generation crop-based biofuels currently available. Bioethanol and biodiesel are already used by motorists, in that forecourt petrol and diesel contains a *c.*5% blend of biofuel. High-blend strength biofuels (e.g. E85 – petrol with an ethanol content of 85%) are not available to the mass market. The GHG savings for first-generation biofuels vary considerably according to the feedstock used, the manufacturing process, and in particular issues of ILUC. Some are calculated to result in GHG emissions that are actually higher than those of fossil fuels. However, the use of biomethane (a purified form of biogas) can result in life cycle GHG emissions savings of over 70–80% compared to petrol. Biogas is typically produced from waste biomass or manure, meaning that there are little or no emissions caused by ILUC. The disadvantages of biomethane are much the same as those of CNG.

Next-generation biofuels: Next-generation biofuels are made using more advanced processes, and usually from non-crop biomass such as stems, leaves and husks, or grasses or woody energy crops, or possibly waste wood. They are therefore less likely to result in competition with food. There are several alternative processes used to create next-generation biofuels. The GHG savings vary significantly depending on the feedstock and the production process; however, they are typically much greater than for first-generation biofuels, partly because they largely avoid the issue of ILUC. However, current production volumes are low, and next-generation biofuels may not make a significant contribution to meeting carbon reduction targets until after 2020. A further issue is that in the future they might need to be prioritised for use in aviation and shipping, sectors in which there are fewer technical alternatives to liquid fuels for GHG reduction.

Hybrid and electric vehicles: The increasing electrification of powertrains is widely regarded as the most likely route to achieving GHG reduction targets for passenger cars. The progression in technology is expected to be from widespread use of stop–start (so-called 'micro hybrid') technology, to a growing market share for hybrid electric vehicles (HEVs or 'full hybrids'), through to plug-in hybrid electric vehicles (PHEVs) and range-extended electric vehicles (REEVs), and ultimately BEVs. Hybrid technology (non-plug-in) is currently gaining market share and can reduce GHG emissions by 15–25%. Currently the average fuel life cycle GHG saving for a BEV over its full life is calculated to be over 50% under UK conditions – that is, with the current mix of grid electricity generation. This could increase to 75% in 2020 and to 83% by 2030 with the anticipated decarbonisation of grid electricity. However, BEVs face major challenges in gaining market share because of their high prices and limited range. Breakthroughs in technology, particularly in the cost and performance of batteries, are required before PHEVs and BEVs can achieve significant market share.

Hydrogen fuel cell vehicles: Renewably produced hydrogen used in fuel cell vehicles (FCVs) offers amongst the largest potential GHG reduction possible (next to BEVs). FCVs also offer the benefit of a range comparable to conventional vehicles. However, they face a number of barriers. They are currently substantially more expensive than conventional vehicles, or even BEVs, as a result of fuel cell costs. There are also very few locations where they can be refuelled. Their actual GHG savings are dependent on the source of the hydrogen. Typically they are expected to achieve around 70% savings in 2030, assuming hydrogen sourced from a mix of natural gas reformation and electrolysis.

In summary, each of these options involves trade-offs between GHG savings, cost, range and required refuelling infrastructure. However, one area which will benefit all these options is that of **improving vehicle energy efficiency through reduced weight and reduced drag**. A greater focus on the use of ultra-lightweight body structures and achieving the lowest possible drag coefficient and frontal area, together with reducing rolling resistance, can substantially reduce the overall energy requirement. This is particularly beneficial for BEVs, where drag and rolling resistance represent the majority of the energy losses. Reducing these losses can allow a smaller battery or fuel cell to be used, reducing costs.

Predicted future market shares of vehicle technologies

In order to understand the likely growth in market shares for the different car technologies available, 14 separate studies were analysed, and their predictions – and the underlying assumptions – were compared. It is important to note that some studies attempt to forecast on the basis of existing trends, whereas others 'backcast' from a future scenario. These two methods can result in significantly differing results.

The technologies covered by the studies reviewed included HEVs, PHEVs, REEVs and BEVs. These studies provided a range of estimated market shares for each of the technologies; from these a series of 'mainstream' predictions (rounded to the nearest 5%) were then identified, as shown in the table.

To put these figures into context, in 2012 the UK market share for hybrid cars was 1.2%. For Plug-in Car Grant eligible vehicles it was just 0.1%, with pure BEVs accounting for 0.06%.

Predicted market share of low-carbon vehicles

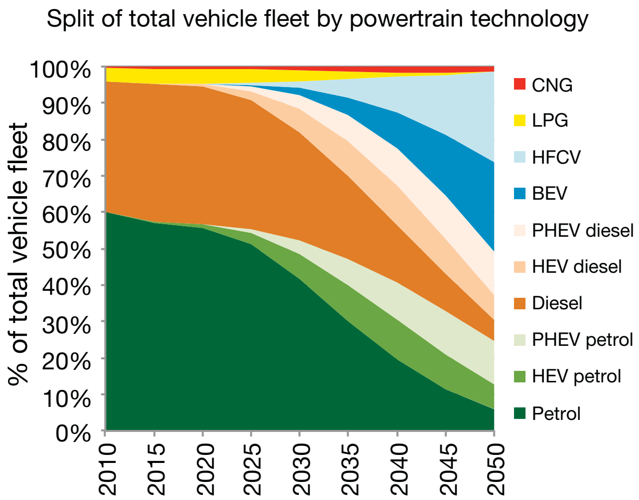
Technology	2020	2030
Full hybrids	5–20%	20–50%
Plug-in hybrids	1–5%	15–30%
Range-extended electric vehicles	1–2%	5–20%
Battery electric vehicles	1–5%	5–20%

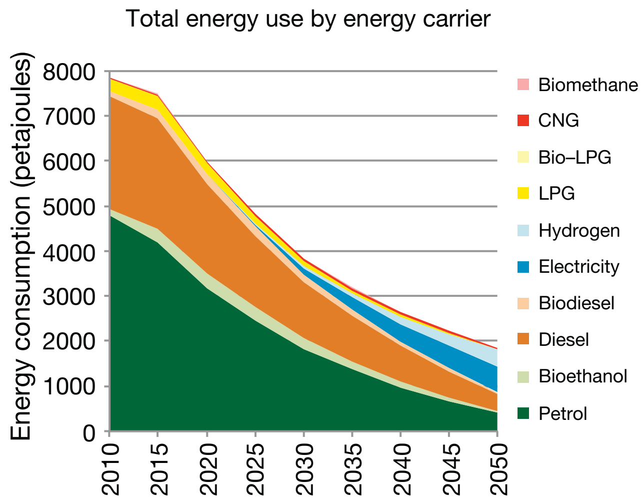
Notes: The ranges presented in the table above are for individual powertrain options, and often from different sources. There will necessarily be interaction between the deployment of different options, and also with conventional ICE powertrains. The respective upper/lower limits for the different technologies cannot therefore be simply added together. There was insufficient data to provide estimates for FCVs. The remainder of the market will remain conventional ICE powertrains.

Each of the studies from which these average figures are taken makes a set of assumptions regarding certain key sensitivities. The factors which appear to have the strongest influence over the predictions are, firstly, future government policy, and, secondly, the likely speed with which breakthroughs in technology, particularly with respect to batteries and fuel cells, will be achieved.

Predicted future market shares of fuels

The expected changes in terms of the fuels which are likely to be used in future vehicles are shown below. These figures show Ricardo-AEA's assessment of the most likely scenario for meeting EU 2050 carbon reduction targets, based on known measures identified in the European Commission's 2011 Transport White Paper and recent concerns about the availability and sustainability of biofuels. On the left-hand side it can be seen that petrol and diesel vehicles are expected to remain the dominant technology in the overall vehicle fleet until at least 2030. However, the plot on the right illustrates how the actual quantities of petrol and diesel used (and as a result the energy provided) will fall dramatically as a result of the continuing improvements in ICE vehicle efficiency.





Source: Ricardo-AEA analysis

Many other factors might affect the speed of uptake of low-carbon cars. These include rising oil prices, potential resource constraints (e.g. for the rare earth metals needed for electric drivetrains), and the possibility of increasing urbanisation leading to a shift away from car ownership to alternatives such as car sharing, improved public transport, and other forms of personal mobility such as electric bikes and scooters – all developments, of course, which would in themselves lower GHG emissions, without reference to low-carbon cars.

Conclusions

In the near future, the expectation is that conventional petrol and diesel vehicles will continue to dominate personal transport, with advances in fuel economy being achieved by means of innovations in engine technology combined with a greater focus on improving vehicle efficiency through reduced weight and drag. At the same time, technologies such as stop–start systems are expected to become commonplace, and full hybrid technology will continue to increase its market share.

In the medium term, if breakthroughs in battery technology deliver the necessary performance improvements and cost reductions, there will be increasing electrification of powertrains. Increasing numbers of vehicles will offer an ‘electric-only’ drive mode, and the numbers of plug-in hybrid models available will increase. BEVs will start to gain market share too, as consumer confidence in electric powertrain technologies increases.

In the longer term, the likely mix of technologies is extremely difficult to predict. The speed with which PHEVs and BEVs (including fuel cell vehicles) will achieve significant market shares is highly dependent on their total cost of ownership in comparison to that of more conventional alternatives. This is, in turn, dependent on factors such as oil prices, further battery and fuel cell cost reductions, and government policies.

In the meantime the key question facing policymakers at present is at what level to set as the target for tailpipe CO_2 emissions in 2025. Our analysis suggests that to achieve a 70 g/km target may require the new vehicle market share for PHEVs and BEVs to reach around 5% by 2025, in combination with further improvements to conventional and hybrid powertrain vehicles. This matches the most pessimistic market uptake projections of such vehicle types. A 60 g/km target would likely require PHEVs and BEVs to gain market shares which are towards the midpoint of the range of current projections.

There is no doubt that meeting a target of 60 g/km would be a challenge. However, some experts believe that this could be achieved, were government and the automotive industry to work to create the right policy framework and to try and ensure that the necessary advances in technology are realised.

About the Authors

Duncan Kay is a senior technical consultant for Ricardo-AEA and has a background of 16 years' experience in the automotive sector, working as a research and development engineer developing new technologies to improve fuel economy and reduce emissions from passenger cars. Since leaving the industry he has spent the last 5 years advising and consulting on a wide range of transport issues, particularly analysis of the automotive industry and transport greenhouse gas emissions reduction. Duncan has led studies for the Low Carbon Vehicle Partnership, the European Environment Agency and the European Commission amongst others. In 2012, he completed a study for the Joint Research Council of the European Commission examining the role of research and development in maintaining the competitiveness of the European automotive industry.

Nik Hill is Ricardo-AEA's Knowledge Leader for Transport Technology and Fuels and has over 13 years of experience of consultancy project work on transportation issues for a range of public and private sector clients. He has particular expertise in transport emissions, low-carbon vehicle technologies and fuels, and in developing models to simulate future emissions trajectories. Nik's expertise includes assessing the energy and environmental impacts of transport, including model development, life cycle analysis and the economic evaluation of future vehicle technologies and fuels. Nik has led a number of influential projects for the UK government and European Commission in recent years, one of which was a high-profile European Commission project to identify and analyse potential options for a long-term policy framework to reduce transport greenhouse gas emissions out to 2050.

Dan Newman is a consultant for Ricardo-AEA with over two years of experience on sustainable transport projects for both governments and the private sector. Dan has particular expertise in battery/hybrid electric vehicles and natural gas fuelled vehicles. He has been involved in a range of work for the European Commission and has recently been instrumental in investigating the effect of environmental regulations and standards on vehicle prices over the past 15 years. Dan has led tasks assessing the impact of information communications technology (ICT) of the large-scale deployment of battery electric vehicles for the European Commission, and has modelled how natural gas can contribute to achieving cost-effective greenhouse gas emissions reductions across the European transportation sector.

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