Exploring the Impact of Policy on Road Transport in 2050

Huw Davies

Original citation & hyperlink:
Davies, H., 2020. Exploring the Impact of Policy on Road Transport in 2050: Opportunities to accelerate reduction in carbon emissions. *Johnson Matthey Technology Review*, *64*(3), pp.252-262.
https://dx.doi.org/10.1595/205651320x15816871073928

DOI 10.1595/205651320x15816871073928
ISSN 2056-5135

Publisher: Johnson Matthey Plc

https://doi.org/10.1595/205651320X15816871073928 *Johnson Matthey Technol. Rev.*, 2020, **64**, (3), 252–262

JOHNSON MATTHEY
TECHNOLOGY REVIEW

www.technology.matthey.com

Exploring the Impact of Policy on Road Transport in 2050

Opportunities to accelerate reduction in carbon emissions

Huw Davies
Research Institute for Future Transport and Cities, Coventry University, Priory Street, Coventry, CV1 5FB, UK

Email: ac2616@coventry.ac.uk

Within the 28 member states of the European Union (EU-28), 71.7% of transport emissions in 2017 were due to road transport and a policy commitment was made to reduce emissions from the transport sector as a whole by 60% by 2050 (against a 1990 baseline) (1). Going forward, and supported by policy, a stratification of passenger car powertrain options is anticipated, with customers able to choose from a zero-tailpipe emission battery electric vehicle (BEV), fuel cell electric vehicle (FCEV) or a selection of hybridised vehicles ranging from a mild to a plug-in hybrid electric vehicle (PHEV). Further to this, technology improvements and connectivity between vehicle and energy generation and supply offer further opportunities to accelerate reduction in carbon emissions in the transport sector. The structure of this new transport paradigm is pathway dependent. Multiple conflicts exist, pulling the system in different directions and threatening its sustainability. This paper explores the link between policy and the impact this has upon the direction that road transport is taking, focusing on technology options and highlighting some of the dichotomies that exist between policy and the requirement for a sustainable road transport solution.

1. Introduction

"In these periods of major change, the established points of reference are being swept away, even in so-called traditional industries" (2).

Sustainable mobility is already on the agenda of every government in the world. The concept of sustainable development, defined by the Brundtland Commission as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (3) has permeated and is now a standard objective in all spheres of life and at government level. It is also at the core of the Sustainable Development Goals (4), recently launched by the United Nations as global objectives for 2030.

Transport plays a fundamental role for economic development and social welfare of a country. The movement of individuals and goods facilitates production and trade, enhances labour mobility and provides customers with access to goods. Transport externalities jeopardise sustainability. Transport externalities include environmental externalities (mainly climate change, air pollution and noise), but also extend to accident externalities and congestion externalities (5–7). The environmental impact of transport is substantial and "based on continuing current rates of growth for passengers and freight, and if no mitigation options are implemented to overcome the barriers, the current transport sector's GHG emissions could increase by up to 50% by 2035 at continued current rates of growth and almost double by 2050" (8).

Most policies in place and most proposed policies by design focus on existing externalities. However, the transport externalities we know today may be replaced by other problems. The world is being shaken up by new technologies and the speed of change is unprecedented. The term 'disruptive technologies' is becoming widespread, as shown by recent reports produced by McKinsey and Company, USA (9) and Deloitte LLP, UK (10). With the help of a comprehensive literature review, the aim of this paper is to understand the impact that current and proposed policy could have on the technological change in the road transport sector and how this will change the nature of the problems encountered and the sustainability.

The paper is organised as follows. Section 2 concentrates on alternative energy vehicles, with particular attention to electric and fuel cell vehicles based on their likely preponderance in the vehicle fleet by 2050. Section 3 concentrates on the UK policy in supporting the development and manufacture of electric vehicles (EVs) and Section 4 on the sustainability considerations resulting from current policy measures. Section 5 brings together the key findings and Section 6 concludes with final thoughts and direction for policy recommendations.

2. Alternative Energy Vehicles in 2050

In terms of sustainability and emissions in particular, the transport sector is coming under increasing scrutiny. The 'Paris Agreement' of 2015 aims to hold the increase in the global average temperature to well below 2°C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change (11). Transport, as the source of nearly a quarter of all Europe's greenhouse gas (GHG) emissions (**Figure 1**), has become one of the focal points. This section focuses on technological improvements that are possible for passenger cars up to 2050 rather than on behavioural change or significant modal shift. The basis for this is that although their modal share would decrease by about 7% between 2010 and 2050, passenger cars will still represent about 67% of total passenger transport activity in 2050 based on European Union (EU) projections (13), whilst a UK study predicted a growth in overall road traffic demand of between 37% and 61% by 2050 (14).

In looking to reduce emissions from the road transport sector, the EU has taken regulatory action, which commits the automotive industry to reach a fleet average of 95 g CO_2 km^{-1} by 2020 (15). Whilst the 2020 target can still be achieved without a radical industrial transformation, the 10 g CO_2 km^{-1}, calculated as the tolerable maximum in 2050 to stay below 2°C global warming (16), will require a much more radical departure from current technological trajectories. Technological innovation will play a major role in taking on this challenge.

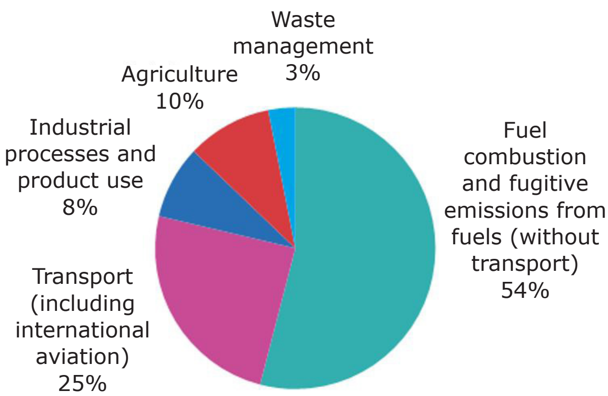

Fig. 1. GHG emission, analysis by source sector, EU-28 2017 (12)

Beyond 2020 and towards 2050, road transport vehicles are very likely to be propelled by a range of low-carbon technologies: battery electric and fuel cell electric propulsion; and varying degrees of hybridisation. Electromobility, either battery or fuel cell electric, will increasingly challenge the paradigm of internal combustion engine (ICE)-based mobility, simply because it is technically impossible to increase the efficiency of ICEs to the levels needed to achieve the emissions requirements (17). However, due to the various political and technological uncertainties, it is far from clear how fast and how radical the market penetration of these alternative energy vehicles will be, even though most predictions and forecasts give them a preponderant role in 2050 (18).

2.1 Vehicle Penetration by 2050

Obtaining accurate predictions about the market penetration rate of battery-electric, fuel cell electric and hybrid-drive technologies is problematic as forecasts diverge considerably (19). Figures vary from a long-lasting niche of a few percent and several hundreds of thousands of EVs sold in 2050 to a 50% market share for hybrids and EVs. For example, one of the future scenarios modelled by the International Energy Agency (IEA), France, termed as the 'BLUE Map' scenario, sets an overall target of a 50% reduction in global energy-related carbon dioxide emissions by 2050 compared to 2005 levels (20). Under this scenario, transport in 2050 is assumed to cut CO_2 emissions by 30%, relative to 2005 levels (21). This reduction is achieved partly by "accomplishing an annual sale of approximately 50 million light-duty pure battery electric vehicles and 50 million plug-in hybrid electric vehicles per year by 2050, which is more than half of all light-duty vehicle sales in that year" (21) (**Figure 2**).

The penetration rate of pure BEVs, PHEVs and FCEVs will be influenced by a range of factors: supplier technologies and vehicle offerings, vehicle characteristics, charging infrastructure and, as a function of these, consumer demand. However, all these factors are largely subject to international discourses and government policies. As an example, a forecast by the consultancy McKinsey and Company (22) track change in drivetrain technology up to 2050 and based on the three different g CO_2 km^{-1} targets. Whilst each of the different forecasts (10 g CO_2 km^{-1}, 40 g CO_2 km^{-1} and 95 g CO_2 km^{-1}) show the coexistence of several powertrain technologies, and with BEV and FCEV increasing their market shares in the future at the expense of petrol and diesel, the rate of change diverges considerably. In the most stringent 10 g CO_2 km^{-1} scenario, hybrid EVs (HEV) and range extended EVs (REEV) serve as a bridging technology that expands its market share for about 20 years but then declines to zero by 2050, whilst in the less stringent 95 g CO_2 km^{-1} HEVs have the dominant market share in 2050 (**Figure 3**) (22).

While predicting future technologies can be uncertain, the imperative to keep global temperature increases below 2°C and to improve urban air quality gives a clear indication that policies to promote investments in low-carbon vehicle technologies will continue. According to a report by IEA, under scenarios for decarbonisation in line with the 2°C global warming target, "three-fourths of all vehicle

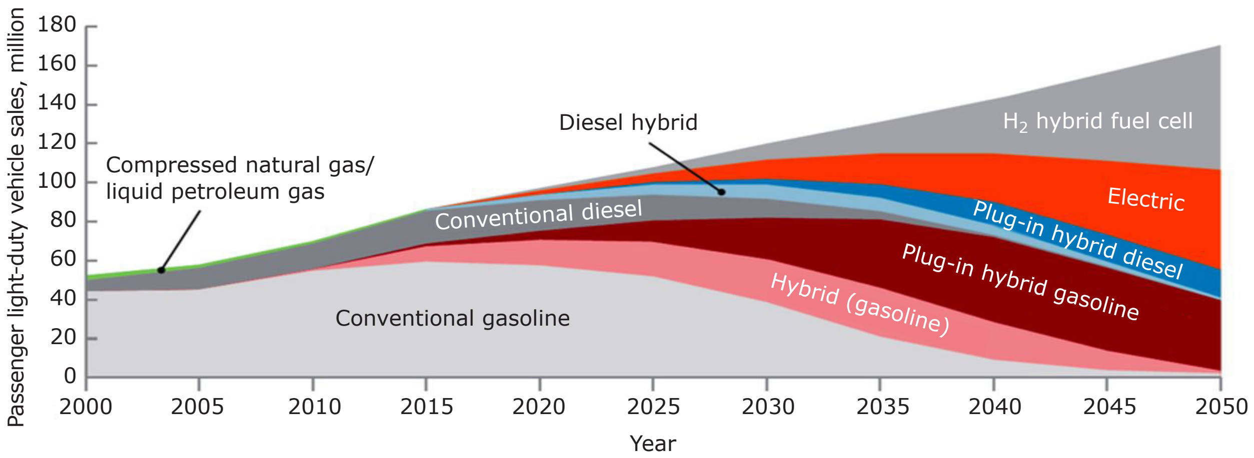

Fig. 2. Annual light-duty vehicle sales by technology type, 'BLUE Map' scenario. Source: IEA (21). All rights reserved

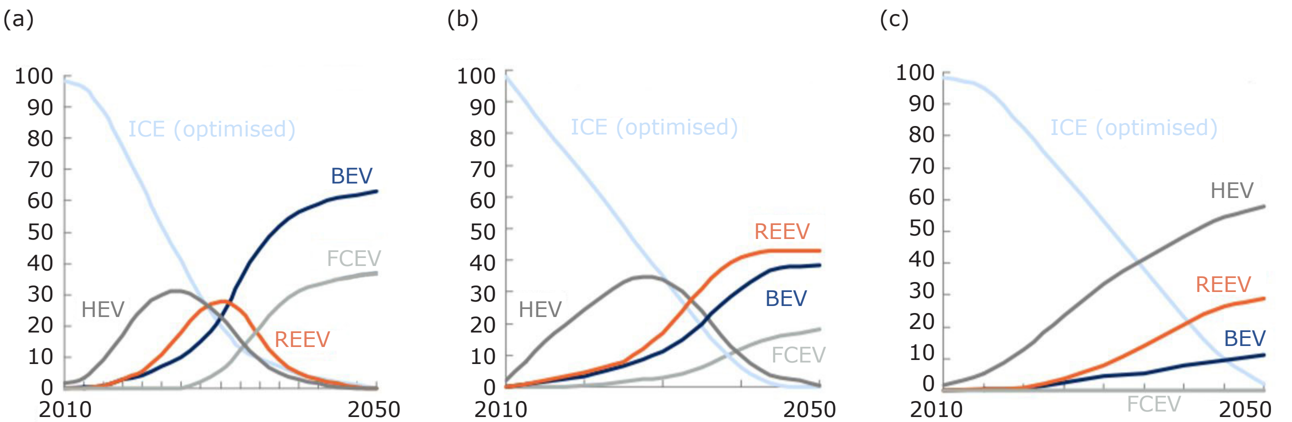

Fig. 3. Example of the predicted change in vehicle drivetrain technologies for one study and based on setting: (a) 10 g CO_2 km^{-1} cap in 2050; (b) 40 g CO_2 km^{-1} cap in 2050; and (c) 95 g CO_2 km^{-1} cap in 2050. Exhibit from (22). Copyright © 2020 McKinsey and Company. All rights reserved

sales by 2050 would need to be plug-in electric of some type" (23).

2.2 Electricity Generation and Supply

This transition to electromobility will also not be without its challenges. As the number of EVs increase, the research focus will move to issues around integration with the energy generation system and electric grids (24). Since battery charging would likely be done in residential areas, the distribution network operator will have to manage the additional consumption in order to avoid congestion on the electric grid, which would have a negative effect on voltage control, power quality (harmonics and subharmonics), supply and demand balance and relay protection. An important issue here is the unpredictable behaviour of users of EVs and their desire to recharge their vehicles when they want (uncontrolled charging).

Linking the automotive fleet to the electric grid will require a range of solutions to adapt demand to grid capacity and to ensure that access to charging is convenient for the customer. In addition, if electromobility is the solution to carbon abatement in the usage phase, then electricity generation will play a substantial role in the lifecycle CO_2 emissions of EVs. In regions that depend heavily on conventional fossil fuels for electricity generation, PHEVs and BEVs may not demonstrate a strong life cycle emissions benefit (25–27). Achieving the targets for CO_2 emission reduction in 2050 will therefore depend heavily on changes in electricity generation. If the achievement of low CO_2 electricity generation around the world does not occur in the 2050 timeframe, the CO_2 emission reduction benefits of BEVs and PHEVs will be much lower. As an example, within the UK the National Grid envisages a carbon intensity for the electricity mix anywhere between 20 g CO_2 kWh^{-1} and 72 g CO_2 kWh^{-1} by 2050 depending on the pathway adopted (**Table I**).

In relation to charging, the National Grid prediction for the UK market is for as many as 11 million EVs by 2030 and 36 million by 2040 leading to possible implications for peak electricity demand. However, if approached and managed appropriately, the charging of the BEV could avoid high peaks in demand at certain times and provide services to the grid.

Enabling an EV to communicate with the electrical grid, would allow the charging load to be spread. Smart charging would help utilities manage network overloads, voltage levels, frequency of electricity and imbalances between supply and demand – for example by absorbing the peaks observed due to more variable renewable energy generation (29). This is known as avoided curtailment. Such a system would lessen the need for additional grid and generation capacity, reducing GHG emissions and avoiding additional infrastructure cost. By 2050, and depending on the right policies being in place and providing the necessary bridge, the charging infrastructure will have been scaled up and standardised and smart charging will be part and parcel of the consumer experience.

2.3 Hydrogen as an Option?

The technology roadmaps that have been published, including those by the European Road Transport Research Advisory Council (ERTRAC), Belgium, the Advance Propulsion Centre UK Ltd (APCUK) and the Society of Automotive Engineers of China (China-SAE), share a view that both the BEV and the FCEV are viable future market solutions (18).

Fuel cell vehicles dependent on hydrogen offer the potential to be large enough to accommodate a family and travel long distances at highway speeds (22, 30–32). The hydrogen required for fuel cell vehicles is a flexible energy carrier that can be produced from any regionally prevalent primary energy source, it can be effectively transformed into any form of energy for diverse end-use applications and has the potential to facilitate significant reductions in energy-related CO_2 emissions (33).

Like BEVs, fuel cell vehicles running on hydrogen also face important challenges. These are the storage and transport of hydrogen in the vehicle,

Table I Carbon Intensity of Electricity (28)

Scenario	2017, g CO_2 kWh^{-1}	2030, g CO_2 kWh^{-1}	2050, g CO_2 kWh^{-1}
Community renewables	266	75	32
Two degrees	266	48	20
Steady progression	266	117	52
Consumer evolution	266	146	72

as well as the provision of a refuelling network. To encourage wide-scale uptake of fuel cell vehicles on hydrogen by consumers, a comprehensive hydrogen refuelling infrastructure will be required. The refuelling network for hydrogen is expected to follow a similar model to petrol and diesel refuelling (34). Hydrogen stations are concentrated in major cities and then link the cities together *via* hydrogen stations on the highway or strategic road network leading to a rapid increase in the proportion of the population with access (**Figure 4**). The question that requires answering is how to supply that network, given that the energy density of hydrogen is significantly less than the fossil fuels it is replacing i.e. simply relying on existing supply channels to meet demand would actually increase road traffic and energy use (through more vehicle movements on the supply chain side). Localised production of hydrogen through electrolysis is possible, but what are the efficiencies of such a system and how would the energy grid cope with the additional demand?

3. Policy Support in the UK

The UK Climate Change Act, which became legislative in 2008, aims to reduce the emissions of all GHGs by 80% by the year 2050 (from a 1990 baseline). The importance of the transport sector in achieving this target is illustrated (**Table II**), with transport contributing one third of all UK CO_2 emissions in 2018 compared to just over one fifth in 1990.

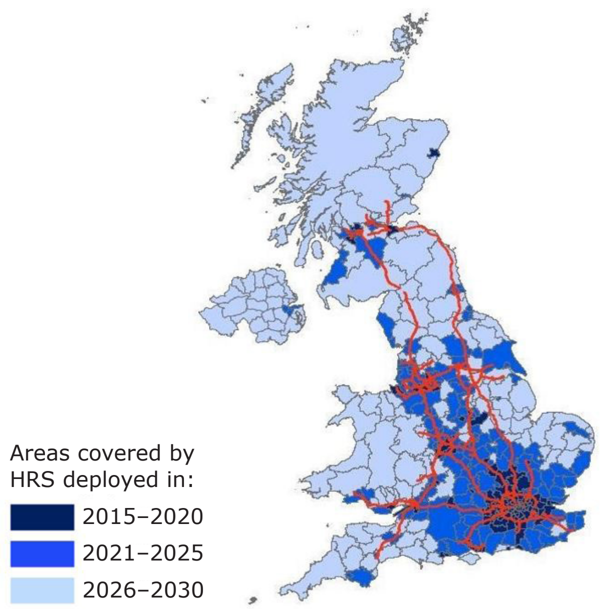

Fig. 4. Development of local hydrogen refuelling station (HRS) network coverage. Reprinted with permission from (35)

Alternative Energy Vehicles in 2050

- Road transport is a significant contributor to GHG emissions
- Regulatory '95 g CO_2 km^{-1} by 2020' not sufficient to meet 'Paris Agreement'
- Battery and fuel cell electric to replace combustion drivetrain, but fleet share uncertain
- Meeting challenges requires integration between transport and energy supply
- Requirement to integrate issues of energy policy, transport policy and social policy

To reduce transport related CO_2 emissions, the UK Government plans to phase out ICEs from new vehicle sales by 2040 and "has set ambitions to ensure that almost every car and van in the UK is a zero-emission vehicle by 2050" (37). However, these ambitions come with much uncertainty and the feasibility has been questioned.

Several risk factors will determine how quickly and deeply alternative energy vehicles will penetrate the UK vehicle mix and whether it will become a sustainable market segment. It is of strategic importance that industry understands these risks that can inform their research and development (R&D) investments. Alternative energy vehicles are a new product in a new industry and their radically different composition potentially means substantial change to production systems and value chains. The risk for industry in investing in the nascent value chain is compounded by competing alternative-vehicle technologies. Even though in the UK the government stance is to be technology neutral, government policies play a key role in how new technologies are supported by the wider stakeholder community (38). This will affect the quantitative nature of the risk and its perception in a significant way.

3.1 Creating a Competitive Electric Vehicle Manufacturing Sector

Despite the ubiquity of automobiles across the world, with around a billion such vehicles currently on the road, the car industry is a barely profitable business. The automotive industry is an extremely capital-intensive sector and the main issues in investing in new technology are capital intensity,

Table II UK Annual CO_2 Gas Emissions, 1990–2018, Headline Results (adapted from (36)[a])

	1990	1995	2000	2005	2010	2015	2017	2018
Transport, CO_2e, million tonnes[b]	125.4	126.8	131.0	134.3	123.4	122.2	124.6	121.4
Total CO_2, CO_2e, million tonnes	596.3	560.1	558.3	557.9	498.3	408.3	373.2	364.1
Transport as % of total CO_2, %	21	23	24	24	25	30	33	33

[a] (36) licensed under the Open Government Licence v 3.0
[b] CO_2e = carbon dioxide equivalents

cost requirements and amortisation of sunk costs. High volumes of output are needed to amortise these costs (39–41). The decision to build a new plant or introduce a new model is a major one, a very risky decision with uncertain outcomes. A result of the high cost of model-specific investment is conservative 'evolutions' of core models in an attempt to minimise risk.

Within this environment the electrification of the drivetrains represents a not inconsiderable challenge for today's automotive industry. Transition to an electrification of the drivetrain will require high investment, implicating a high economic risk for the industry, especially if reasonable sales numbers are not generated. This comes at the same time as the need to continue to invest in development of ICE and to ramp up investment in connected and autonomous vehicle technologies.

One result of the need to invest in electrification is that it has incited traditional manufacturers to consider joining forces and so increase their investment capacity, but also their ability to realise economies of scale. The competitiveness of a BEV is going to be directly connected to the efficiency of the value chain. In the short term the approach is for process improvements and reduction in cost focused on the areas of high value and for the EV this is the battery. Hence, new production plants with high capacities for battery systems will have to be implemented. Recent announcements around the establishment or enlargement of battery cell manufacture include: BYD Company Ltd (20 GWh by 2020) and Contemporary Amperex Technology Co Ltd (CATL) (50 GWh by 2020) in China; LG Electronics (6 GWh expanding to 15 GWh) and Samsung SDI (3 GWh) in Europe; and LG Electronics (3 GWh) and Tesla (35 GWh) in the USA (42). When these figures are taken into account together with existing installed capacity at other sites, it is clear that Asia is currently leading, with China producing twenty-two times more batteries than Europe (43). Further to this, the development of battery technology is one of the critical factors in the diffusion of EVs. Volume production, together with increasing energy density of the battery, will lead to the realisation of a driving range increase and at the same time a price decrease. In the UK, the Automotive Council commissioned roadmap on electric energy storage targets a cost reduction from around US\$130 to nearer US\$50 per kWh between 2017 and 2035 and for energy density to double from 250 Wh kg^{-1} to 500 Wh kg^{-1} over the same time period (44).

3.2 UK Government Policy in Support of Battery Development

Policy requirements call for the electrification of the vehicle fleet. The industry, in managing risk, has focused on the development and manufacture of batteries as the preferred strategy. 'Batteries for Electric Cars' is a case study in industrial strategy, written by Sir Geoffrey Owen on behalf of the Policy Exchange, UK (45). Written under consultation with government officials, financial analysts, academics and industrial experts, it provides an extensive timeline of battery innovation, highlighting how different countries came to gain technological supremacy when it comes to electrification. It also highlights the UK's "honourable place in the history of the lithium-ion battery, thanks to the work of John Goodenough and his team at Oxford University in the 1970s. Several of the scientists who worked with Goodenough, such as Peter Bruce, now Wolfson Professor of Materials at Oxford, went on to build successful academic careers and are internationally respected researchers in the battery field".

The opportunity for the UK to become a world leader in the EV industry certainly has the potential to be prosperous. The UK Government released its Industrial Strategy in 2017 which identifies government policies related to the UK's economic future (46). The transition to EVs is heavily explored in the Industrial Strategy and as part of the four 'grand challenges', specifically the future of mobility grand challenge. As a result of the 2017 Industrial Strategy, the UK Government Department for Transport produced 'The Road to Zero', a report which isolated the policies related to achieving a cleaner transportation network (47). In 2017 the UK Government also released the clean growth strategy, which includes additional policies related to the future of clean transportation (48). In addition to the plan for new cars and vans to be effectively zero emission by 2040 and for a zero emission vehicle fleet by 2050, the ambition is to put the UK at the forefront of the design and manufacturing of zero emission vehicles.

For the UK to meet the Climate Change Act 2008 transition and reduce dependency on Asia for EVs, there needs to be significant improvements in the UK's ability to develop and mass manufacture batteries. Sir Geoffrey Owen explicitly states that several considerations influenced the government's focus on the EV battery, including to ensure that UK-based car assemblies continue to build cars within the UK instead of moving abroad (the concern is that the location of the battery manufacture will provide the nucleus around which the industry gravitates as opposed to the location of the final vehicle assembly as happens at present). In response, the UK Government intention is to encourage large Asian technology companies to invest heavily in the UK, building manufacturing plants and research facilities and boosting local economies. The Industrial Strategy Challenge Fund (ISCF) Faraday Battery Challenge, created in 2017, is a direct result of the Industrial Strategy and focuses predominantly on encouraging research facilities to concert research efforts into battery technology. The challenge offers investment of £246 million, with £78 million going to The Faraday Institution, UK, £88 million to business collaborative R&D projects and £80 million going to improve the development of UK battery manufacturing capabilities (49). The Faraday Challenge is now a proven scheme which has seen research progress and increased investment is predicted for the considerable future to meet the strict 2050 deadlines in the Climate Change Act 2008.

Policy Support in the UK Targets

- Reduction of GHG emissions (road transport a significant contributor)
- Phase out combustion drivetrain 2040
- Zero emission vehicle fleet 2050
- Investment in UK EV capability (EVs represent a high economic risk for industry)
- Support development of battery technology in UK
- Develop UK battery manufacture capacity to support UK automotive sector

4. Achieving the Sustainability Goal

The highly developed car industry is capable of producing sophisticated cars at low production costs. To reach the targets required to meet the Paris Agreement will require alternative drivetrain technology and for the industry the BEV is at present the most market viable solution. However, it takes courage to start the production of large numbers of EVs and the decision is not purely a technical one. It is a combination of science, technology, engineering and public policy that defines the type of EV that will be successful in the marketplace.

The current policy framework allows for a number of potentially divergent pathways. The one discussed in the previous section focused on improving the value proposition by reducing the cost of the high value components, in this case the battery, with the objective of aligning the cost of the EV to the present combustion engine incumbent. Examples of original equipment manufacturers (OEMs) that have adopted this pathway include Jaguar, UK, with its I-PACE, Tesla, USA, with the Model S, Model X and Model 3 and Chevrolet, USA, with the Bolt. Each combines existing approach to vehicle manufacture (materials and processes), hence realising a low-cost base vehicle platform, combined with a battery that has a high energy capacity and relative low cost (achieved through economies of scale associated with the battery manufacture). A further approach, exemplified by BMW, Germany, with its i3, is to increase the overall efficiency by reducing the vehicle weight through innovative manufacturing methods and material choices. This approach recognises that the customer requirement of increasing range and reducing cost can potentially be achieved by focusing on reducing the size of the battery: a lightweight vehicle can cover longer distances with the same battery capacity. A further, and more extreme approach to lightweighting, is the Ped-elec (Coventry University, UK). The dichotomy is that mobility concepts used in urban areas are, at present, extensions of those used outside of the urban environment. They are inherently less efficient. Ped-elec responds to a call for new personal mobility based on energy used per unit mass moved (50).

Based on adoption rate (sales of each vehicle type) it is clear that the industry is gravitating to one particular pathway, reducing the cost of the high value battery whilst retaining the existing approach to manufacture of the vehicle (materials and processes). The option of weight reduction (focusing on energy used per unit mass moved) is a higher cost approach relative to providing additional battery capacity to overcome the lower vehicle efficiencies. Indeed, the need to realise increasing economies of scales in the area of battery manufacture are worrying national governments (UK included) concerned that the battery manufacture will act as the nucleus around which the rest of the industry gravitates; presently the industry gravitates around the location where final assembly of the vehicle takes place. However, whilst this is the preferred option, is it the most sustainable?

EV manufacturing requires more energy and results in more carbon emissions than manufacturing a conventional car (51). A study conducted by the American Chemical Society (ACS) estimated that the Ford Focus EV (Ford Motor Company, USA) has 39% higher 'cradle to gate' emissions then a conventional Ford Focus (52). In fact, Ellingsen *et al*. stated that EVs of all sizes may require 70,000 km to become cleaner than conventional vehicles to make up the manufacturing debt (53).

Various studies on the growth in EV and hence the demand for raw materials required in battery manufacture highlight that certain key materials (such as cobalt, nickel and copper) are at risk from supply constraints. In response, development has begun looking at materials such as iron to replace the cobalt commonly found in batteries (54) whilst research activity into the recycling of battery packs is also a priority area of research. At present there are no facilities for recycling EV batteries in the UK. Processes such as hydrometallurgical recycling and leaching are currently seen as energy efficient methods of recovering spent battery materials, aiming to reduce the cost of recycled batteries metals. Currently research is being undertaken to recycle larger percentages of battery material, with some promising results. Natarajan reports that 99.9% of lithium, 98.7% cobalt and 99.5% of magnesium were leached out of a cathode with a purity of between 98.7% and 99.4% (55). Another study, related to lithium-ion phone batteries, saw 90.02% of cobalt and 86.04% of lithium restored to maximum concentration (56). These tests are currently resigned to laboratories and not available in the UK on a commercial scale. Whilst the metals recycled from EV batteries are deemed to be of sufficient quality to be used in new EV batteries with no performance issues, due to issues of cost, recycled lithium costing three times that of new lithium, and the individual material compositions of each EV battery, bulk battery recycling on a commercial scale is currently not considered economically viable.

Achieving the Sustainability Goal

- Current policy focus is on emissions during vehicle operation
- Industry interpretation defines preferred pathway as electrification of existing solutions
- Open questions identified around preferred pathway sustainability include:
    - Raw material limitations
    - Supply chain emissions
    - Life cycle energy consumption
- Policies review or revision is required to respond to open questions

5. Discussion

In Section 2, the case for alternative energy vehicles as a response to meeting policy objectives was made. Although there is some uncertainty of the share of each technology in the powertrain portfolio, it is clear going forward that ICEs will represent only a small percentage of the total vehicle fleet or disappear altogether. It is further evident that there are multiple interest groups in the alternative energy vehicle market and that in preparation for the new mobility paradigm envisaged for 2050 investments will need to be made in new infrastructure and connectivity. Hence, there needs to be an orchestration of policy intervention to integrate issues of energy policy, transport policy and social policy.

In Section 3, there was a discussion around the policy support that the UK Government has in place to realise its ambition of a world leading UK alternative energy vehicle sector. It is clear that the industry, in transitioning to electrification, faces considerable risk. The industry chooses to leverage existing competencies in vehicle design and manufacture, and to achieve cost reduction and range improvements through a focus on the battery. In response the UK Government has put in place support for battery development, leveraging existing research competencies in this area by coordinating activities, and for battery manufacture by looking to attract inward investment and securing the future of automotive manufacturing in the UK.

In Section 4, the policies in support of transitioning to an alternative energy vehicle fleet on the one side and supporting the development of the UK capability in response were brought together in order to explore sustainability. The issue is that the way in which the industry responds to the challenge of emissions reduction creates a cleaner vehicle fleet, but does not necessarily consider optimising the efficiency or sustainability. The problem is that to square the circle – to meet the customer demand of increased range at reduced cost – the industry has looked to economies of scale at the manufacturing level and at the same time look for incremental improvements in the batteries. This enables vehicles to utilise larger batteries at less cost, but at the same time leads to heavier vehicles that fail to optimise efficiency and with increased energy demand can lead to stressing of the energy grid. A further problem is that larger batteries consume more materials and there is risk that certain material supply chains are being stressed and may not be able to respond to future demand, posing critical challenges regarding sustainability and security of supply chain. Whilst interventions, for example greater recycling and the retention of previously processed materials in the value chain, could influence this, the costs associated with these interventions would go counter to the objective of reducing the cost of the battery through economies of scale. Whilst lighter vehicles would be a move in the right direction, and a pathway exists for such vehicles within existing policy framework, the existing requirements for measuring the environmental performance of vehicles focus on emissions at the tailpipe and the move to electric drive removes a check on vehicle weight. Policy intervention is required to correct the above. This policy can target control of vehicle mass directly or can influence it indirectly through a move towards life cycle analysis of CO_2, each approach having its merits and challenges.

6. Conclusion

The transition to electrification of the vehicle drivetrain represents a considerable risk to the vehicle manufacturing sector. The UK has put in place policies to support both the production and research parts of the equation, but at the same time there is potential mismatch between the direction that is set by these policies and creating a sustainable road transport sector. New policies are required that orchestrate closer coordination across the separate policy areas: promoting lighter vehicles will reduce the stress on raw material supply chains; development of recharging networks will reduce range anxiety and align with the drive to reduce mass through enabling smaller batteries; and improvements in connectivity will lead to greater leverage of both vehicle and energy network capability.

References

1. Greenhouse Gas Emissions from Transport in Europe", European Environment Agency, Copenhagen, Denmark, 17th December, 2019, 27 pp
2. R. Stephan and R. Plana, *Sci. American*, 2015, **312**, (2), 18
3. "Our Common Future: Report of the World Commission on Environment and Development", A/42/427, UN Documents, The United Nations, Secretary General, New York, USA, 4th August, 1987
4. United Nations, Sustainable Development Knowledge Platform, Sustainable Development Goals: https://sustainabledevelopment.un.org/sdgs (Accessed on 24th April 2020)
5. D. M. Newbery, *Oxford Rev. Econ. Policy*, 1990, **6**, (2), 22
6. I. W. H. Parry, M. Walls and H. Harrington, *J. Econ. Lit.*, 2007, **45**, (2), 373
7. K. A. Small and E. T. Verhoef, "The Economics of Urban Transportation", Routledge, Abingdon, UK, 2007, 276 pp
8. R. Sims, R. Schaeffer, F. Creutzig, X. Cruz-Núñez, M. D'Agosto, D. Dimitriu, M. J. Figueroa Meza, L. Fulton, S. Kobayashi, O. Lah, A. McKinnon, P. Newman, M. Ouyang, J. J. Schauer, D. Sperling and G. Tiwari, 'Transport', in "Climate Change 2014: Mitigation of Climate Change: Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change", eds. O. Edenhofer, R. Pichs-Madruga, Y. Sokona, J. C. Minx, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow and T. Zwickel, Ch. 8, Cambridge

University Press, New York, USA, 2014, pp. 599–670

9. J. Manyika, M. Chui, J. Bughin, R. Dobbs, P. Bisson and A. Marrs, "Disruptive Technologies: Advances that will Transform Life, Business and the Global Economy", McKinsey and Company, New York, USA, May, 2013, 162 pp
10. W. Goodall, T. Fishman, S. Dixon and C. Perricos, "Transport in the Digital Age: Disruptive Trends for Smart Mobility", Deloitte LLP, London, UK, March, 2015, 21 pp
11. 'Adoption of the Paris Agreement', Framework Convention on Climate Change, Paris, France, 30th November–11th December, 2015, FCCC/CP/2015/L.9/Rev.1, United Nations, New York, USA, 12th December, 2015, 32 pp
12. 'Greenhouse Gas Emission Statistics: Emission Inventories', Eurostat, European Union, Luxembourg, June, 2019
13. P. Capros, A. De Vita, N. Tasios, D. Papadopoulos, P. Siskos, E. Apostolaki, M. Zampara, L. Paroussos, K. Fragiadakis, N. Kouvaritakis, L. Höglund-Isaksson, W. Winiwarter, P. Purohit, H. Böttcher, S. Frank, P. Havlík, M. Gusti and H. P. Witzke, "EU Energy, Transport and GHG Emissions Trends to 2050: Reference Scenario 2013", European Union, Luxembourg, 2013, 173 pp
14. G. Marsden, J. Dales, P. Jones, E. Seagriff and N. Spurling, "All Change? The Future of Travel Demand and the Implications for Policy and Planning", The First Report of the Commission on Travel Demand, Lancaster, UK, 2018, 63 pp
15. Regulation (EU) 333/2014, *Official J. Eur. Union*, 2014, **57**, (L103), 15
16. M Linder, 'Fuel Cell Electric Vehicles – Outlook on Market Potential and Industry Challenges', F-CELL, Stuttgart, Germany, 27th September, 2011
17. T. Altenburg, "From Combustion Engines to Electric Vehicles: A Study of Technological Path Creation and Disruption in Germany", Discussion Paper 29/2014, Deutsches Institut für Entwicklungspolitik gGmbH, Bonn, Germany, 2014, 44 pp
18. D. Wu, J. Ren, H. Davies, J. Shang and O. Haas, *World Electr. Veh. J.,* 2019, **10**, (2), 29
19. V. A. Katić, 'Plug-in Electric Vehicles - State of Technology and Market Perspectives', X International Symposium on Industrial Electronics INDEL 2014, Banja Luka, Bosnia and Herzegovina, 6th–8th November, 2014, Faculty of Electrical Engineering, University of Banja Luka, Bosnia and Herzegovina, 2014, 9 pp
20. "Energy Technology Perspectives 2010: Scenarios and Strategies to 2050", International Energy Agency, Paris, France, 2010, 710 pp
21. "Technology Roadmap: Electric and Plug-In Hybrid Electric Vehicles", International Energy Agency, Paris, France, 2009, 52 pp
22. "Evolution: Electric Vehicles in Europe: Gearing up for a New Phase?", Amsterdam Roundtable Foundation, Amsterdam, The Netherlands, 2014, 56 pp
23. "Global EV Outlook: Understanding the Electric Vehicle Landscape to 2020", International Energy Agency, Paris, France, 2013, 41 pp
24. A. Ştefana and M. Eremia, *U. P. B. Sci. Bull. Series C*, 2015, **77**, (1), 197
25. H. C. Davies, 'Impact of Electric and Hybrid Vehicles on Fuel Consumption and Emissions', *Engineering and Technology Reference*, 2015, 11 pp
26. O. Inderwildi, C. Carey, G. Santos, X. Yan, H. Behrendt, A. Holdway, L. Maconi, N. Owen, T. Shirvani and A. Teytelboym, "Future of Mobility Roadmap: Ways to Reduce Emissions While Keeping Mobile", ed. D. King, Smith School of Enterprise and the Environment, University of Oxford, UK, 2010, 95 pp
27. J. Liu and G. Santos*, Int. J. Sust. Transport*., 2015, **9**, (3), 159
28. "Future Energy Scenarios", National Grid Electricity System Operator, Warwick, UK, July, 2019, 166 pp
29. L. M. Cipcigan, P. N. T. Wells, P. A. H. F. Nieuwenhuis, H. C. Davies, L. E. Whitmarsh and P. Papadopoulos, 'Electricity as a Transportation Fuel: Bridging the Gaps in the Electric Vehicle Value Chain', European Electric Vehicle Congress, Brussels, Belgium, 19th–22nd November, 2012, Cardiff University, Wales, UK, 12 pp
30. B. H. Long, "The Zero Carbon Car: Green Technology and the Automotive Industry", The Crowood Press Ltd, Marlborough, Wiltshire, UK, 2013, 208 pp
31. "Future of Highways", Arup, London, UK, 2014, 57 pp
32. 'GM Outlines All-Electric Path to Zero Emissions', General Motors, Michigan, USA, 2nd October, 2017
33. H. C. Davies and N. Datardina, *Renew. Energy*, 2013, **60**, 355
34. "Fuelling Britain's Future" A Report for the European Climate Foundation, Cambridge Econometrics, Cambridge, UK, 9th March, 2015, 65 pp
35. "Phase 1 Results", UK H_2 Mobility, April, 2013, 44 pp
36. "2018 UK Greenhouse Gas Emissions, Provisional Figures", Department for Business, Energy and Industrial Strategy, The Stationery Office, London, UK, 28th March, 2019, 19 pp
37. "Electric Vehicles: Driving the Transition", Fourteenth Report of Session 2017–19, HC 383, Business, Energy and Industrial Strategy

Committee, House of Commons, London, UK, 19th October, 2018, 66 pp

38. F. M. Özel, H. Davies and P. Wells, *Int. J. Elec. Hybrid Vehicles*, 2017, **9**, (3), 222
39. P. Wells, *IIMB Manag. Rev*., 2013, **25**, (4), A200
40. P. Wells and P. Nieuwenhuis, 'Micro Factory Retailing: A Radical Business Concept for the Automotive Industry', Just Auto, Aroq Ltd, Bromsgrove, UK: https://www.just-auto.com/analysis/a-radical-business-concept-for-the-automotive-industry_id86618.aspx (Accessed on January 2020)
41. F. M. Özel, C.-S. Ernst, H. C. Davies and L. Eckstein, *Int. J Elec. Hybrid Vehicles*, 2013, **5**, (1), 1
42. M. Steen, N. Lebedeva, F. Di Persio and L. Boon-Brett, "EU Competitiveness in Advanced Li-ion Batteries for E-Mobility and Stationary Storage Applications – Opportunities and Actions", Joint Research Centre, European Union, Luxembourg, 2017, 49 pp
43. N. Lutsey, M. Grant, S. Wappelhorst and H. Zhou, "Power Play: How Governments are Spurring the Electric Vehicle Industry", The International Council on Clean Transportation (ICCT), Washington, USA, 15th May, 2018, 35 pp
44. "Technology Roadmaps: Electrical Energy Storage", The Advanced Propulsion Centre UK Ltd, Coventry, UK, 14 pp: https://www.apcuk.co.uk/technology-roadmaps/ (Accessed September 2019)
45. G. Owen, "Batteries for Electric Cars: A Case Study in Industrial Strategy", Policy Exchange, London, UK, 18th April, 2018, 42 pp
46. "Industrial Strategy: Building a Britain Fit for the Future", The Stationery Office, London, UK, November, 2017, 254 pp
47. "Clean Growth Strategy: An Ambitious Blueprint for Britain's Low Carbon Future", Department for Business, Energy and Industrial Strategy, HM Government, London, UK, 12th October, 2017
48. "The Road to Zero: Next Steps Towards Cleaner Road Transport and Delivering our Industrial Strategy", Department for Transport, HM Government, The Stationery Office, London, UK, 2018, 43 pp
49. "Powering Britain's Battery Revolution", The Faraday Institution, Didcot, UK, November, 2018, 2 pp
50. H. C. Davies and O. Turrell, 'Ped-Elec: Development of a New Value Chain Approach to the Provision of an Urban Mobility Solution', International Electric Vehicle Symposium and Exhibition (EVS32), Lyon, France, 19th–22nd May, 2019
51. D. Hall and N. Lutsey, "Effects of Battery Manufacturing on Electric Vehicle Life-Cycle Greenhouse Gas Emissions", The International Council on Clean Transportation (ICCT), Washington, USA, February, 2018, 12 pp
52. H. C. Kim, T. J. Wallington, R. Arsenault, C. Bae, S. Ahn and J. Lee, *Environ. Sci. Technol*., 2016, **50**, (14), 7715
53. L. Ager-Wick Ellingsen, B. Singh and A. H. Strømman, *Environ. Res. Lett*., 2016, **11**, (5), 054010
54. M. Romare and L. Dahllöf, "The Life Cycle Energy Consumption and Greenhouse Gas Emissions from Lithium-ion Batteries: A Study with Focus on Current Technology and Batteries for Light-Duty Vehicles", No. C 243, IVL Swedish Environmental Research Institute Ltd, Stockholm, Sweden, May, 2017, 48 pp
55. S. Natarajan, A. B. Boricha and H. C. Bajaj, *Waste Manage*., 2018, **77**, 455
56. G. Jian, J. Guo, X. Wang, C. Sun, Z. Zhou, L. Yu, F. Kong and J. Qiu, *Procedia Environ. Sci*., 2012, **16**, 495

The Author

Huw Davies' primary research interest is in the regulation of vehicle systems and components. He is a Chartered Engineer, Fellow of the Institution of Mechanical Engineers and Fellow of the Higher Education Academy. He has a passion for automotive engineering and the automotive industry. His experience covers: low carbon vehicles; automotive industry; motorsport engineering and vehicle design; and vehicle safety and injury biomechanics.