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WHY ELECTROMOBILITY AND WHAT IS IT?

Anders Grauers
Department of Signals and Systems, Chalmers University of Technology*

Steven Sarasini
Department of Energy and Environment, Chalmers University of Technology**

Magnus Karlström
Chalmers Industriteknik

* Automatic control research group
** Division of Environmental Systems Analysis
Chapter reviewer: Björn Sandén, Environmental Systems Analysis, Energy and Environment, Chalmers

In this chapter we examine the notion of electromobility and aim to provide a working definition of the term that underpins the analyses presented in the rest of this e-book. We also describe electromobility in technological terms by presenting various technological configurations of electric vehicles, charging infrastructure and energy supply. We then proceed to examine why electromobility is currently supported as a favourable means to transform road transport by discussing drivers and barriers of change in the automotive industry. Whilst electromobility represents a significant technical challenge, it also requires complex social changes. By arguing from different perspectives we hope to illustrate that electromobility is best understood by considering a range of systemic perspectives found in this and later chapters of this e-book.

WHAT IS ELECTROMOBILITY?

In this e-book we define electromobility as a road transport system based on vehicles that are propelled by electricity. Some road vehicles are equipped with technologies that make them capable of producing their own electricity (e.g. hybrid electric vehicles). Others utilise energy supplied by a source of electricity *outside* the vehicle – usually the electric grid. This definition works well for battery electric vehicles as well as for vehicles that do not store electrical energy such as trolley busses.

A key feature of our definition is that it focuses on systemic aspects of electromobility. A transport system using electricity from the grid, for instance, can utilise

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energy from many different sources without major modifications to electric vehicles or energy supply systems. This allows for local variations in energy supply and gradual changes to energy supply systems. Electromobility may thus improve the flexibility and robustness of the transport sector in that electrified vehicles can utilise different types of energy sources. Electricity can be produced from nuclear power, fossil fuels and abundant renewable resources such as solar and wind. This could make electromobility more favourable than other technological alternatives such as vehicles that utilise biofuels, because the production of biofuels is limited by the availability of biomass (see Chapter 5 for a comparison of system efficiencies).[1] Electromobility can also help to reduce CO_2 emissions, especially if electricity is produced using renewable sources (Chapter 6). However, if vehicles utilise electricity produced from coal, the climate impacts of electric propulsion could be negative when compared to gasoline or diesel fuelled vehicles. This exemplifies that systems thinking is key to understanding the benefits and drawbacks of different electric vehicle technologies and systems.

Furthermore, electromobility is a complex phenomenon that will involve technological development, policymaking, innovation, new business models, new driving behaviour and new linkages between industries. The systemic aspects of electromobility thus reach far beyond mere technical aspects and a transition to electric propulsion must be understood as a process of socio-technical transformation.

TECHNOLOGIES FOR ELECTROMOBILITY

Electromobility requires several new technologies. This section provides an overview of the currently most interesting technological alternatives and configurations. It is, however, not an exhaustive list of all possible technologies (see also Chapter 3).

Figure 2.1 shows examples of energy sources and technologies that can transfer energy to electric vehicles. Note that energy sources can be selected irrespective of the technology used for transferring energy to vehicles. The primary means of transferring energy to vehicles is to charge the vehicle while it is parked using a cord or via wireless charging. In order to extend vehicles' driving range it is also possible to use rapid chargers that significantly recharge batteries in about 10 to 30 minutes. Alternatively, battery switching involves exchanging discharged batteries for fully charged ones, usually at a switching station. To reduce (or eliminate) the need for battery capacity it is also possible to supply electric vehicles with energy whilst in motion, either during the whole drive or parts of it. A final way to supply vehicles with electrical energy is to produce hydrogen via electrolysis and store energy in hydrogen tanks rather than batteries.

Three electromobility drivetrain configurations are presented in this chapter: battery electric vehicles (BEVs), continuous power supply electric vehicles (both a conductive and an inductive version) combined with electric road systems (ERS, see also Chapter 14), and fuel cell vehicles (FCVs) (Figure 2.1). Due to limitations in each of these, some hybrid drivetrains are also of interest since the combination of two drivetrains can benefit from their respective strengths and compensate for weaknesses.

1 See Systems Perspectives on Biorefineries 2013 for discussions on various aspects of biofuel use.

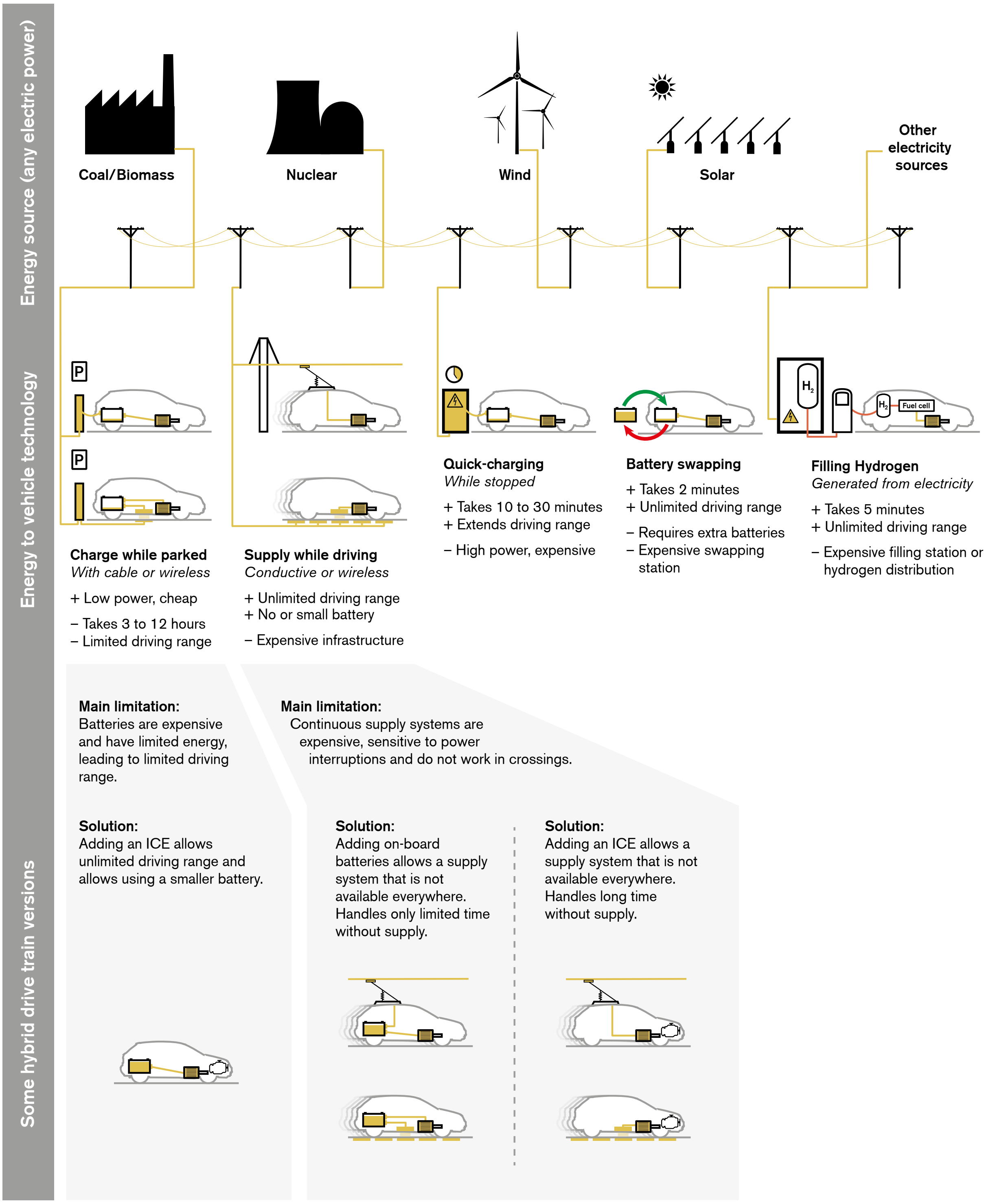

Figure 2.1 Examples of electricity sources, drivetrain configurations and technologies to transfer electrical energy to vehicles.

BEVs run solely on electrical energy from a battery and have a fully electric drivetrain. Batteries can be charged in many different ways as shown in Figure 2.1. A major limitation of BEVs is that the driving range is dependent on battery size, which in turn is constrained by cost and weight.

Plug-in hybrids (PHEV) and range extender vehicles are electric vehicles that combine battery-powered electric machines and combustion engines. This combination can reduce range limitations; allow the use of smaller and cheaper on-board batteries; and reduce the need for a charging infrastructure. The most likely backup power source in such vehicles in the short term is an internal combustion engine. In the long term other types of backup power sources may be used such as fuel cells. Plug-in hybrids come in various configurations with different types of transmission and with different ratios between the size of the combustion engine and the electric machine (see Chapter 3). From an energy-system perspective they all have the same basic functionality of allowing vehicles to run on electricity from the grid, but whenever there is a limit due to battery capacity they can run on alternative fuels until the battery is recharged.

Vehicles with a continuous power supply draw energy from the electricity grid whilst in motion and thus reduce the need to store energy on-board. However the construction of a road infrastructure that integrates conductive power lines or inductive rails requires large investments, and the system would be vulnerable to fluctuations in electricity supply. Hence hybrid configurations that include on-board energy storage devices (batteries or some other secondary power source) may be more attractive. The secondary energy source can be used in road junctions where it is difficult to construct a continuous supply infrastructure; on roads where a continuous supply infrastructure are not economically warranted or not yet installed; and in the event of fluctuations in electricity supply.

Fuel cell vehicles (FCV) are vehicles that carry energy in the form of a fuel such as hydrogen that can be transformed into electricity on-board using fuel cells. FCVs allow for longer driving distances, but require a hydrogen-refuelling infrastructure. Refuelling takes only a few minutes and is much faster than charging batteries, even where fast charging is available. During operation a fuel cell cannot quickly change the power output and FCVs typically also use a small battery to match rapid changes in power demand (a hybrid solution). The battery is also beneficial during acceleration since it can provide peak power, allowing for a smaller fuel cell. It can also store energy during deceleration, which reduces fuel consumption.

These electromobility technologies can be applied in a variety of vehicle types including heavy vehicles (such as buses and long haul trucks), conventional passenger cars, microcars (such as the Renault Twizzy), electric scooters and bicycles, and vehicles that are already electrified such as forklifts, trams, trains and trolley buses.

In sum, there are various technological alternatives associated with electromobility, each with its own set of advantages and disadvantages. Presently it is unclear which, if any, of these alternatives will play a major role in a transformation of the transport sector.

WHY ELECTROMOBILITY NOW?

In this section we switch our attention to the various reasons behind the current interest in electromobility. We note that whilst these reasons offer significant impetus for the electrification of road vehicles, there are various barriers to electromobility, which are for the most part non-technological. We draw on systems approaches to describe the nature of these barriers, which are typically social, economic and to some extent psychological.

Before we address these issues it is important to note that electromobility is not entirely new. BEVs have existed for over a century. Several individuals experimented with electric vehicles in Europe during the latter half of the 19th century and in the US the Electric Carriage and Wagon Company developed the first commercially available electric vehicles in 1897. However, petrol-driven vehicles began to dominate in the US after 1920, mainly because of the development of a more comprehensive road infrastructure. Petrol-driven vehicles could travel faster and further and were seen as superior to electric vehicles that were slow and which had limited range.

Notwithstanding, petrol-driven vehicles can be described as having undergone a process of electrification ever since. During the 20th century electronic components and sub-systems have replaced non-electronic counterparts in fuel injection systems, engine ignition, and engine management (Figure 2.2). One could thus argue that the drivetrain is the last remaining non-electronic element and that its electrification appears to be predestined given the apparent path-dependency of road vehicles.

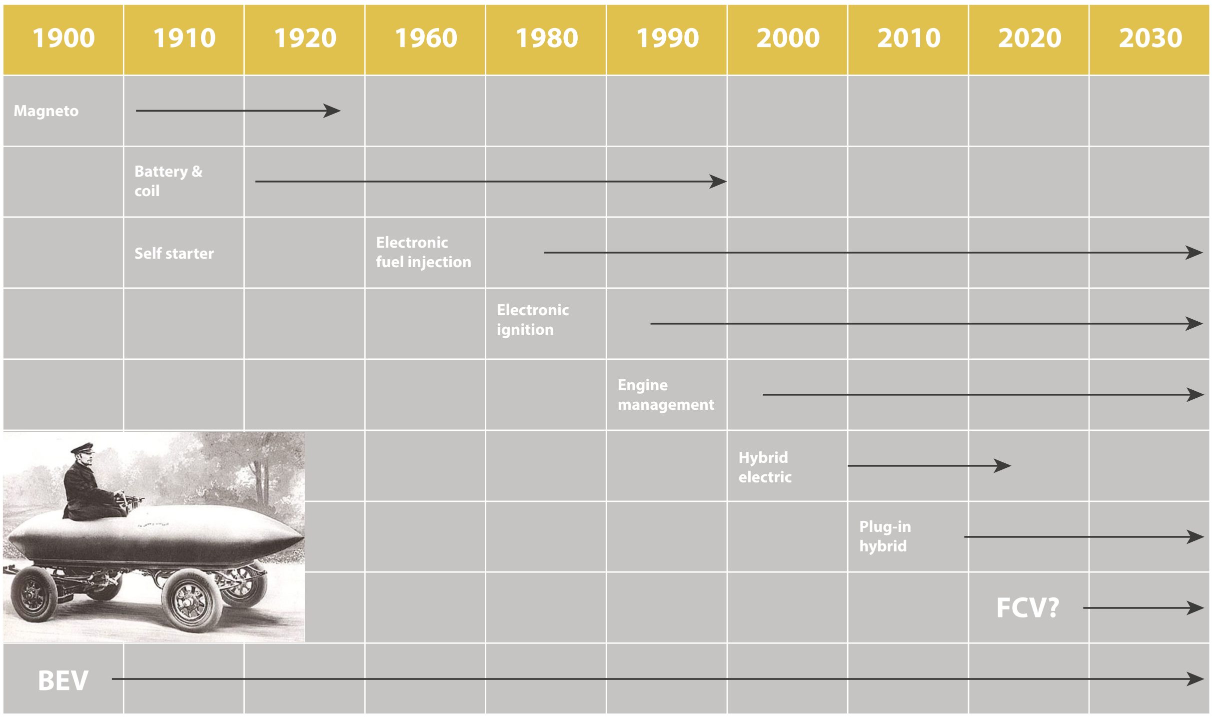

Figure 2.2 the electrification of road vehicles in a historical perspective.[2]

2 Source: Nieuwenhuis, P. (2012) The challenge of decarbonising the car, chapter 2 in: Nilsson, M., Hillman, K., Rickne, A. and Magnusson, T. (eds.) *Paving the Road to Sustainable Transport; Governance and Innovation in Low-carbon Vehicles*, Routledge Studies in Ecological Economics, London: Routledge.

However, substituting the ICE with electrified drivetrains is no simple task. Technologies associated with the internal combustion engine (ICE) are at present hugely significant for road transport and have been developed continuously for around a century. Transforming the road transport system is a major technological challenge in that new technologies must compete with the maturity and efficiency of the ICE. The ICE has evolved alongside infrastructures such as oil extraction, refinement and distribution, and the road infrastructure itself. Furthermore, the ICE has evolved alongside various social systems, such as suburban living and commuting. These systems are all intertwined, and to some extent one could describe them using the notion of lock-in,[3] which means that they mutually reinforce one another and are thus difficult to change. A transition to electromobility thus requires not just technological changes, but broader and more systemic transformations that are in some cases non-technological. For this reason we adopt a systemic approach that serves to highlight the complexities of the road transport system and which can help us examine the range of drivers and barriers related to the electromobility transition.

A large technical system (LTS) is a complex system of technological artefacts that interacts with other technical systems and with actors and institutions.[4] The LTS that encompasses ICE-based road transport represents such complexities. The ICE in road vehicles is itself part of a complex machine that is the automobile, and which is associated with a complex socio-technical system. As noted above, the ICE is supported by other LTS such as that of oil extraction, refinement and distribution. It is also supported by road infrastructures and a range of institutions spanning regulations, standards, policies and subsidy schemes to social norms and ideas related to the automobile itself. This complex set of physical and non-physical entities is what makes the ICE an artefact – it is not just a technological 'object' but also an artefact whose 'meaning' is encompassed in the various social phenomena that support its existence. The interdependencies between these various facets of the ICE mean that the road transport system is to an extent 'locked-in' to a specific path that is resistant to change – at least until recently.

Electromobility is perhaps a reflection of a technological discontinuity in the automotive industry. The latter is currently subject to various pressures and factors that have made paramount the need for technological change. The current and renewed interest in electromobility can be explained in terms of a number of overarching drivers of change in the automotive industry. These drivers of change have elsewhere been described as 'megatrends'[5] and include concerns for energy security; air pollution and climate change legislation; support for industrial competitiveness; recent technology improvements; and growing interest for electromobility in key markets such as China.

In 2010, petroleum accounted for more than 90% of the energy used for transport, implying that more than 60% of all oil used globally was consumed by the transport sector.[6] Oil dependence poses problems in terms of energy security since oil

3 Unruh, G.C., (2000). Understanding carbon lock-in. *Energy Policy,* 28, 817–830.

4 Hughes, T. 1983. Networks of power. Baltimore: Johns Hopkins University Press. W. E. Bijker, T. P. Hughes, & T. J. Pinch (eds.), The social construction of technological systems. Cambridge, MA: MIT Press.

5 Conrady R. 2012. Status quo and future prospects of sustainable mobility. In Trends and Issues in Global Tourism 7, 237-260.

6 IEA 2012, Key World Energy Statistics 2012

is a finite and geopolitically sensitive resource. The energy security problem may result in fuel price shocks or supply interruptions. Oil dependence also contributes to climate change, and the transport sector is presently responsible for 25% of energy-related CO_2 emissions.[7] Notwithstanding, there are strong drivers for an increased demand for oil in the transport sector. Since transportation is strongly correlated with income growth – particularly in emerging economies – the size of the global road vehicle fleet is likely to grow dramatically in the coming decades. Without a major shift in transportation technology or demand, oil use and CO_2 emissions will follow the same trajectory. In other words, oil dependency is increasingly seen as unsustainable in both environmental and economic terms.

Furthermore, the economic crises of 2008 had a huge impact on the automotive industry, and several industry players faced bankruptcy. National governments were forced to intervene and prevent potential job losses using financial support packages. In many cases support was provided on a conditional basis. Large portions of the money had to be spent on green technology. Money was also made available for battery manufacturing, vehicle development and subsidies for purchasing green cars. The automotive industry is of strategic importance to the many regional and national economies. For instance, 12 million people are employed (directly or indirectly) in the European automotive industry. The European automotive industry also spent EUR 28 billion on R&D 2009.[8] Electromobility is considered by many governments to be of strategic importance for the long-term survival of national automotive industries. Finally, the global automotive industry has experienced major structural changes following the emergence of rapidly developing economies. China currently represents the largest vehicle market in the world and its importance will increase in tandem with Chinese economic growth. Many expect that 30% of all cars produced globally will be sold in China in 2025.[9] The Chinese government is a strong advocate of electromobility and this alone represents a driver for the global automotive industry.

From an LTS perspective, problems that accumulate over time can bring about technological change by harnessing the problem-solving capabilities of a range of actors ('system builders' in LTS parlance). These types of macro-level forces have also been described in the literature on technological transitions as 'landscape changes',[10] and typically refer to changes in the socio-technical landscape (e.g. economic pressures, social trends and environmental issues) that can bring about systemic technological transitions. Industries periodically experience transitions to new technologies, and new technologies sometimes serve to create altogether new industries in a manner that destroys existing competences and industrial practices.[11] The current state of the automotive industry is perhaps one of fluidity whereby numerous technologies are being researched, developed, and tested in niche markets. In other words, electromobility presently reflects attempts by an existing industry to bring about a technological transition.

7 IEA. 2012. Energy Technology Perspectives 2012 Pathways to a Clean Energy System.
8 Action plan for the EU automotive industry in 2020. European Commission. 2012.
9 KPMG's Global Automotive Executive Survey 2012.
10 Geels, F. W., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case study. Research Policy 31 pp. 257-1273
11 Utterback, J., 1994. Mastering the Dynamics of Innovation. Harvard Business School Press, Boston, MA.

A range of recent technological developments supports the electromobility transition. Developments in batteries, electronics and computers have increased the competitiveness of plug-in vehicles compared to those propelled by the ICE. For example, most electric vehicles built in the 90's used lead-acid batteries. The flagship vehicle of the electrification wave in California, General Motors EV1, used a nickel metal hydride battery. The battery pack of EV1 had an energy density of around 20 Wh/kg, whereas most of the lithium-ion battery packs used today have an energy density of 80-120 Wh/kg. In terms of battery technology alone, energy densities have increased fivefold over the last two decades. Moreover, several studies predict that the cost of batteries for plug-in vehicles will decrease.[12] Reductions in the cost of batteries will boost the competitiveness of plug-in vehicles. Some automakers are thus confident that plug-in vehicles will be commercially viable alternative to the ICE in the short term for some vehicle users.

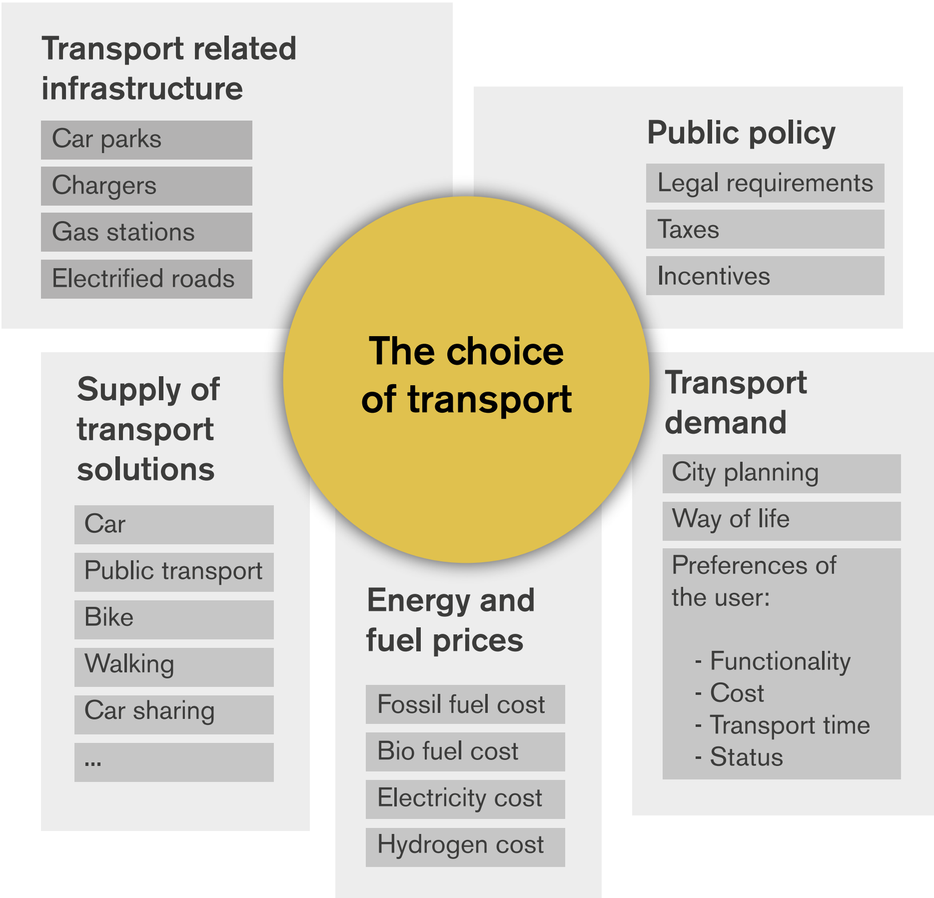

Figure 2.3 Some of the main factors that influence the choice of transport solutions

We know from history that the fluid phase is usually followed by one of selection whereby a dominant design gleans sufficient support from a range of actors and serves to reduce the number of available technological alternatives.[13] However, there are several barriers that must be overcome before electromobility can make

12 The Lithium-Ion Battery Value Chain. Francesco Pavoni. Roland Berger. 12 oct 2012. International Conference on Energy and Automotive Technologies.

13 Utterback, J.M., Abernathy, W.J., 1975. A dynamic model of process and product innovation. Omega 3, 639–656; Utterback, J.M., 1994. Mastering the Dynamics of Innovation: How Companies Can Seize Opportunities in the Face of Technological Change. Harvard Business School Press, Boston, MA.

significant inroads vis-à-vis road transport. Vehicles are a central element of road transport systems. However, the technologies utilised for vehicle propulsion are influenced by other factors such as the cost and availability of technological alternatives, fuel costs, the availability of infrastructure, public policies and demand for mobility (see Chapter 8 for an approach that models the impacts of some of these aspects). Figure 2.3 illustrates some of the main factors that influence the utilisation of vehicles and propulsion technologies. A transition to electromobility requires concurrent changes to these other factors, which makes a transition more difficult.

Technological development is often driven by user preferences or by the possibility for companies to gain advantages over competitors. However user preferences are not the main drivers of electromobility. For the most part users are satisfied with the ICE and most electromobility solutions are presently inferior to the ICE in terms of driving range and cost. Furthermore, fossil fuels are not sufficiently expensive to incentivise more expensive electric vehicles for most users. In other words, there are currently few market forces for electromobility in the absence of significant policy measures (see Chapter 11 and 12 on consumer attitudes and new business models for electric vehicles). However electromobility can partly be explained that some companies want to gain advantages over competitors. Some automakers are proactive and are investing heavily in electromobility despite a lack of customer demand at present (see Chapter 15 on knowledge development).

A lack of consumer interest poses a significant obstacle for electromobility. Electromobility solutions are, in the eyes of most users, inferior to combustion engine vehicles and they are more expensive. Electromobility is thus unlikely to be driven by market forces alone, which means that policy has a key role to play. Hence new fuel economy and CO_2 legislation has been implemented in different parts in the world. Electromobility is a means for automakers to comply with legislation that sets performance standards for new vehicles. Especially important are the renewed ZEV mandate legislation in California; the EU goal of 95 g CO_2/km and the Chinese targets for plug-in electric vehicles by 2020.

ACTOR EXPECTATIONS AND THE ROLE OF PUBLIC POLICY

As noted above, public policy is likely to play a significant role for electrification given that market forces alone are unlikely to drive a transition towards electromobility. The extent to which governments can lead this transition depends in part on the level of support that policy can provide (see Chapter 13 on the effect of some policy instruments). It also depends on the efficacy with which policy ‘selects’ technologies such as those associated with electromobility.

There is evidence to suggest that the automotive industry supports public policies that seek to bring about a transition in the transport sector. ACEA, the main industry association for European automakers, is in favour of policy-based support for alternative fuels and has highlighted electromobility as a key area of interest. However ACEA is also in favour of technology-neutral policies, that is, policies that focus on performance criteria such as vehicles’ CO_2 emission levels and energy efficiency rather than policies that provide support for a particular technology at the expense of others.[14] However, there also is evidence to suggest that policymakers must adopt a more technology-specific approach as regards electromobility. In particular, policies are required to support R&D (particularly for battery technologies) and to ensure the development and deployment of charging infrastructure given that the latter would not be built without policy interventions.[15] Whilst these divergent preferences may reflect differences in policies that seek to stimulate supply (technology push) contrasted with those focused on demand (performance pull); it appears to be the case that technology-specific policies are needed to promote the commercialisation of electric vehicles.

The role of technology-specific policies that promote the commercialisation of EVs is evident in other parts of the world. In California the Air Resources Board (CARB) has since 1990 been developing legislation to mitigate various types of air pollution from road transport. CARB's 'Advanced Clean Cars' program promotes the commercialisation of different alternative vehicle technologies.[16] The program makes two key stipulations regarding 'Low Emission Vehicles' (LEVs) and 'Zero Emission Vehicles' (ZEVs). LEVs refer to vehicles with lower levels of smog-forming pollutants and greenhouse gases, and ZEVs refer to vehicles that have zero emissions during the use-phase. CARB has legislated that a growing proportion of vehicles sold in the state of California has to be LEVs and ZEVs.

Whilst these stipulations appear to be technology-neutral, CARB also specifies the types of vehicle technologies that can meet these performance standards. CARB categorises BEVs and FCVs as 'zero emission' vehicles, and PHEVs, HEVs and PZEVs[17] as 'low emission' vehicles. Existing legislation requires that 62,500 ZEVs and 141,000 PHEVs be sold in California between now and 2017. CARB also argues that the Advanced Clean Cars program will deliver various benefits. In 2025 new cars will release 75% less smog-forming pollutants than the new ICE cars of today; 3-6% lower GHG emissions per year; improvements in fuel economy of 37-50MPG by 2025; and concurrent reductions in the total-cost of ownership of between USD 5,300-9,400 per vehicle (for cars).

However, creating technology-specific policies that promote technological transitions is a challenging task. Road transport is complex in that vehicles are required for different purposes, i.e. different driving patterns and different types of haulage. Creating technology-specific policies to suit these various purposes is challenging because policies must fulfil specific aims and goals within certain technological and economic constraints. A simple way to illustrate this point is to examine European transport policy. Vehicle electrification is generally considered within the auspices of EU institutions as one of many technological alternatives that will assist in achieving transport policy goals, of which two key aspects are environmental sustainability (primarily focused on reducing CO_2 emissions) and economic development (focused on both industrial competitiveness and reducing dependency on foreign oil derivatives). A recent public consultation entitled 'Study on clean transport systems' reveals some of the ways in which actors bring to bear

14 ACEA (2011) ACEA comments on the White Paper on Transport Policy.
15 EC (2010) Study on Clean Transport Systems. European Commission, Directorate-General for Mobility and Transport.
16 CARB (2012) California Air Resources Board: Advanced Clean Cars.
17 PZEVs refers to partial zero emission vehicles, or 'gasoline cars that meet the strictest air quality standards'.

their varying expectations regarding vehicle technologies.[18] Respondents included public, private and third sector organisations and individuals.

The results are as follows. Firstly, respondents regarded electricity to be the most important fuel for the transport sector in the long-term – more important than biofuels, hydrogen, methane, synthetic fuels and LPG. Second, respondents regarded electricity as the most plausible alternative fuel for road and rail applications, but not water or air, where biofuels play a more significant role. Third, respondents felt that different types of electrified road vehicles are useful for different haulage ranges. BEVs, for instance, were expected to be the most operable alternative by 2020 for short-haul passenger and freight purposes, whereas hydrogen fuel cell vehicles were expected to be a viable solution for medium and long-haul trips by 2050. Furthermore, road vehicles linked directly to the grid were more favourable than FCVs for short-haul passenger applications, but less so for medium- and long-haul applications.

These findings of course reflect majority views – the fact is that respondents display divergent sets of expectations regarding both the manner in which electrified vehicles will develop and the role they will adopt in the future transport system. Hence the need for technology-specific policies represents a significant challenge for governments, especially since expectations regarding vehicle technologies tend to change over time following, among other things, technological developments and market trends. Whilst industries tend to prefer policies that are robust and predictable, in practice it provide concrete indications of how policy will develop given the current state of flux in the automotive industry. Notwithstanding policymakers are offering strong support for electromobility and policy appears to assign a major role for technology in bringing about change.

SUMMARY

Several technological alternatives to the ICE have emerged as a result of problems related to the existing road transport system. One option is electromobility, which we define as a road transport system based on vehicles that are propelled by electricity whose energy is supplied by a source of electricity *outside* the vehicle. This chapter discussed electromobility in terms of technological alternatives and examined a range of factors that provide a stimulus for and barriers to change in the road transport system. At present there are various technological paths for us to choose between. It may be the case that these paths remain open, but history suggests that the current fluid phase, which is characterised by the creation, development and trial of technological alternatives will probably be followed by the emergence of a dominant design and the growth of new markets and industries. However, several actors both within and outside the automotive industry depict the future of road transport as one of technological diversity, with applications for different configurations of electrified vehicles for different purposes. Understanding the desirability of these alternatives means that we must look much further than vehicles themselves, and understand how factors such as energy supply, emissions and other socioeconomic and ecological factors influence future alternatives for road transport.

18 EC (2010) Study on Clean Transport Systems. European Commission, Directorate-General for Mobility and Transport.

There are, however, several pressures that make electromobility a desirable option. These include the availability and low cost of electricity relative to other fuels; the potential for electrified vehicles to help resolve environmental problems such as climate change and urban pollution; improvements in electromobility technologies; and the potential growth of a new industry which can deliver economic benefits and new jobs. However, there are also various barriers to electromobility, ranging from user expectations and preferences as regards road vehicles; the 'range anxiety' associated with BEVs; and the costs of key technologies such as battery systems. It is still unclear if electromobility will overcome these barriers and be a large part of our transport future. Consumers are perhaps not the main driver of change in the road transport system whereas policy appears to be an important and influential factor that can help to overcome these barriers. Ecological problems are also transmuted via public policy.

One could argue that electromobility is a technological transition that is supported by a range of forces such as environmental problems, social and economic concerns, technological developments and public policy. However electromobility addresses only some of the problems related to the current road transport system. Global trends towards urbanisation, particularly in rapidly developing countries, are coupled with increased urban traffic congestion and road related deaths. Furthermore, whilst electromobility offers promise in terms of reducing tailpipe emissions and decreasing some countries' dependence on geopolitically sensitive resources such as oil, it does not resolve problems related to other resources such as materials and rare metals that are used in vehicles (see Chapter 7). Technology will hopefully play a part in solving these problems, but many other changes are required to create a sustainable transport system.