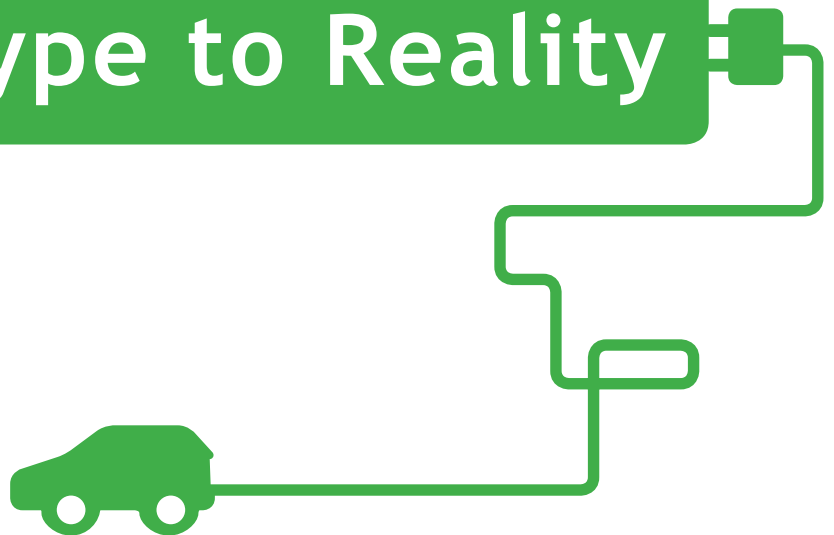


# HOW TO AVOID AN ELECTRIC SHOCK

**ELECTRIC CARS**  
From Hype to Reality



**How to avoid an electric shock**  
Electric cars: from hype to reality

November 2009

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## About Transport & Environment

Transport & Environment's mission is to promote transport policy that is based on the principles of sustainable development. That means minimising the use of energy and land and reducing harmful impacts on the environment and health while maximising safety and guaranteeing sufficient access for all.

The work of our Brussels-based team is focused on the areas where European Union policy has the potential to achieve the greatest environmental benefits. Such policies include technical standards for vehicle fuel efficiency and pollutant emissions, environmental regulation of international transport including aviation and shipping, European rules on infrastructure pricing and environmental regulation of energy used in transport.

Naturally our members work on similar issues with a national and local focus. But their work also extends to public transport, cycling policy and other areas largely untouched by the EU. Transport & Environment's role in this context is to bring our members together, adding value through the sharing of knowledge and campaigning strategies.

Established in 1990, we represent around 50 organisations across Europe, mostly environmental groups and sustainable transport campaigners.

We are politically independent, science-based and strictly not-for-profit.

## Introduction

Visitors to the 2009 Frankfurt Motor Show could have been left with only one impression: the future is electric. Virtually every manufacturer exhibited a car powered by batteries. Electric cars are the talk of the town.

The atmosphere among many policymakers is equally highly charged. China, the U.S. and France are among the governments that have so far pledged to spend up to EUR 10 billion in the next five years in tax incentives, levies, subsidies and consumer bonuses to help car companies develop electric cars, according to the Boston Consulting Group<sup>1</sup>.

In September, the president of the European Commission José Manuel Barroso, declared that “decarbonising...the transport sector... as well as the development of clean and electric cars” would be key priorities for the next five years.

The world has changed. Transport in the EU consumes two thirds of the oil we use and causes 28% of our CO<sub>2</sub> emissions. Greenhouse gas emissions from transport are also projected to grow in future, while other sectors are cutting back. Decarbonisation of transport will be essential if the world is to have a hope of keeping global warming below 2 degrees centigrade.

A truly sustainable transport system is difficult to foresee without a shift away from oil towards more sustainable sources of energy. Current biofuels policy is creating more problems than it solves, and the oil business is increasingly moving towards highly damaging sources such as extraction of oil from tar sands and oil shale. In that context, electrification of transport does currently seem to be the technological pathway most likely to deliver the deepest carbon cuts.

The first aim of this report is not to add to the hype, nor to pour cold water on the enthusiasm for electric cars. It is to take a close hard look at the facts. It asks the question: what role can electric cars play in the decarbonisation of transport? It is an attempt to look behind the hype, and an attempt to bring the available scientific evidence to the attention of policymakers and the public. It is not definitive. Indeed, in a number of areas our research uncovered a distinct lack of good data. That in itself is a reason for policymakers to pause for thought.

National policies are not covered. Neither are the array of measures that will be needed to cut transport emissions and other negative impacts by the degree necessary. Road pricing, taxation policies and traffic management, for example, are not discussed but will all be necessary for a serious attempt at getting transport emissions under control.

The second aim, and perhaps the most important, is to offer some guidance to EU policymakers about what to do, and what not to do in the case of electric cars. In particular we look at how current legislation will need to change if electric cars are to be a success. And by success, we mean playing a serious role in a strategy to decarbonise transport.

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<sup>1</sup> <http://online.wsj.com/article/SB125606654494097035.html>

# Summary

## Chapter 1: A short history of electric vehicles

History shows that public and industrial interest in electric cars has surged in response to external pressures such as spikes in the price of oil, regulatory pressure to improve air quality and, more recently, legislation to cut CO<sub>2</sub> emissions.

Electric cars have failed to reach the mass market in the past, because these external pressures were not maintained or the problems were resolved through other means, and because they simply could not compete against conventional combustion-engined vehicles.

## Chapter 2: Scenarios for the uptake of electric and hybrid vehicles

The scenarios analysed on the development of electric vehicles clearly show that, in the short term, hybrids will penetrate global markets sooner and more easily than fully fledged electric vehicles. The main reason is that new vehicle technology is likely to penetrate slowly; it usually takes 10 to 20 years to achieve 5% of new sales.

Scenarios on the penetration of plug-in hybrid and electric vehicles indicate only a modest penetration by 2020, at best, and a correspondingly limited impact on CO<sub>2</sub> emission reductions by 2030.

Most scenarios even think it unlikely that electric vehicles will number more than 25% of new sales by 2050. Faster market penetration would require a combination of competitive technologies and strong policy incentives or regulations.

## Chapter 3: Electric vehicles and greenhouse gas emissions

Electric cars can help reduce CO<sub>2</sub> emissions from the transport sector provided two conditions are met: first, they must be more energy-efficient than state-of-the-art conventional vehicles on a 'tank to wheel' basis; second, the electricity to power the cars must be sourced from renewable sources.

The first of these conditions appears to have been met: electric vehicles are between two and three times more efficient than petrol hybrid and advanced diesel vehicles on a 'tank-to-wheel' basis.

The second condition, which depends on 'well-to-wheel' environmental impacts, is far from guaranteed, as it depends on the type of electricity generation. Electric cars powered by wind or solar energy are obviously superior. But if the electricity comes from coal, hybrids perform better.

#### **Chapter 4: The impact of electric vehicles on the power sector**

The extra electricity required to power electric vehicles will need to be addressed through increased generating capacity and new approaches to grid management. All this will have an impact on decisions on future investment in the power sector.

Even if the grid has the capacity and the basic infrastructure to meet the needs of electric cars, the new demand patterns they will create may mean greater use of coal and nuclear power.

There is compelling evidence that electric cars offer a good opportunity to store intermittent renewable energy sources, such as wind energy. However, there is no strong evidence that car batteries will be attractive tools to provide vehicle-to-grid (V2G) transmission. Evidence suggests other technologies are cheaper and better at this.

#### **Chapter 5: Batteries for electric vehicles**

The performance and cost of batteries is one of the biggest potential obstacles to the success of EVs, as it defines the electric range, performance characteristics and costs. Among the battery-types, lithium-ion batteries seem to be most promising, although no studies expect their costs to reduce rapidly.

There is potential for improvement in performance and reduction of costs in the medium term, but not enough to suggest electric cars could compete head-on with conventional vehicles within the next two decades.

Further evaluation of the environmental impacts of battery disposal and recycling is required, and data on the energy consumption of battery production and recycling is lacking.

#### **Chapter 6: Costs and consumer acceptance**

Electric and hybrid vehicles are more expensive to buy and cheaper to run than conventional cars. In many cases, the fuel cost savings completely outweigh initial costs. Even the most expensive option, a fully electric car, reduces CO<sub>2</sub> at acceptable costs to society (below €100/tonne).

However, the high upfront costs prevent large market take-up. And the low running costs would lead to extra demand for car transport.

For these technologies to play a big role in our future transport system both issues need to be addressed. That could be done through innovative business models and through smart government policies. The latter should focus on fostering these business models and keeping avenues open for taxation of electricity. On board metering of electricity use would be a key requirement.

#### **Chapter 7: Electric vehicles and EU policy**

See next section: EU policy recommendations

## EU policy recommendations

Without a doubt, electric and plug-in hybrid cars can help reduce CO<sub>2</sub> emissions and oil consumption.

EU law, particularly the regulation to reduce CO<sub>2</sub> from cars, has been instrumental in steering car industry investment towards cleaner powertrains. In theory, the EU emissions trading system implies that plug-in electric cars would not increase CO<sub>2</sub> emissions, because the power sector is covered by the scheme.

But those same laws have important flaws. And if they remain unchanged, sales of electric cars will likely lead to higher overall CO<sub>2</sub> emissions and oil consumption. That may be counterintuitive, but it is nevertheless true.

Electrification of the transport sector is an opportunity. It would be highly unfortunate if electric cars become just another missed opportunity like the failure of biofuels and hydrogen before. That is entirely possible. But it can be avoided.

Below we highlight three aspects of EU legislation that will need to be changed if electric cars are to be a success. This is a starting point, not the end of the story.

### **CO<sub>2</sub> standards for cars should be tightened**

The most secure way to make electrification of transport a reality is to significantly tighten long-term CO<sub>2</sub> standards for cars to 80 g/km by 2020 and 60 g/km by 2025, and to ramp up fuel taxes. This gives the industry the required long-term security for investments in low-carbon car technology and infrastructure. Focusing on fostering electric cars without tightening CO<sub>2</sub> standards will be self-defeating as it takes away the main incentive for industry to invest in making electrification a reality.

Zero-CO<sub>2</sub> rating and supercredits for electric cars must be abolished; electric cars should be rewarded for their energy efficiency, not for moving emissions from exhaust pipes to powerstation chimneys.

### **Quantity and quality of electricity used in electric cars must be measured**

On-board metering of the quantity and quality of electricity is likely to be a critical boundary condition to manage and regulate demand and quality of electricity delivered to electric vehicles.

### **The power sector has to be decarbonised**

Existing loopholes in the ETS need to be closed and the cap further tightened, strong post-2020 targets for renewable energy in the power sector could be pursued along with emissions performance standards for power stations.

**Commission President Barroso has pledged to pursue decarbonisation of the transport sector, with an important role for electrification of transport. Therefore, further initiatives from the Commission regarding standardisation, building of infrastructure and type approval of electric vehicles can be expected. This report outlines some of the elementary principles of such a package.**

**There is a tremendous opportunity to make electrification of transport work for the environment. It should not be missed.**



# 1 A short history of electric vehicles

## Summary:

History shows that public and industrial interest in electric cars has surged in response to external pressures such as spikes in the price of oil, regulatory pressure to improve air quality and, more recently, legislation to cut CO<sub>2</sub> emissions.

Electric cars have failed to reach the mass market in the past, because these external pressures were not maintained or the problems were resolved through other means, and because they simply could not compete against conventional combustion-engined vehicles.

## 1.1 The birth of the electric car

Electric vehicles (EVs) are not new – the first was invented around 1832 and preceded the appearance of cars powered by the internal combustion engine. Vehicle and battery design improved in 1881, prompting electric vehicles to flourish. France and Great Britain were first to see the widespread development of electric vehicles, in the late 19th century. America followed, with the first large-scale commercial application, the entire New York taxi fleet, in 1897.

By the turn of the century, cars were in increasing demand in America, and were available in steam, electric, or petrol versions.<sup>2</sup> The years 1899 and 1900 were the highpoint for electric cars in America: they outsold all other types of car. Electric vehicles had many advantages over their competitors in the early 1900s. They did not have the vibration, smell, and noise associated with gasoline cars, and it was not necessary to change gear. Steam-powered cars had no need for gear shifting, either, but they suffered from long start-up times: up to 45 minutes on cold mornings. Neither was the limited range of electric vehicles a problem, as the only good roads were concentrated in cities (Inventors 2009).

## 1.2 Decline

Production of electric vehicles peaked in 1912, and they were successful until the 1920s. A number of factors contributed to their decline in the following years:

- an improved road network made longer range vehicles more attractive, while the invention of the electric starter for gasoline cars eliminated the need for the cumbersome hand crank;
- crude oil was discovered in Texas, cutting the price of gasoline and making it affordable for more consumers;
- Henry Ford's mass production of internal combustion engine vehicles cut the price of these cars to \$500-1,000. In contrast, the cost of electric vehicles continued to rise.

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<sup>2</sup> Hybrid vehicle technologies also originated at the beginning of the century. The first hybrid car engine technology was patented by Belgian inventor Henri Pieper in 1909. It had been developed 11 years earlier by Ferdinand Porsche. Porsche's second car design was a series hybrid (like the Chevrolet Volt, due out in 2010) in which a combustion engine ran a generator that powered the electric motor. Its battery could take Porsche's hybrid car nearly 40 miles—the same as promised by the Volt (Hybrid cars 2009).

These three factors - limited range, cheap oil and cheaper mass produced internal combustion engines – thus contributed to the decline of electric vehicles and by the 1930s, they had all but disappeared.

### 1.3 1970s: a renewed interest

In the late 1960s and early 1970s, concerns about air pollution and the OPEC oil embargo resulted in renewed interest in electric cars among consumers and producers. From 1972 to 1974, the price of crude oil quadrupled from about \$3 to over \$12 per barrel, as a result of the Yom Kippur war,<sup>3</sup> and continued to hover around \$12-14 until 1978 (Williams 2007). In the US, high oil prices and a new regulation (the 1970 Federal Clean Car Incentive Program), prompted the development of hybrid and electric vehicles (e.g. CitiCar). In 1976, Congress passed the Electric and Hybrid Vehicle Research, Development and Demonstration Act. The law was intended to spur the development of new technologies, including improved batteries, motors and other hybrid-electric components. But the programme fell short of its target - to facilitate the building of 2,500 electric and hybrid cars between June 1978 and December 1979, and later to increase production to 5,000 and then 50,000 vehicles annually. It was subsequently cancelled by the Reagan administration.

Besides the US, Japan had a \$19m technical research programme into electric vehicles. Meanwhile, in France, a network of large firms, backed by state funding, sought to create a market for electric vehicles. Electricity giant EdF was the most active partner, and brought together a group of public companies that were potential purchasers of electric vehicles: the Post Office, EdF, Paris airport, train company SNCF and Paris public transport organisation RATP, among others. The group set out to evaluate the needs of potential users and to work with industry to find solutions. It quickly became apparent, however, that with the existing battery technology, demands would be impossible to meet (Cowan and Hulten 1996).

Most projects launched in the 1970s were based on the assumption that battery technology would improve rapidly. But this did not happen, and electric and hybrid vehicles continued to remain uncompetitive (Cowan and Hulten 1996).

### 1.4 1990s: air pollution laws put EVs back in the picture

In the early 1990s, a few automakers resumed production of electric vehicles, prompted by California's landmark Zero Emission Vehicle (ZEV) Mandate. The mandate required 2% of California's vehicles to be ZEVs by 1998 and 10% by 2003. However, the EVs were produced in very low volumes and as the ZEV mandate was weakened over the years, the automakers ceased production – Toyota was the last major carmaker to stop producing electric vehicles, in 2003 (EEA 2005).<sup>4</sup> Japan also had a plan to introduce 200,000 EVs by 2000, but that programme, too, failed to deliver.

Oil price fluctuations continued to be a determining factor in the level of interest in

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<sup>3</sup> The Yom Kippur started with an attack on Israel by Syria and Egypt on 5 October 1973. The US and many other Western countries supported Israel, which resulted in an oil embargo by Arab oil exporting nations. While Arab nations curtailed production by 5 million barrels per day, about 1 million barrels were replaced with increased production by other countries, while the net loss of 4 million barrels extended to 1974, representing 7 percent of production (Williams 2007).

<sup>4</sup> In 2002 G.M. and DaimlerChrysler sued the California Air Resources Board (CARB) to repeal the ZEV mandate first passed in 1990. Federal government under The Bush Administration joined that suit.

EVs. After a spike in the price of crude oil in 1990 following the Iraqi invasion of Kuwait and the ensuing Gulf War, prices entered a period of steady decline. Consumption, meanwhile, continued to grow—, especially in fast-growing Asian economies. Between 1990 and 1997, world oil consumption increased by 6.2m barrels per day (Williams 2007).

In Switzerland, local air pollution regulations limiting vehicle access to city centres boosted demand for electric vehicles, while several other EU countries (France, Italy and Sweden) invested in R&D and demonstration projects. In Germany, R&D investments in EVs were mostly led by the industry (IEA 1993: 12-14).

The European Commission also sponsored R&D into EV technology under its JOULE I and II programmes. The European Electric Road Vehicle Association (AVERE, established 1978) and the Association of Cities Interested in the Use of Electric Vehicles (CITELEC) also received Commission funding (IEA 1993: 12-14).

While the electric vehicles of the 1990s satisfied the driving requirements of many fleet operators and two-car families in the US, their cost - \$30,000-\$40,000 (1998) made them prohibitively expensive, even when tax credits and incentives were taken into account (Inventors 2009). California's decision to force the car manufacturers to supply low, ultra low and zero emission vehicles was instrumental in pushing the car industry to develop electric vehicles (Cowan and Hulten 1996), but as regulatory pressure eased, so the interest waned and production of EVs ceased.

## 1.5 2007-9: climate change brings new urgency

Rising oil prices, increased societal concern about climate change, and a series of regulations<sup>5</sup> focusing on fuel, energy efficiency and CO<sub>2</sub> emissions prompted a renewed industry focus on more fuel efficient vehicles and electrification in late 2008, particularly in Europe (Deutsche bank 2008).<sup>6</sup>

The EU targets, in particular, have been instrumental in creating clarity and certainty for carmakers that investment in low carbon technology will pay off.

In addition, many countries, cities and states have imposed taxes, fees, and other restrictions on less fuel-efficient or higher CO<sub>2</sub>-emitting vehicles, and providing incentives for the purchase of more efficient vehicles.

Certain countries and regions have also created incentives for electric cars, in particular, recently agreed EU legislation in several cases will impact on the development of electric cars (see Chapter 7).

Oil prices have increased almost constantly since the end of 2001, reaching a record

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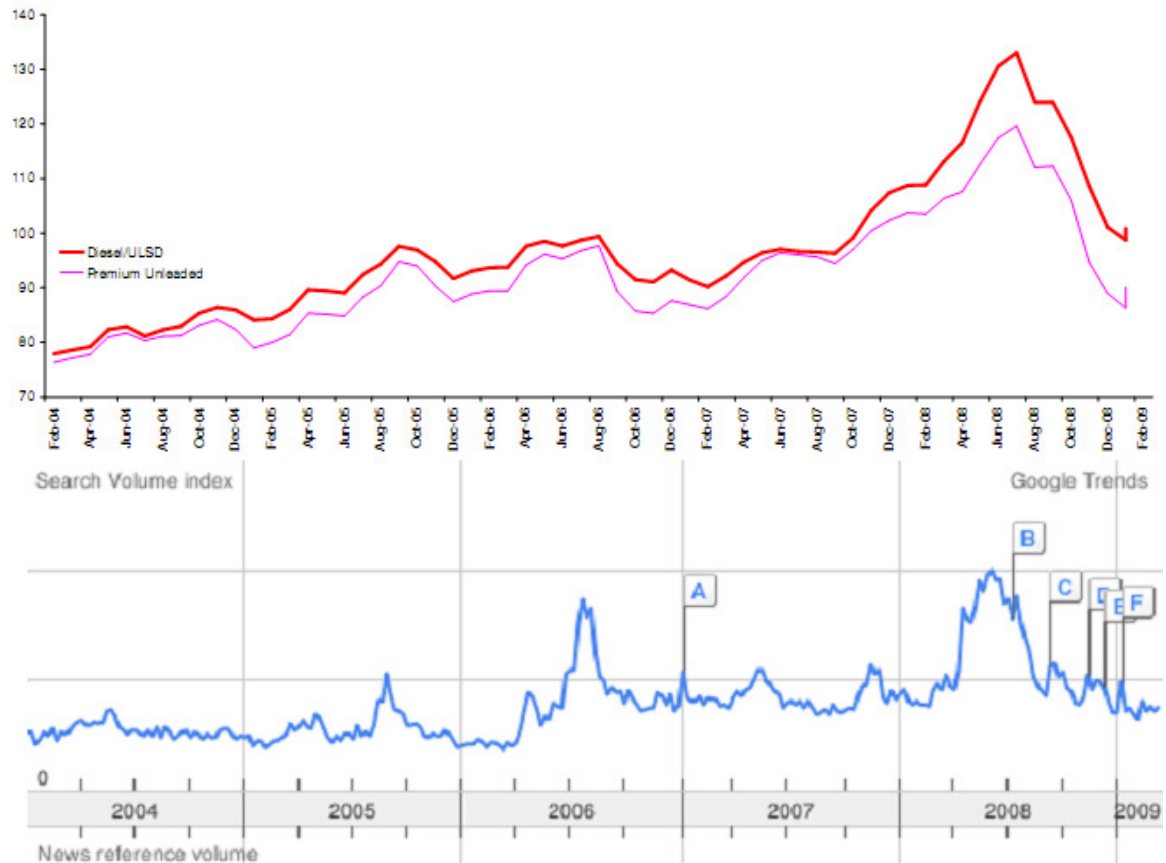
<sup>5</sup> In the EU, the Cars and CO<sub>2</sub> regulation adopted in 2008 requires car companies to cut fleet average emissions by some 15% from 2007 levels by 2015, to roughly 135 g/km (ca. 45 mpg). A long-term target of 95 g/km was also set for 2020, but will be reviewed.

In the US, President Obama announced on 19 May 2009, that the U.S. Environmental Protection Agency and the U.S. Department of Transportation intend to work together to jointly develop rules to reduce greenhouse gas emissions to average 250 g/mile and increase fuel economy levels of passenger vehicles to 35.5 mpg through model year 2016 – four years earlier than required by the 2007 Energy Independence and Security Act (EISA) and reflects an agreement between the US government and the State of California to unify regulation of the car industry.

<sup>6</sup> U.S. segment market share for light trucks fell 720 basis points in May 2008. On the other hand sales in hybrids rose 39% in 2007 and are up 17% YTD 2008 (Deutsche bank 2008).

\$147.27 per barrel on 11 July 2008. It is thought that the fall in prices from the end of 2008, due largely to the economic crisis, is just a temporary decline and that prices will continue their upward trajectory in the long-term.<sup>7</sup> Sensitivity to the threat of oil price rises and the growth in regulation has once again spurred new interest in electric cars.

Graph 1 below shows the correlation between the surge in public interest for EVs and oil prices.



Graph 1: Correlation between petrol prices in the UK (above) and public interest in electric cars, as illustrated by Google searches on the term 'electric car'

In conclusion, electric vehicles have been considered a promising technology at repeated intervals over the last century. However, in each instance they have failed to live up to expectations after just a short time, due largely to competition with the internal combustion engine. The continued high price, limited range, lack of investment in the technology and absence of charging infrastructure have combined to prevent the technology penetrating the market in any significant way.

<sup>7</sup> The interim report by the U.S. Commodity Futures Trading Commission (CFTC) Interagency Task Force found that speculation had not caused significant changes in oil prices and that fundamental supply and demand factors provide the best explanation for the crude oil price increases. The report forecast that this imbalance would persist in the future, leading to continued upward pressure on oil prices, and that large or rapid movement in oil prices are likely to occur even in the absence of activity by speculators (Wikipedia 2008).

The Californian ZEV mandate is a clear example of that. It set a target for a specific technology, but this technology failed due to a lack of pressure on conventional technology and low fuel taxes.

## 2 Scenarios for the uptake of electric and hybrid vehicles

### Summary:

The scenarios analysed on the development of electric vehicles clearly show that, in the short term, hybrids will penetrate global markets sooner and more easily than fully fledged electric vehicles.<sup>8</sup> The main reason is that new vehicle technology is likely to penetrate slowly; it usually takes 10 to 20 years to achieve 5% of new sales.

Scenarios on the penetration of plug-in hybrid and electric vehicles indicate only a modest penetration by 2020, at best, and a correspondingly limited impact on CO<sub>2</sub> emission reductions by 2030.

Most scenarios even think it unlikely that electric vehicles will number more than 25% of new sales by 2050. Faster market penetration would require a combination of competitive technologies and strong policy incentives or regulations.

This chapter looks into what different scenarios say about the potential for market penetration of electric and hybrid vehicles, and reviews their assumptions. We begin our review with scenarios that take a global outlook and then examine the findings of a scenario for the UK as an example of an EU member state. No scenario for the uptake of electric and hybrid vehicles for the EU as a whole has been identified in the existing literature.

### 2.1 Global scenarios

#### 2.1.1 International Energy Agency

The International Energy Agency (IEA) considered the likely uptake of electric vehicles in a number of scenarios for 2050.<sup>9</sup>

The Agency's ACT scenario suggests modest electrification levels (50% hybridisation by 2050 and including significant plug-ins).

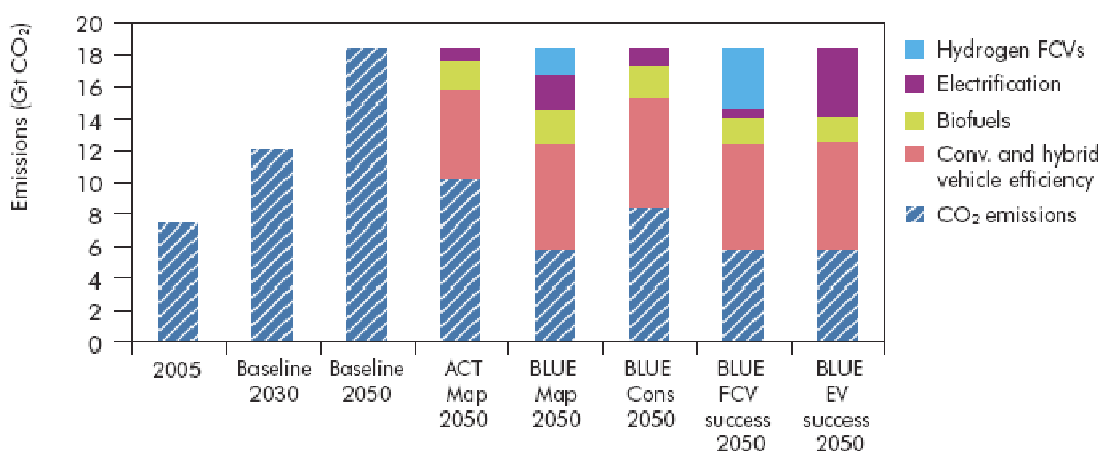
Its most optimistic set of scenarios (BLUE), considers three conditions: a conservative outcome (plug-in hybrid cars reach 40% of new sales and hybrid trucks reach 80% of the fleet), a fuel cell vehicles scenario (FCV reach 90% of new car sales and 60% of the truck fleet in 2050) and an electric vehicles scenario (EVs reach 90% of new sales and trucks reach 50% of the fleet by 2050).

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<sup>8</sup> The US National Highway Traffic Safety Administration (NHTSA) projects a 20% hybridisation rate for the U.S. new car market by 2015, and Global Insight projects 47% for the U.S. by 2020. (Note that U.S. market share for hybrids was just 3% in 2007.) In Europe, according to Deutsche bank (2008: 8) hybridisation is projected to reach 50% of new vehicle sales by 2015. These assumptions seem pretty high and will depend on the policy framework in place, i.e. stringent efficiency requirements.

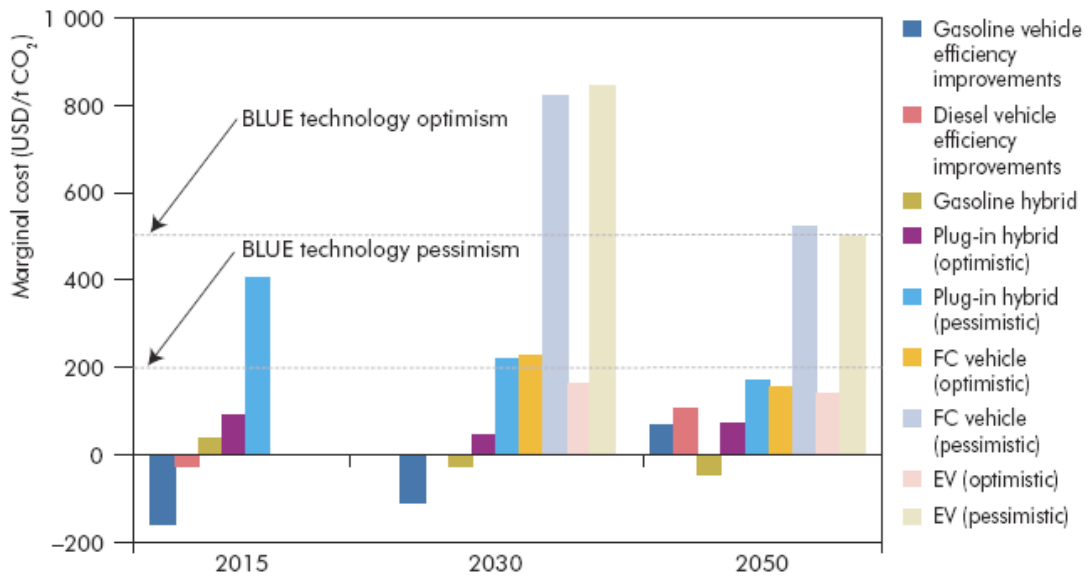
<sup>9</sup> The ACT Map scenario implies adoption of a wide range of technologies with marginal costs up to \$50 per tonne of CO<sub>2</sub> saved when fully commercialised. This scenario implies employing existing technologies to bring emissions down to current levels by 2050. BLUE scenarios look into reducing emissions by 50% by 2050 and require urgent implementation of unprecedented and far-reaching new policies in the energy sector. The BLUE Map scenario requires deployment of all technologies involving costs of up to \$200 per tonne of CO<sub>2</sub> saved when fully commercialised (IEA 2008: 38-9).

Further increases in efficiency and in the use of low-CO<sub>2</sub> fuels contribute to an emissions cut from transport to 20% below the 2005 level in all of the BLUE variants except BLUE conservative, where they are about 10% above 2005 levels. The difference between the BLUE conservative variant and the other BLUE variants shows that emission reductions to below today's levels can only be achieved if transport technologies that are not available at an acceptable cost today come through to commercialisation. In the BLUE Map scenario, efficiency gains for all transportation modes provide about half the CO<sub>2</sub> reduction. The other half comes from the use of alternative fuels such as biofuels, hydrogen and electricity (IEA 2008: 95).



Graph 2: Potential for emission reductions under different scenarios (IEA 2008: 95).

The IEA also looks into the costs of achieving CO<sub>2</sub> emission reductions in its optimistic scenarios (see graph 3). By 2050, most advanced technology costs have come down substantially. The cost of new fuel cell vehicles drops between 2030 and 2050 and by 2050 is below USD 200/t in the optimistic case. For electric vehicles, costs dip below USD 200/t in 2030. The optimistic case assumes successful research, development and demonstration; good rates of technology learning and robust sales. In the pessimistic case, the extra cost of FCVs and EVs is around USD 500/t, taking into account vehicle plus life-cycle fuel costs (IEA 2008: 98).



Graph 3: 2015-2050, the abatement cost for light-duty vehicles determines the marginal abatement cost for the BLUE Map scenarios (IEA 2008: 98).

### 2.1.2 McKinsey

A McKinsey report on reducing emissions from the automotive sector also looks at the global transport system. It considers three scenarios (improving internal combustion technologies; a mixture of hybrid, electric and internal combustion technologies; and a hybrid and electric technologies scenario) up until 2030. Its calculations of well-to-wheel emissions from electrification of vehicles assume an aggressive reduction in the carbon intensity of electricity generation, from 600 to 250 t CO<sub>2e</sub>/GWh (McKinsey 2009: 5).

The hybrid and electric scenario assumes a rapid transition towards a world of electricity-based powertrains (the components in a vehicle that generate power and deliver it to the wheels). Sales of hybrid and electric cars would rise from 26% in 2020 to 60% in 2030, as illustrated in the graph below.

In the mixed technology scenario, global sales of hybrid and electric cars would reach 16% in 2020 and rise to 42% in 2030. Total predicted sales of vehicles would be around 90 million in 2030, compared with 61 million in 2010 (McKinsey 2009: 7). According to this scenario, sales of hybrid and electric vehicles in 2030 will be 37.8 and 54 million vehicles, respectively.

In the most aggressive electrification scenario, greenhouse gas emissions from the transport sector might be reduced by 81% relative to the no-action baseline. This report does not detail the timing of the transition, but lists certain factors that will dictate it: costs, a technical breakthrough that significantly reduces battery system costs, and development of an infrastructure that supports vehicle charging on a mass scale (McKinsey 2009: 7-8).

The report also says that the benefits from CO<sub>2</sub> emission reductions would outweigh incremental upfront investment costs (McKinsey 2009: 8).





No scenario has been developed that envisages the uptake of electric vehicles in the EU as a whole. However, a thorough UK projection has been prepared by the UK Department for Transport (DfT). It develops four scenarios for the introduction of electric cars until 2030. These range from business-as-usual, which assumes that current incentives are left in place and no additional action is taken, to an 'extreme range' scenario, which assumes that there is high demand for electric cars and that the only restriction is short-term availability. The outcomes of these scenarios are illustrated in the table below.

Number of Vehicles in UK Car Parc						
	2010		2020		2030	
Scenario	EV	PHEV	EV	PHEV	EV	PHEV
Business as Usual	3,000	1,000	70,000	200,000	500,000	2,500,000
Mid-Range	4,000	1,000	600,000	200,000	1,600,000	2,500,000
High-Range	4,000	1,000	1,200,000	350,000	3,300,000	7,900,000
Extreme Range	4,000	1,000	2,600,000	500,000	5,800,000	14,800,000

Table 1: The uptake of electric vehicles in the UK (BERR and DfT 2008: 5).

## 3 Electric vehicles and greenhouse gas emissions

### Summary:

Electric cars can help reduce CO<sub>2</sub> emissions from the transport sector provided two conditions are met: first, they must be more energy-efficient than state-of-the-art conventional vehicles on a 'tank to wheel' basis; second, the electricity to power the cars must be sourced from renewable sources.

The first of these conditions appears to have been met: electric vehicles are between two and three times more efficient than petrol hybrid and advanced diesel vehicles on a 'tank-to-wheel' basis.

The second condition, which depends on 'well-to-wheel' environmental impacts, is far from guaranteed, as it depends on the type of electricity generation. Electric cars powered by wind or solar energy are obviously superior. But if the electricity comes from coal, hybrids perform better.

This chapter starts by examining studies on reducing greenhouse gas emissions from the entire transport sector. It then looks into lifecycle emissions of electric vehicles compared with conventional vehicles. Local emissions of other pollutants or noise are not considered, although studies do indicate that electric vehicles could greatly reduce both noise emissions in urban environments and emissions of air pollutants such as particulates, nitrogen oxides, and volatile organic compounds.

### 3.1 Potential for greenhouse gas savings for the transport sector

#### 3.1.1 UK projections

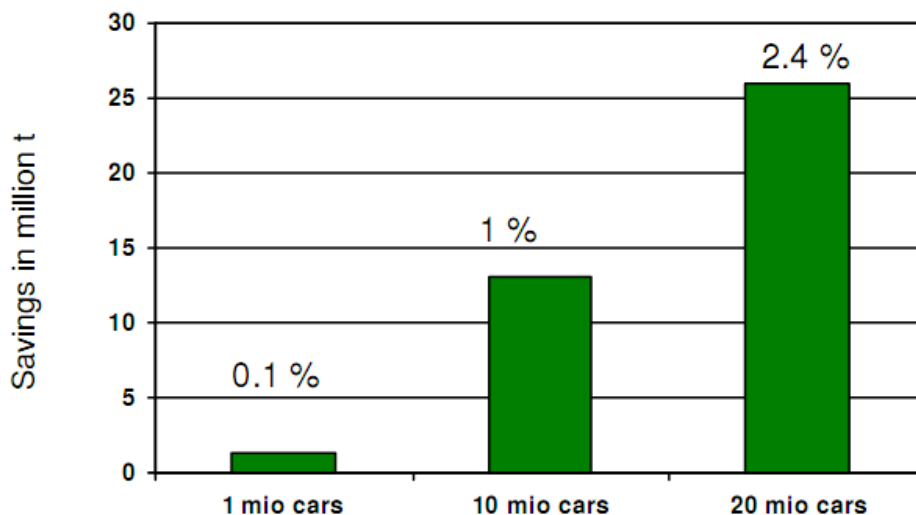
Table 2 summarises potential carbon dioxide savings using the UK scenario mentioned in the previous chapter (BERR and DfT report 2009: 15). Every scenario offers modest greenhouse gas emission reductions until 2020. By 2030, the high and extreme range scenarios offer substantial greenhouse gas emission reductions. This delay is due to the time taken for fleet renewal, which usually takes a minimum of 10 years.

Defra long term marginal factor	CO <sub>2</sub> saving (T) (% of 1990 UK Road Transport CO <sub>2</sub> Emissions)		
	2010	2020	2030
Business as Usual	6,000 (0.005%)	261,000 (0.24%)	2,276,000 (2.08%)
Mid-Range	8,000 (0.007%)	1,053,000 (0.96%)	3,708,000 (3.39%)
High-Range	8,000 (0.007%)	2,088,000 (1.91%)	9,495,000 (8.68%)
Extreme Range	8,000 (0.007%)	4,361,000 (3.99%)	17,254,000 (15.77%)

Table 2: Comparison of CO<sub>2</sub> Savings for the Scenarios for Uptake of EVs and PHEVs for the UK. Savings are expressed as a percentage of overall CO<sub>2</sub> emissions from road transport in 1990, taken as 109.4 million tonnes (BERR and DfT 2008: 15).

### 3.1.2 The case of Germany

A 2009 WWF study into the impact of electric cars on CO<sub>2</sub> emissions looked into emissions savings that could result from 1, 10 or 20 million electric cars in Germany. The study assumes that the average car's CO<sub>2</sub> emissions in 2020 will be around 130g/km and further assumes that EVs are fuelled exclusively from renewable energy sources, thus having 'real zero emissions'. Every kilometre driven using electric power, under this calculation, will thus save 130g CO<sub>2</sub>. Yet even according to the study's best-case scenario, 20 million electric cars on Germany roads by 2030, the overall greenhouse gas emission saving to the country would be just 2.4% (graph 6).



**Fig. 1:** Savings in million tonnes of carbon (green bars) and in relation to overall German emissions (shown in percent)

Graph 6: Savings in million tons of CO<sub>2</sub> due to introduction of EVs (WWF 2009).

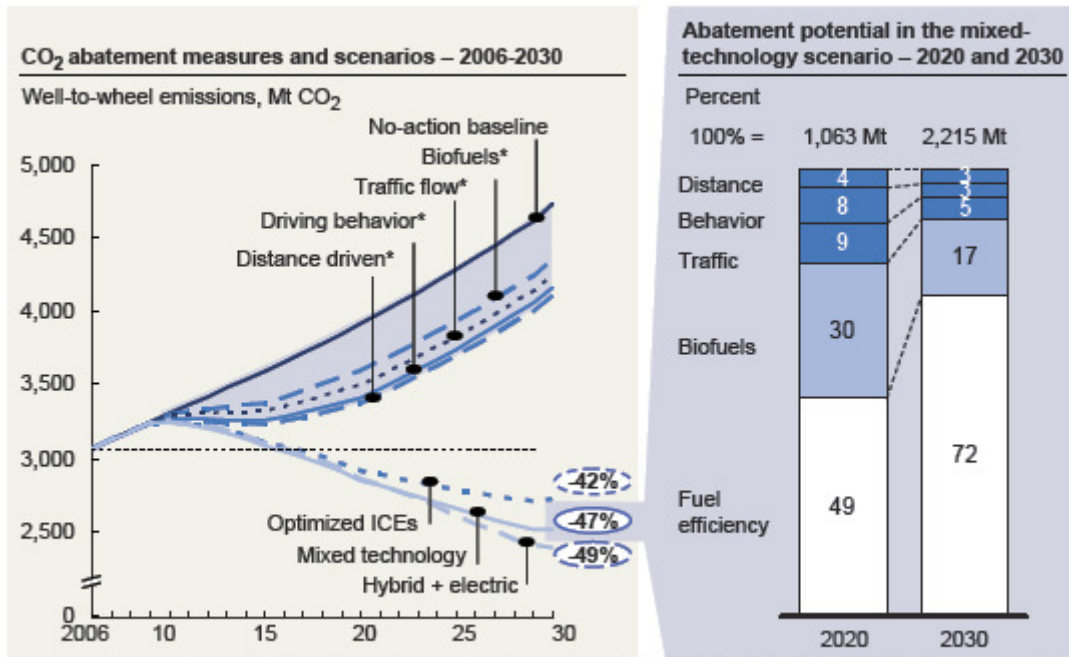
The conclusion from this study must be that electric vehicles will not offer significant greenhouse gas savings over the short term.

### 3.2 Improve internal combustion engines instead?

If we are to reach the 80% greenhouse gas emissions reduction target by 2050, as recommended by the IPCC, it will clearly be important to improve the efficiency of internal combustion engines, as well as developing alternatives. The McKinsey report, mentioned above states that focusing solely on optimising internal combustion engines would likely be more cost effective, but it would do little to prepare the automotive sector for a transition to new propulsion systems capable of achieving greater emission reductions in the long term (McKinsey 2009: 3).

The same report estimates that optimising the fuel efficiency of internal combustion engines (together with other measures such as changing driving behaviour, regulating traffic flow and so on, the so-called 'integrated approach') could result in a 42 percent emissions saving relative to the no-action baseline, equivalent to a global fleet average emission of 170 g CO<sub>2</sub>/km by 2030 (see graph 7).

In McKinsey's more aggressive scenario, a further 7% could be saved by adding hybrid and electric vehicles to the mix. The same scenario also assumes a rapid transition to the introduction of electricity-based powertrains, an aggressive reduction in the carbon intensity of electricity from 600 t CO<sub>2</sub>/GWh in 2006 to 250 t by 2030, and the optimisation of remaining internal combustion engines vehicles. Average well-to-wheel emissions from new vehicles worldwide in this scenario would decline from 270 grams CO<sub>2</sub>/km travelled in 2006 to 130 grams CO<sub>2</sub>/km in 2030 (McKinsey 2009: 5-6).



\* Emissions reductions for biofuels, traffic flow, driving behavior and distance driven based on mixed-technology scenario.

Source: McKinsey analysis

Graph 7: Potential to save GHG emissions from different scenarios (McKinsey 2009: 6).

Boston Consulting Group came to similar conclusions when it analysed the potential for cutting emissions in the transport sector. Assuming 586 g CO<sub>2</sub>eq/kWh from the power sector, it calculated that electric vehicles offer 50% improvement potential, compared to advanced internal combustion engines' potential for 12% improvement. This reduction comes at a price: by 2020, the optimisation of internal combustion vehicles is estimated to cost 140 USD per percentage point of emission reductions, compared to 280 USD per percentage point for electric vehicles (BCG 2009: 4).

### 3.3 Life-cycle analysis of electric vehicles: efficiency and carbon footprint

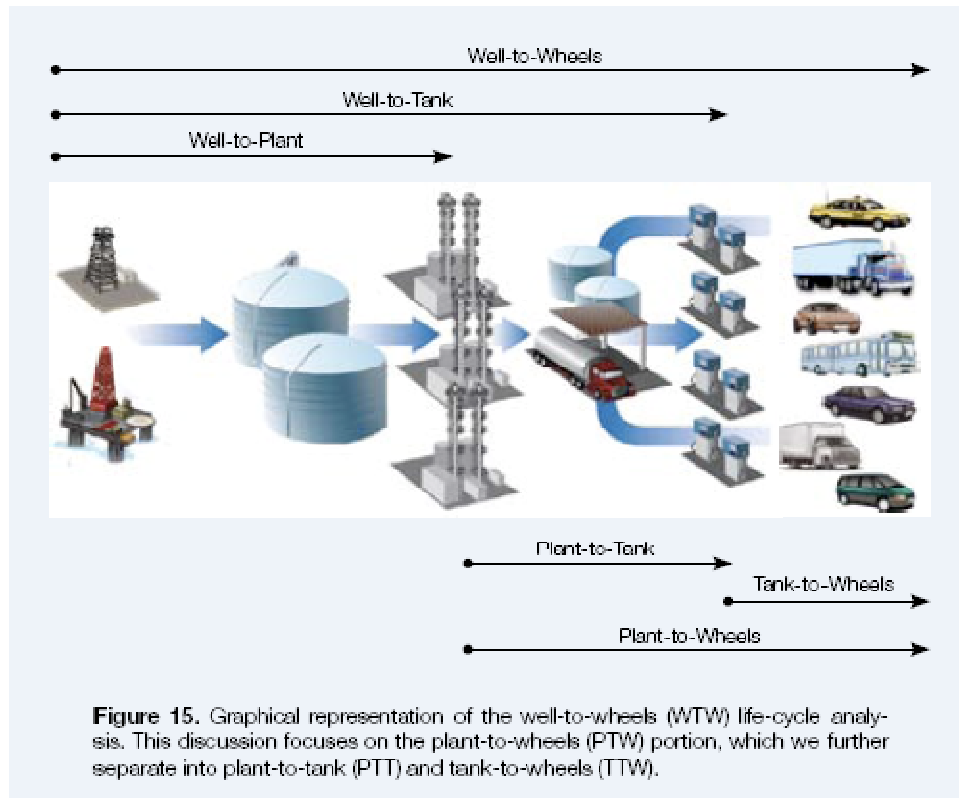


Figure 1: Well-to-wheel analysis (Kendall 2008: 81).

A lifecycle assessment (LCA) is the investigation and valuation of the environmental impacts of a given product or service caused or necessitated by its existence. In this section we will focus on the evaluation of greenhouse gas emissions resulting from the vehicle's use, on a well-to-wheel basis which includes well-to-tank (production of fuel) and also tank-to-wheel (the combustion of fuels resulting in a car's use) analysis (see Figure 1 above). Full LCA also includes emissions from vehicle production and end of life, but these elements will not be discussed here. The reason for focusing on emissions from vehicle use is the fact that these represent around 90% of total emissions. In the case of conventional internal combustion engine vehicles, the emissions from vehicle use usually account for 75% of overall emissions, a further 14% of emissions come from oil extraction and refining, while the remaining 11% is emitted during the production and end-of-life treatment of the vehicle.

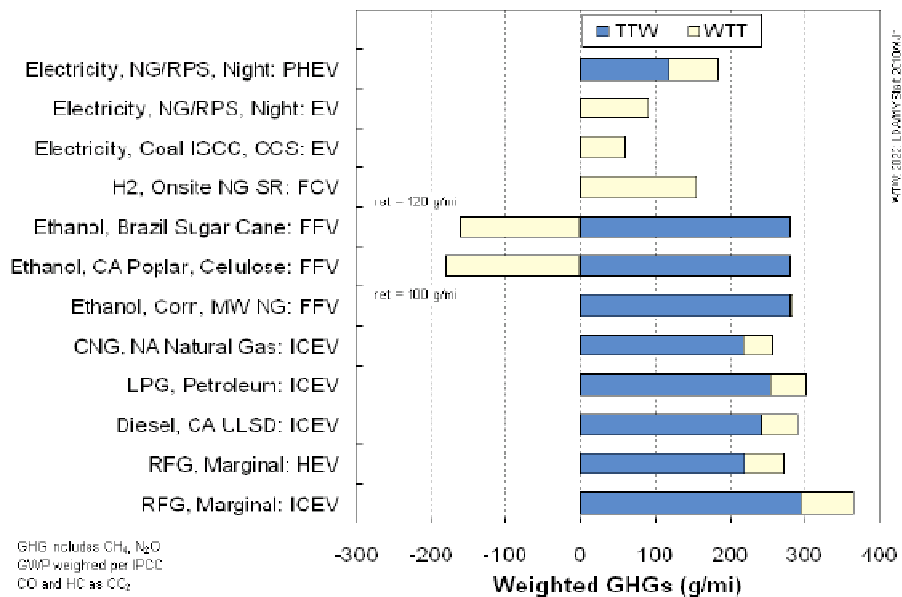
In the case of electric cars this proportion is different, as cars are zero emissions on a tank-to-wheel basis and the majority of the emissions come from electricity production (well-to-tank). The environmental performance of EVs is therefore largely dependent on the carbon intensity of the power generation. This chapter seeks to explain what the GHG emissions of electric cars are, compared to other alternative technologies, and what is their potential for GHG emission reductions in the transport sector as a whole and on the basis of an individual vehicle. We separate the analysis into well-to-tank and tank-to-wheel.

#### 3.3.1 Attempting to compare well-to-wheel analyses of electric cars to bioenergy and hydrogen

At EU level, there is a distinct lack of data on well-to-wheel emissions from electric cars. Well-to-wheel studies of vehicles are the responsibility of the JEC<sup>11</sup> which is dominated by the car and oil industries. JEC analysis effectively ignores electric vehicles by excluding vehicles with a top speed below 180 km/h and a minimum range of under 600 kilometres. These limitations are bizarre given that no European country has a legal speed limit above 130 km/h<sup>12</sup>, and that the average daily driving distance is 27 kilometres, or less than five percent of the range of the threshold chosen (Kendall 2008: 135).

Based on the limited existing data, electric cars seem to be more efficient compared to other alternative technologies. Studies suggest that it is more efficient to use biomass as a fuel to generate electricity than in the form of a biofuel for cars. Bioenergy can be used either to power internal combustion engines in the form of biofuels or burned in stationary applications to produce heat and electricity, which can later be used to power electric vehicles. However, although it is a renewable resource, it is limited by the amount of available land and water. Bioelectricity produces an average of 81% more transportation kilometres and 108% more emissions offsets per unit area of cropland than cellulosic ethanol (Cambell, Lobell and Field, (2009: 1055).

Hydrogen is also less efficient than electric vehicles due to conversion losses. According to Kendall (2008: 145), the well-to-wheel efficiency of hydrogen vehicles is 28%, while the overall efficiency of electric vehicles is 34%. This is mostly due to the smaller conversion efficiency of a fuel cell (54%) compared to lithium-ion batteries (94%). A comparison with other technologies is illustrated in graph 8 below.



Graph 8: Example of well-to-wheel analysis for different fuels (California Energy Commission 2007: ES-9).<sup>13</sup>

<sup>11</sup> An abbreviation for the first letters of JRC, EUCAR and CONCAWE, respectively the Commission's Joint Research Center, EUCAR (representing major European vehicle manufacturers) and CONCAWE (representing most oil companies operating in Europe).

<sup>12</sup> Some stretches of the German motorway network have no speed limit.

<sup>13</sup> RPS – Renewable portfolio standard, NG – natural gas, PHEV – plug-in hybrid vehicle, CCS – carbon capture and sequestration, H<sub>2</sub>, hydrogen, FFV – flexible fuel vehicle, IGCC – integrated gasification combined cycle, MW – molecular weight, RFG – reformulated gasoline, HEV – hybrid electric vehicle, LPG – liquefied petroleum gas, ULSD – ultra low sulphur diesel.



### 3.3.2 A more efficient electric powertrain (tank-to-wheel analysis)

Electricity's main contribution to greenhouse gas emission reductions in vehicles is due to the greater efficiency of electric vehicles on a tank-to-wheel basis compared with conventional vehicles.<sup>14</sup> Even if the electricity is produced by more carbon-intensive means than petrol or diesel, the car can still drive further for the energy supplied. Calculations vary, however, regarding exactly how much more efficient an electric vehicle is or what potential it has for improvement. (One analysis, presented by Gary Kendall, is illustrated in table 3.) It should be noted that in most available studies, electric vehicles are not compared with future state-of-the-art internal combustion vehicles; and also, that it is difficult to predict advances in electric technologies.

The higher tank-to-wheel efficiency is reflected in recently-adopted legislation in the EU and beyond. The EU Renewable Energy Directive (see Chapter 7) sets a target for the amount of renewable energy that should be used in the EU. Renewable electricity consumed in electric cars can count 2.5 times more towards the EU target than biofuels, in order to take into consideration the more efficient electric powertrain.

In California, the Low Carbon Fuels Standard introduced "Vehicle Efficiency Adjustment Factors" in recognition of the fact that vehicles running on certain fuels are more energy-efficient than others. For electric vehicles the estimated efficiency is three times higher than the conventional car (see table 4).<sup>15</sup>

Primary energy efficiencies		Liquid Pathway (ICEV)	Electron Pathway (BEV)
Plant-to-Tank	Plant efficiency	83%	35-42%
	Transmission & Distribution		92%
Tank-to-Wheels		18-23%	65%
Plant-to-Wheels (life-cycle)		15-19%	21-25%

Table 3: Comparative primary energy efficiencies of ICEVs and BEVs across the plant-to-wheels life cycle. (Kendall 2008: 86).<sup>16</sup>

<sup>14</sup> Most of emissions (around 85%) from conventional fuels come from combustion on a tank-to-wheel basis. Only around 15% of life cycle emissions are created during production and distribution. EVs on the other hand have no tailpipe emissions, but considerably more can be created during electricity production – depending on the source of electricity.

<sup>15</sup> This is how they the case for electric vehicles is explained in Low Carbon Fuels Standard: "The well-to-wheel CO<sub>2</sub> emissions from electric vehicles, in units of g CO<sub>2</sub>e/MJ of energy delivered to the vehicle, are generally higher than for gasoline vehicles. However, electric vehicles require much less energy to travel a specified distance. As a result of their much lower per mile energy consumption, electric vehicles emit less greenhouse gases than gasoline vehicles on a per mile basis, even though they emit more per unit of energy consumed."

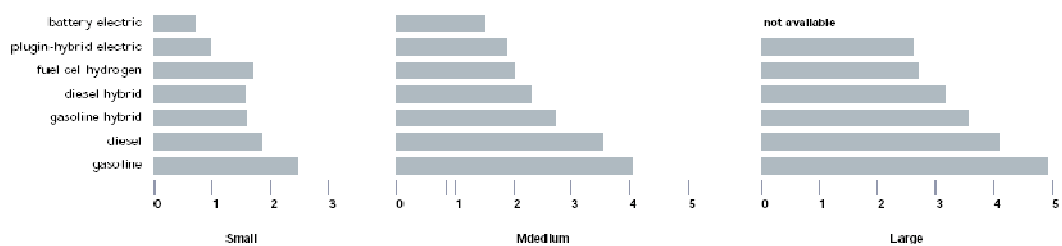
<sup>16</sup> US department of energy DOE web site states that fuel economy tank-to-wheel of gasoline is 15-20%, while the one of electric vehicle is 86%. Electric vehicles are also relatively more efficient at low speeds, which is not the case of internal combustion engines (Deutsche Bank 2008: 8).

Light- and Medium Duty Applications (Fuels Used in Vehicles Substituting for Gasoline Vehicles)		Heavy-Duty/Off-Road Applications (Fuels Used in Vehicles Substituting for Diesel Vehicles)	
Fuel/Vehicle Combination	EER Values Relative To Gasoline	Fuel/Vehicle Combination	EER Values Relative to Diesel
Gasoline (including 6% and 10% ethanol blends) Used In Gasoline Vehicles or 85% Ethanol/15% Gasoline Blends Used In Flexible Fuel Vehicles	1.0	Diesel Fuel Used in A Diesel Vehicle or Biomass-Based Diesel Blends	1.0
Compressed Natural Gas Used in Spark-Ignited Vehicles	1.0	Compressed or Liquefied Natural Gas Used in a Heavy-Duty Spark Ignited or Compression Ignition Engine	0.9
Electricity Used in a Battery Electric or Plug-In Hybrid Electric Vehicle	3.0	Electricity Used in a Battery Electric or Plug-In Hybrid Electric Heavy-Duty Vehicle	3.0
Hydrogen Used in a Fuel Cell Vehicle	2.3	Hydrogen Used in a Heavy Duty Vehicle	1.9

Table 4: The efficiency of different vehicle types. (CARB 2009).

At the same time, the Californian Air Resources Board (CARB) admits that this efficiency comparison is based on relatively limited data. Nevertheless, table 4 shows that according to their estimates the electric powertrain represents the most efficient alternative in terms of tank-to-wheel analysis. This is illustrated by the so-called “Energy Economy Ratio” (EER), which refers to the factor that is used to account for differences in energy efficiency among different types of fuels and vehicles.

Assessments by Greenpeace and Fiat (Graph 9 and Table 5) compare the energy consumed by electric, conventional and hybrid vehicles on a tank-to-wheel basis. Both calculate that electric vehicles are two to three times more efficient than conventional vehicles (Greenpeace adds the aspect of vehicle size to the energy consumption).



Graph 9: Energy consumption of different vehicle sizes in litres of gasoline/100 km (Greenpeace 2009: 177).

	<b>UE extra-urban cycle</b>
BEV vehicle (Citroen Berlingo II)	140 Wh/t/km
BEV vehicle (Doblò by Micro-vett)	164 Wh/km
Mid size BEV vehicle	310 Wh/km (Well To Wheels) (150 Wh/km after battery)
Diesel/Gasoline/ methane vehicles	570-670 Wh/km (Well To Wheels)
Hybrid vehicles	390-530 Wh/km (Well To Wheels)

A small sized EV (500 kg) can be designed to have a consume  
**of less than 70Wh/km** in an NDEC cycle

Table 5: Typical lifecycle energy consumption of different vehicle types. (Perlo 2009).

Further research (excluding extremely small and low-performance cars) indicates that the energy-use of a typical mid-size electric vehicle is in the range of 150-200 Wh/km. In comparison, very efficient mid-size diesels and hybrids achieve values of around 450 Wh/km.

But how does all this translate into greenhouse gas emissions? Since electric cars do not have tailpipe emissions, their emissions performance must be evaluated according to how the electricity that powers them is generated.

### 3.3.3 Emissions from power plants (well-to-tank analysis)

Calculating the electric pathways - 'well-to-plant' - for electric vehicles depends on the energy generation mix, and how this will evolve in the future. This has not yet been properly evaluated at the EU level, and depends on many factors, including oil price, carbon price, investment decisions by companies and incentives by governments. Furthermore, electricity grid mix varies widely depending on the region, time of day and season (Kromer and Heywood 2007: 75).

In light of current targets for renewable energy, most governments and energy companies assume that the carbon intensity of the EU electricity mix will gradually decrease over the coming years.<sup>17</sup>

Variations in the carbon and energy intensity of different fuels make the GHG and energy use results very sensitive to assumptions. Hence, in addition to being highly uncertain, the grid mix has the highest impact on the results (ibid.).

Two crucial aspects on which GHG emissions depend are: regional and temporal variations in the marginal electricity generation<sup>18</sup> and the stage of market penetration of the vehicle (Kromer and Heywood 2007: 78). In most respects, however, the

<sup>17</sup> Eurelectric predicts that carbon intensity of EU electricity mix would decline from 410 g CO<sub>2</sub>/kWh in 2007 to 130 g CO<sub>2</sub>/kWh in 2030. According to their calculations well-to-wheels analysis electric vehicle emits 80 g of CO<sub>2</sub>/km in 2007 and around 30 g of CO<sub>2</sub>/km in 2030 (Eurelectric 2009: 2-3).

<sup>18</sup> According to Kromer and Heywood (2007: 78) off-peak charging scenario is probably most reflective of reality, particularly if appropriate price signals are in place.

characteristics of the current electric grid are less important than the future interaction of EVs and PHEVs with the grid. This is because EVs will comprise a small fraction of the in-use fleet for many years to come; hence, the near-term environmental impact (positive or negative) is marginal (Kromer and Heywood 2007: 79).

The uncertainties in the emissions rates of electricity generators can be divided into three major ones:

- 1.) Uncertainty over how the electric grid will evolve over time, which dictates the mix of generators available for charging a vehicle.
- 2.) Uncertainty over the size of the electric vehicle market, which could dictate whether capacity expansions will account for sizeable demand for electricity from plug-in vehicles.
- 3.) Uncertainty over which electricity generation (coal, gas, renewables) is triggered by additional demand from electric vehicles at a certain time of the day, which varies on a regional basis (Kromer and Heywood 2007: 80).

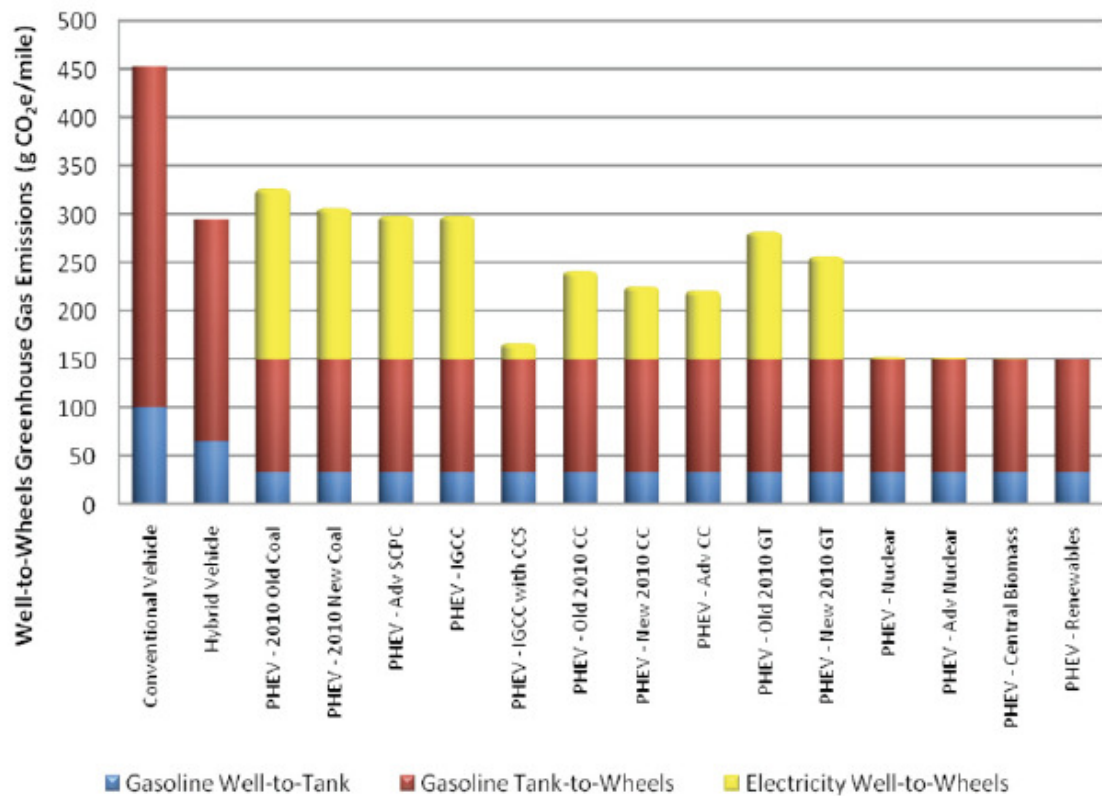
Several studies have tried to evaluate the carbon footprint of electric and plug-in hybrid vehicles, comparing them with conventional and other technologies. Graph 8 (above) illustrates how EVs compare with other technologies on a lifecycle basis, while graphs 11 and 12 show how the life cycle greenhouse gas emissions from plug-in electric vehicles<sup>19</sup> differ regarding the source of electricity. The studies reveal that even if the electricity is produced using coal, emissions from electric vehicles are still less than those of conventional vehicles. However, graphs 10 and 11 reveal that, when comparing emissions of hybrid and plug-in hybrid vehicles, the source of electricity becomes crucial in determining whether any greenhouse gas savings are achieved.

If we look at marginal power plant charging, time of day is crucial. If charging is shifted towards night time, capital-intensive power plants (coal and nuclear) become more competitive. These power plants could also be hydro or wind. Charging at peak times will increase costs and grid load, but the energy may be sourced from responsive low-carbon electricity sources, such as natural gas or pumped storage.

Greenhouse gas reduction benefits of electric and plug-in hybrid vehicles are thus highly dependent on the charging regime and the structure of the power network. The less carbon-intensive the electricity grid, the more savings can be made by an electric vehicle compared to a hybrid. If, on the other hand, coal dominates the supply mix, plug-in hybrids will increase GHG emissions (Kromer and Heywood 2007: 82).

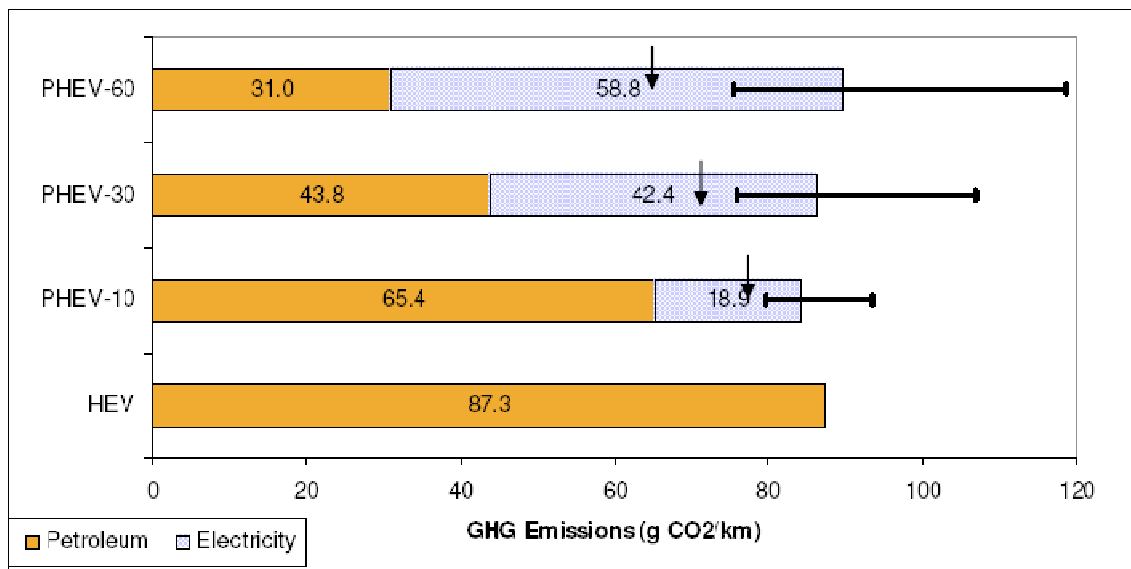
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<sup>19</sup> Plug-in hybrids employ two different primary energy sources (electricity and petroleum) in two distinct driving modes (charge-sustaining and charge-depleting), so typical driving patterns must be accurately characterised. The methodology for this was established in the US (the SAE J1711 standard) and further refined by EPRI (Kromer and Heywood 2007: 60).



**Year 2010 comparison of PHEV 20 GHG emissions when charged entirely with electricity from specific power plant technologies (12,000 miles driven per year).**

Graph 10: The impact of the source of electricity on GHG emissions (EPRI and NRDC 2007: 7).



Graph 11: Breakdown of GHG emissions for the hybrid vehicle and plug-in hybrids with varying range. The low-end of the uncertainty bar corresponds to natural gas generation; the high-end corresponds to coal; and the base case corresponds to the average grid. The arrows indicate the emissions rate of the clean grid mix (Kromer and Heywood 2007: 82).

A study by the British ministry of transport (DfT 2008: 14) has compared the lifecycle greenhouse gas emissions of electric vehicles, taking into account electricity generation and the extraction of petrol and diesel. It found (see table 6) that electric vehicles emit significantly less carbon dioxide than conventional vehicles over their lifetime, and that the savings will increase as renewable energy sources assume a greater share of the grid mix. If the electricity mix were to shift towards renewable energy sources as anticipated by this study, by 2030 the emissions from an electric vehicle would be a third of those of a petrol vehicle (BERR and DFT 2009: 15).

<b>Vehicle Manufactured in 2010</b>				
	Electric		ICV	
	GaBi 4 factors grid mix	Defra long term marginal factor	Petrol	Diesel
Emission factor well to wheel gCO <sub>2</sub> e/km	106	69	172	156
Lifetime vehicle carbon use kg CO <sub>2</sub> - equiv	19,161	12,384	30,916	28,012
<b>Vehicle Manufactured in 2020</b>				
Emission factor well to wheel gCO <sub>2</sub> e/km	56	56	144	130
Lifetime vehicle carbon use kg CO <sub>2</sub> - equiv	10,132	10,062	25,864	23,435
<b>Vehicle Manufactured in 2030</b>				
Emission factor well to wheel gCO <sub>2</sub> e/km	41	47	120	109
Lifetime vehicle carbon use kg CO <sub>2</sub> - equiv	7,390	8,514	21,639	19,606

Table 6: Comparison of an EV and an ICV over the vehicle life (defined as 180,000 km). (BERR and DFT 2008: 14)

**To conclude, it appears that the overall impact of the introduction of electric vehicles on carbon emissions will be slight until 2030 and will, in addition, depend largely on the electricity source. On a lifecycle basis, EVs can offer substantial emission reductions if they are powered from renewable energy sources. If they trigger additional demand for coal, on the other hand, it makes more sense to encourage hybridisation.**

## 4 The impact of electric vehicles on the power sector

### Summary:

The extra electricity required to power electric vehicles will need to be addressed through increased generating capacity and new approaches to grid management. All this will have an impact on decisions on future investment in the power sector.

Even if the grid has the capacity and the basic infrastructure to meet the needs of electric cars, the new demand patterns they will create may mean greater use of coal and nuclear power.

There is compelling evidence that electric cars offer a good opportunity to store intermittent renewable energy sources, such as wind energy. However, there is no strong evidence that car batteries will be attractive tools to provide vehicle-to-grid (V2G) transmission. Evidence suggests other technologies are cheaper and better at this.

Electric cars will lead to greater electricity consumption, which will have several impacts on the power sector. This chapter looks into how much additional electricity will be needed and what this will mean for grid management, taking Germany as a case study. It also reviews literature on the potential for electric vehicles to serve in providing storage for intermittent renewable energy sources and their potential to provide energy back to the grid through the so-called vehicle-to-grid (V2G) system.

### 4.1 Additional energy and generating capacity

According to Eurelectric (2009), a complete shift towards electric vehicles would increase electricity consumption in the EU27 by 15%. Similarly a report by ERTRAC (2009) calculates that one million electric vehicles travelling an average 10,000 km a year would require about 1 TWh of energy: “a minor fraction of the annual electricity output of an EU member state, e.g. for Germany it would be less than one percent”.

The UK Department for Transport’s report (2008: ii) states that the UK has “sufficient generating capacity to cope with the uptake, assuming that charging is managed and targeted at off-peak periods, where there is currently surplus capacity”. It suggests that this could be achieved through variable tariffs. (DfT 2008: 40). However, if owners start charging their vehicles during peak hours, significant investment in local network capacity may be required (ibid. 42).

In the US, a study by Pacific Northwest National Laboratory (PNNL) concluded that the American grid could support 94 million electric vehicles (43% of cars on the road), if they are charged during the evening only, or 158 million vehicles (73%), if the charging is spread over a 24-hour period in an optimal fashion (Kromer and Heywood 2007: 83). However, the amount of excess capacity varies between regions (e.g. it is quite small in California).

According to the IEA’s Blue “EV Success” scenario (2008: 425), total transport electricity demand would reach 20% of total world electricity demand, requiring more than 2,000 GW of additional capacity. In the early days of plug-in hybrid and EV sales, much of the demand may involve night-time recharging using existing capacity. As the stock of the vehicles grows, and particularly if quick-recharging

technology emerges, substantial daytime charging will also occur, likely increasing peak demand in most regions.

## 4.2 Grid management

Demand patterns determined by the number of electric vehicles and by charging patterns, will determine grid management. It is assumed that charging could be managed through smart-metering and financial incentives – so-called smart-charging. There is also scope for taxation measures, to be implemented once electric vehicles become more mainstream, in order to replace the shortfall in income from fuel taxes.

Electric vehicles may also serve as storage facilities for intermittent renewable energy sources; this could be backed up with financial incentives to consumers by grid operators and power companies. However, smart-charging is a prerequisite for electric cars to enable management of the grid, as more renewable energy sources are introduced (cars should be able to charge, when renewable energy sources are abundant). In this way, the potential synergies between plug-in loads and intermittent renewables could enable greater market penetration of these resources (Kromer and Heywood 2007: 77).

It has also been suggested that electric car batteries may be used to power specific electric markets: vehicle-to-grid power (V2G). A study by Kemptom and Tomić (2004) established that the energy market and vehicle fleet are complementary in such a way that strengths and weaknesses could be reconciled between drivers and grid managers. V2G could potentially provide storage for renewable energy generation, for example by wind power. However, there is a lot of scepticism over whether batteries could fulfil this storage function in a useful way, due to the limited number of recharging cycles a battery has.<sup>20</sup>

The demand for electricity varies widely depending on time and season. To meet this demand generators with different profiles would be needed. These generators are generally dispatched in economic merit order (from lowest variable cost to highest). Nuclear, hydro-electric and some coal plants form the low-cost baseload generators, plus intermittent renewables when available. After the baseload resources, higher variable cost units such as natural gas (especially combined cycle natural gas) and older coal plants are used to respond to intermediate power requests. The highest cost but most responsive resources are typically combustion turbines running on gas or oil; these are used to respond to short-term peaks in demand (Kromer and Heywood 2007: 77). Graph 12 shows a simplified schema of typical power dispatch order and load profile.

## 4.3 Impact of electric vehicles on the grid

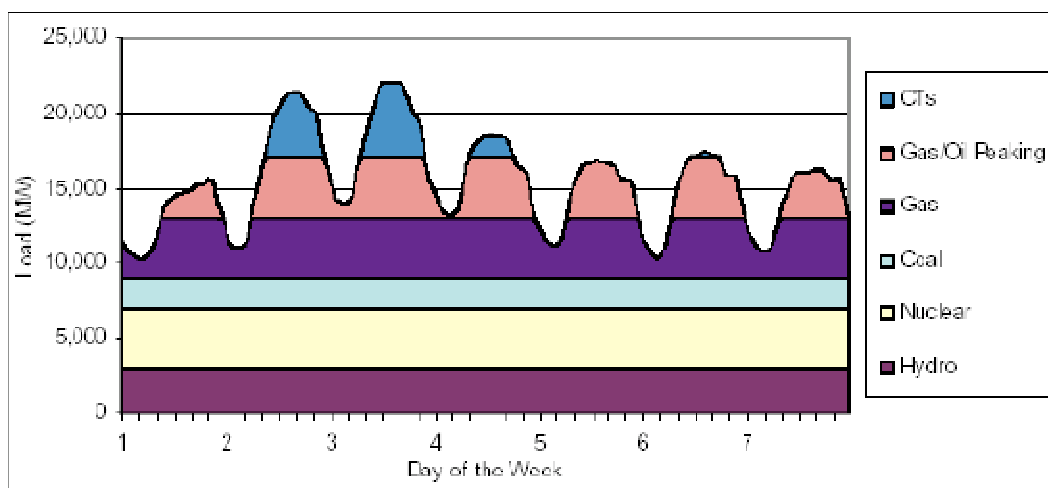
The impact of electric vehicles on the grid goes beyond questions of additional demand and peak loads to look at how the additional demand will be met, and how

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<sup>20</sup> The four power markets are baseload, peak, spinning reserves and regulation. The two most relevant for Vehicle-to-grid are spinning reserves, which are supplied by generators set-up and ready to respond quickly in case of failures (they would typically be called 20 times a year for 10 minutes to an hour), and regulation, which is used to keep the frequency and voltage steady and might be called 400 times a day for up to a few minutes a time. Spinning reserves and regulation are being paid in part just for being available, a 'capacity payment' per hour available. In the US the costs for them constitute 5-10% of electric generation costs or about 10 billion USD per year (Kemptom and Tomić 2004: 3).



this will affect the power sector overall. The marginal power plant also determines the electricity price. The WWF study finds that for Germany, the marginal power plant is coal (see graph 15),<sup>21</sup> which would give higher per km emissions than liquid fuel engines. In the US, marginal generation in the near future lies somewhere between 100% coal and 100% natural gas, and will vary on a regional basis (Kromer and Heywood 2007: 80).



Graph 12: Illustrative example of electric grid dispatch (Kromer and Heywood 2007: 78).

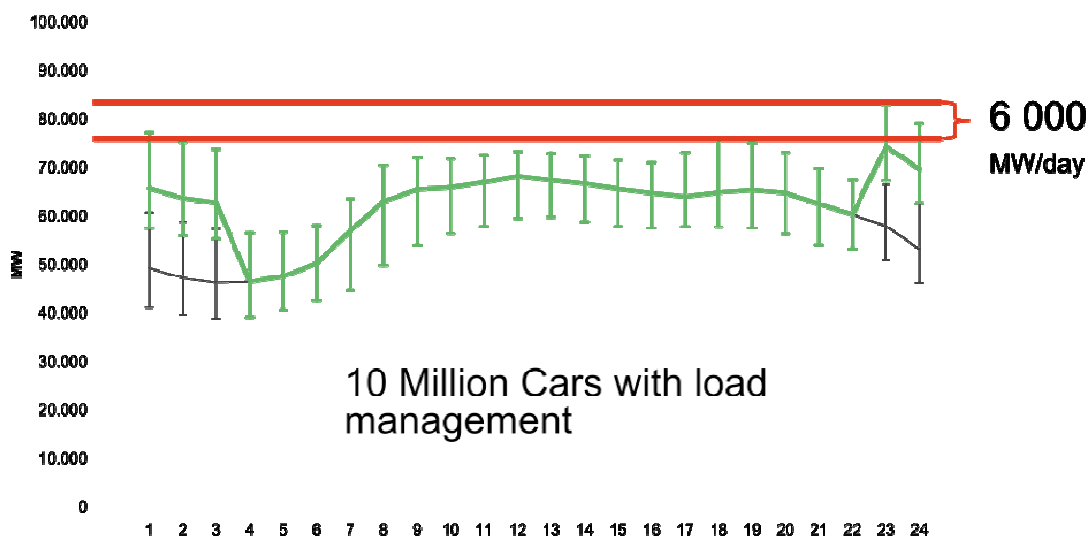
As the plug-in vehicle market matures and vehicle-associated grid-loads stabilise, these loads would eventually be incorporated into future build decisions. This does not mean that they would drive capacity *additions* per se (at least in the next several decades), but rather that they could increase the demand for baseload generators.

Significantly, plug-in demand can increase the penetration of wind as a baseload resource. This is because the load profile of a night-time charging regime is well-matched to the generating profile of a wind resource, which also tends to peak at night. Over time, plug-in demand would act like base-load demand, with the effect that, at high levels of market penetration, the additional grid load should be characterised in terms of the average grid emissions rate (Kromer and Heywood 2007: 79-80).

## 4.4 The example of Germany

A 2009 study by WWF Germany examined the impact of electric cars on electricity demand and the power sector in Germany. It found that no adjustments to the transmission structure would be required to incorporate 1 million vehicles in the grid. However, a number over 1 million (the German target for 2020) would affect the power sector, and 10 million would lead to a significant increase in demand and peak loads.

<sup>21</sup> The Swedish Energy Agency assessed that the marginal power plant in Sweden would be coal. However they calculated that the CO<sub>2</sub> emissions from EVs run on coal-based electricity are 50 per cent lower than GHG emissions from a very efficient diesel car (4.0 l per 100 km).



Graph 13: The impact of car charging on the grid management (WWF Germany 2009)

According to the study, unmanaged charging would lead to raised current peak loads by over 16,000 MW/day and require extra capacity to be installed (see table 7). Managing the charging of 10 million cars over the course of the night would level the load profile to 6,000 MW/day, but would still generate peak loads (green peaks in graph 13) higher than today's load profile (black peaks in graph 13). The levelled profile would make conventional large-scale base load power (i.e. nuclear and coal) more profitable.

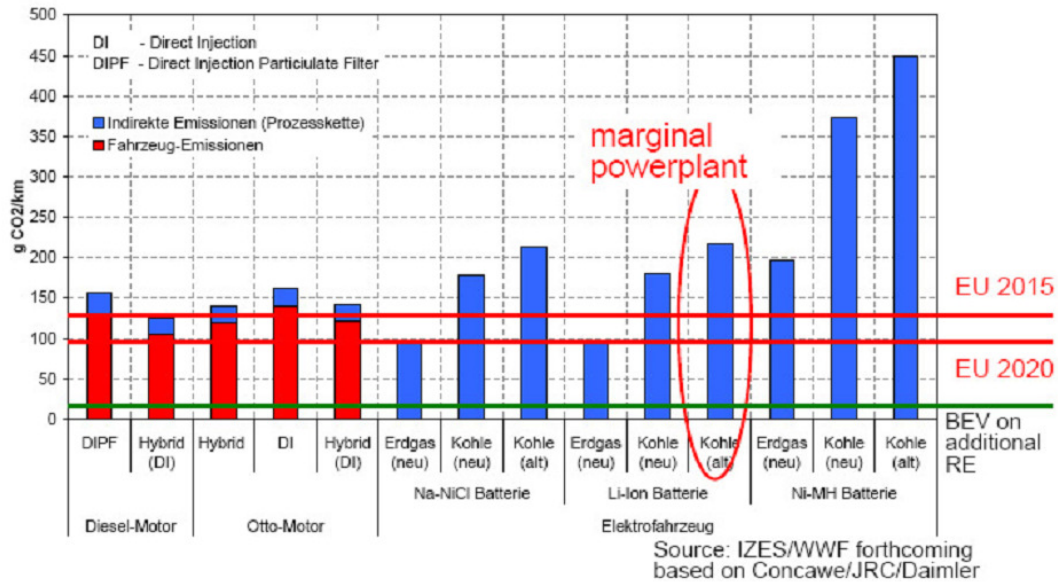
Scenario <sup>1</sup>	Time horizon	Number of vehicles	Charging time	Additional, average power demand	Annual peak load on the day in question
<b>Once-off charging per working day without load management</b>	<b>Until 2020</b>	<b>1 million</b>	<b>5 h</b>	<b>2,000 MW</b>	<b>78,000 MW</b>
	<b>After 2020</b>	<b>10 million</b>		<b>16,000 MW</b>	<b>94,000 MW</b>
		<b>20 million</b>		<b>33,000 MW</b>	<b>&gt; 100,000 MW</b>
<b>Once-off, quick-charging per working day without load management</b>	<b>Until 2020</b>	<b>1 million</b>	<b>2 h</b>	<b>5,000 MW</b>	<b>81,000 MW</b>
	<b>After 2020</b>	<b>10 million</b>		<b>40,000 MW</b>	<b>118,000 MW</b>
		<b>20 million</b>		<b>80,000 MW</b>	<b>158,000 MW</b>
<b>Once-off charging per day with load management</b>	<b>Until 2020</b>	<b>1 million</b>	<b>5 h</b>	<b>2,000 MW</b>	<b>76,000 MW</b>
	<b>After 2020</b>	<b>10 million</b>		<b>16,000 MW</b>	<b>84,000 MW</b>
		<b>20 million</b>		<b>33,000 MW</b>	<b>100,000 MW</b>

Table 7: Power demand and peak load for different fleets (WWF Germany 2009).

These findings raise the question of whether mass-market introduction of EVs might drive additional coal power plant installation. However, in the sense that EVs would require considerable load management, with smart grids and smart metering, they

would also promote the adjustments required to adapt the grid to permit a higher share of renewable energies.

## CO2-emissions of different fuel pathways



Graph 14: Specific emissions by different vehicle drives and process chains of power supply (WWF Germany 2009).

The question of how the electrification of transport could be managed in such a way as to boost renewables rather than existing baseload is a vexed one, and will be the subject of a forthcoming study commissioned by T&E and other NGOs.

## 5 Batteries for electric vehicles

### Summary:

The performance and cost of batteries is one of the biggest potential obstacles to the success of EVs, as it defines the electric range, performance characteristics and costs. Among the battery-types, lithium-ion batteries seem to be most promising, although no studies expect their costs to reduce rapidly.

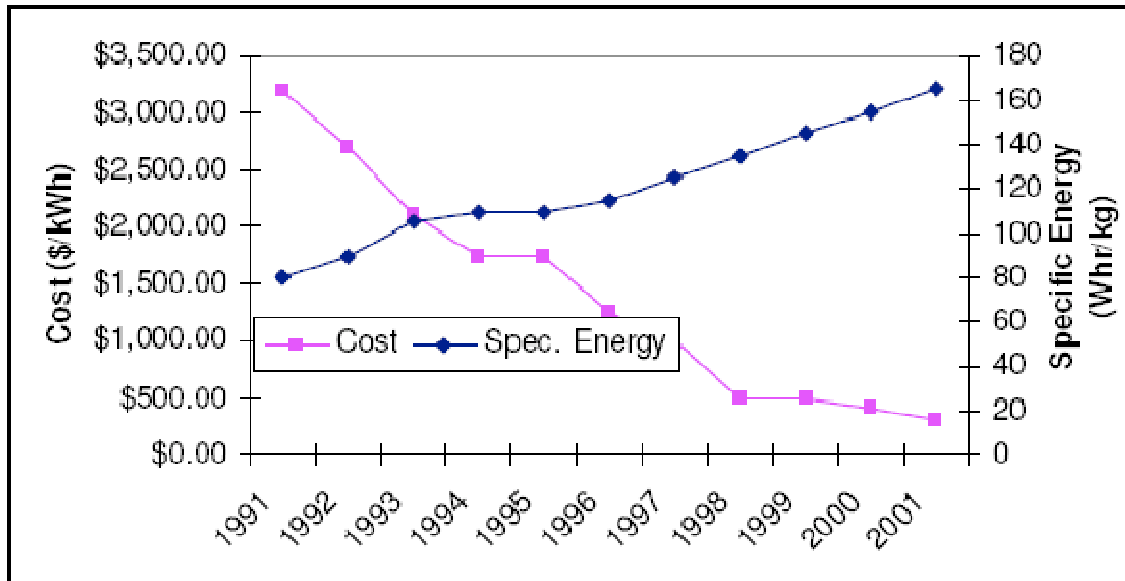
There is potential for improvement in performance and reduction of costs in the medium term, but not enough to suggest electric cars could compete head-on with conventional vehicles within the next two decades.

Further evaluation of the environmental impacts of battery disposal and recycling is required, and data on the energy consumption of battery production and recycling is lacking.

Studies and articles all agree that the widespread roll-out of electric vehicles (EVs) and plug-in electric hybrids (PHEVs) will depend on advances in battery technology, principally improvements in cost, performance and safety (DfR 2008: 28). Meanwhile, interest in developing batteries for cars is very high within industry, as the worldwide market for hybrid electric vehicles is expected to more than triple by 2015, to 2.3 billion USD (The Economist 2007).

Batteries can account for up to 75% of the extra cost of hybrid and plug-in hybrid electric vehicles. Li-ion batteries can cost from 770 EUR per kWh to 2,000 EUR per kWh. Electric cars usually use between 0.11 and 0.2 kWh/km, while most cars have a range of 160 km. This means a battery for such an electric car needs between 17 and 32 kWh. Today, the market for advanced rechargeable batteries for hybrids remains relatively small – some 900 million USD - and is dominated by PEVE, a Toyota subsidiary, which makes nickel metal hydride (NiMH) batteries. However, most studies expect lithium ion technology to supplant NiMH (Deutsche bank 2008: 9, DfR 2008: 28), as they can provide 1.4-2 times as much power and energy for a given weight or size, and have greater potential cost savings compared with NiMH technology, which depends heavily on the raw material price of nickel.

Assumptions vary regarding the cost reduction potential of lithium-ion batteries, but this is thought to lie in economies of scale and optimisation of manufacturing processes (DfR 2008). Compared with computer chips, which have doubled in performance roughly every two years for decades, batteries have improved very slowly in their 200 year history (The Economist 2008). Graph 15 shows that, in the decade 1991-2001, the cost of lithium ion batteries decreased substantially, while capacity increased. However, battery prices are still unlikely to fall sufficiently in the medium term to enable pure EVs to compete with conventionally-powered vehicles.



Graph 15: Improvements in lithium-ion battery technology, 1991-2001 (Kromer and Heywood 2007: 22).

## 5.1 Different kinds of batteries

It is a major technical challenge to produce batteries able to store large amounts of energy that can be released and recharged quickly. There are two kinds of battery: a standard battery allows a lot of energy to be stored, but the energy can be released or recharged only slowly; and a supercapacitor, which stores a limited amount of energy at the surface of the electrode and is quick to charge and discharge (The Economist 2009). A battery that can both store a lot of energy and discharge it rapidly is essential for electric cars. Graph 16 depicts the approximate energy and power densities required for various vehicle batteries, while the characteristics of different batteries are discussed below.

### 5.1.1 Lead acid

Lead-acid batteries were invented in 1859 and were used in the first electric cars. Small lead-acid battery packs provide short bursts of power to starter motors in virtually all cars; they are also used in large back-up power systems, and make up about half of the worldwide rechargeable battery market. However, it is not expected that this technology would improve to the level to be used in PHEVs and EVs.

### 5.1.2 Nickel cadmium

Nickel-cadmium batteries were introduced around 1900 and used in situations where more power was needed. These batteries provide emergency backup power on planes and trains. For most of the 20th century lead-acid and nickel-cadmium cells dominated the rechargeable battery market, and both are still in use today (Economist 2008). However, the toxicity of cadmium, plus the fact that the batteries store relatively limited energy for a given weight or volume, compared to newer technologies, undermines their potential.

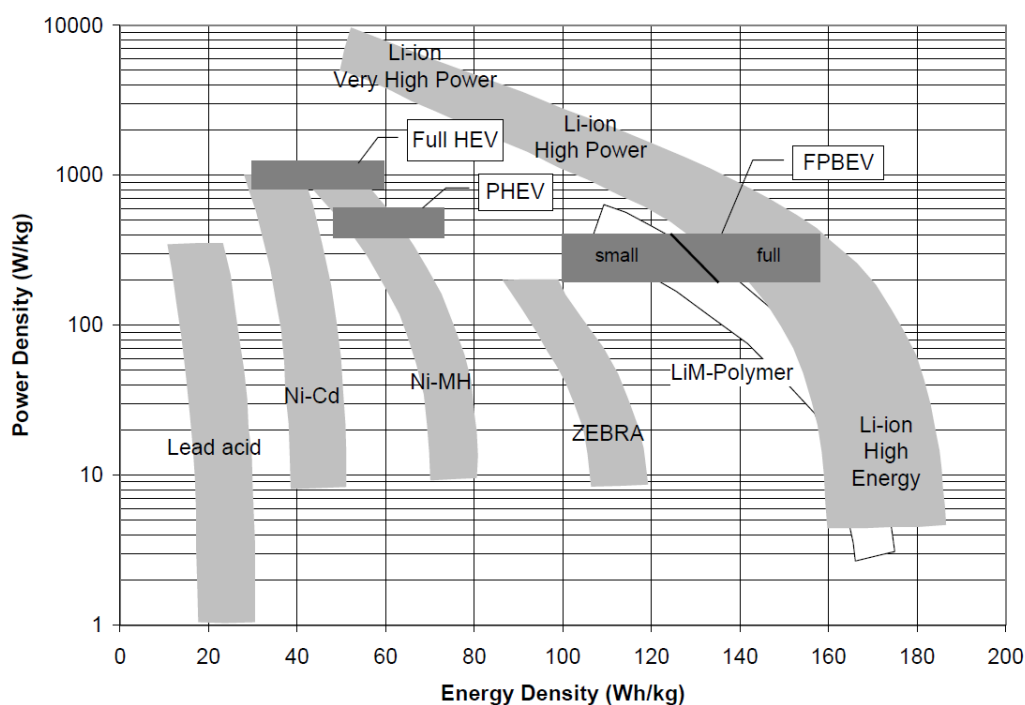
### 5.1.3 Sodium nickel chloride

Sodium nickel-chloride (ZEBRA) batteries have mainly been tested for heavy duty vehicles and are characterised by their long lifetime and relative high-energy density at low costs. However, they do not meet the power requirements of EVs and HEVs, and are therefore only produced in low volumes (CARB 2007).

### 5.1.4 Nickel-metal hydride

Nickel-metal-hydride (NiMH) batteries evolved from the nickel-hydrogen batteries used to power satellites. They are expensive and bulky, but do offer high energy-density and last a long time. Nickel-metal-hydride batteries have been adapted for use in cars, and are expected to work for eight to 10 years. They must endure hundreds of thousands of partial charge and discharge cycles as they absorb energy from regenerative braking, or supply short bursts of power to aid in acceleration.

NiMH batteries present a good energy to weight ratio. Their disadvantage is a high current operation during charging (exothermic reaction), which makes thermal management and cooling essential (and may explain why higher A/C efficiency is sought in hybrid cars (JRC IMPRO report 2008)). Another drawback is their limited potential for further cost reductions, as the raw material price is unlikely to fall, and a battery requires 5 to 10 kg of nickel per kWh.



Graph 16: Potential of Battery Technologies for HEV, PHEV and EV Applications (CARB 2007: 25).

### 5.1.5 Lithium ion

Lithium-ion (Li-ion) is currently the dominant battery technology in portable applications. Introduced to the market by Sony in 1991, the batteries account for 70% of the \$7 billion market for portable, rechargeable batteries (Economist 2008). Due to the high capacity of active materials and a single cell voltage of 3.6V, Li-ion provides the highest energy density of all rechargeable systems operating at room

temperature: approximately twice the specific energy of NiMH and three times that of lead-acid batteries (EUROBAT 2005: 6). Besides being light, they do not suffer from any 'memory effect': the loss in capacity that results when a battery is recharged without being fully depleted. However, while lithium-ion seems to be the most plausible candidate for future deployment, its success is not assured; it tends to become unstable if it is overheated, overcharged or punctured (The Economist 2008).

There is also the question of weight. A vehicle with a range of 100 km is 250 to 300 kg heavier than a conventional combustion engine vehicle. Experts predict that the energy density of lithium-ion batteries could at most double from 150 Wh/kg to 300 Wh/kg on the cell-level (Kromer and Heywood 2007).

In other potential improvements to electric vehicle batteries, a common lithium compound has been shown able to release and take up lithium ions in seconds (article published in *Nature*, by Byoungwoo Kang and Gerbrand Cedar), thereby reducing full-battery charging time to under 30 minutes. The compound, lithium iron phosphate (LiFePO<sub>4</sub>), is already found in many li-ion batteries common to electric vehicles, making such a charging system available to market in as little as two years.

This compound could conduct electricity very quickly and handle repeated charges without degrading, making it possible to have smaller, lighter, quick-charging batteries. However, to employ this invention, significant investments in manufacturing and infrastructure would be required, as the standard electricity grid could not provide enough current to fully charge batteries within minutes (Earth to Tech 2009).

An alternative to the development of fast-charging batteries might be battery swapping stations, such as those proposed by Better Place, a US-based electric vehicle service provider. It aims to supply cars and power on a long-term contract basis, similar to mobile phone providers. The client pays for the distance driven and, at the end of the contract, owns the car. Such business models are important, as they can deal with the main drawback of electric cars: high purchase price and the cheap cost of driving.

## 5.2 Lithium resources and availability

Compared with other rechargeable-battery chemistry options, the lithium-ion approach has many advantages and is seen by experts as the most promising technological pathway. Lithium is not the only commodity required for their manufacture, however: demand for certain other materials will likely also rise significantly with vehicle electrification including cobalt, nickel and copper, for use as battery inputs, and aluminium and alloyed steel products for vehicle construction (see table 8.) (Deutsche bank 2008: 42). None of these other materials appears to pose as much risk of resource scarcity as lithium, however.

	2012	2015	2018	2020
Lithium	10,703	33,301	62,544	85,870
Nickel	5,946	18,501	34,747	47,261
Cobalt	2,378	7,400	13,899	18,904
Aluminum	2,378	7,400	13,899	18,904
Manganese	3,568	11,100	20,848	28,357
Iron	3,568	11,100	20,848	28,357
Phosphate	3,568	11,100	20,848	28,357
Copper	21,406	66,603	125,088	170,140
Graphite	6,279	19,537	36,693	49,908
Hard Carbon	3,140	9,768	18,346	24,954

Table 8: Likely rises in commodity demand due to electrification of the vehicle market (tonnes) (Deutsche bank 2008: 42).

A report on global lithium reserves by the USGS (US Geological Survey) has identified a world reserve of 4.1 million tonnes, with a reserve base of 11 million tons (see table 9, USGS 2009). This means that 4.1 million tonnes are economically recoverable, with the remainder being proven geological reserves, but not necessarily economic to recover at the present time. Almost half of the reserve base (5.4 million tonnes) is in Bolivia and is practically unexploited. The highest production in 2008 (12,000 tonnes) took place in Chile (USGS 2009). According to the UK Department for Transport lithium for use in batteries would have a minimal impact on reserves even if production were scaled up (DfT report 2008: 13).

**World Mine Production, Reserves, and Reserve Base:** Reserves and reserve base estimates for Australia have been revised based on new information.

	Mine production		Reserves <sup>2</sup>	Reserve base <sup>2</sup>
	2007	2008 <sup>1</sup>		
United States	W	W	38,000	410,000
Argentina <sup>2</sup>	3,000	3,200	NA	NA
Australia <sup>2</sup>	6,910	6,900	170,000	220,000
Bolivia	—	—	—	5,400,000
Brazil	180	180	190,000	910,000
Canada	707	710	180,000	360,000
Chile	11,100	12,000	3,000,000	3,000,000
China	3,010	3,500	540,000	1,100,000
Portugal	570	570	NA	NA
Zimbabwe	300	300	23,000	27,000
World total (rounded)	<sup>3</sup> 25,800	<sup>3</sup> 27,400	4,100,000	11,000,000

Table 9: World lithium production and reserves (tonnes) (USGS 2008).

According to projections by Deutsche Bank (2008: 42) for automotive lithium-ion cell production, and growth assumptions for other markets, lithium ion demand could reach the 200,000 tonnes maximum production capacity, excluding Bolivia, by 2017. If Bolivian production comes online, supplies will not become scarce before 2030. The demand forecast assumes a continued 7% annual growth rate in demand for the metal from consumer electronics and other current uses. It expects the economic disadvantages of the Bolivian site, combined with rapidly increasing demand, to push up the price of lithium in the medium term.

If it were possible to recycle the lithium from end-of-life batteries into a material that could be used in new batteries, the issue of lithium depletion could be mitigated. Although no data exists at present to indicate this might be possible, researchers at CSIRO in Australia have developed a concept for an improved solvent extraction process to recover and purify cobalt and lithium from batteries (DfR report 2008: 13).



Looking ahead, Deutsche Bank (2008: 42) predicts that additional mining sites may have been discovered by 2017 or so, as well as new technologies that enable lithium mining from other sources, as well as large-scale battery recycling. Such conditions, should they arise, would enable lithium to remain a viable, relatively abundant source of power for automobiles over the long term (ibid). At this point in time, however, these assumptions remain open to question.

## 5.3 Environmental concerns

### 5.3.1 Extraction

A number of environmental issues associated with the production, use and disposal of lithium-ion (Li-ion) batteries require further investigation. Lithium is extracted using two main methods: mining spodumene or petalite ore and using evaporation ponds on salt lakes. The mining methods may cause environmental damage in fragile ecosystems, notably in the largest salt lakes in Atacama Desert in Chile and Bolivia. Extraction from sea water could be another option in the future, but is more energy-intensive (EEA draft report 2009).

As for the use of batteries, it is generally assumed that Li-ion batteries do not contain harmful elements for the environment and can be recycled (DfR report 2008: 13). This does require further investigation, however, as large numbers of grid-connected vehicles will increase the volume of raw materials consumed and waste produced, and will require a significant scaling-up of existing collection and recycling programmes (Kendall 2008: 171). An encouraging aspect in this respect is that battery collection and recycling is widely practised in the automotive sector, in contrast with consumer batteries: in the US 98% of all automotive lead-acid batteries are recycled (Battery University 2008). However, it is not clear whether recycled batteries could be re-used in cars or other applications. A report from CARB (2007: 138) suggests that batteries no longer meeting vehicle requirements could be used as energy storage sub-systems on the electric grid.

Recycling of NiMH and NiCd batteries is better established and has to some extent been analysed in the literature. Nickel cadmium batteries have to be kept separate from other recovery systems due to handling precautions. NiMH batteries require no special recovery system and, thanks to the value of the nickel and cobalt they contain, their scrap has a positive value and can be used in the steel industry. (JRC IMPRO report 2008).

## 6 Costs and consumer acceptance

### Summary:

Electric and hybrid vehicles are more expensive to buy and cheaper to run than conventional cars. In many cases, the fuel cost savings completely outweigh initial costs. Even the most expensive option, a fully electric car, reduces CO<sub>2</sub> at acceptable costs to society (below €100/tonne).

However, the high upfront costs prevent large market take-up. And the low running costs would lead to extra demand for car transport.

For these technologies to play a big role in our future transport system both issues need to be addressed. That could be done through innovative business models and through smart government policies. The latter should focus on fostering these business models and keeping avenues open for taxation of electricity. On board metering of electricity use would be a key requirement.

This chapter will look into the costs – both upfront and running costs - of electric vehicles. Along with limited range, upfront cost remains the biggest obstacle to consumer acceptance of the technology. It will also look into the cost effectiveness of hybrid and electric vehicles, and suggest ways to overcome the cost barriers.

### 6.1 Estimates of upfront costs

According to the European Commission's research body, the JRC (2008, 139-140), hybrid vehicles on the market cost on average €3,000-5,000 more than comparable conventional models. The additional cost of hybridisation is €3,500 per medium-sized vehicle.

Frost and Sullivan put extra costs for full petrol hybrids at 2,000–2,500 USD and for hybrid diesels at 5,000–5,500 USD (a diesel engine typically costs 10% more than a petrol engine with similar power). These additional costs arise mainly from the power electronics and battery system (the battery accounts for 30% to 50% of an HEV's additional cost).

The Deutsche Bank report contains different figures (see table 11). Here, the additional cost of a hybrid car would be in the range 600-2,200 USD.

However, costs depend not only on the level of hybridisation, but also on battery size, which determines the range and weight of the vehicle. Table 10 reveals the implications of increasing the vehicle's electric range. A vehicle with a 100-mile range incurs a manageable weight and cost penalty, but cannot be considered competitive due to its limited range (Kromer and Haywood 2007: 88). A vehicle with a 200-mile range is substantially more costly and heavier. This will probably remain an issue in the future too.

	<i>Units</i>	<b>100 Miles</b>	<b>200 Miles</b>	<b>400 Miles</b>
<b>Road Load</b>	<i>Wh/mi</i>	220	240	280
<b>Max. DoD<sup>37</sup></b>	<i>%</i>	90%	100%	100%
<b>Battery Energy</b>	<i>kWh</i>	25	48	112
<b>Battery Wt</b>	<i>kg</i>	170	320	750
<b>Vehicle Wt</b>	<i>kg</i>	1300	1620	2260
<b>Battery Cost</b>	<i>\$</i>	\$6,250	\$12,000	\$28,000

Table 10: Vehicle characteristics of electric vehicles with varying electric range. The calculations assume a 150 Wh/kg battery that costs \$250/kWh (Kromer and Haywood 2007: 88).

Apart from cost, another barrier is the limited range. We have found no studies that conclude electric cars can be competitive on range. Although an average driving pattern with a high share of short trips is perfectly suited to EVs, vehicle purchase is usually determined by the maximum needed range, which would rule out EVs (although not PHEVs). Either way, it is clear that driving habits, range requirements and recharging options (off-peak, smart charging, etc.) will have to be explored in demonstration projects and pilot studies.

The cost and range factors outlined are likely to persist until 2030. As such, without a dramatic shift in consumer expectations, the electric vehicle is likely to remain a niche vehicle (Kromer and Haywood 2007: 90).

## 6.2 Savings in fuel costs

The role of fuel taxes is illustrated in table 12. This shows that the purchase of electric cars would offer the most benefit to a German consumer, who could save almost 2,000 EUR in fuels costs annually. But this neglects the fact that private consumers purchase vehicles on the basis of their capital cost rather than running costs (BERR and DfT 2008: ii).

	Battery Cost	Non Battery Incremental Cost	Total Cost	Fuel Efficiency Gain
Micro Hybrid	\$100	\$500	\$600	5% - 10%
Mild Hybrid	\$600	\$1,000	\$1,600	10% - 20%
Full Hybrid	\$1,200	\$1,000	\$2,200	25% - 40%
PHEV	\$6,000	\$2,000	\$8,000	40% - 65%
Electric Vehicle	\$11,000	\$0	* \$11,000	100%

\* = Incremental costs offset by elimination of ICE and other components

Table 11: Costs and potential efficiency gains (Deutsche bank 2008: 10).

	Electricity	US	Gasoline		
			Brazil	UK	Germany
Cost per Gallon / kWh	0.10	4.00	5.95	8.38	9.28
Miles per Gallon / kWh	5	35	35	35	35
Fuel Cost per Mile	0.02	0.11	0.17	0.24	0.27
Battery Depr per Mile	0.08	-	-	-	-
Miles per Year	15,000	15,000	15,000	15,000	15,000
Fuel Cost per Year	1,500	1,714	2,550	3,591	3,977

Source: Deutsche Bank

Table 12: Running costs for electric vs. gasoline cars [dollars] (Deutsche bank 2008: 19).

### 6.3 Cost effectiveness

McKinsey (2009: 12-13) presents the costs and greenhouse gas emission savings for improved powertrain efficiency, aerodynamics and rolling resistance (including weight reduction) in different vehicles:

- Optimised internal combustion engines (ICEs). Technology available today can improve the fuel efficiency of gasoline vehicles by about 39 percent at an additional cost (relative to the cost of an average vehicle without the same technologies) of around €3,000 per vehicle. Changes to diesel vehicles could boost fuel efficiency by 36 percent over current levels at an additional cost of around €2,600 more than today.
- Hybrid-electric vehicles (HEVs). Current hybrid-electric technology can improve vehicle fuel efficiency relative to its conventional equivalent by about 30 percent; add further weight reduction and fuel efficiency could increase by an average of 44 percent. The incremental per-vehicle cost is almost €4,000 today.
- Plug-in hybrid-electric vehicles (PHEVs). PHEV technology combined with other optimised features could yield fuel-efficiency improvements of 65-80 percent in some regions relative to current internal combustion engine (ICE) vehicle performance, although the incremental cost per vehicle would be almost €16,126 today for a vehicle with an electrical driving range of 60 kilometres.
- Electric vehicles. By 2030, EVs could provide well-to-wheel emission reductions of 70 to 85 percent relative to today's ICE vehicles, with virtually zero tail-pipe emissions. With cost reductions for batteries in the range of 5 to 8 percent per year, incremental per-vehicle costs are likely to decline from €36,000 today to €5,800 over the next two decades, for vehicles with a driving range of 160 kilometres. Electric vehicles capable of such distances will remain more costly than their ICE equivalents, suggesting that less costly, lower-range EV derivatives may be more likely to prevail. In addition, infrastructure investments will be required on a large scale to support an electric vehicle fleet of any significance. (McKinsey 2009: 12-13).

According to the study, the first two technologies would be negative-cost: in other words fuel savings more than outweigh technology costs. The latter two technologies would cost 13 and 74 Euros per tonne of CO<sub>2</sub> abated, respectively. These are not extraordinarily high abatement costs, and well within the range of estimates for the external costs of a tonne of CO<sub>2</sub>.

### 6.4 The way forward

This chapter shows that the advanced vehicle concepts, including electric cars, are in

principle not prohibitively expensive for society: initial investment costs are significant but completely or almost completely offset by lower fuel costs.

Both upfront costs and fuel savings are highest for electric cars, and this points to a clear policy dilemma: they are too expensive to be taken up in great numbers, and the very low running costs imply there is a clear danger for a negative rebound effect on transport volumes, i.e. people would drive more.

Specific business models and guarantees to mitigate the cost factor might include battery leasing and paying for distance driven, and warranties to cover the battery pack for the life of the vehicle.

Government policy has an important role to play in this area. Government policies would have to focus on facilitating such business models and open up avenues for the taxation of electricity used by cars. This points to the need for installing meters on board electric cars capable of monitoring consumption. This reinforces earlier remarks on the need of meters in cars to measure the amount and environmental quality of electricity used.

## 7 Electric vehicles and EU policy

This chapter looks into the main strands of EU law that apply, directly or indirectly, to electric cars, as well as the likely impact of EVs and PHEVs in the wider EU environmental law framework.

Conclusions for policymakers can be found at the end of the chapter, in section 7.5.

### 7.1 The Cars and CO<sub>2</sub> Regulation

The cars and CO<sub>2</sub> regulation sets a mandatory average CO<sub>2</sub> emissions target for new passenger cars of 130 g CO<sub>2</sub>/km by 2015 and 95 g CO<sub>2</sub>/km for 2020. As mentioned in Chapter 1, these targets have been instrumental in creating clarity and certainty for carmakers that investment in low carbon technology would pay off.

However the legislation as currently defined contains some counterproductive elements.

Electric cars get a zero CO<sub>2</sub> rating in the regulation, because only tailpipe emissions are counted. A carmaker that sells 1% electric cars in a given year can thus leave the rest of his fleet 1% less efficient and still comply. This is under the assumption that carmakers will try to minimise compliance costs, which becomes more plausible as targets get tougher. The net result for oil use and CO<sub>2</sub> emissions is zero, assuming that electric and conventional cars have similar mileage and EVs do not lead to extra power sector emissions. Under a more realistic assumption (EVs have lower mileage than conventional cars, and power sector emissions are not completely mitigated), the net result of more EV sales is higher oil use and CO<sub>2</sub> emissions.

The regulation also defines so-called 'supercredits' for cars with emissions below 50 g CO<sub>2</sub>/km, allowing manufacturers to count these cars 3.5 times for their overall car fleet in 2012 and 2013. The supercredit is reduced to 1 (i.e. phased out) in 2016. If car manufacturers sell a lot of electric cars, this provision would effectively reduce the level of the CO<sub>2</sub>/km target for the entire fleet of a manufacturer. For example, if under a supercredit regime of 3.5, 1% electric cars were sold, the remaining 99% would only have to meet an average emissions target of 134.6 g/km, instead of 130. Even assuming electric cars are indeed zero emission (assuming the electricity comes from renewables), this would increase average emissions from new cars by 2.5%, to over 133 g/km instead of 130.

The logical result of these loopholes is that a manufacturer that sells one electric car can sell up to 3.5 cars with 260 g/km of CO<sub>2</sub>, i.e. gas guzzling SUVs, and still hit a 130 g/km fleet average target. Even when the supercredits are phased out in 2016, manufacturers that sell one EV, can still sell one gas guzzler with emissions at twice the target level.

The conclusion from this assessment is that the current regulatory framework on cars and CO<sub>2</sub> makes it quite likely that the more EVs are sold, the more oil will be used and the more CO<sub>2</sub> is emitted. This arguably runs counter to the two prime objectives of the law: reduce CO<sub>2</sub> emissions and oil consumption.

## 7.2 The Emissions Trading Scheme

The EU's Emissions Trading Scheme (ETS) is an economic policy instrument designed to control emissions by providing economic incentives for achieving emission reductions. The EU ETS applies at present to over 40% of all greenhouse gas emissions in the 27 EU Member States and has been operating since January 2005. The revised directive adopted as part of the so-called 'climate package' in December 2008 defines a cap on emissions of 21% below 2005 levels by 2020. This target will be reviewed pending the outcome of the international climate negotiations in Copenhagen in December 2009.

CO<sub>2</sub> emissions from electric cars are indirectly covered by the EU ETS through a cap on emissions from the power sector. This means that, in principle, any additional demand for electricity production would have to be met by emission reductions in another sector. In practice, this may not be the case, for two reasons.

The first is that over half of emission reductions may be offset through the Clean Development Mechanism (CDM), which funds emissions savings in developing countries. Additional demand for electricity could thus lead to extra emissions, if this extra demand is met by fossil energy sources and if the emissions are offset through CDM projects.

The second reason is that the ETS cap is only set until 2020, and after this period it will be renegotiated. Extra power sector emissions for electric vehicles might play a role in setting a future cap.

It is sometimes argued that electric cars have zero emissions because electricity falls under the ETS. This section shows this argument is not watertight.

## 7.3 The Renewable Energy Directive

The Renewable Energy Directive, adopted in 2008, sets national renewable energy targets for Member States, based on their current shares of renewables as well as their GDP. The law also sets a specific 10% target for renewables in transport. The transport target has to be met individually by each EU Member State and they can choose to do this either through use of biofuels or renewable electricity in cars and trains. Most of the target will likely be met by biofuels, which are a source of concern, particularly as their indirect impacts are not taken into account. Renewable electricity used in electric cars will count 2.5 times towards the target and as an additional incentive member states can base their claims either on their national or the EU average renewable electricity, whichever is higher.

Because of the way the law is designed, renewable electricity in transport will displace the use of biofuels. Since biofuels under the current regime are more likely to increase than decrease emissions this can be considered to be a positive impact.

For a further explanation of the transport target under the renewable energy directive, see the NGO publication Biofuels: Handle with Care at [www.transportenvironment.org/low-carbon-fuels/](http://www.transportenvironment.org/low-carbon-fuels/).

## 7.4 The Fuel Quality Directive

The revised Fuel Quality Directive (FQD), also adopted in 2008, sets a 10% target to reduce greenhouse gas emissions from transport fuels by 2020 (Article 7a of the directive). Two thirds of this target is mandatory, while 4% is voluntary. From the voluntary part, 2% of the reduction could be met by electric cars and carbon capture and storage<sup>22</sup> technology. Fuel suppliers can meet the target by various measures, such as switching to cleaner crude oil sources, improving extraction of conventional fuels, using biofuels, natural gas or hydrogen and electricity as a road transport fuel.

It seems that any average electricity share used will probably count as reducing greenhouse gas emissions from fuels due to the higher efficiency of electric engines compared to internal combustion engines. But this will only be the case if the well-to-wheel carbon intensity and quantity of electricity in road transport can be adequately measured. For this reason, it is important that adequate metering is ensured through use of a meter inside the electric car. The metering should also measure the carbon intensity of the electricity supplied.

For more details on the FQD, see the T&E briefing at:  
[www.transportenvironment.org/low-carbon-fuels/](http://www.transportenvironment.org/low-carbon-fuels/)

## 7.5 EU policy recommendations

Without a doubt, electric and plug-in hybrid cars can help reduce CO<sub>2</sub> emissions and oil consumption.

EU law, particularly the regulation to reduce CO<sub>2</sub> from cars, has been instrumental in steering car industry investment towards cleaner powertrains. In theory, the EU emissions trading system implies that plug-in electric cars would not increase CO<sub>2</sub> emissions, because the power sector is covered by the scheme.

But those same laws have important flaws. And if they remain unchanged, sales of electric cars will likely lead to higher overall CO<sub>2</sub> emissions and oil consumption. That may be counterintuitive, but it is nevertheless true.

Electrification of the transport sector is an opportunity. It would be highly unfortunate if electric cars become just another missed opportunity like the failure of biofuels and hydrogen before. That is entirely possible. But it can be avoided.

Below we highlight three aspects of EU legislation that will need to be changed if electric cars are to be a success. This is a starting point, not the end of the story.

### CO<sub>2</sub> standards for cars should be tightened

The most secure way to make electrification of transport a reality is to significantly tighten long-term CO<sub>2</sub> standards for cars to 80 g/km by 2020 and 60 g/km by 2025, and to ramp up fuel taxes. This gives the industry the required long-term security for investments in low-carbon car technology and infrastructure. Focusing on fostering electric cars without tightening CO<sub>2</sub> standards will be self-defeating as it takes away the main incentive for industry to invest in making electrification a reality.

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<sup>22</sup> [http://en.wikipedia.org/wiki/Carbon\\_capture\\_and\\_storage](http://en.wikipedia.org/wiki/Carbon_capture_and_storage)



Zero-CO<sub>2</sub> rating and supercredits for electric cars must be abolished; electric cars should be rewarded for their energy efficiency, not for moving emissions from exhaust pipes to powerstation chimneys.

### **Quantity and quality of electricity used in electric cars must be measured**

On-board metering of the quantity and quality of electricity is likely to be a critical boundary condition to manage and regulate demand and quality of electricity delivered to electric vehicles.

### **The power sector has to be decarbonised**

Existing loopholes in the ETS need to be closed and the cap further tightened, strong post-2020 targets for renewable energy in the power sector could be pursued along with emissions performance standards for power stations.

**Commission President Barroso has pledged to pursue decarbonisation of the transport sector, with an important role for electrification of transport. Therefore, further initiatives from the Commission regarding standardisation, building of infrastructure and type approval of electric vehicles can be expected. This report outlines some of the elementary principles of such a package.**

**There is a tremendous opportunity to make electrification of transport work for the environment. It should not be missed.**

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