Department of Transport
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# Forecast Uptake and Economic Evaluation of Electric Vehicles in Victoria

Final Report

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Prepared for

Department of Transport

Prepared by

**AECOM Australia Pty Ltd**
Level 9, 8 Exhibition Street, Melbourne VIC 3000, Australia
T +61 3 9653 1234 F +61 3 9654 7117 www.aecom.com
ABN 20 093 846 925

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# Executive Summary

There is a growing awareness of the urgent need for governments to address the potentially significant benefits of electric vehicle (EV) technologies. Current trends in energy supply and use are economically, environmentally and socially unsustainable in the longer term.

EV technology offers Victoria potentially significant economic benefits by the late 2020s. However, such economic benefits could be realised earlier through effective policies which:

- reduce first mover costs in the short term; and
- promote rapid take-up once non-ICE vehicle price premiums reduce to levels that make them affordable to most consumers.

Therefore, opportunities exist for policy makers in Victoria to use the Department of Transport's Electric Vehicle Trial to develop future policies which could assist with EV technology market penetration. To ensure the successful take up of EV technologies in Victoria, the Government, automotive industry, electric utilities and other stakeholders should work together to formulate common goals.

Reducing EV purchase costs in the short term through research and development (R&D) investment is critical for market entry and acceptance of EV technology. Industry also has an important role to play here in focusing R&D effort on addressing resource issues and establishing secure supply chains. Policy makers have the opportunity to develop policies that stimulate R&D and technology innovation aimed at reducing production costs and increasing supply of new technology. Such supply policies are mostly beneficial in early stages of innovation processes during the R&D stages.

Public awareness campaigns for consumers can be used to address informational barriers about energy efficient technologies. Consumer willingness to change behaviours and accept different types of vehicles (and perhaps driving patterns) will be an area of uncertainty and one that industry can play a significant role in assisting to address.

*Implications for Policy Makers*

AECOM's analysis indicates that even without government action, within 10 to 15 years, non-ICE vehicles will achieve a significant presence in all segments of the Victorian vehicle market, with a significant role for PHEVs and EVs, particularly in later years as vehicle prices fall and infrastructure availability increases. Between 2025 and 2030, the accumulated economic impact of this transition will provide a positive economic benefit, even when future financial and environmental savings are discounted.

The results of this study are necessarily qualified by the accuracy of the input data – in particular data in relation to the main drivers of consumer preference. The Victorian Electric Vehicle Trial presents a significant opportunity by which to collate a more robust data on revealed consumer preferences, which over time could enhance the accuracy of the modelling.

In analysing the costs and benefits, there is considerable uncertainty around the future path of key variables; in particular fuel and technology costs. Sensitivity testing reveals that the outcomes are highly sensitive to the price of oil, the rate at which the price of non-ICE vehicles declines to become on a par with conventional ICE vehicles, and supply constraints. Whilst unremarkable in themselves, these results suggest areas for further analysis within five years as electric vehicles become commercially available; either to refine the data or to analyse policy interventions by which real-world conditions might be altered.

Finally, the analysis reveals that the key variables affecting the rate and timing of this transition are:

- The capital costs associated with vehicle purchase, in relation to the costs for conventional ICE vehicles;
- The effect of world oil prices upon fuel prices for ICE vehicles;
- Supply constraints in the Australian market (world manufacturing capacity, and supply of imported vehicles to Australia as opposed to other countries); and
- The provision of charging infrastructure in the medium term to support EVs.

The first variable is unlikely to be impacted by the decisions of Australian policy makers, notwithstanding the support given to Toyota for the production of hybrid vehicles under the former Green Car Innovation Fund.

Arguably the latter three variables could be addressed effectively by government. Whilst Government's cannot easily influence world oil prices, they can reduce consumer's reliance on them and hence exposure to price fluctuations. Further analysis may be warranted to probe the costs and benefits of any such action. However, the significance of price premiums in influencing consumer choice suggests that price parity may constitute a "tipping point"; a necessary prerequisite for the large scale deployment of non-ICE vehicles. Interventions to support the deployment of non-conventional vehicles should be cognisant of this possibility, and care taken to optimise the timing of any intervention.

**Introduction**

In recent years, electric vehicles (EVs) and plug in hybrid electric vehicles (PHEVs) have enjoyed significant interest, with most major vehicle manufacturers announcing their intention to release electric models within the next few years. Building on strong demand for hybrid electric vehicles (HEVs), it seems likely that demand for these emerging vehicle technologies will increase rapidly, albeit off a very low base.

Popular interest in these technologies has built on concern about the impacts of climate change and to a lesser extent, air pollution. It has also been driven by increasing awareness that rising oil prices may significantly increase the operational costs of vehicles powered by a conventional internal combustion engine (ICE), and hence many people are attracted to vehicles with reduced running costs. However, notwithstanding strong interest, overall rates of penetration for non-ICE vehicles are low, and greenhouse gas emissions from transport continue to comprise a significant component of the Australian inventory.

Australian communities and their governments are grappling with the task of reducing greenhouse gas emissions from the transport sector; including consideration of the respective roles of government, consumers and industry in supporting the introduction of new vehicle technologies.

For each individual technology, the question arises *"What is the appropriate role for government in supporting new technologies, and what can most effectively be accomplished by the private sector"?*

The Victorian Government has committed $5 million over five years towards increasing the use of low emission vehicles, to help Victoria understand the process, timelines and barriers for moving to electric vehicle technologies.

The analysis in this report was commissioned by the Victorian Department of Transport to contribute to this aim by modelling the likely penetration of electric vehicles (including hybrid vehicles, plug-in hybrid electric vehicles and electric vehicles) under various scenarios, in the absence of significant government policy interventions.

The analysis itself does not produce recommendations for government policy action. However, by testing different scenarios, and the sensitivity of the model to particular factors, the analysis reveals areas where intervention may be warranted; namely:

- The capital costs associated with vehicle purchase, in relation to the costs for conventional vehicles;
- Supply constraints in the Australian market; and
- The provision of charging infrastructure.

The analysis also provides some indications of the likely timelines for uptake of electric vehicles in the Victorian market; which in turn may assist in identifying timelines for government intervention and support.

Finally, the analysis confirms intuitive findings that through the avoidance of greenhouse gas emissions and air pollution, and the reduced fuel costs associated with shifting from fossil fuels to electricity, the cumulative effect of the uptake of electric vehicles is likely to produce a net economic benefit to society from as early as 2026, and no later than 2031.

### The model

This study builds on similar work undertaken by AECOM in 2009 for the NSW Department of Environment, Climate Change and Water. As part of the 2009 NSW study, AECOM developed an economic model to assess the economic viability of plug-in electric vehicles (both pure electric vehicles as well as plug-in hybrid electric vehicles) for the NSW metropolitan passenger vehicle, light commercial vehicle and taxi markets.

AECOM's model includes unique features which provide nuanced insight into the drivers for take-up of electric vehicles and overall economic benefits of such a shift. In particular, AECOM's model directly calculates likely take-up rates using known data about the relative importance of different criteria in shaping consumer vehicle purchasing decisions. The benefit of this approach is two-fold. Firstly, it avoids use of assumptions about take-up of vehicles based on past behaviour; as this is a new market, there is minimal information on past experience from which to draw meaningful assumptions about the future of electric vehicles in Australia. Secondly, by directly estimating take-up, it is possible to consider the impact of various potential sensitivities around prices (electricity price, fuel price, vehicle price) and how these affect take-up.

In developing the model, AECOM undertook original research to generate data inputs for the model, including:

- Undertaking a global survey of EV and HEV models to determine premiums when compared to an equivalent ICE vehicle;
- Consulting with industry in relation to likely supply constraints between now and 2020;
- Estimating fuel costs per kilometre for each vehicle class-based on assessments about improvements in efficiency of both conventional and electric vehicles in the period;
- Estimating the costs of additional infrastructure to allow high speed (Level 2) household charging; and
- Analysing the overall likely annual demand for vehicles.

In applying the model for this study, AECOM further refined data inputs by undertaking extensive consultation with industry, as well as incorporating Victorian specific data where available.

### Analysis and Key Findings

*The scenarios*

The analysis considers three scenarios against a base case. The characteristics of these four scenarios are described below:

- **Base Case** - assumes there are only Internal Combustion Engines (ICEs) and Hybrid Electric Vehicles (HEVs) available, with no Plug-in Hybrid Electric Vehicles (PHEVs) or pure Electric Vehicles (EVs).
- **Scenario 1** - assumes there is Level 1 household charging. Level 1 charging only requires a standard power outlet.
- **Scenario 2** - assumes there is Level 1 and Level 2 household charging, and Level 2 public charging in the Victorian Metropolitan region. Level 2 charging requires a charging interface to be wired into a building's electricity supply to provide the necessary protections from higher voltages.
- **Scenario 3** - assumes there is Level 1 and Level 2 household charging, Level 2 public charging in the Victorian Metropolitan Region and electric vehicle service stations that offer quick charge or battery replacement.

The analysis also differentiates between vehicles on the basis of size (small, medium and large), distance travelled (high, medium and low), and vehicle type (passenger, light commercial, or taxi).

*What will consumers purchase?: Vehicle Choice Results*

The vehicle choice model forecasts the proportion of market share for new vehicle sales for each of the different vehicle types (ICEs, EVs, PHEVs and HEVs). The analysis is based on central forecasts of oil price, electricity price and CPRS/carbon tax policy, and known information about the historic drivers for consumers in the vehicle market.

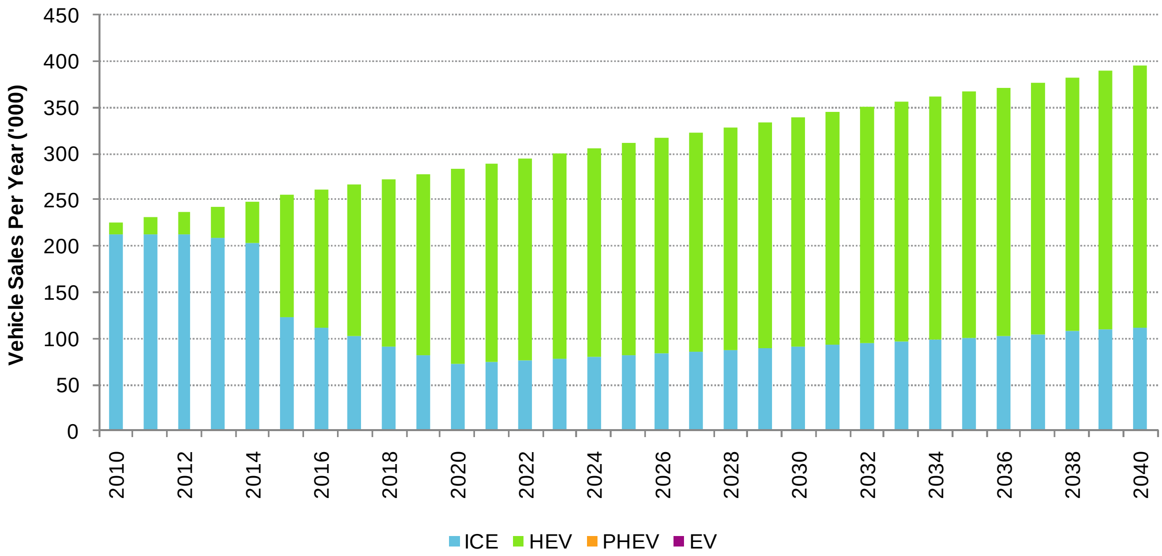
The forecast for annual vehicle sales for the Base Case are shown in **Figure E1**. There are no sales of PHEVs or EVs under the Base Case. The sale of HEVs grows gradually to 2014 then increases rapidly following the removal of the supply constraint in 2015 and the convergence of HEV purchase prices to that of an ICE vehicle in 2020.

Under Scenario 1, PHEVs and EVs are introduced into the market in 2012 and make up a small share of new vehicle sales until 2020 (see **Figure E2**). When supply becomes unconstrained in 2020 there are increased sales of PHEVs, however EVs remain a relatively small proportion under this scenario as charging facilities are restricted to household only.

Vehicle sales under Scenario 2 are shown in **Figure E3**. The results are similar to those under Scenario 1, however sales of PHEVs and EVs are stronger due to the improved provision of charging infrastructure and post-2025, following price parity with ICE vehicles occurring.

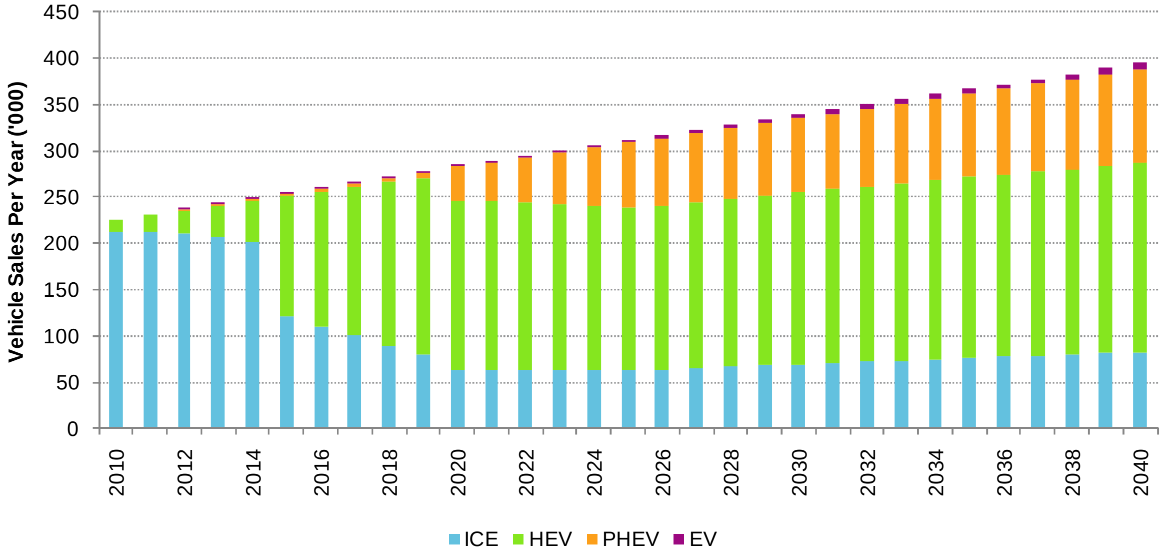
Under Scenario 3, the trends exhibited under Scenario 2 are further enhanced with the introduction of commercial charging stations, as shown in **Figure E4**. PHEVs and EVs gradually become the dominant engine configuration in the mid-2020s as prices converge with ICE vehicles. The share of HEVs declines dramatically as PHEVs grow to hold the largest share of sales by the mid-2020s. PHEVs remain the largest proportion of sales in 2040 however EVs represent an increasing proportion of sales of approximately 20% by 2040.

**Figure E1 Vehicle sales per year in Base Case**



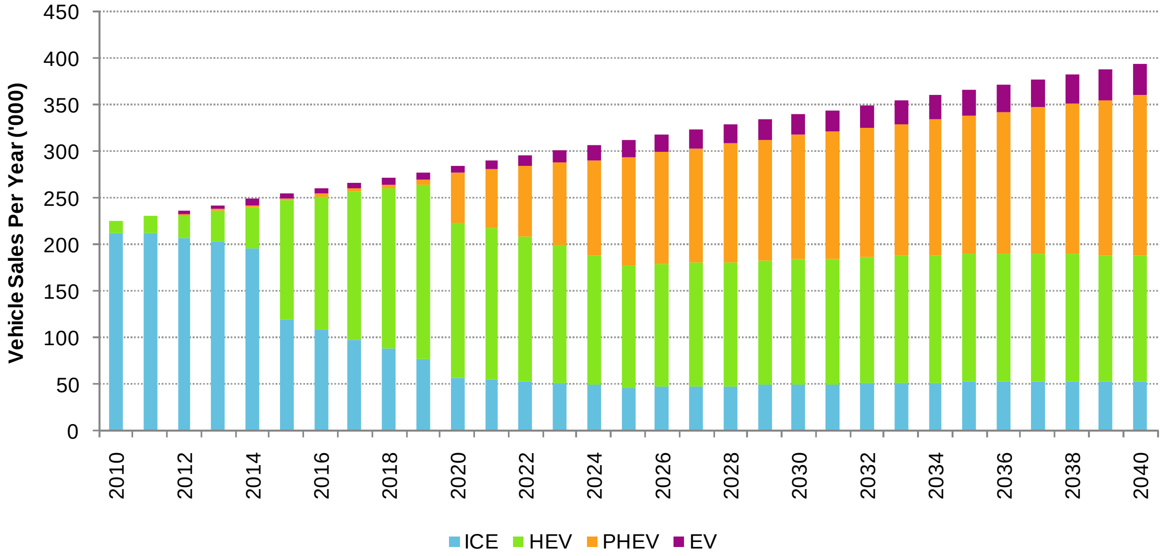

Source: AECOM

**Figure E2 Vehicle sales per year in Scenario 1**



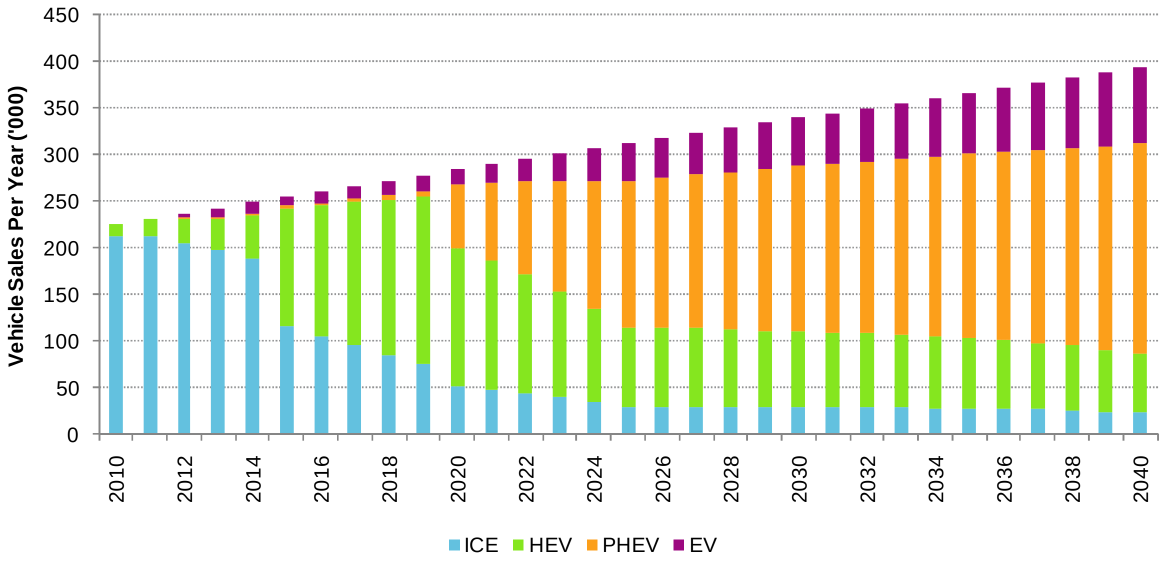

Source: AECOM

**Figure E3 Vehicle sales per year in Scenario 2**




Source: AECOM

**Figure E4 Vehicle sales per year in Scenario 3**




Source: AECOM

In all scenarios (except the base case) the take-up of PHEVs is stronger than that of EVs in the early years due to superior range and the ability to use both electricity and petrol as a fuel. However, in later years there is a shift towards EVs as purchase prices converge to parity with ICE, battery improvements result in increased vehicle range and higher fuel prices make EVs more competitive. In all scenarios (except the base case) the penetration of electric vehicles increases as the availability of charging infrastructure increases.

In summary, the vehicle choice model suggests:

- A transition to HEVs in the near term (5-10 years); PHEVs over the medium to long term (10-20 years) and EVs over the long term (15 years plus).
- Take-up of PHEVs and EVs is sensitive to the year in which parity with ICE vehicles is achieved and any supply constraints into the Australia market.
- The provision of charging infrastructure (both public charging units and commercial stations) as represented through the different scenarios, has a significant impact on the sales of EVs.
- There are increased sales of HEVs in the near term. This occurs as supply becomes unconstrained and there is no requirement for charging infrastructure, and importantly, prices are expected to converge to values similar to those of ICE vehicles as early as 2020. However, as EV and PHEV prices gradually reach parity, vehicle range improves and more charging infrastructure becomes available, larger vehicles and vehicles that travel large distances tend to purchase a higher proportion of EVs. This is primarily due to increased operating costs (as global oil prices rise) inducing these vehicle owners to switch to more efficient technologies to achieve fuel cost savings.

*A net positive over time: Economic and Financial Analysis*

AECOM's economic and financial analysis utilises the results from each scenario considered in the vehicle choice model. We consider the overall costs and benefits to the community under each scenario when compared to the base case, as well as assessing the sensitivity of results to changed assumptions. The analysis is cumulative, and discounts both future costs and benefits, on the premise that costs and benefits which accrue in the distant future should be valued less than costs and benefits which accrue in the present or near future. The analysis also values externalities, such as the avoided costs of air pollution and greenhouse gas emissions.

Significantly, under all scenarios, the electric vehicle market is both economically and financially strong in the long run. The net present value becomes positive after 2031 in all scenarios (at a discount rate of 5% real pre-tax). Over a 30-year evaluation period, the economic benefits range from $1.8 billion in Scenario 1 to $23.4 billion in

Scenario 3. This is largely driven by decreasing vehicle purchase costs of non-ICE vehicles, at the same time as operating cost savings increase. In addition there are large savings in greenhouse gas and air pollution emissions.

The net benefits increase with the level of charging infrastructure, as this increases the take-up of EVs. Higher levels of charging infrastructure also bring forward the breakeven year.

**Table E1 Present value of benefits incremental to the Base Case**

| | Scenario 1 | | | Scenario 2 | | | Scenario 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| NPV ($m) | to 2020 | to 2030 | to 2040 | to 2020 | to 2030 | to 2040 | to 2020 | to 2030 | to 2040 |
| Financial benefits | | | | | | | | | |
| Vehicle purchase | -$550 | -$1,110 | -$1,170 | -$1,170 | -$2,570 | -$2,960 | -$1,940 | -$4,050 | -$4,630 |
| Vehicle operation | $90 | $870 | $2,490 | $410 | $4,090 | $12,070 | $860 | $7,810 | $22,250 |
| Charging infrastructure^ | $0 | $0 | $0 | $0 | $10 | $80 | -$80 | -$70 | $640 |
| *Subtotal* | -$460 | -$250 | $1,320 | -$770 | $1,530 | $9,180 | -$1,160 | $3,690 | $18,260 |
| Externalities | | | | | | | | | |
| GHG emissions | $0 | $10 | $50 | $10 | $60 | $240 | $20 | $140 | $500 |
| Air pollution | $20 | $170 | $480 | $90 | $820 | $2,340 | $200 | $1,680 | $4,600 |
| **Economic benefits** | -$430 | -$60 | $1,850 | -$670 | $2,420 | $11,760 | -$940 | $5,520 | $23,350 |
| Breakeven year | 2031 | | | 2027 | | | 2026 | | |

Source: AECOM. Note: Based on central forecasts of oil price, electricity price, carbon tax/CPRS policy and shadow cost of carbon. All values are discounted to 2010 at 5%, and are rounded to the nearest $10m.
^ Net charging infrastructure is capital cost of charging infrastructure less the premium that customers pay to cover cost of infrastructure.
† Includes GHG emissions from vehicles and electricity generation.

The sensitivity analysis identifies significant issues for policy makers in relation to vehicle prices, fuel prices and discount rates. In particular:

- In the short- to medium term, the level of take-up (and consequential economic benefits) of non-ICE vehicles is highly influenced by the price of these vehicles relative to ICE vehicles. Measures to reduce costs in the short term result in economic benefits being realised earlier.
- Take-up of EVs and PHEVs is sensitive to oil prices, but less so to electricity prices and the carbon tax/CPRS. Should oil prices rise beyond forecasts, then measures to increase the uptake of EVs will produce economic benefits.
- Increasing the availability of charging infrastructure and reducing the ICE captive markets (i.e. reducing barriers to ownership) will encourage take-up of electric vehicles when prices become more affordable and bring forward economic benefits.

# 1.0 Introduction

## 1.1 Project context

Electric vehicle technology is likely to play an important role in the future of motor vehicles in Australia. Electric vehicle variants may, depending on how electricity is generated, cut greenhouse gas emissions and air pollution, while reducing Australia's oil import dependency and exposure to crude oil prices.

In 2009, AECOM undertook a study on the economic viability of electric vehicles in metropolitan NSW for the NSW Department of Environment, Climate Change and Water (AECOM, 2009). The aim of the study was to identify market and economic conditions under which such vehicles provide a net benefit to society. The study involved the development of a vehicle choice model that was used to estimate the take-up of electric vehicles under different infrastructure scenarios for the passenger vehicle, light commercial vehicle and taxi markets.

In February 2010, AECOM was commissioned by the Victorian Department of Transport to undertake a study that builds on the NSW electric vehicle study for application in the Victorian context. Therefore this study should be read in the context of the 2009 NSW report, a copy of which can be found on the following link http://tinyurl.com/NSWElectricVehiclesReport. As a number of assumptions made for the NSW report have been updated with Victorian-specific values or with more up-to-date information, the results of this study are not directly comparable with those found in the NSW report.

## 1.2 Objectives

The overall objectives of this study are to:

- Understand how different factors such as vehicle prices, fuel prices and charging infrastructure affect take-up of electric vehicles; and
- Test the impact of various policies on electric vehicle take-up and the resulting economic and financial costs and benefits.

## 1.3 Study area

The study area is defined as "Metropolitan Victoria" which includes the Melbourne Statistical Division and regional centres such as Geelong, Ballarat, Bendigo, Shepparton and the La Trobe Valley. As a result, all rural areas are excluded from the analysis.

## 1.4 Engine configurations

As well as the standard internal combustion engine (ICE) vehicle, this report focuses on three alternate engine configuration types, each of which are described in **Table 1**.

**Table 1 Engine configurations**

| Configuration | Description |
|---|---|
| Hybrid electric vehicles (HEV) | Hybrid electric vehicles combine both an internal combustion engine with an electric engine, with electrical energy stored in batteries. Vehicle propulsion is a mix of the ICE and electric powertrains typically dependent on vehicle speed (urban/non-urban use). Hybrids are more fuel efficient than regular ICE vehicles as they take advantage of the complementary power generating characteristics of the two technologies. |
| Plug-in hybrid electric vehicles (PHEV) | Plug-in hybrids (PHEVs) are similar to regular hybrids in that they combine the use of combustion and electric motors, however PHEVs are capable of being recharged by plugging in to the electricity grid. Charging can be achieved through a conventional household wall socket and at charging stations similar to existing petrol stations.<br><br>The batteries in a PHEV are typically larger than those in a hybrid leading to a greater all-electric range that is sufficient for average metropolitan use. The trade off for larger batteries and greater range is increased battery cost, size and weight. The ICE is used to extend driving range beyond battery capacity for longer distances and to recharge the battery itself. |
| Electric vehicles (EV) | Pure electric vehicles are powered only by electricity stored in batteries. EVs face similar limitations as hybrids and PHEVs due to the need for batteries. In EVs, battery shortcomings are highlighted as there is no ICE to boost range and acceleration, for example. To increase range, more or larger batteries are required with costs and weight also increasing. Improvements in battery technology will gradually address these issues. |

Source: AECOM

## 1.5 Report structure

The remainder of the report is structured as follows:

**Chapter 2.0** describes AECOM's methodology.

**Chapter 3.0** presents the results of the vehicle choice model.

**Chapter 4.0** presents air pollution and greenhouse gas emissions externality results.

**Chapter 5.0** presents the economic and financial results.

**References** lists sources cited in this report.

**Appendix A** summarises the outcomes of the industry consultation.

**Appendix B** presents further detail on the vehicle choice model.

## 1.6 Acronyms

| | |
|---|---|
| A | Ampere |
| $CO_2$-e | Carbon dioxide equivalent |
| CPRS | Carbon pollution reduction scheme |
| EV | Pure electric vehicle |
| EVSE | Electric Vehicle Supply Equipment |
| GST | Goods and Services Tax |
| HEV | Hybrid electric vehicle |
| ICE | Internal combustion engine |
| kW | Kilowatt |
| kWh | Kilowatt-hour |

| | |
|---|---|
| LCV | Light commercial vehicle |
| LPG | Liquefied petroleum gas |
| MWh | Megawatt hour |
| PHEV | Plug-in hybrid electric vehicle |
| V | Volt |
| VKT | Vehicle kilometres travelled |

# 2.0 Methodology

This chapter sets out the methodology and assumptions used to forecast the take-up of vehicles, and conduct the cost benefit analysis to assess economic and financial viability. The methodology is equivalent to that developed by AECOM for application in the NSW context (AECOM, 2009). Where necessary, input assumptions were updated to equivalent Victorian values. Furthermore, to inform the update of the model, AECOM consulted with industry experts to seek comment on the robustness of key assumptions. The results of the consultation are presented in **Appendix A**.

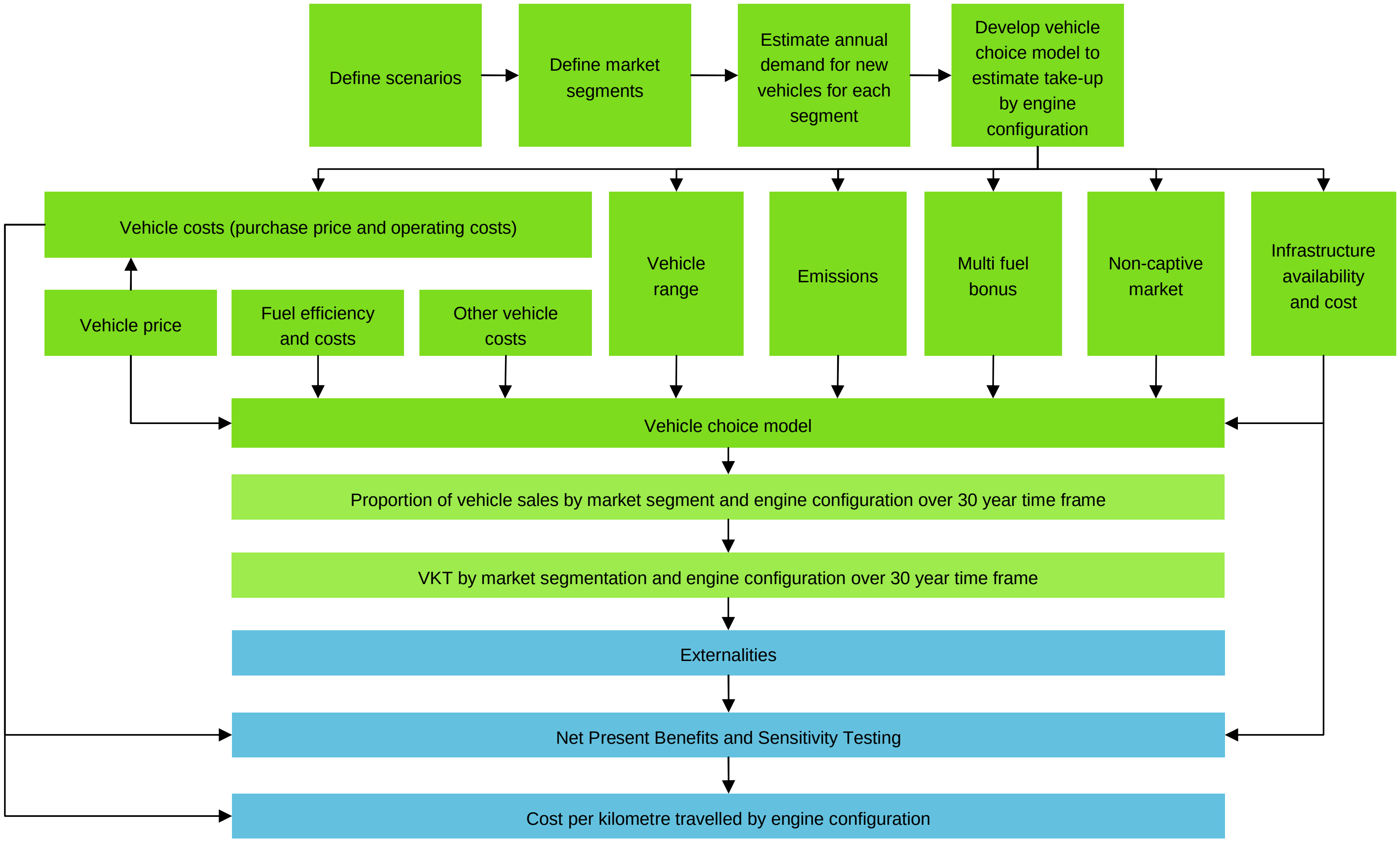
**Figure 1** provides an overview of the AECOM methodology. Each of these steps is discussed in more detail below.

## 2.1 Key assumptions and parameters

The key parameters used throughout this study are defined below:

| | |
|---|---|
| **Economic and Financial Evaluation** | This study includes both an economic and a financial evaluation.<br>The economic evaluation considers the project from a society wide perspective and considers all of the costs and benefits including some effects that are not quantified in monetary terms such as greenhouse gas emissions and air pollution.<br>The financial evaluation concentrates on the costs and benefits which accrue within the market, including to consumers of vehicles and the vehicle industry. |
| **Discount rate (for economic appraisal)** | A 5% per annum real discount rate is adopted in the evaluation to calculate present values. This study also undertakes sensitivity tests at the discount rates of 3.2% and 10.2% (representing a risk-free and a high-risk premium rate respectively) |
| **Discount rate (for financial appraisal)** | A 5% per annum real discount rate is adopted in the evaluation to calculate present values. This study also undertakes sensitivity tests at the discount rates of 3.2% and 10.2% (representing a risk-free and a high-risk premium rate respectively). |
| **Price Year** | All costs and benefits in the evaluation are presented in 2010 constant prices. |
| **Evaluation period** | An evaluation period of 30 years will be applied to this study. The electric vehicle market is expected to see significant changes (in terms of technology, prices and take-up) over the next 30 years. Due to this long time frame anything less than 30 years may not provide meaningful results. 30 years is also the standard timeframe for evaluation of transport infrastructure projects (DOT, 2010). |

**Figure 1 Overview of methodology**



## 2.2 Scenario specification

Many studies do not estimate take-up of different engine configurations and instead make assumptions based on experience elsewhere. This study has decided to directly estimate take-up for two reasons. Firstly, as this is a new market there is minimal information on past experience from which to draw meaningful assumptions about the future of electric vehicles in Australia. Secondly, by directly estimating take-up it will be possible to consider the impact of various potential sensitivities around prices (electricity price, fuel price, vehicle price) and how these affect take-up.

The model has been built to allow flexibility and sensitivity testing around the key variables. As such, the scenarios are focused around the different levels of infrastructure that may be required to facilitate the electric vehicle market. The level of infrastructure will affect the demand for take-up of electric vehicles through prices and ease of charging. It will also be a significant factor in the cost side of the cost benefit analysis.

The charging requirements of electric vehicles will vary depending on a number of factors including the size of the battery, how depleted it is, and the rating for the charging circuit. As such, it is best to think about battery recharging times in terms of “miles-per-minute”.

### 2.2.1 Charging levels

Recharging of EVs or PHEVs will require approx 0.15-0.25 kWh per km depending upon vehicle size and powertrain efficiency. These figures vary depending on the size or weight of the vehicle, as well as its powertrain efficiency and charging circuit topology.

Electric vehicles have an on-board charger to convert AC mains supply into DC power to charge the battery. However, off-vehicle charging stations are also becoming available. In these stations, the AC to DC conversion is undertaken in a dedicated unit and will allow much faster charging as higher electrical currents can be delivered safely.

Standards for electric vehicle charging have not yet been established within Australia and indeed are still under development worldwide. The only EV available on sale in Australia at present, the Blade Electron, uses a standard 240V/10A household plug/socket to charge. In the UK, the Mitsubishi i-MiEV also uses a standard 240V/13A household plug/socket to charge. However, charging at higher currents (to allow faster charging) within the home is likely to require special plugs, sockets and charging interfaces to be installed for safety protection.

In the US and European Union, tiered levels of charging capability have been developed for industry to harmonise around. As it is not yet known which standard will be adopted in Australia, AECOM have undertaken consultation with industry as well as having reviewed the proposed standards in the US (SAE J1772) and European Union (IEC 62196) and charging equipment already available or under development. For this study, the following charging levels have been adopted, as shown in **Table 2**.

- **Level 1** charging only requires a standard power outlet[1], since all charging electronics required to support Level 1 can be carried on board the vehicle.
- **Level 2** charging uses a vehicle’s on-board charging system, but draws higher power for faster charging. This will require a “charging interface” known as Electric Vehicle Supply Equipment (EVSE) to be hard wired into a building’s electricity supply to provide necessary protections from the higher voltages/currents. Some household chargers have interfaces which are compatible with smart metering (thus controlling the power delivered to the vehicle at certain times of day). Level 2 charging points will be available in public places as well as in the home, but only if the appropriate equipment has been installed by an electrician.
- **Level 3** charging involves fast-charging using off-board charging equipment to provide DC current directly to the battery. The power rating of such chargers (50 to 250kW) will greatly exceed the capabilities of typical residential (and in many cases, commercial) circuits and therefore will not occur at home. It will most-likely only be performed in purpose-built commercial or industrial facilities.

[1] In Australia, standard household sockets are only rated to 10A. Sockets rated to 15A are available (as used for high powered devices such as air conditioners) but would require installation by a qualified electrician.

**Table 2 Charging levels**

| Level | Circuit Rating | Power consumption (from mains supply) (kW) | Charging Rate (km/min) | Charge Time for 40km (mins) |
|---|---|---|---|---|
| Level 1 | 240V AC (single phase) 10 -15A | 2.4 to 3.6 | 0.2 to 0.3 | 133 to 200 |
| Level 2 | 240V AC (single phase) 32A[2] | 7.7 | 1.6 | 63 |
| Level 3 | 415V AC (3-phase) 125 - 330A<br><br>(Output 400-700V DC, 125 to 550A) | 50 to 250 | 4.2 to 21 | 2 to 10 |

Source: AECOM and Dr. Andrew Simpson

Further detail on the charging infrastructure used for this study is given in **Section 2.14.2**.

### 2.2.2 Base Case

The Base Case is the scenario against which the other scenarios will be compared. The base case will assume there are only internal combustion engines (ICEs) and hybrid electric vehicles (HEVs) available and no plug-in hybrid electric vehicles (PHEVs) or pure electric vehicles (EVs).

### 2.2.3 Scenario 1

Scenario 1 assumes that there is Level 1 household charging only.

### 2.2.4 Scenario 2

Scenario 2 assumes that there is Level 1 and Level 2 household charging (it is possible to switch between a slow and fast charge) and Level 2 public charging available within the Victorian metropolitan region. Public charging at this level typically takes place in car parks, hotels, shopping centres, street parking. Level 1 public charging is available in California and many cities in Europe, as highlighted by **Figure 2**. Consensus has generally been reached in North American and Europe on Level 2 charging standards, and so there are likely to be developments in relation to Level 2 infrastructure in the near future.

[2] It is possible that Level 2 charging will require 3-phase which would require upgrades to the household service and possibly the street.

**Figure 2 Public charging facilities**

**(a) California** **(b) NCP car park, London**


Source: Zoomilife, sourced 1 June 2009

### 2.2.5 Scenario 3

Scenario 3 assumes that there is Level 1 and Level 2 household charging (it is possible to switch between a slow and fast charge), Level 2 public charging available within the Victorian metropolitan region and electric vehicle service stations that offer Level 3 DC quick charge or battery replacement.

Whilst electric vehicle service stations are not currently available, many companies are indicating they plan to move into this space:

- EVOASIS, an American firm, recently announced plans to convert abandoned petrol stations in London to electric charging stations for EVs (see **Figure 3**).
- In May 2009, the first public high voltage charging station for electric vehicles was installed at the Gateway Center in East Woodland California.
- Better Place recently demonstrated a battery swap station in Japan, but are yet to proceed with their commercial deployment.
- In May 2010, Nissan introduced a Quick EV charger to be supplied to its EV dealers, providing 50kW DC output power.

**Figure 3 Proposed charging stations in London**

Source: Zoomilife, sourced 1 June 2009

The different scenarios are summarised in **Table 3**.

**Table 3 Scenarios**

| Scenario | Base Case | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|---|
| Household charging | No | Level 1 | Level 1 and 2 | Level 1 and 2 |
| Public charging unit | No | No | Yes | Yes |
| Electric vehicle charging station | No | No | No | Yes |

The differing charging regimes affect the model in the following ways:

- Electricity prices to EV and PHEV users (the proportion of electricity which is drawn from the home or public charging facilities) (described in **Section 2.8.2**);
- The proportion of the market who may purchase and EV or PHEV (Described in **Section 2.13**); and
- Capital costs of equipment (to infrastructure providers and consumers) (described in **Section 2.14**);
- The availability of charging infrastructure relative to petrol stations (a parameter within the vehicle choice model) (Described in **Section 2.14**).

## 2.3 Market segmentation

### 2.3.1 Define study area

The study area is defined as “Metropolitan Victoria” which includes the Melbourne Statistical Division and regional centres such as Geelong, Ballarat, Bendigo, Shepparton and the La Trobe Valley. As a result, all rural areas are excluded from the analysis.

### 2.3.2 Define market segmentations

The model to assess the cost and benefits of electric vehicle take-up needs to balance practicability and accuracy. In order to ensure accuracy, a number of different market segments have been defined. **Table 4** summarises the 11 different segments. For simplicity, the vehicle market is segmented according to:

- Vehicle type – passenger, light commercial vehicle or taxi;
- Vehicle size – small, medium or large; and
- Distance travelled – low, medium or high vehicle kilometres travelled (VKT).

Engine sizes and VKT ranges are only distinguished for passenger vehicles and not distinguished for light commercial vehicles or taxis. This is considered reasonable as the VKT distribution for these types of vehicles is assumed to be more narrowly grouped around the average. For example, taxis are generally used around the clock. Moreover, engine size variations are not expected to be as significant for light commercial vehicles and taxis as they are for passenger cars. In addition, the number of vehicles in these categories is considerably smaller than in the passenger car category.

**Table 4 Market segments**

| Segment | Vehicle type | Vehicle size | VKT |
|---|---|---|---|
| 1 | Passenger | Small | Low |
| 2 | Passenger | Small | Medium |
| 3 | Passenger | Small | High |
| 4 | Passenger | Medium | Low |
| 5 | Passenger | Medium | Medium |
| 6 | Passenger | Medium | High |
| 7 | Passenger | Large | Low |
| 8 | Passenger | Large | Medium |
| 9 | Passenger | Large | High |
| 10 | LCV | N/A | N/A |
| 11 | Taxi | N/A | N/A |

#### Vehicle size

For passenger cars, vehicles are distinguished according to size. Vehicle size is an important category to consider as it will impact on the potential externality emissions. Also, there are likely to be variations in the availability of PHEVs and EVs depending on vehicle size as well as different market take-up between different sized vehicles.

Three engine sizes are distinguished based on FCAI segmentation criteria[3]:

- Small – light passenger, small passenger and compact sports utility vehicle (SUV);
- Medium – medium passenger and medium SUV; and
- Large – large passenger, upper large passenger, people movers, large SUV and luxury SUV.

#### Distance travelled

Passenger vehicles have also been distinguished by the average vehicle kilometres travelled. This is an important factor as the expected VKT, and hence fuel efficiencies, will influence the financial viability of buying different types of vehicles. Data from the Department of Transport VISTA database was used to assess the distribution of VKT for each vehicle size. As a result, average daily vehicle kilometres travelled for passenger vehicles are distinguished as:

- Low – 1 to 20 km ;
- Medium – 21 to 60 km; and
- High – above 61 km.

### 2.3.3 Define engine configuration

In addition to the market segmentation according to vehicle type, size and VKT, different types of engine configurations are distinguished, namely:

- Internal combustion engines (ICE) consuming fuels such as petrol, diesel, and LPG;
- Hybrid electric vehicles (HEV);
- Plug-in hybrid electric vehicles (PHEV); and
- Pure electric vehicles (EV).

[3] FCAI, Segmentation Criteria, available at: http://www.fcai.com.au/sales/segmentation-criteria

## 2.4 Estimate annual demand for new vehicles

Estimates of new vehicle demand are based on historical vehicle sales for each vehicle type as set out in this section. It is assumed that the decision of whether or not to buy a car is independent of the available engine configuration technologies.

### 2.4.1 Passenger cars

Demand for new passenger vehicles has been projected from historical new vehicle sales for Victoria provided by the Department of Transport. As the study area only includes Melbourne and regional centres, the Victorian historical sales were prorated based on ABS data for vehicle ownership in the study area.

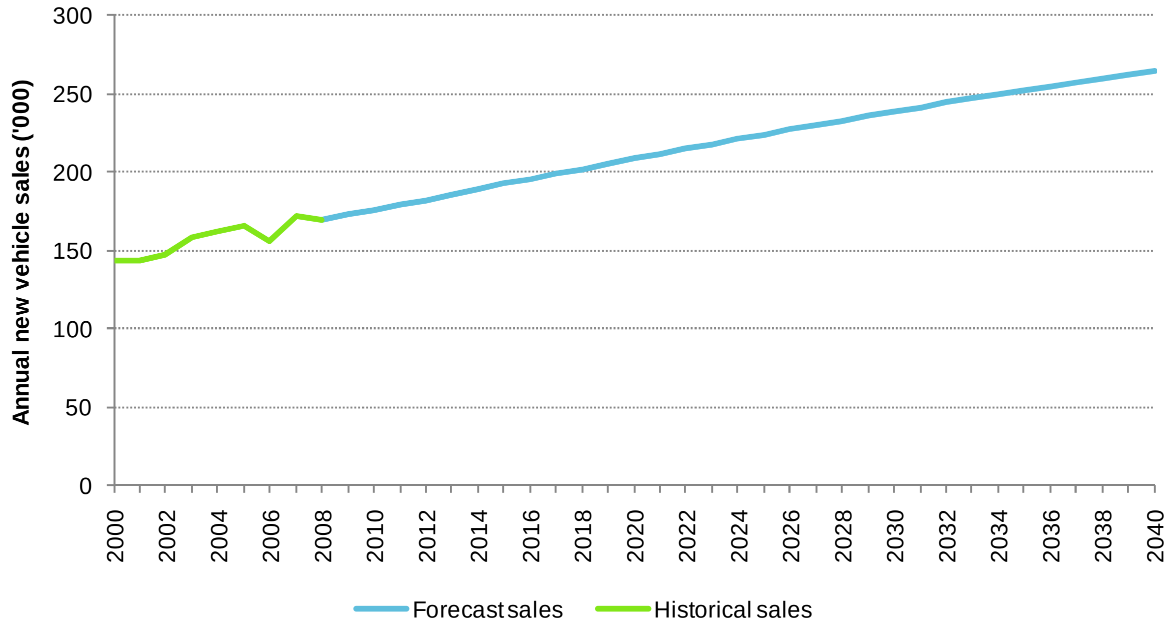
Estimates for annual growth are based on forecasts as used for inputs to the Melbourne Integrated Transport Model. Vehicle sales for each vehicle type are then projected forward to 2040 growing from the initial (actual) 2008 value. As the 2008 value from the DoT data was for an incomplete year, published ABS 2008 sales were used (following pro-rating as described above). **Table 5** shows the assumed annual growth rate for each period and **Figure 4** presents forecast passenger vehicle sales in relation to historical vehicle sales.

**Table 5 New vehicle sales growth rates**

| Period | 2008 – 2015 | 2016 – 2020 | 2021 – 2025 | 2026 – 2030 | 2031 – 2035 | 2036 – 2040 |
|---|---|---|---|---|---|---|
| Annual growth rate | 1.82% | 1.64% | 1.45% | 1.27% | 1.11% | 0.98% |

Source: AECOM based on Melbourne Integrated Transport Model

**Figure 4 Historical and forecast passenger vehicle sales**




Source: AECOM based on data provided by Victorian Department of Transport and Melbourne Integrated Transport Model

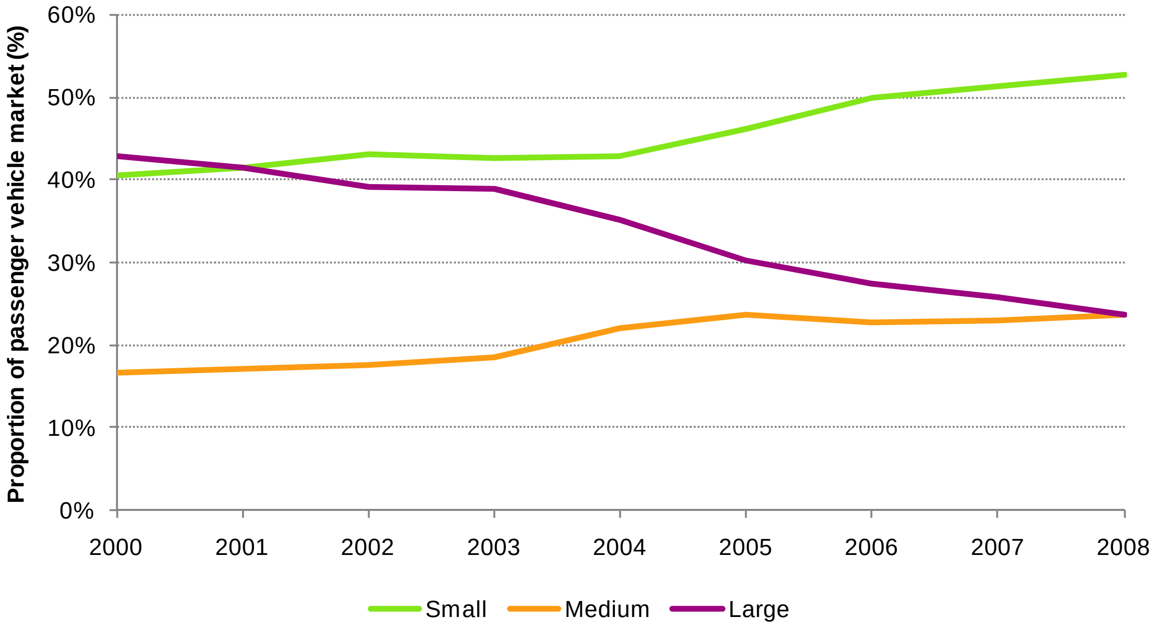
**Projections by size and VKT**

For each individual segment, demand is calculated as a proportion of total passenger vehicle demand based on assumptions for market share by vehicle size and historical VKT. There are two reasons why total projections of new vehicles need to be differentiated by vehicle size and the VKT driven:

- PHEVs and EVs will not be available in all vehicle sizes at the same time; and
- The demand for PHEVs and EVs is likely to differ when considering different vehicle sizes and anticipated VKT.

Analysis of new passenger vehicle sales data indicates that there has been a shift away in demand away from large passenger vehicles. **Figure 5** shows how the market shares of small and medium sized passenger vehicles has risen to 53% and 24% respectively in 2008, while the market share of large vehicles has fallen to 24% in 2008.

**Figure 5 Market share of new passenger vehicle sales by vehicle size**




Source: AECOM based on data provided by Victorian Department of Transport

As consumer preferences for different size vehicles are changing and will likely continue to change over time it has been assumed that the current market share for each vehicle size will continue to change over the forecast years. While the share of large passenger vehicles has fallen, some of this share has been taken up by SUVs, however due to uncertainty with the categorisation of SUVs, this study assumes that market shares for small, medium and large vehicles will trend from current proportions towards a shares of 60%, 30% and 10% respectively by 2020 as shown in **Table 6** It is assumed that the shift in demand will stabilise at this point as there will always be a segment of the market who prefer large vehicles.

VKT data for each vehicle size was sourced from the Department of Transport VISTA database for 2007. This allowed the three vehicle size market segments to be further disaggregated into low, medium and high daily VKT. As historical data was not available, the proportion of each vehicle size category in each VKT range was assumed constant at the 2007 level. As a result the total VKT travelled by each vehicle size will increase only with an increase in the total number of vehicles. **Table 7** shows the proportion of VKT ranges in each vehicle size category and **Table 8** shows the average daily and annual VKT.

**Table 6 Passenger vehicle market share by vehicle size assumptions**

| Vehicle Size | 2008 | 2020 | 2030 | 2040 |
|---|---|---|---|---|
| Small | 53% | 60% | 60% | 60% |
| Medium | 24% | 30% | 30% | 30% |
| Large | 24% | 10% | 10% | 10% |

Source: AECOM based on Victorian Department of Transport. Note values may not sum to 100% due to rounding.

**Table 7 Proportion of VKT ranges in each vehicle size category**

| Vehicle Size | Low (1-20km) | Medium (21-60km) | High (above 61km) |
|---|---|---|---|
| Small | 37% | 39% | 24% |
| Medium | 33% | 38% | 29% |
| Large | 30% | 38% | 33% |

Source: VISTA database. Note the VISTA database does not include vehicle size categories that correspond directly with the FCAI segmentations as set out in **Section 2.3.2**. As a proxy, AECOM has assumed the following size categories: small – less than 4 cylinders; medium – 5-6 cylinders; and large – greater than 6 cylinders.

**Table 8 Average daily and annual VKT**

| Vehicle Size | Low (1-20km) | Medium (21-60km) | High (above 61km) |
|---|---|---|---|
| **Average daily VKT** | | | |
| Small | 9.9 | 36.7 | 133.0 |
| Medium | 9.9 | 37.2 | 144.6 |
| Large | 11.1 | 40.5 | 143.7 |
| LCV | | 62.3 | |
| Taxi | | 318 | |
| **Average annual VKT** | | | |
| Small | 3,619 | 13,413 | 48,532 |
| Medium | 3,619 | 13,591 | 52,774 |
| Large | 4,034 | 14,775 | 52,448 |
| LCV | | 22,726 | |
| Taxi | | 116,079 | |

Source: VISTA database

The projections of overall passenger vehicle sales shown in **Figure 4** can therefore be combined with the proportions of vehicles in each size category and VKT range. **Table 9** provides the projections of new sales by size and VKT range.

**Table 9 Projections for new passenger vehicle sales by size and VKT**

| Year | Small | | | Medium | | | Large | | |
|---|---|---|---|---|---|---|---|---|---|
| | Low VKT | Medium VKT | High VKT | Low VKT | Medium VKT | High VKT | Low VKT | Medium VKT | High VKT |
| 2010 | 35,049 | 37,179 | 22,435 | 14,420 | 16,458 | 12,620 | 11,174 | 14,175 | 12,280 |
| 2015 | 40,541 | 43,006 | 25,951 | 17,455 | 19,921 | 15,275 | 8,969 | 11,378 | 9,857 |
| 2020 | 46,350 | 49,167 | 29,669 | 20,750 | 23,683 | 18,160 | 6,196 | 7,860 | 6,809 |
| 2025 | 49,821 | 52,849 | 31,891 | 22,304 | 25,456 | 19,520 | 6,660 | 8,448 | 7,319 |
| 2030 | 53,058 | 56,283 | 33,963 | 23,753 | 27,110 | 20,788 | 7,092 | 8,997 | 7,795 |
| 2035 | 56,066 | 59,474 | 35,888 | 25,100 | 28,647 | 21,966 | 7,494 | 9,507 | 8,236 |
| 2040 | 58,863 | 62,441 | 37,679 | 26,352 | 30,077 | 23,062 | 7,868 | 9,981 | 8,647 |

Source: AECOM

### 2.4.2 Light commercial vehicles

As with passenger vehicles, projections for demand for new light commercial vehicle sales are estimated from historical sales data. The average growth in vehicles sales between 2000 and 2008 was around 6%. This strong growth is expected to continue in the medium to long term consistent with projected economic growth and associated activities in the freight and service sectors (BITRE, 2007).

The growth in LCV sales has been assumed to remain high at 6% per year declining annually to 3% per year in 2030, as per BITRE's long run growth projections. Projected sales figures are shown in **Table 10**.

**Table 10 Projections for new light commercial vehicle sales**

| Year | LCV |
|---|---|
| 2010 | 34,604 |
| 2015 | 44,515 |
| 2020 | 55,033 |
| 2025 | 65,995 |
| 2030 | 77,252 |
| 2035 | 89,556 |
| 2040 | 103,820 |

Source: AECOM

### 2.4.3 Taxis

According to the Victorian Taxi Directorate as at 31 August 2010 there are 4,767 taxis licenses registered in the metropolitan and outer suburban regions. Registration requirements for taxis stipulate that they must be replaced when their age reaches 6.5 years (VicRoads, 2005). This has been used to estimate the number of new vehicles per annum. It has been assumed that the number of taxi licences in each year will grow in line with population.

## 2.5 Estimate number of vehicles purchased by configuration

### 2.5.1 Model development

In emerging markets such as electric vehicles, establishing market shares requires the development of primary data from stated preference surveys. In the absence of such data, one common practice is to adopt parameter values from previous stated preference studies. An extensive literature review determined that the most important factors affecting the vehicle purchase decision included vehicle price, fuel cost, vehicle range, tailpipe emissions, availability of recharging infrastructure, and the option of using different fuel types.

In this context, AECOM has chosen to develop a synthetic multinomial logit choice model[4] to forecast future market shares for ICE, HEVs, PHEVs and EVs. Notwithstanding that heterogeneity in vehicle choice is a well established phenomenon, AECOM has chosen to use a multinomial logit structure as it is transparent, easily understood by stakeholders and does not require assumptions on the degree of heterogeneity in choice, which would be required if a more sophisticated choice model were developed. Further detail on the vehicle choice model is presented in **Appendix B**.

### 2.5.2 Model parameters

**Table 11** presents the final parameter values used in AECOM's synthetic multinomial logit vehicle choice model. These were then used to calculate utility (and hence probability through the multinomial logistic function) in the vehicle choice model. These utility calculations given for the years 2010 to 2040 were then used to determine the total new vehicle sales for each engine configuration (i.e. ICE, HEV, PHEV and EV). Prior to this however, the vehicle choice model required information on all relevant variables. The following sections discuss this in more detail.

**Table 11 Assumed parameter values**

| Parameter | Units | Value |
|---|---|---|
| Vehicle price | $ | -0.00012 |
| Fuel cost | c / km | -0.12500 |
| Range | km | 0.00358 |
| Tailpipe emissions | Proportion of ICE | -0.59028 |
| Availability of infrastructure | Proportion of ICE | 2.38426 |
| Multi-fuel bonus | Dummy | 0.59491 |
| EV constant | Dummy | 0 |

Source: AECOM

## 2.6 Vehicle price

New vehicle prices were estimated from a survey of 34 global electric vehicle products for the 2009 to 2012 model years and 28 US HEVs for the 2009 to 2010 model years (AECOM, 2009). An equivalent ICE vehicle was used for the price of ICE vehicles to ensure a consistent comparison. AECOM also undertook industry consultation on the information collected.

There was limited information on the expected price of PHEVs. A report by the International Energy Agency concludes that electric vehicles will cost around US$10,000 more than a comparable PHEV. Applying this figure to our estimates makes PHEVs cheaper than HEVs which does not seem realistic. As such, it has been assumed PHEVs will be similarly priced to EVs. The basis for this assumption is that the cost reduction from a smaller battery (compared to EV) is offset by the cost of the internal combustion engine. In addition, the cost of batteries per kWh is higher for PHEVs compared to EVs. A large proportion of taxis in Victoria are Ford Falcons and as such prices for taxis are assumed to be equal to prices for large passenger vehicles.

[4] A vehicle multinomial logit model is called synthetic when elasticities are imposed on, rather than derived from, the choice model and where constants are calibrated to better reflect current market shares of existing vehicle classes.

The survey of prices also revealed, that for the cars available in Australia (HEVs), there is a premium of around $10,000 over US prices. This likely reflects the supply constraints for non-ICE vehicles imported to Australia (described in **Section 2.15**) . It has been assumed that there will be similar supply constraints for PHEVs and EVs. **Table 12** sets out the prices assumed in the model for the different market segmentations and engine configurations.

**Table 12 Vehicle prices in 2010 by size and configuration**

| Car size | ICE | HEV | PHEV | EV |
|---|---|---|---|---|
| **Price premium relative to ICE** | | | | |
| Passenger Small | N/A | $17,000 | $21,000 | $21,000 |
| Passenger Medium | N/A | $17,000 | $30,000 | $30,000 |
| Passenger Large | N/A | $18,000 | $50,000 | $50,000 |
| Light Commercial Vehicle | N/A | $20,000 | $64,000 | $64,000 |
| Taxi | N/A | $18,000 | $50,000 | $50,000 |
| **New vehicle price** | | | | |
| Passenger Small | $20,000 | $37,000 | $41,000 | $41,000 |
| Passenger Medium | $27,000 | $44,000 | $57,000 | $57,000 |
| Passenger Large | $48,000 | $66,000 | $98,000 | $98,000 |
| Light Commercial Vehicle | $40,000 | $60,000 | $104,000 | $104,000 |
| Taxi | $48,000 | $66,000 | $98,000 | $98,000 |
| **Price parity with ICE** | | | | |
| Year | N/A | 2020 | 2025 | 2025 |

Source: AECOM and Dr. Andrew Simpson.

Note that the price parity years differ to those in Appendix A, following further consultation undertaken after publishing the Model Parameter Update report.

### 2.6.1 Future battery costs

Estimates of future costs of electric vehicle variants are typically related to the cost of batteries. However as **Table 13** shows, battery costs vary widely and are further complicated by a lack of clarity about which cost is being estimated (e.g. the cost of a cell, the cost of a battery pack for an original equipment manufacturer). However, there seems to be a strong consensus that in general the price of lithium ion batteries will decline in the future and most likely by a significant amount.

**Table 13 Forecasts for battery costs**

| Author/Year | View | Expected evolution (units are US$ unless otherwise stated) |
|---|---|---|
| Boston Consulting Group, BCG, (2010). | Experience and scale effects will decrease the cost of batteries. Automatisation (minimising scrap rates and labour) and cheaper equipment will also have a positive impact.<br><br>Cost target of the USABC by 2020 is unlikely to be attained unless there is a technological breakthrough in battery chemistry that leads to fundamentally higher energy densities without significantly increasing the cost of either battery materials or the manufacturing process. | **2009:**<br>-*Supplier's cell cost:* \$650 to \$790 per kWh.<br>-*Cost to an OEM:* \$990 to \$1220 per kWh.<br>-*End user price* (assuming an average margin): \$1400 to \$1800 per kWh.<br><br>**2009 to 2020:**<br>-*Cost to an OEM:* Decreases by 60 to 65% per kWh, to \$360 to \$440 per kWh, respectively.<br>-*End user price*: Falls to \$570 to \$700 per kWh.<br><br>Underlying falling prices is a parallel decline in the cost of cells, to \$270 to \$330 per kWh. Decline of the cost of cell is less rapid because around 30% of cell costs are independent of production volume. |
| Deutsche Bank (2009, 2010). | Lower lithium ion battery prices in the future. | The price of lithium-ion batteries are likely to decline by 25%-50% over the next 5-10 years. There are already bids of 400 \$/kWh for large volume EV battery contracts in the 2011-12 time period, implying a reduction of 30%. The latest report (2010) by DB forecasts battery costs to decline by 7.5% CAGR to a cost of around \$250/kWh in 2020. |
| Nemry et al. (2009). | | **Short term:**<br>-Citing Kalhammer et al 2007: Lithium ion battery cost will fall as low as \$395 per kWh and \$260 per kWh for a PHEV10 and PHEV40, respectively (assuming 100,000 of units produced).<br>-Citing Aderman 2008: The range of \$600 to \$700 per kWh is seen as more realistic.<br>-Citing Anderson 2009: Under the optimistic scenario by 2015, the cost of a battery would be around 370 \$/kWh and by 2030 of around \$250 \$/kWh. Under the pessimistic scenario, values are around \$790 for 2015/30. |
| National Academy of Science (2010). | Lithium ion battery technology has been developing rapidly but costs remain high and there is limited potential for further significant reductions.[5] | Assembly packs currently cost about \$1700 per kWh. Costs are expected to decline by about 35% (to 1105 \$/kWh) by 2020 but more slowly thereafter, |
| Pike Research (2009) | Lower lithium ion battery prices in the future. | Price of lithium-ion batteries will decline from around \$1000 per kWh today to \$810 in 2011, and will continue to drop to \$470 in 2015. |
| Bosch (2009) | Reduction in the production of lithium ion batteries will be possible and significant. | Battery pack to cost about 350 euros per kWh by 2015 (66% of current cost). |
| Powertrain (2010) | Large capital investment, experience and economies of scale will render to the reduction of battery costs. | Battery costs will decline from 475 euros per kWh in 2010 to 200 euros per kWh in 2020. |

Source: AECOM

[5] This conclusion has been challenged by the Electrification Coalition who note that the National Research Council overestimated both current battery prices and that future prices in comparison with several other studies.

### 2.6.2 Vehicle price parity

A key factor within the model is the estimation of the point in time when vehicle price parity is reached; that is when the purchase prices of HEVs, PHEVs and EVs are equivalent to that of a conventional ICE vehicle. In the same way that a petrol- and diesel-engined car are priced comparatively today, industry expects there to be a point in time when a particular model of car will be available with an ICE, HEV, PHEV or EV powertrain at a similar price range. Extensive consultation with industry (detailed in Appendix A) was undertaken in this regard.

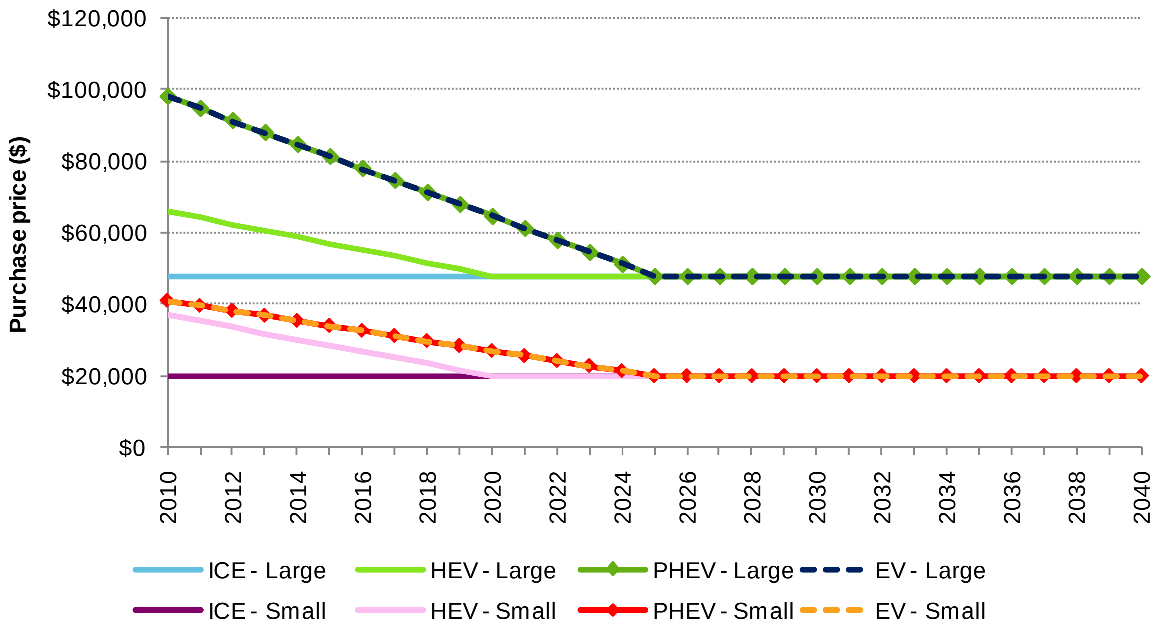
Vehicle pricing is not directly related to cost of manufacture. Other factors that affect pricing include country of sale, market competition and expected rate of investment recovery. By way of example the Nissan Leaf will sell for US$3,2780 (A$35,750) in the USA and 3.76 million yen (A$44,330) in Japan before subsidies. This large difference in price reflects the cost of marketing in the two countries as well as the degree of market demand and competition in the segment. Consultees also cited the example of the Mitsubishi i-MiEV, whose cost in the UK was reduced by GBP10,000 overnight following the announcement of the launch price of the Nissan Leaf (What Car, 2010). Thus, whilst it is recognised that battery costs will continue to decline and indeed at some point the manufacturing cost of EVs may be lower than a PHEV, HEV or ICE (as they have fewer components), there may not be a corresponding reduction in price.

Changes in HEV, PHEV and EV prices are also determined by other factors such as powertrain and chassis improvements that are not necessarily shared between each engine configuration. As a result forecast prices are subject to a large degree of uncertainty.

HEVs are assumed to reach price parity with ICE vehicles in 2020; this is broadly in line with industry expectations such as Toyota, which expects that by 2020 HEVs will be the prominent engine configuration in their fleet. PHEV and EV purchase prices are assumed to reach price parity with equivalent ICE vehicles in 2025.. **Figure 6** shows forecast vehicle purchase prices by vehicle configuration for small and large passenger vehicles.

Due to the uncertainty around future prices, extensive sensitivity testing on prices was undertaken as detailed in **Section 5.2.**

**Figure 6 Assumed vehicle prices for small and large vehicles by engine configuration**




Source: AECOM

## 2.7 Fuel efficiency

### 2.7.1 ICE

Petrol fuel efficiencies were determined from a survey of motor vehicle efficiencies as published by Green Vehicle Guide[6] and industry consultation. Efficiencies were identified for representative vehicles in each category (small, medium and large passenger; and LCV). However LPG versions of the standard petrol vehicles were not necessarily available, therefore representative LPG efficiencies for passenger vehicles (all sizes) and LCVs were determined from the ABS Survey of Motor Vehicle Use as shown in **Table 14**.

**Table 14 ABS reported fuel efficiencies**

| Vehicle type | Petrol | LPG | LPG to Petrol Ratio |
|---|---|---|---|
| Passenger car (all sizes) | 11.2 | 17.7 | 1.580 |
| Light Commercial Vehicle | 13.7 | 14.7 | 1.073 |
| Taxi | 11.2 | 17.7 | 1.580 |

Source: ABS (2007)

As the ABS data did not have LPG efficiencies separated into vehicle size categories, to maintain consistency with the petrol efficiencies, LPG efficiencies were determined by pro-rating petrol efficiencies. That is, LPG efficiencies were calculated by multiplying the petrol efficiency with the ratio of LPG to petrol efficiencies as reported by ABS Survey of Motor Vehicle Use (see **Equation 1**).

**Equation 1 LPG efficiency calculation**

$$LPG\ efficiency = Petrol\ efficiency \times (ABS\ LPG\ efficiency \div ABS\ petrol\ efficiency)$$

Changes to ICE efficiencies over time are based on *Modelling the Road Transport Sector* (BITRE & CSIRO, 2007) which indicated that efficiencies will improve by 30% between 2006 and 2050. This is equivalent to an annual improvement of 0.84%.

**Table 15 ICE fuel efficiencies**

| Vehicle type | Petrol (L/100km) | Diesel (L/100km) | LPG (L/100km) | Annual change |
|---|---|---|---|---|
| Passenger small | 7.8 | 5.9 | 12.3 | 0.84% |
| Passenger medium | 9.7 | 7.3 | 15.3 | 0.84% |
| Passenger large | 13.8 | 10.4 | 21.8 | 0.84% |
| Light Commercial Vehicle | 11.2 | 8.4 | 12.0 | 0.84% |
| Taxi | 13.8 | 10.4 | 21.8 | 0.84% |

Source: AECOM based on ABS, Green Vehicle Guide, BITRE & CSIRO and industry consultation

### 2.7.2 HEV

Efficiencies for hybrids are modelled relative to ICE efficiencies as investments in hybrid technology are expected to generate continued efficiency gains over ICE. However these improvements will decline over time as the potential for improvement gets eroded by improved combustion technologies.

**Table 16** summarises the efficiency improvement of HEV relative to ICE in 2010 and 2050 as determined for the NSW study by Simpson (2009). Efficiency improvements decline by 20% between 2010 and 2050, equivalent to

[6] http://www.greenvehicleguide.gov.au/

an annual change of 0.5%. For example, in 2010 a small passenger HEV is assumed to be 47% more efficient than the equivalent ICE, yielding a fuel consumption rate of 5.31 L / 100km. This is supported by the literature, for example Deutsche Bank (2009) find that HEV efficiency gains are in the range of 25% to 40%. The Electric Power Research Institute's study also indicates that fuel consumption for the petrol component of a PHEV will decrease by approximately 18% between 2010 and 2050, equivalent to a 0.45% annual change (Electric Power Research Institute, 2007).

**Table 16 HEV fuel efficiencies relative to ICE fuel efficiencies**

| Vehicle type | Efficiency improvement relative to ICE | | Annual change (% p.a.) | Fuel consumption in 2010 (L / 100km) |
|---|---|---|---|---|
| | 2010 | 2050 | | |
| Passenger Small | 47% | 30% | 0.43% | 5.31 |
| Passenger Medium | 32% | 15% | 0.43% | 7.35 |
| Passenger Large | 23% | 6% | 0.43% | 11.22 |
| Light Commercial Vehicle | 33% | 16% | 0.43% | 8.42 |
| Taxi* | 23% | 6% | 0.43% | 11.22 |

Source: Simpson, A. (2009)

* Assumed to be the same as large passenger vehicles.

### 2.7.3 EV

Efficiencies for electric vehicles were identified through a survey of current and planned models. It has been assumed that the overall efficiency improvement arising from powertrain improvements, increased range and performance is 20% between 2006 and 2050, equivalent to 0.45% per annum based on information provided by Simpson (2009) for the NSW study. **Table 17** shows the assumed efficiencies.

**Table 17 EV electricity efficiency by vehicle category in 2010**

| Vehicle type | Electricity (kWh/100km) | Annual Change |
|---|---|---|
| Passenger small | 19.0 | 0.45% |
| Passenger medium | 16.5 | 0.45% |
| Passenger large | 21.5 | 0.45% |
| Light Commercial Vehicle | 18.5 | 0.45% |
| Taxi* | 21.5 | 0.45% |

Source: Simpson, A. (2009). Survey of current and planned EVs

* Assumed to be the same as large passenger vehicles.

The values in **Table 17** represent energy consumption from the recharging plug rather than energy consumption whilst driving. Whilst, it seems counter-intuitive that small EVs would have higher energy consumption than medium EVs, small EVs tend to have the smallest batteries with the lowest power rechargers (typically Level 1 as standard). Medium and large EVs tend to have larger batteries and normally come with higher power (Level 2) rechargers as standard. There can be a significant difference in the recharging efficiencies between Level 1 and 2, since the power electronics operates more efficiently at the higher Level 2 powers. Therefore, the smallest and cheapest EVs will often be quite inefficient because they use inefficient recharging circuits.

### 2.7.4 PHEV

The efficiency of a PHEV is dependent on the proportion of distance travelled propelled by the ICE powertrain or the electric powertrain. AECOM assumed that PHEVs will use the electric powertrain for 50% of kilometres in 2012 increasing to 80% in 2035 based on a report that BITRE and CSIRO prepared for the Treasury on modelling the transport sector for the Treasury's modelling of the introduction of emissions trading in Australia (BITRE & CSIRO, 2007). This corresponds to an annual change of 1.03% (see **Table 18**).This is consistent with the literature, for example the Electric Power Research Institute's (2009) study indicates that the proportion of electric powertrain usage is 49% for a PHEV with 20 mile (32km) range.

Fuel efficiencies in 2010 are therefore equal to the efficiencies shown in **Table 15** and **Table 17** for the ICE and electric components respectively.

**Table 18 PHEV proportions on ICE and electric powertrains (all vehicles)**

| Powertrain | 2012 | 2035 | Annual Change |
|---|---|---|---|
| % EV powertrain | 50% | 80% | 1.03% |
| % ICE powertrain | 50% | 20% | -1.03% |

Source: AECOM and Dr. Andrew Simpson

### 2.7.5 Summary

**Table 19** summarises the assumed fuel efficiencies for each vehicle type in 2010 and the annual change (improvement) in efficiency.

**Table 19 Fuel efficiency parameters in 2010 and annual change**

| | Petrol (L/100km) | Diesel (L/100km) | LPG (L/100km) | Electricity (kWh/100km) | Annual change |
|---|---|---|---|---|---|
| **ICE** | | | | | |
| Passenger small | 7.8 | 5.9 | 12.3 | N/A | 0.84% |
| Passenger medium | 9.7 | 7.3 | 15.3 | N/A | 0.84% |
| Passenger large | 13.8 | 10.4 | 21.8 | N/A | 0.84% |
| Light Commercial Vehicle | 11.2 | 8.4 | 12.0 | N/A | 0.84% |
| Taxi | 13.8 | 10.4 | 21.8 | N/A | 0.84% |
| **HEV** | | | | | |
| Passenger small | 5.3 | N/A | N/A | N/A | 0.43% |
| Passenger medium | 7.3 | N/A | N/A | N/A | 0.43% |
| Passenger large | 11.2 | N/A | N/A | N/A | 0.43% |
| Light Commercial Vehicle | 8.4 | N/A | N/A | N/A | 0.43% |
| Taxi | 11.2 | N/A | N/A | N/A | 0.43% |
| **EV** | | | | | |
| Passenger small | N/A | N/A | N/A | 19.0 | 0.45% |
| Passenger medium | N/A | N/A | N/A | 16.5 | 0.45% |
| Passenger large | N/A | N/A | N/A | 21.5 | 0.45% |
| Light Commercial Vehicle | N/A | N/A | N/A | 18.5 | 0.45% |
| Taxi | N/A | N/A | N/A | 21.5 | 0.45% |
| **PHEV** | | | | | |
| Passenger small | 7.8 | N/A | N/A | 19.0 | 0.84%/0.45% |
| Passenger medium | 9.7 | N/A | N/A | 16.5 | 0.84%/0.45% |
| Passenger large | 13.8 | N/A | N/A | 21.5 | 0.84%/0.45% |
| Light Commercial Vehicle | 11.2 | N/A | N/A | 18.5 | 0.84%/0.45% |
| Taxi | 13.8 | N/A | N/A | 21.5 | 0.84%/0.45% |

Source: AECOM and Dr. Andrew Simpson; ABS; Green Vehicle Guide.

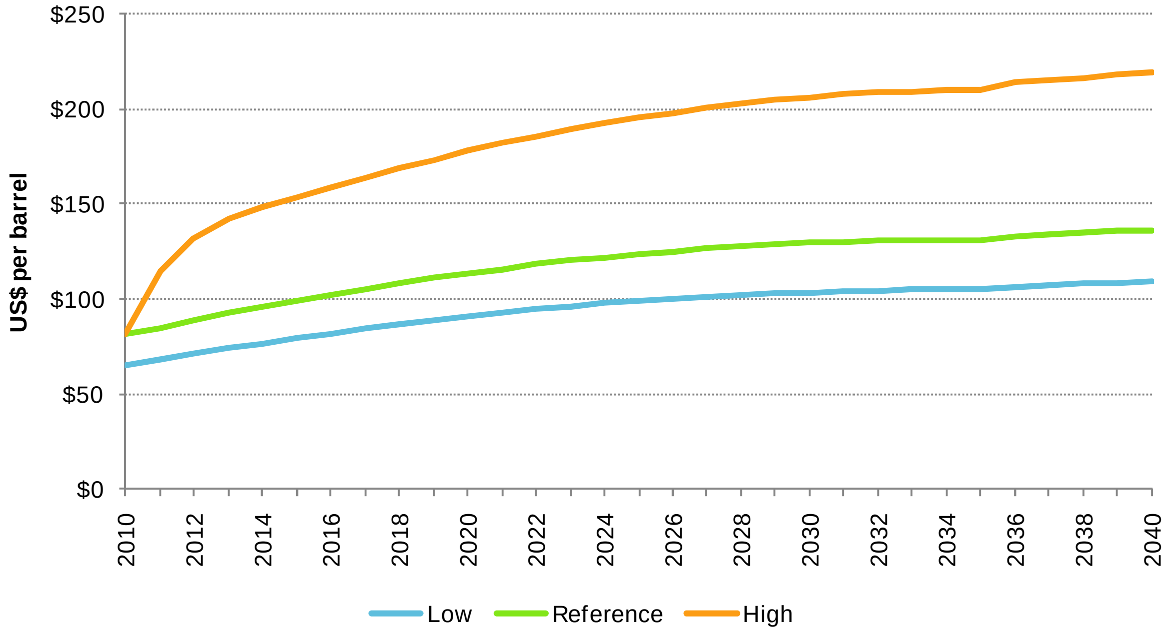
## 2.8 Fuel and electricity costs

### 2.8.1 Conventional fuel

The forecasts of fuel price were estimated using world forecasts of oil price and the past relationship to retail prices for petrol and diesel. Published forecasts for world crude oil prices have been adopted from the Energy Information Administration (EIA). There are three crude oil price scenarios that have been used to estimate the price of liquid fuels (and are illustrated in **Figure 7**):

- High – corresponds to EIA high price scenario;
- Reference – corresponds to the EIA reference scenario; and
- Low – equal to a 20% discount from the reference scenario.

**Figure 7 Crude oil price scenarios**




Source: AECOM based on EIA (2010)

The relationship between crude oil and petrol has been determined by regressing spot crude oil prices against historical average metropolitan Melbourne petrol prices (at the pump) obtained from FuelTrac for the period 1999 to 2010. This final pump price has then been broken down into components: a base price, excise, CPRS and GST as shown in **Table 20** and discussed below. GST has been applied at 10%.

#### Base prices

Base prices for diesel, biofuels and LPG have been calculated as a proportion of the base petrol price. Diesel base price is assumed to be 100% of the petrol base price as suggested by current prices where petrol and diesel are approximately on par. Data from MotorMouth suggests that LPG prices are approximately 40% of petrol price. As fuel prices are a small part of the total fuel mix for this study it has been assumed that they increase in line with petrol prices.

#### Excise

The current fuel excise is $0.381/litre and is applied to petrol and diesel. It should also be noted that while LPG does not presently have an excise, a fuel tax is scheduled to begin on 1 June 2011. However no legislation has yet been passed; in the absence of a stated value, it is assumed that the value of the LPG tax from 2011 onwards is equal to the current petrol excise at $0.381/litre. Excise values are assumed to remain constant.

### Carbon Tax and Carbon Pollution Reduction Scheme (CPRS)

The design and implementation timeline of an emission trading scheme, carbon tax or other carbon pricing mechanism is subject to significant uncertainty. However, key Commonwealth international commitments, most notably the Copenhagen Accord currently enjoy bi-partisan support nationally and form a reasonable basis for analysis. At the time of publication, a revised carobon tax is being proposed by the Commonwealth Government. However, details on the cost of permits and its impact upon fuel prices have not yet been released. Therefore, in the absence of new policy guidance, this study has assumed an emissions trading scheme in the form of the previously tabled Carbon Pollution Reduction Scheme (CPRS), adjusted to 2010 prices.

The CPRS is assumed to increase the price of fossil fuels used within the transport and electricity generation sectors. The CPRS component for each fuel is calculated as the product of the CPRS price and the fuel emissions factor. For further discussion on the CPRS price see **Section 2.8.2**.

The current CPRS guidance suggests that any increase in fuel prices due to the cost of carbon may be offset by a reduction in fuel excise in the short term. Fuel taxes will be cut on a cent for cent basis to offset the initial price impact on fuel associated with the introduction of the CPRS and allow motorists three years to plan for potentially higher fuel prices. This will be periodically assessed for three years and this offset adjusted accordingly. At the end of this three year period, the Government will review this adjustment mechanism. As such, there has been CPRS price effect on fuel for the first three years of its introduction.

**Table 20** shows the emissions factors (in kg $CO_2$-e per litre) for each fuel that have been calculated from the energy content and emissions factor (in kg $CO_2$-e per GJ) as given by the National Greenhouse Account Factors (Dept. of Climate Change and Energy Efficiency, 2010). Energy content and emissions factors are assumed to remain constant over time.

**Table 20 Emission factors for fuel**

| Fuel | Energy content (GJ / kL) | Emissions per GJ (kg $CO_2$-e/GJ)* | Emissions factor (kg $CO_2$-e / L)* |
|---|---|---|---|
| Petrol/gasoline | 34.20 | 72.22 | 2.470 |
| Diesel | 38.60 | 75.11 | 2.899 |
| LPG | 26.20 | 65.20 | 1.708 |

* for Scope 1 and 3 emissions for post-2004 vehicles that conform to Euro design standards

Source: Department of Climate Change and Energy Efficiency (2010)

**Table 21 Calculation of petrol price under reference oil price scenario (AUD unless stated)**

| Year | Crude Oil (US$ / barrel) | Petrol price components ($ / L) | | | | |
|---|---|---|---|---|---|---|
| | | Base | Excise | CPRS | GST | Total |
| 2010 | 81.5 | 0.86 | 0.38 | 0.00 | 0.12 | 1.37 |
| 2015 | 99.4 | 0.96 | 0.38 | 0.02 | 0.14 | 1.50 |
| 2020 | 113.6 | 1.04 | 0.38 | 0.10 | 0.15 | 1.67 |
| 2025 | 123.7 | 1.09 | 0.38 | 0.12 | 0.16 | 1.75 |
| 2030 | 129.5 | 1.12 | 0.38 | 0.15 | 0.17 | 1.82 |
| 2035 | 131.5 | 1.13 | 0.38 | 0.18 | 0.17 | 1.87 |
| 2040 | 136.4 | 1.16 | 0.38 | 0.22 | 0.18 | 1.94 |

Source: AECOM

### 2.8.2 Electricity price

Electricity prices paid by consumers are modelled as the sum of wholesale electricity prices, network costs and retail margins, and any carbon pricing component (selected through the carbon emission policy options). The individual components of future electricity prices are not independent of one another. Higher emission permit prices will make alternate energy sources more viable compared to coal fired power generation, which will in turn change the mix of installed generation and result in changes in wholesale electricity prices and potential differences in distribution network changes, as well as a general reduction in the grid emission intensity.

The Australian Treasury has produced a White Paper, *Australia's Low Pollution Future - the Economics of Climate Change Mitigation* (Treasury, 2008), containing modelling of Australia's electricity generation under different scenarios. The results of this modelling have formed the basis for consumer electricity price forecasts produced by AECOM. The alternative scenarios modelled in the Treasury White Paper are as follows:

- Reference case – no additional emission reduction measures (excludes the expanded mandatory renewable energy target);
- CPRS-5 – 5% reduction from 2000 emission levels by 2020; and
- CPRS-15 – 15% reduction from 2000 emission levels by 2020.

In addition to retail electricity supply costs, the price paid by electric vehicle consumers varies by point of charging under the different scenarios. This assumes that any investment to provide charging infrastructure will be recouped through higher electricity prices.

**Carbon emissions policy**

As noted earlier, there is significant uncertainty surround the implementation and timing of a carbon pricing policy. As such this study has applied the most recent CPRS policy to this study. The CPRS was introduced to Parliament for the third time in February 2010 and will place a limit, or cap, on the amount of carbon pollution industry can emit. It will require affected businesses and industry to buy a 'pollution permit' for each tonne of carbon they contribute to the atmosphere, providing a strong incentive to reduce pollution.

In February 2011, the Commonwealth Government announced a two-stage plan for a carbon price mechanism which will start with a fixed price period for three to five years before transitioning to an emissions trading scheme similar to the CPRS. The Government proposes that the carbon price commences on 1 July 2012, subject to the ability to negotiate agreement with a majority in both houses of Parliament and pass legislation this year.

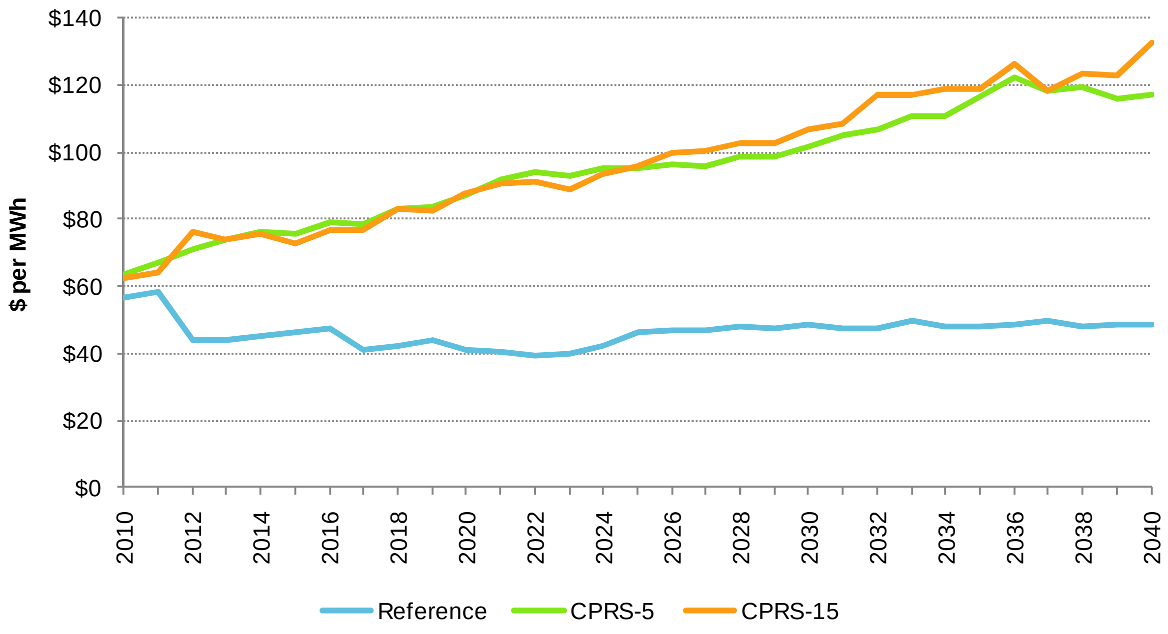
The price of the CPRS/carbon tax permits will impact on electricity prices, fuel prices and the electricity emission factors. In order to ensure consistency with CPRS prices, electricity prices and electricity emissions factors, this study has used the 2008 Treasury modelling forecasts for all three series. Given the uncertainty surrounding the ultimate design and implementation of the CPRS/carbon tax, this study has conservatively assumed that the CPRS/carbon tax will be introduced in 2015 with a $10 fixed permit price in the first year of operation

**Wholesale electricity costs**

Forecasts of wholesale electricity prices, as detailed in the Treasury White Paper are shown in **Figure 8**. There is considerable variation in wholesale electricity prices between the reference case (no emission reduction measures) and the CPRS scenarios considered.

AECOM have updated the results to present value prices and estimated wholesale electricity prices, excluding CPRS permit costs to allow for adjustments for changes to government policy relating to CPRS since the Treasury modelling was undertaken.

**Figure 8 Forecast Australian wholesale electricity prices ($2010)**




Source: Treasury (2008)

### Network charge and retail margin

Distribution network charges and retail supply margins have been estimated as the difference between the Treasury retail price forecasts and wholesale supply price forecasts. There is some limited variation in network costs and margins for each of the scenarios considered.

### Upgraded residential network connection charge (for Level 2 household charging)

To allow for Level 2 charging at residential properties, it is possible that the residential electricity network will need to be upgraded at the point of connection to the premises and possibly the local distribution network as well.

To account for the pass through of these costs to consumers, 20% increase in network access charges and retail margin has been assumed for electricity supplied to residential premises with Level 2 charging available.

### Public charging point network charge (for Level 2 public charging)

Public charging points are expected to recover the upfront capital cost of installation through higher electricity prices paid by users. The additional cost per MWh supplied was estimated based on assumptions of capital cost ($3,000), economic life (10 years), charging capacity (7.7 kW), utilisation or time for which the station is supplying electricity (assumed to be 20%) and expected return on capital (7% real). For the stated assumption values, the premium charged to users of the public charging point, in addition to retail electricity costs is around $31 per MWh, or approximately $0.25 per charge (based on 8 kWh consumed per charge).

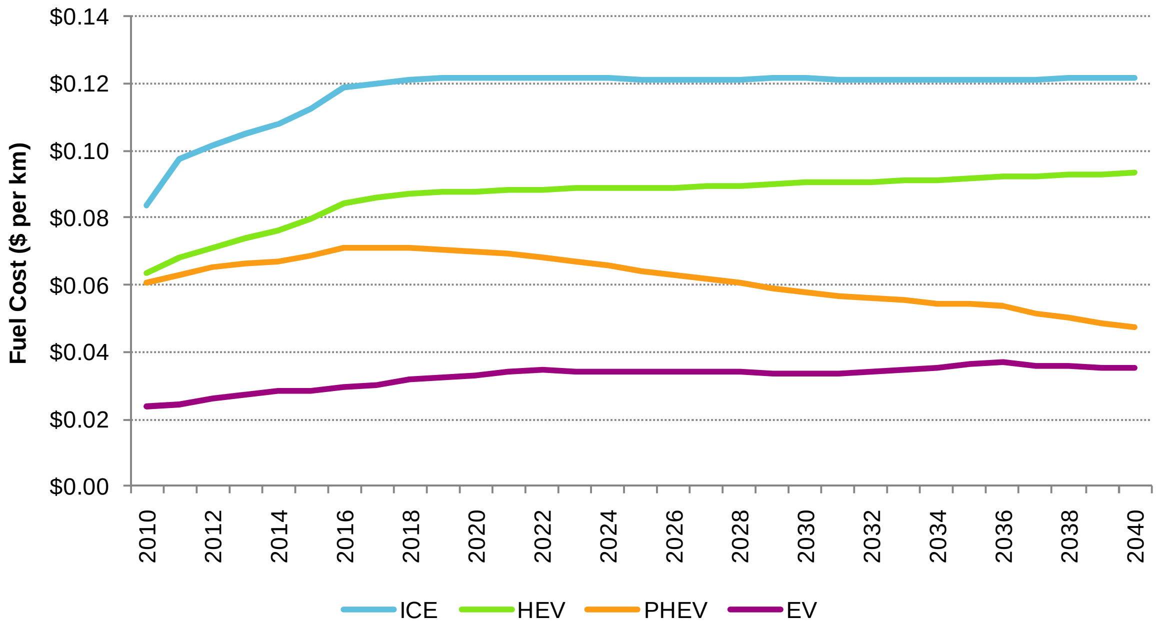
### Commercial charging station network charge (for Level 3 fast charging)

Similar to public charging stations, commercial charging stations are expected to recover their capital costs through higher electricity prices paid by consumers charging at the station. To determine the additional cost per MWh supplied, assumptions regarding the capital cost ($500,000), economic life (25 years), charging capacity (250 kW), utilisation or time for which the station is supplying electricity (assumed to be 10%) and expected return on capital (7% real) have been made. For the stated assumption values, the premium charged by the charging station operator in addition to retail electricity costs is around $195 per MWh, or approximately $1.50 per charge (based on 8 kWh consumed per charge).

### 2.8.3 Fuel cost per kilometre

**Figure 9** brings together the fuel efficiencies and forecast prices for fossil fuels and electricity into a cost per kilometre. The cost advantage of electricity reduces slightly over time but remains significantly below fossil fuel prices.

**Figure 9 Fuel cost per kilometre by engine configuration – small passenger vehicle**




Source: AECOM

## 2.9 Other vehicle costs

### 2.9.1 Registration and insurance

Vehicle registration costs were obtained from VicRoads[7], Transport Accident Charge (TAC) and from the Transport Accident Commission[8] and comprehensive insurance from RACV[9]. Additionally, the comprehensive insurance costs for taxis were obtained from the Taxi Fare Review 2007-08 (Essential Services Commission, 2008) and escalated to 2010 prices.

It has been assumed that the registration cost will not vary by the engine configuration. In practice, government policy may reduce registration costs for low emission technologies[10]. However, given registration costs are a small proportion of the total cost of operating a vehicle it has been assumed to remain the same.

**Table 22** sets out the annual registration, TAC and comprehensive insurance costs.

[7] www.vicroads.gov.au
[8] www.tac.vic.gov.au
[9] www.racv.com.au
[10] At the time of publication, VicRoads are offering a $100 discount on registration costs for HEVs and PHEVs, but not EVs.

**Table 22 Insurance and registration costs**

| Vehicle type | Transport Accident Charge (includes insurance duty) | Comprehensive Insurance | Registration |
|---|---|---|---|
| Small Passenger | $429 | $632 | $183 |
| Medium Passenger | $429 | $762 | $183 |
| Large Passenger | $429 | $732 | $183 |
| LCV (business use) | $430 | $949 | $183 |
| Taxi | $2,174 | $4,852 | $183 |

Sources: VicRoads; RACV; Transport Accident Commission; and Essential Services Commission

### 2.9.2 Maintenance

Maintenance costs for ICE vehicles are based on vehicle repair and maintenance costs published by (Austroads, 2008a). Maintenance costs for electric vehicle variants are then expressed as a proportion of the equivalent ICE cost.

Electrical components such as traction motors and controllers require very little maintenance. An EPRI (2004) study estimates that the maintenance cost for a HEV are around 88% of an ICE and maintenance costs for a PHEV are around 75% of an ICE. These differences are largely driven by a reduction in the frequency of brake pad replacements. Industry consultation supported these values and also indicated that EV maintenance costs are around 70% of an equivalent ICE.

Battery replacement costs are assumed to be negligible as battery life is expected to equal or exceed vehicle life within the near future. Even though there are uncertainties surrounding the life of electric vehicle batteries, it is considered reasonable to assume that any battery replacement costs that do occur are unlikely to occur within the first decade. As a result, battery replacement costs for later years would be discounted and also influenced by economies of scale and industry learning curves.

**Table 23** shows the maintenance cost assumptions applied in this study.

**Table 23 Maintenance costs per kilometre (cents per km)**

| | ICE | HEV | PHEV | EV |
|---|---|---|---|---|
| Relativity with ICE | N/A | 88% | 75% | 70% |
| Passenger small | 5.86 | 5.16 | 4.40 | 4.10 |
| Passenger medium | 4.45 | 3.92 | 3.34 | 3.12 |
| Passenger large | 4.34 | 3.82 | 3.26 | 3.04 |
| Light Commercial Vehicle | 5.10 | 4.49 | 3.83 | 3.57 |
| Taxi | 4.34 | 3.82 | 3.26 | 3.04 |

Source: AECOM based on Austroads (2008a) and industry consultation

## 2.10 Range

The vehicle range influences the sales of new vehicles through the choice model. Vehicle range assumptions for 2010 based on the survey of electric vehicles are shown in **Table 24.**

**Table 24 Vehicle range assumptions for 2010 (km)**

| Category | ICE | HEV | PHEV | EV |
|---|---|---|---|---|
| Passenger Small | 500 | 500 | 500 | 120 |
| Passenger Medium | 550 | 550 | 550 | 200 |
| Passenger Large | 550 | 550 | 550 | 300 |
| LCV | 550 | 550 | 550 | 160 |
| Taxi | 550 | 550 | 550 | 300 |

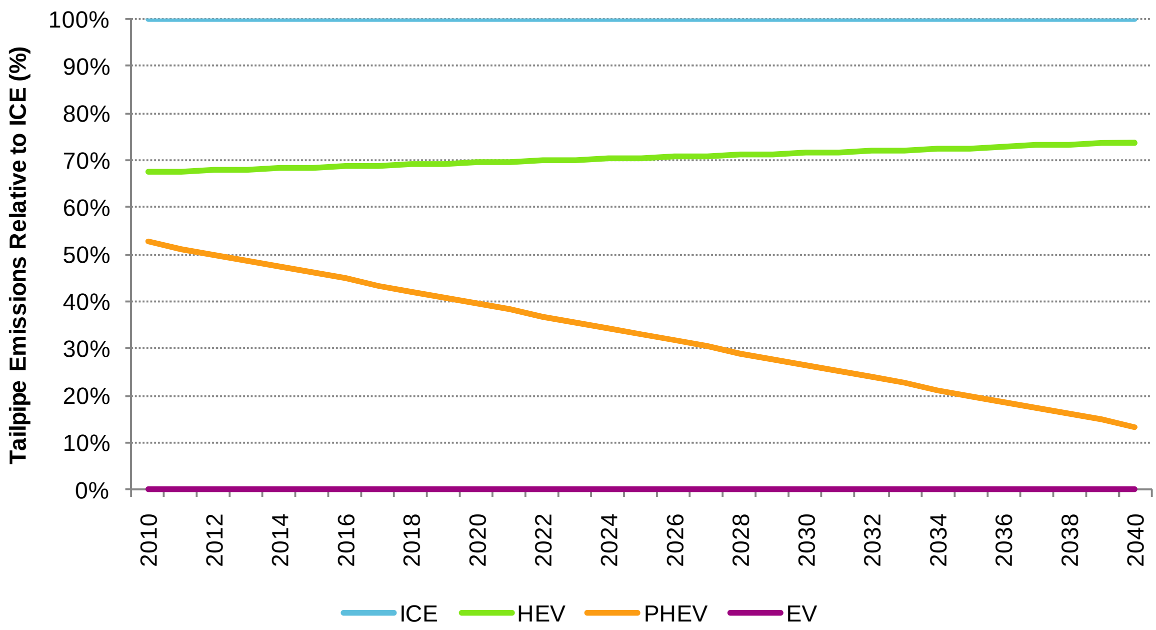
Source: AECOM (2009, section 4.13)

The vehicle range for all vehicles grows over time due to fuel efficiency improvements. ICE and HEV vehicle range increases in line with fuel efficiency improvements. EVs are assumed to grow due to fuel efficiency as well as battery improvements. It is assumed a battery storage capacity improvement of 5% per annum, equivalent to a doubling in vehicle range every 12-13 years. This is consistent with industry expectations which expect a doubling in vehicle range every 10 years. PHEV vehicle range will increase due to both increases in the ICE range and the EV range. It has been assumed to be the maximum of either the ICE range or EV range.

## 2.11 Emissions

The tailpipe emissions relative to an ICE vehicle influences the sales of new vehicles through the choice model. **Figure 10** sets out the proportion of tailpipe emissions relative to the ICE for HEVs, PHEVs and EVs. Importantly, the consumer only considers tailpipe emissions so emissions from electricity generation are ignored (these are however, taken into account within the cost-benefit analysis where they are treated as an environmental externality). The large change for PHEVs is driven by the increased proportion of electric drive time that occurs over time.

**Figure 10 Tailpipe emissions relative to ICE vehicles – small passenger vehicle, low VKT**




Source: AECOM

## 2.12 Multi-fuel bonus

The vehicle choice model also takes account of the number of options to fuel vehicles. Both hybrids, the HEV and the PHEV, receive a bonus for their ability to run off two different sources of fuel. Note this is perceived ability not actual which is why the HEV (which only runs on fossil fuels) is also given a bonus.

## 2.13 Non captive market

The vehicle choice model cannot take account of differences in VKT (see suggested further work) as there are no published data sources to calibrate a parameter. However, it is believed that distance travelled is an important market segment that will affect the take-up of electric vehicles. As such, the data has been split into a captive and non captive market before going through the vehicle choice model based on the different levels of available infrastructure.

**Table 25** sets out the assumptions used to determine the proportion of vehicle sales which can be PHEVs or EVs. For example, in Scenario 1 where there is only household charging it has been assumed that people who have a low average VKT would consider purchasing a PHEV or EV as household charging will meet their usage patterns. This reduces to 50% for people who have a medium average VKT and zero for people who have a high average VKT. Similarly, no one purchasing a light commercial vehicles or taxi would consider purchasing a PHEV or EV whilst there is only household charging. These proportions change over the Scenarios as more charging infrastructure becomes available.

**Table 25 Proportion of market segment that may purchase an EV or PHEV by Scenario**

| Category | Base | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|---|
| Low VKT | 0% | 100% | 100% | 100% |
| Medium VKT | 0% | 50% | 75% | 100% |
| High VKT | 0% | 0% | 50% | 100% |
| Light Commercial Vehicle | 0% | 0% | 0% | 100% |
| Taxi | 0% | 0% | 0% | 100% |

Source: AECOM

## 2.14 Infrastructure availability and cost

### 2.14.1 Availability

A key factor in the vehicle choice model is the availability of public vehicle charging infrastructure relative to ICE vehicles (e.g. availability of battery swap stations or public charging points relative to the number of petrol stations). This is linked to the different scenarios modelled. The assumptions of level of infrastructure are summarised in **Table 26**.

- HEVs and PHEVs are assumed to have 100% charging infrastructure relative to ICE vehicles.
- Under the Base Case, both PHEVs and EVs are assumed to have no charging infrastructure (either in the home or in public places).
- For EVs, it has been assumed that under Scenario 2, public charging points provide the equivalent of 50% of ICE infrastructure. Under Scenario 3, this increases to 75% as some service stations switch to become battery swap stations or provide fast battery chargers in addition to petrol/diesel.

**Table 26 Proportion of available charging infrastructure relative to ICE vehicles (e.g. service stations)**

| Category | Base | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|---|
| ICE | 100% | 100% | 100% | 100% |
| HEV | 100% | 100% | 100% | 100% |
| PHEV | 0% | 100% | 100% | 100% |
| EV | 0% | 0% | 50% | 75% |

Source: AECOM

### 2.14.2 Cost

The cost of infrastructure is broken down into the cost to physically install the different levels of infrastructure as well as any costs involved with upgrading the electricity network to support the charging infrastructure.

Currently, it has been assumed that there will be no requirements to upgrade the electricity network. This assumes the use of smart metering so that households charge overnight during off peak periods and any significant investments are known in advance and can be built into investment plans with little additional costs. It is possible that Level 2 charging will require 3-phase which would require upgrades to the household service and possibly the street. The cost of the charging infrastructure will vary by the different scenarios.

#### Base Case

There will be no costs under the Base Case.

#### Scenario 1 (Household Only Charging)

The costs under Scenario 1 are minimal. Level 1 household charging utilises standard electrical circuits and power outlets and all charging electronics required to support Level 1 can be carried onboard the vehicle. However, as standard household sockets are only rated to 10A (which provides only 2.4kW of power and hence a 200 minute charge time for 40km), a socket rated to 15A (similar to those used for air conditioners) may require to be installed by an electrician. The cost of this installation has been estimated to be $400, declining to $200 reflecting technology improvements.

#### Scenario 2 (Household and Public Charging)

*Level 2 Household Charging*

Level 2 charging uses a vehicle's on-board charging system, but draws higher power for faster charging. This requires a "charging interface" known as Electric Vehicle Supply Equipment (EVSE) to be hard wired into a building's electricity supply to provide necessary protections from the higher voltages/currents. Additionally, special plugs/sockets with in-cable protection devices will be required to connect the vehicle to the EVSE. Level 2 charging can therefore be performed at home, but only if the appropriate equipment has been installed by an electrician. Based upon consultation with industry (Appendix A), it has been assumed that households will face an additional cost of $1500 for an electrician to fit a charging interface and that costs decline by 50% by 2020 reflecting technology improvements.

*Level 2 Public Charging Units*

Besides charging technology providers such as Coulomb Technologies, Elektromotive and Better Place, electricity utilities and vehicle manufacturers are supporting the deployment of charging infrastructure. Companies such as Électricité de France (EDF), Toyota, Renault-Nissan, Volkswagen, E.ON, CLP Power Hong Kong and TEPCO are involved in various partnerships or programs to rollout electric vehicles and/or supporting infrastructure.

**Table 27** provides a summary of the publically available information on the costs of charging infrastructure. Based on this review and industry consultation a price of $3000 per unit has been used in the model and are assumed to decline by 50% by 2020 reflecting learning curve and technology improvements.

**Table 27 Summary of charging units**

| Company | Description |
|---|---|
| Coulomb Technologies/ Charge Point (Australia) | Last year the city of Amsterdam announced plans to deploy 200 EV charging stations before 2012. They have appointed California's Coulomb Technologies to install the charging stations at a cost of US$5000 each (approximately A$6200)[11]. |
| Elektromotive | In 2008, the City of Westminster installed 12 electric vehicle charging points using Electromotive, at £3300/unit (approximately A$6600) (Westminster Council press release[12]). The charging stations have since been rolled out across London. |
| Toyota | In June 2009, Toyota Industries announced a new public charging station (AutoblogGreen, 2009). Toyota developed this unit with Nitto Electric Works and it's designed to feed single phase electric power at 200 V and 16 A. The charging units will cost ¥450,000 or about A$5,600 at current exchange rates. |
| Tesla Motors | Tesla is a sports electric vehicle manufacturer that also sells charging units for their vehicles which range from USD600 to USD1950. A home charging unit capable of a 4-hour charge sells for USD1950 and a portable unit costs USD1500 but is not capable of achieving as fast a charge as the home unit. A spare connector is also sold for USD600 but is only capable of recharging at approximately 5 miles per hour. |
| Nissan | When Nissan launches the Leaf they will also offer customers a home charging dock. The average cost of the charging dock including installation is US $2,200 (Nissan, 2010a). |
| Better Place | Better Place estimate that it will cost $500,000* to build battery swap stations. |

Source: AECOM

* Note does not include land costs

**Scenario 3 (Household Charging, Public Charging and Electric Vehicle Service Stations)**

The household charging and public charging will incur the same costs as in Scenarios 1 and 2. The cost of an electric vehicle service station is as yet unknown. Better Place estimate that it will cost $500,000 to build battery swap stations.

The ChaDEMO Association[13] is moving to develop a standard for Level 3 DC fast charging stations. Companies within the association are developing stations capable of delivering 50kW of power. Instead of using vehicles' onboard charging systems, AC power is rectified within an off-board station to DC and then delivered to the vehicle at high voltage and currents enabling faster charging (around 10 minutes for 40km). One company within the association, AeroVironment has also developed a DC fast charger capable of delivering up to 250kW of power[14].

The power supply for DC fast chargers is typically 3-phase, 415V supply at high currents (200-400V). Another approach has been developed by Evoasis with their EVSTAT Level 3 fast charge stations. EVSTAT stations are electrical "sub-stations" in their own right, using utility power stored during off-peak generation to supply EV and PHEV battery power at peak demand hours, thereby reducing the load placed on energy utilities during these periods. EVSTAT stations also generate on-site power from green energy sources built into the structure, with over 6000 square feet of photovoltaic (PV) panels, further reducing station energy dependency during sunrise-to-sunset operating hours. Evoasis supports the concept that with the right incentives in place, the impact on the electricity network can be minimised.

In 2010, Nissan unveiled its DC quick charge station[15] priced at 1.75m Yen, equivalent to approximately A$17,500.

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[11] Cleantech.com, NRC Handelsblad March 2009

[12] http://www.westminster.gov.uk/councilgovernmentanddemocracy/councils/pressoffice/news/pr-4234.cfm

[13] http://chademo.com/

[14] http://evsolutions.avinc.com/uploads/products/3_AV_EV250-FS_061110_public_high.pdf

[15] http://www.nissan-global.com/EN/NEWS/2010/_STORY/100521-01-e.html

Based upon industry consultation, it has been assumed that a charging station will cost $500,000 per station to build (either as a swap station, or a site with multiple DC fast chargers) and are assumed to decline by 50% by 2020 reflecting learning curve and technology improvements.

**Table 28 Summary of charging unit costs**

| | Residential charging (Level 1) | Residential charging (Level 2) | Public charge unit (Level 2) | Commercial station (DC fast charge or battery swap) |
|---|---|---|---|---|
| Cost per unit (2010) | A$400 | A$1500 | A$3000 | A$500,000 |
| Cost per unit (2020) | A$200 | A$750 | A$1500 | A$250,000 |
| Economic life | N/A | N/A | 10 | 25 |
| Expected return on capital | N/A | N/A | 7% p.a. | 7% p.a. |
| Utilisation | N/A | N/A | 10% | 20% |

Source: AECOM

## 2.15 Supply constraints

### 2.15.1 World manufacturing capacity

A large number of electric vehicle models are expected to be launched in the near future. Deutsche Bank has estimated that at least 120 hybrid, PHEV or EV models will be available worldwide by 2012 (Deutsche Bank, 2009). Whilst many new models are planned, there is some uncertainty as to how many will be produced and whether this will be sufficient to meet consumer demand.

Currently available electric vehicles are manufactured in relatively small quantities with demand generally exceeding supply. This has resulted in limited availability and customer waiting lists. For example, Tesla Roadsters are currently unavailable in markets outside of North America and Europe and waiting lists within those regions are in the order of 4 to 6 months.

At its launch in July 2009, Mitsubishi had a sales target of 1,400 i-MiEV vehicles in Japan to June 2010[16], planning to concentrate sales there so to stimulate the development of a charging station network . However, in 2010 the company announced plans to ramp up production to 30,000 units per annum in 2012[17].

Similarly, Nissan plans to initially restrict availability of the Nissan Leaf electric vehicle to Japan, Europe and the United States before a worldwide release in 2012 (Nissan, 2010b). Nissan plans to increase electric vehicle production capacity from around 50,000 vehicles per year in 2010 to 500,000 vehicles per year.

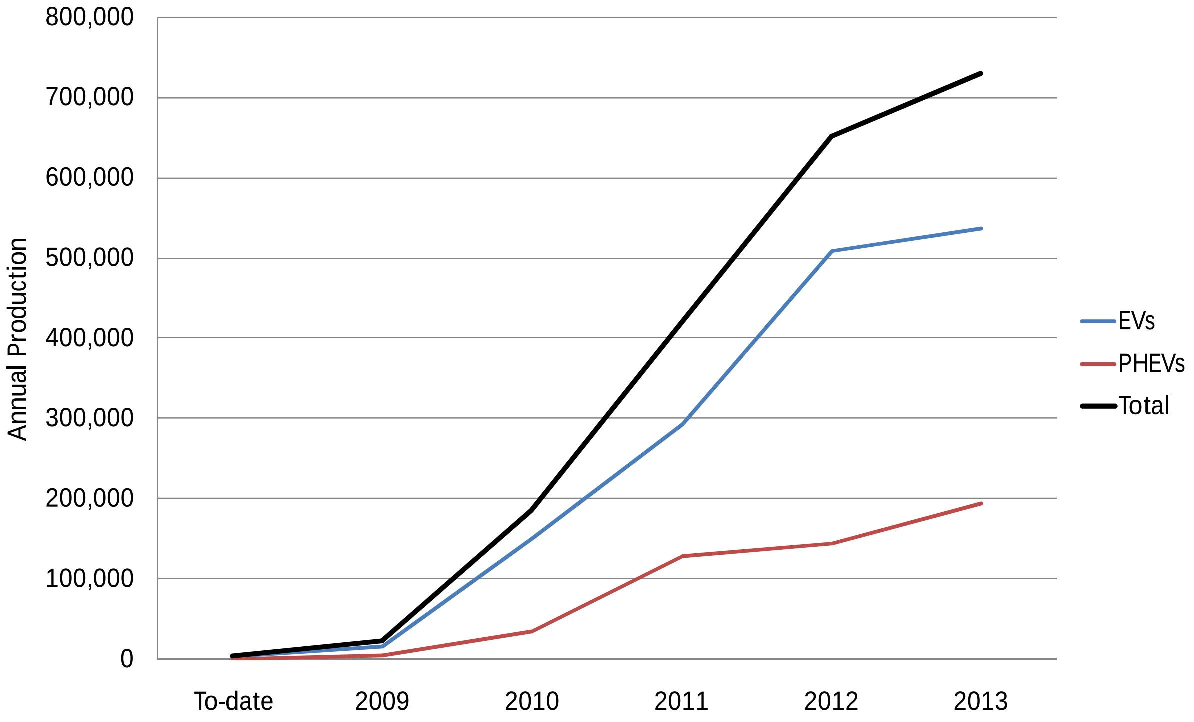
Prior to its launch in late 2010, General Motors stated that they believed that there will initially be much greater demand than available supply for the Chevy Volt. However, GM has stated that production can be increased dramatically to meet high demand (GM-Volt.com, 2010). It is understood that the Volt Detroit assembly plant is expected to produce 50,000 to 60,000 vehicles per year initially but is capable of producing up to 200,000 vehicles annually at peak production.

**Figure 11** charts the projected cumulative volumes for EV and PHEV production using announcements made in the automotive media. These targets should be considered as being at the optimistic end of the spectrum but, if true, would see global production volumes approaching one million plug-in vehicles within five years from now. This is supported by a study from Frost & Sullivan (2009) which estimates that the European market for EVs is likely to be about 480,000 units by 2015. The European market currently accounts for around 30% of global production (OICA, 2007).

[16] http://www.mitsubishi-motors.com/publish/pressrelease_en/products/2009/news/detail1940.html

[17] http://www.japantoday.com/category/business/view/mitsubishi-motorsto-triple-electric-car-output

**Figure 11 Industry plans for global production of EVs and PHEVs**




Source: AECOM and Dr. Andrew Simpson using announcements made in the automotive media

### 2.15.2 Australian supply

With the exception of some hybrid models (for example, the Toyota Hybrid Camry), AECOM is not aware of any current plans by vehicle manufactures to produce electric vehicles in Australia (with the exception of Blade Electric Vehicles, which undertakes small scale post-market conversion of Hyundai Getz vehicles to all-electric power). As such, it is likely that local electric vehicle demand will be required to be met by imports of vehicles manufactured elsewhere.

For the 2009 NSW Study, AECOM assumed that 1% of total world electric vehicle supply would be available for purchase in Australia as per sale of HEVs to date. However, it is possible that future electric vehicle supply will not be distributed in the same proportions as conventional vehicles.

It is likely that electric vehicle manufacturers may focus their available supply and marketing efforts on countries with suitable infrastructure, consumer preference and driving habits rather than simply distribute electric vehicles to different markets in the same proportions as conventional vehicles. In addition, companies like Better Place have made agreements with vehicle manufacturers to ensure the availability of vehicles in locations where infrastructure investments will be made.

Australia has the potential to be an attractive location for electric vehicle manufacturers to supply vehicles, despite the relatively small market size. Australia is a wealthy, stable country with very high levels of car ownership and car use. Additionally, Better Place has announced that Australia will be one of the first locations in which it will roll out electric vehicle charging infrastructure, further increasing the attractiveness of the Australian market. As such, it is possible that Australia will receive more than 1% of global electric vehicle production in the near future.

**Table 29** shows the vehicle supply parameters applied in this study.

**Table 29 Vehicle supply parameters**

| Parameter | HEV | PHEV | EV |
|---|---|---|---|
| Australian proportion of global market | 1% | 1% | 1% |
| Year of first availability in model | 2010 | 2012 | 2012 |
| End of supply constraint | 2015 | 2020 | 2020 |
| Initial world supply | 1,000,000 | 150,000 | 500,000 |
| Annual growth in supply: | | | |
| • To 2015 | 35% | 20% | 40% |
| • From 2016 onwards | 35% | 20% | 30% |

Source: AECOM and Dr. Andrew Simpson based on industry consultation

## 2.16 Model outputs

The above analysis will be used to calculate the following model outputs which will feed into the cost benefit analysis:

- Proportion of vehicle sales by market segment and engine configuration;
- Vehicle kilometres travelled (VKT) by market segment and engine configuration;
- Infrastructure costs;
- Vehicle costs (purchase price and operating costs);
- Cost per kilometre travelled for the different market segmentations and engine configurations; and
- Externalities (quantities and values) including greenhouse gas emissions and air pollution.

## 2.17 Summary of assumptions and recommended sensitivity

This study considers a 30 year time frame for a relatively new market. As such, there is much uncertainty around the future path of many of the key variables. This study has used the best available information to forecast variables and built a model that will allow extensive sensitivity testing around the key variables and that can be easily updated as new information becomes available. The key areas of sensitivity testing are highlighted in **Table 30**.

The key factors likely to affect the outcomes of this study include:

- Vehicle price and changes over time;
- Fuel prices (fossil fuels and electricity); and
- Fuel efficiencies and changes over time.

**Table 30 Summary of key assumptions**

| Variable | Current Assumption / Suggested Sensitivity |
|---|---|
| **General model** | |
| Discount rate – economic | 5%<br>Sensitivity at 3.2% and 10.2% (Risk-free 10-year bond rate, and 10-year bond rate with 7% risk premium added) |
| Discount rate – financial | 5%<br>Sensitivity at 3.2% and 10.2% (Risk-free 10-year bond rate, and 10-year bond rate with 7% risk premium added) |
| **New vehicle sales** | |
| Demand for new passenger vehicles | Assumed growth as set out in **Table 5**.<br>Sensitivity test – high vehicle growth rate of 1.75% per annum to 2040 |
| Projections of new passenger vehicle sales by vehicle type | Currently assume shift from large to medium vehicles continues. In 2008:<br>- Small – 52% of new sales<br>- Medium – 24%<br>- Large – 24%<br><br>Assume that this changes by 2020 to:<br>- Small – 60%<br>- Medium – 30%<br>- Large – 10%<br><br>Sensitivity test – keeping market shares at 2010 proportions. |
| Proportion of VKT ranges in each vehicle size category | It is assumed that VKT proportions by vehicle type will be unchanged in the future. |
| Proportion of new LCV sales | Assume grows at 6% p.a. in 2010 declining to 3% p.a. in 2040<br>Sensitivity test – maintain growth rate at 6% p.a. to 2040. |
| Taxis | Assume to grow in line with population. |
| **Vehicle price** | |
| Fixed vehicle price | Prices based on global survey<br>- $10,000 premium in Australia compared to US prices<br>- No growth in ICE prices<br>- HEVs reach price parity with ICEs in 2020<br>- PHEVs and EVs reach price parity with ICEs in 2025<br><br>Sensitivity tests on different price parity years and growth rates. |
| **Fuel efficiency** | |
| Fuel type | Current fossil fuel mix remains same.<br>- Passenger vehicles: 79.5% petrol, 5% diesel and 15.5% LPG.<br>- LCV: 49.9% petrol, 32.5% diesel and 17.8% LPG.<br>- Taxi: 100% LPG.<br><br>Sensitivity test: 69.5% petrol, 15% diesel and 15.5% LPG for passenger vehicles |
| Growth in fuel efficiencies | - ICE: 37% between 2006 to 2050<br>- HEVs: relative to ICE. See **Table 16**<br>- EVs: 20% increase to 2050. See **Table 17**.<br>- PHEV: EV 50% of kilometres in 2006 increasing to 80% in 2035. |

| Variable | Current Assumption / Suggested Sensitivity |
|---|---|
| **Fuel costs** | |
| Oil price | Three scenarios:<br>- High – corresponds to EIA (Energy Information Agency) high price scenario;<br>- Reference – corresponds to the EIA reference scenario; and<br>- Low – equal to a 20% discount from the Reference scenario. |
| Base prices | - Diesel – 100% petrol price<br>- LPG – 40% of petrol prices |
| Excise | The current fuel excise is $0.381/litre and is applied to petrol and diesel. LPG tax is scheduled to begin on 1 June 2011 (will be same as petrol excise in terms of $/litre) |
| CPRS | Price based on forecast by Treasury modelling (2008)<br>Sensitivity tests: No CPRS, CPRS-15, and CPRS delayed until 2020. |
| GST | 10% (No sensitivity) |
| **Electricity prices** | |
| Wholesale prices | Prices from Treasury modelling (2008). Sensitivity tests using prices at +/- 20% of Treasury reference price |
| Carbon emissions policy | Prices from Treasury modelling:<br>- Reference<br>- CPRS-5<br>- CPRS-15 |
| Residential network charge | Equal to network charge as determined by Treasury |
| Additional residential network charge | 20% premium on residential network charge |
| Commercial charging station network charge | Equal to residential network charge plus a premium see **Section 2.8.2** |
| Public charging point network charge | Equal to residential network charge plus a premium see **Section 2.8.2** |
| **Other vehicle costs** | |
| Fuel cost per km | Derived from fuel efficiencies and prices for fossil fuels and electricity |
| Registration | Fixed registration from VicRoads – no growth |
| Insurance | Transport Accident Charge – no growth<br>Comprehensive insurance – no growth |
| Maintenance | Maintenance costs defined relative to ICE costs:<br>- HEV – assumed 12% less than equivalent ICE;<br>- PHEV – assumed 25% less than equivalent ICE; and<br>- EV – assumed 30% less than equivalent ICE.<br>Sensitivity for EV at 50% of an equivalent ICE. |

| Variable | Current Assumption / Suggested Sensitivity |
|---|---|
| **Other assumptions** | |
| Range | - ICE and HEV – 500km for small passenger; 550km for all other categories<br>- EV – range from 120km to 300km depending on vehicle category. See **Table 24.**<br>- PHEV – range is equal to maximum of EV or ICE<br>- All grow over time in line with increased fuel efficiencies<br>- EVs also grow from 5% per annum increase in battery storage. |
| Emissions | Derived from fuel efficiency, fuel emissions factor and vehicle segment |
| Infrastructure | Availability relative to ICE vehicles:<br>- ICE and HEV – 100% availability for all scenarios<br>- PHEV and EV – availability depends on scenario. See **Table 26**. |
| Multi-fuel bonus | HEVs and PHEVs receive bonus<br>Sensitivity undertaken with and without multi-fuel bonus |
| Non-captive market | Proportion of market that may purchase EV or PHEV dependent on VKT and scenario. See **Table 25**. |
| Supply constraints | There are expected to be global supply constraints until at least 2012 and as such, a supply constraint has been built into the model to ensure it reflects current market conditions.<br>- HEV – 1,000,000 HEVs currently in global production, growing by 35% per year. Australia will receive 1% of global supply. Supply will be constrained until 2015.<br>- PHEV - by 2012 there will be 150,000 PHEVs in global production and 1% of these will reach Australia. Production will grow at 20% per year and be constrained until 2020.<br>- EV – by 2012 there will be around 500,000 EVs in global production and 1% of these will reach Australia. Production will grow at 40% per year until 2015 and by 30% per year from 2016 onwards. Supply will be constrained until 2020.<br><br>Sensitivity tests:<br><br>- Supply of non-ICE vehicles to Australia unconstrained<br>- Australia receives 5% of global supply of non-ICE vehicles (instead of 1%)<br>- Supply into Australia becomes unconstrained at 2020, 2025, and 2025 for HEVs, PHEVs and EVs respectively. (5 years later than central case)<br>- Supply into Australia becomes unconstrained at 2025 for HEVs, PHEVs and EVs respectively. |
| Cost of infrastructure | Base – no costs<br>Scenario 1 – no costs<br>Scenario 2<br>- $1500 per household for Level 2 EVSE<br>- $3000 per Level 2 public charging unit<br>Scenario 3<br>- $1500 per household for Level 2 EVSE<br>- $3000 per Level 2 public charging unit<br>- $500,000 per charging station (battery swap or equipped with DC fast chargers)<br>Cost of charging units and charging stations assumed to decline by 50% by 2020. |

# 3.0 Vehicle Choice Results

A key part of this study is the vehicle choice model which determines what proportion of new vehicle sales are for the different vehicle types. These results are based on central forecasts of oil price, electricity price and CPRS policy.

## 3.1 Vehicle sales for different scenarios

Annual vehicle sales for the Base Case are shown in **Figure 12**. There are no sales of PHEVs or EVs under the Base Case. The sale of HEVs grows gradually to 2014 then increases rapidly following the removal of the supply constraint in 2015 and the convergence of HEV purchase prices to that of an ICE vehicle in 2020. The removal of the supply constraint represents a step-change in 2015. In practice, it is expected that a more gradual ramping up of sales would occur over a number of years.

Under Scenario 1, PHEVs and EVs are introduced into the market in 2012 and make up a small share of new vehicle sales until 2020 (see **Figure 13**). When supply becomes unconstrained in 2020 there are increased sales of PHEVs, however EVs remain a relatively small proportion under this Scenario as charging facilities are restricted to household only.

Vehicle sales under Scenario 2 are shown in **Figure 14**. The results are similar to those under Scenario 1, however sales of PHEVs and EVs are stronger due to the improved provision of charging infrastructure and post-2025, following price parity with ICE vehicles occurring.

Under Scenario 3, the trends exhibited under Scenario 2 are further enhanced with the introduction of commercial charging stations, as shown in **Figure 15.** PHEVs and EVs gradually become the dominant engine configuration in the mid-2020s as prices converge with ICE vehicles. The share of HEVs declines dramatically as PHEVs grow to hold the largest share of sales by the mid-2020s. PHEVs remain the largest proportion of sales in 2040 however EVs represent an increasing proportion of sales of approximately 20% by 2040.

In summary, the sales of PHEVs and EVs are highly dependent on any supply constraints into the Australian market, when price parity with ICE vehicles is achieved and the provision of charging infrastructure.

The vehicle choice model takes account of:

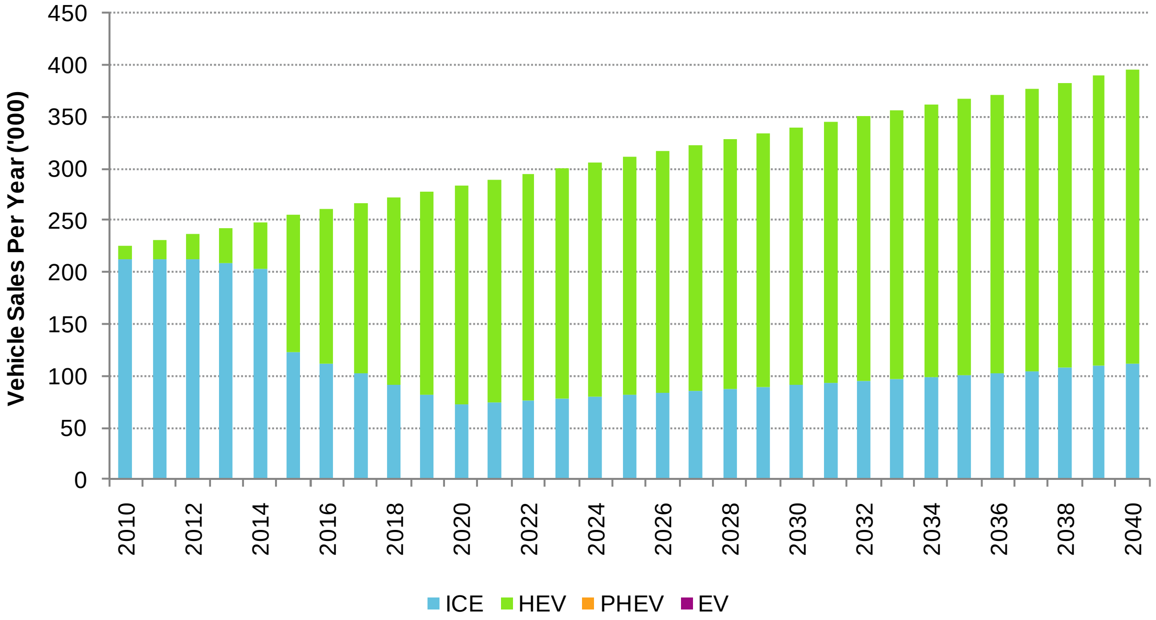
- Vehicle cost;
- Fuel cost;
- Range
- Emission;
- Infrastructure; and
- Multi-fuel bonus.

The vehicle price and fuel costs have a large negative impact on the vehicle choice decision, and in contrast the range and infrastructure have a large positive impact. Emissions and multi-fuel bonus are smaller factors in the decision making process.

In early years, the take-up of PHEVs is stronger than that of EVs due to superior range and the ability to use both electricity and petrol as fuel. However, in later years there is a shift towards EVs as purchase prices converge to parity with ICE, battery improvements result in increased vehicle range and higher fuel prices make EVs more competitive

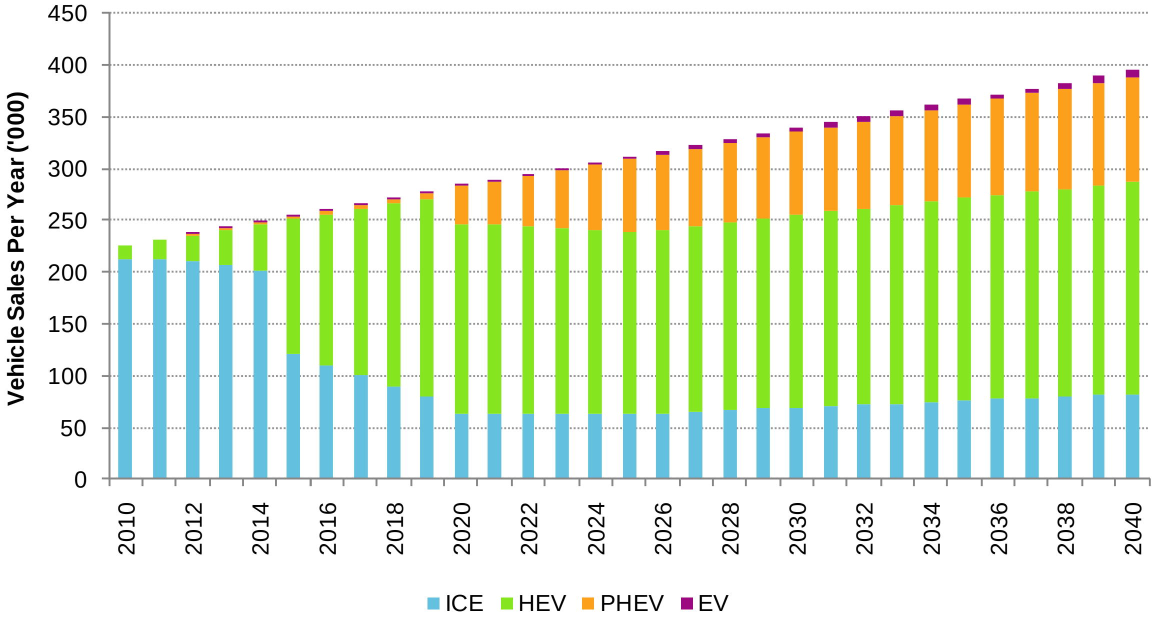
Over time, as EVs become cheaper and their range improves, there will be a shift towards EVs provided charging infrastructure becomes readily available.

**Figure 12 Vehicle sales per year in Base Case**



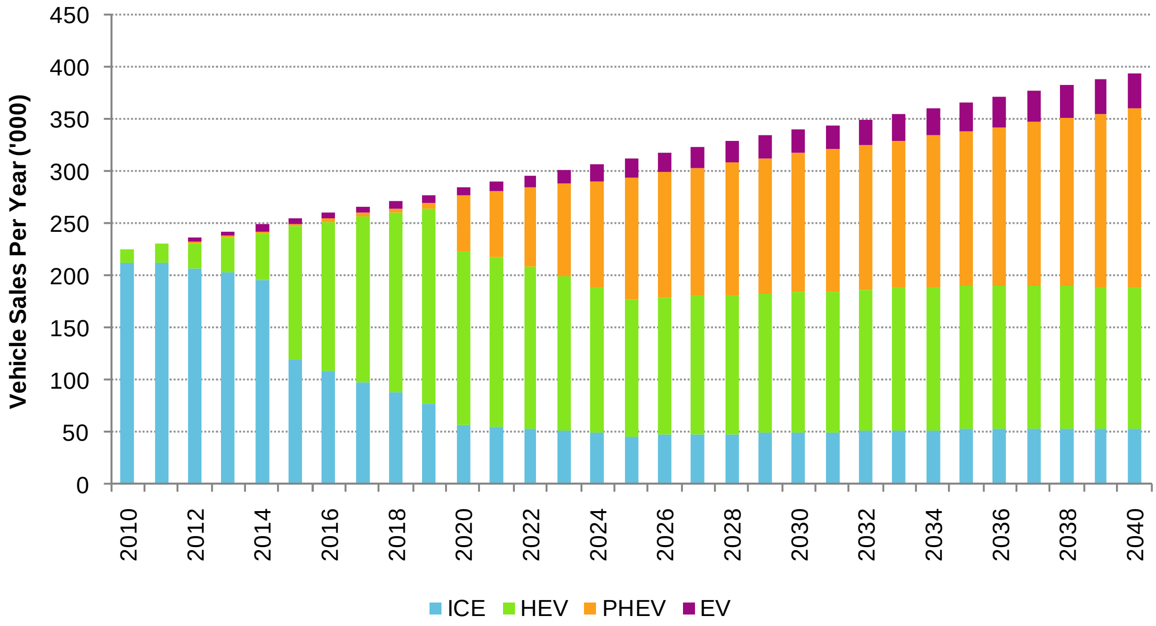

Source: AECOM

**Figure 13 Vehicle sales per year in Scenario 1**



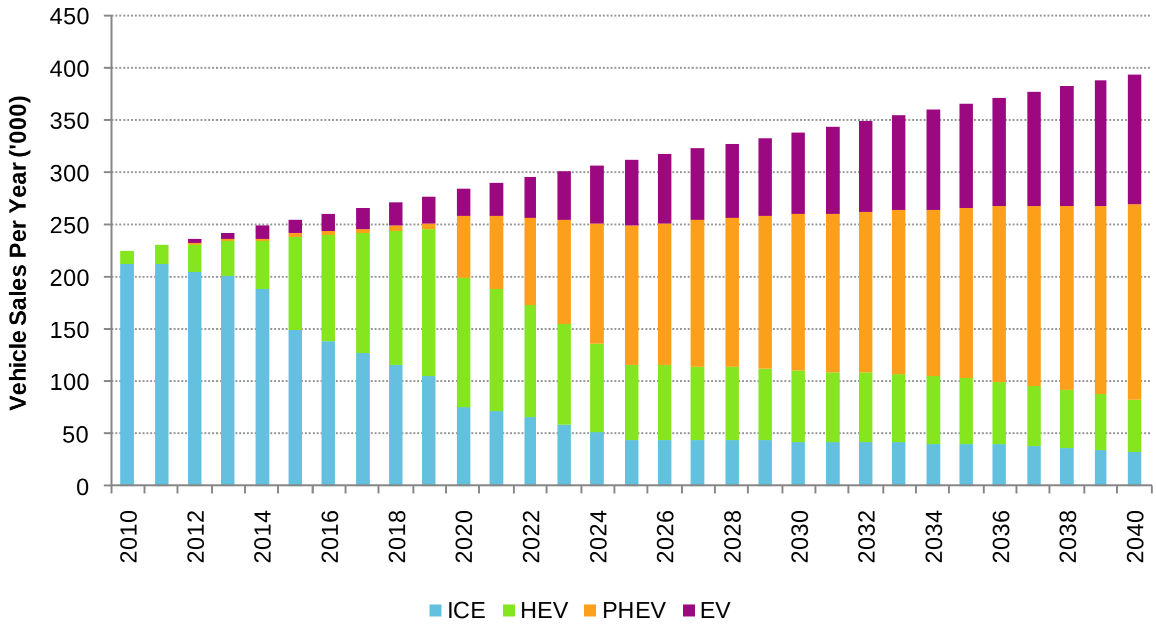

Source: AECOM

**Figure 14 Vehicle sales per year in Scenario 2**




Source: AECOM

**Figure 15 Vehicle sales per year in Scenario 3**




Source: AECOM

## 3.2 Proportion of vehicle sales for different market segmentations

As set out in **Figure 16(a)**, new vehicle sales under all Scenarios comprise mainly ICE vehicles. HEVs make up 5-7% of passenger vehicles depending on size, while only 2% of taxis are HEVs.

Under Scenario 1 (see **Figure 16(b)**), by 2040 a large proportion of passenger vehicles sales are PHEVs, ranging from 62-92% as vehicle size increases. A small number of EVs are sold with the largest share being 7% in the large passenger vehicle category. For passenger vehicles, the largest proportion of HEVs comes in the small category with 26% of market share. Light commercial vehicles and taxis are predominantly HEVs with no PHEVs or EVs.

An increase in EV sales in 2040 compared to Scenario 1 can be seen for Scenario 2 in **Figure 16(c)**. EVs take market share away from PHEVs as public charging infrastructure becomes available. In the small, medium and large vehicle categories, EVs respectively constitute 10%, 16% and 19% of the market. Interestingly, the shares of each engine configuration for light commercial vehicles becomes more balanced, with ICEs, HEVs and PHEVs having 20%, 39% and 34% market shares with EVs filling the remaining 8% of the market. There are no PHEVs or EVs sold in the taxi market.

Following the introduction of commercial charging stations in Scenario 3, electric vehicle sales are further increased as shown in **Figure 16(d)**. HEVs are 25% of the market for small passenger vehicles however for medium and large sizes, EVs continue to take market share from PHEVs. Over time, as purchase prices converge, the main differences between engine configurations are driven by operating cost savings which are less for small cars as they typically travel less and have better fuel efficiencies.

For large passenger vehicles, EV market share is 30%, PHEV market share is 69% with the remaining 1% shared between ICE and HEV. Almost identical proportions are seen in the taxi market as they are considered to be similar to large passenger vehicles.

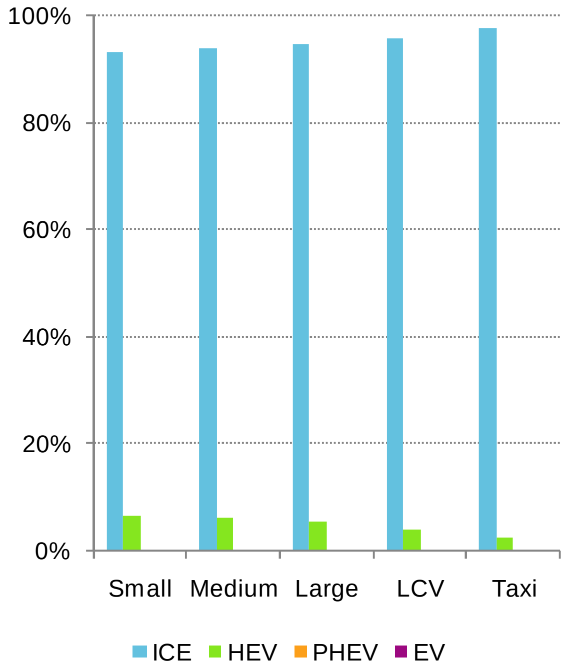
## 3.3 Summary

In summary, the vehicle choice model predicts:

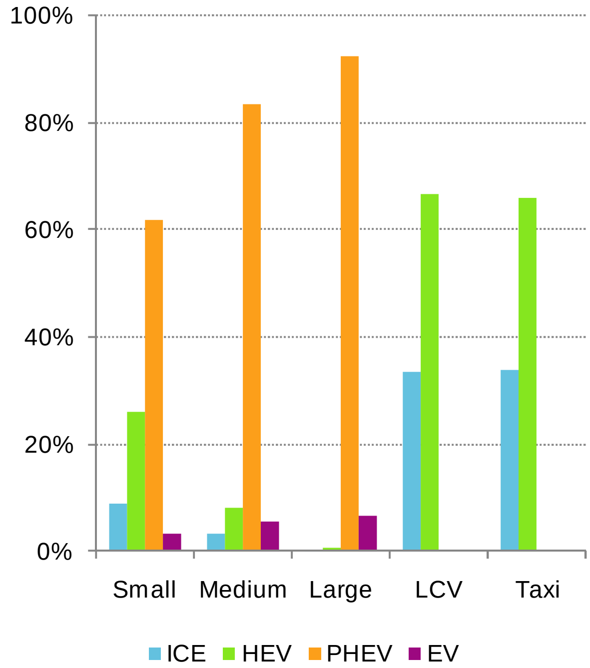
- A transition to HEVs in the near term (5-10 years); PHEVs over the medium to long term (10-20 years) and EVs over the long term (15 years plus).
- Take-up of PHEVs and EVs is sensitive to the year in which parity with ICE vehicles is achieved and any supply constraints into the Australia market.
- The provision of charging infrastructure (both public charging units and commercial stations) as represented through the different scenarios, has a significant impact on the sales of EVs.
- There are increased sales of HEVs in the near term for the small passenger vehicle category. This occurs as supply becomes unconstrained and there is no requirement for charging infrastructure. However, as prices gradually reach parity, vehicle range improves and more charging infrastructure becomes available, larger vehicles and vehicles that travel large distances tend to purchase a higher proportion of EVs. This is primarily due to increased operating costs (as global oil prices rise) inducing these vehicle owners to switch to more efficient technologies to achieve fuel cost savings.

**Figure 16 Proportion of vehicle sales by size and configuration**

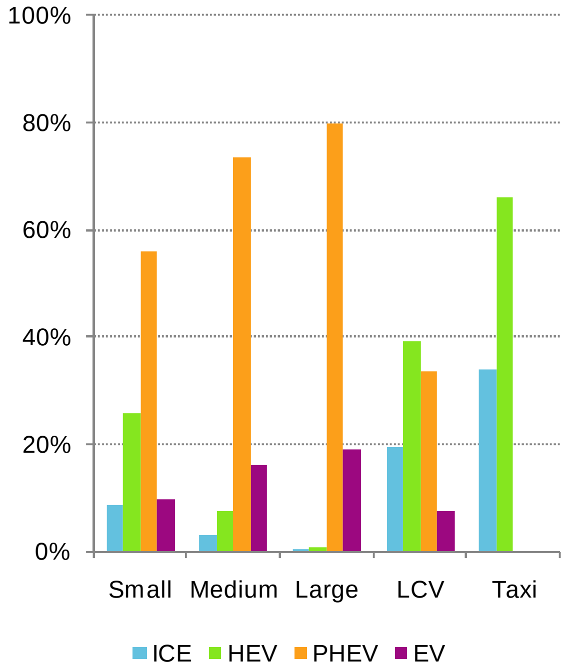
**(a) 2010 (all scenarios)**



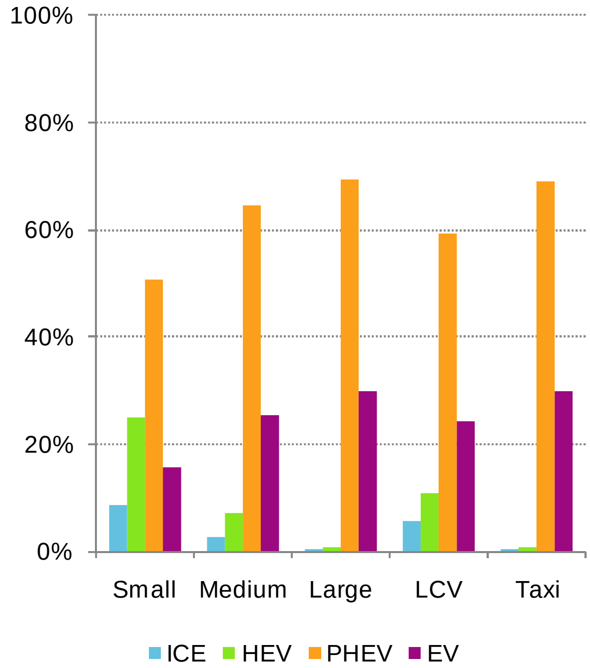

**(b) 2040 (Scenario 1)**




**(c) 2040 (Scenario 2)**




**(d) 2040 (Scenario 3)**




Source: AECOM

# 4.0 Externalities

In order to calculate the change in externalities, emission factors have to be determined. Both physical emission factors for different pollutants and the economic values of these factors need to be applied. This study has considered greenhouse gas emissions from both fossil fuels and electricity, and air pollution arising from vehicles. Air pollution from electricity generation has not been included because electricity is purchased from the National Electricity Market operating across all states in eastern Australia and therefore cannot be attributed to any particular generation type or location.

## 4.1 Air pollution

### 4.1.1 Emission factors

Tailpipe emissions on a per kilometre travelled basis have been estimated from figures published in Victorian Transport Facts (Apelbaum Consulting, 2007) and are shown in **Table 31**.

It has been assumed there will be no air pollution for electric vehicles and for hybrid vehicles air pollution will only arise from the proportion of drivetime using fossil fuels. As vehicle fuel efficiencies improve over time, allowing vehicles to travel increased distances from the same amount of fuel, emissions per kilometre are expected to decrease. It has been assumed that the per kilometre emission factors in **Table 31** are applicable to new vehicles in 2010, but will decrease in proportion with fuel efficiency gains in future years.

**Table 31 Air pollution emissions factors (g / km)**

| Fuel | $CH_4$ | $N_2O$ | $NO_x$ (40km/h) | CO (40km/h) | NMVOC (40km/h) | $PM_{10}$ |
|---|---|---|---|---|---|---|
| **Passenger vehicles** | | | | | | |
| Petrol | 0.006 | 0.053 | 0.070 | 1.620 | 0.030 | 0.014 |
| Diesel | 0.003 | 0.027 | 0.270 | 0.330 | 0.040 | 0.041 |
| LPG | 0.006 | 0.008 | 0.040 | 0.830 | 0.010 | 0.014 |
| **Light commercial vehicles** | | | | | | |
| Petrol | 0.002 | 0.053 | 0.030 | 0.850 | 0.010 | 0.011 |
| Diesel | 0.001 | 0.017 | 0.600 | 0.210 | 0.020 | 0.037 |
| LPG | 0.002 | 0.007 | 0.030 | 0.720 | 0.010 | 0.012 |

Source: Apelbaum Consulting (2007)

### 4.1.2 Externality value

Austroads (2008b) guidelines provide a default value for air pollution externalities of 2.54 cents per vehicle kilometre (2007$) for passenger vehicles in urban areas. This value has been escalated to 2.78 cents per vehicle kilometre (2010$) and is assumed to represent emissions for an average vehicle. Emissions for each market segments have been scaled by the segment fuel efficiency relative to the average fuel efficiency.

### 4.1.3 Summary

**Table 32** sets out the total air pollution and cost savings by 2040 under each scenario. The savings increase substantially across the scenarios as take-up of EVs increases. By 2040, Scenario 3 results in a saving of around $3.3 billion compared to the Base Case. Scenario 2 has total savings of around $1.6 billion and Scenario 1 has savings of around $0.3 billion.

Note that the model only includes vehicles purchased after 2010 and is therefore not measuring the total vehicle stock.

**Table 32 Total air pollution savings by 2040**

| Air pollutant | Scenario 1 (tonnes saved by 2040) | Scenario 2 (tonnes saved by 2040) | Scenario 3 (tonnes saved by 2040) |
|---|---|---|---|
| $CH_4$ | 300 | 1,300 | 2,500 |
| $N_2O$ | 2,600 | 12,400 | 24,100 |
| $NO_x$ | 3,500 | 19,600 | 38,300 |
| CO | 81,500 | 354,800 | 684,700 |
| VOC | 500 | 2,400 | 4,900 |
| $PM_{10}$ | 800 | 3,800 | 7,500 |
| Cost savings (Discounted to 2010 at 5%) | $480m | $2,340m | $4,600m |

Source: AECOM. Note pollution and cost savings are rounded to the nearest 100 tonnes and $10m respectively.

## 4.2 Greenhouse gas emissions

The greenhouse gas emissions will be different for the different types of fuel used in the different engine configurations under consideration. As such, fossil fuel emissions and electricity emissions have been considered separately.

### 4.2.1 Emission rates

**Fossil Fuels**

Estimates of emissions from the combustion of individual fuel types are made by multiplying the quantity of fuel by a fuel specific energy content factor and a fuel specific emissions factor. **Table 33** sets out the guidance from the Department of Climate Change and Energy Efficiency in the National Greenhouse Accounts (NGA) Factors.

**Table 33 Emission factors for fuel**

| Fuel | Energy Content Factor (GJ/kL) | Emission Factor (kg $CO_2$e/GJ) | | | |
|---|---|---|---|---|---|
| | | $CO_2$ (Scope 1)[1] | $CO_2$ (Scope 3)[2] | $CH_4$ | $N_2O$ |
| Gasoline | 34.2 | 66.7 | 5.3 | 0.02 | 0.2 |
| Diesel | 38.6 | 69.2 | 5.3 | 0.01 | 0.6 |
| LPG | 26.2 | 59.6 | 5.0 | 0.3 | 0.3 |

Source: Department of Climate Change and Energy Efficiency (2010)

Note: These figures are for post-2004 vehicles that conform to Euro design standards

1. Scope 1 emissions are those produced directly at the point of emission release (i.e. combustion of fuel)

2. Scope 3 emissions are those produced indirectly in the extraction, production and transport of fuels (also known as well-to-tank emissions)

It is assumed that the emission factors for fuel will not change over time. Fossil fuels may become more difficult to extract over time requiring more use of energy upstream. There is insufficient information to model this so it has been assumed to remain constant.

## Electricity

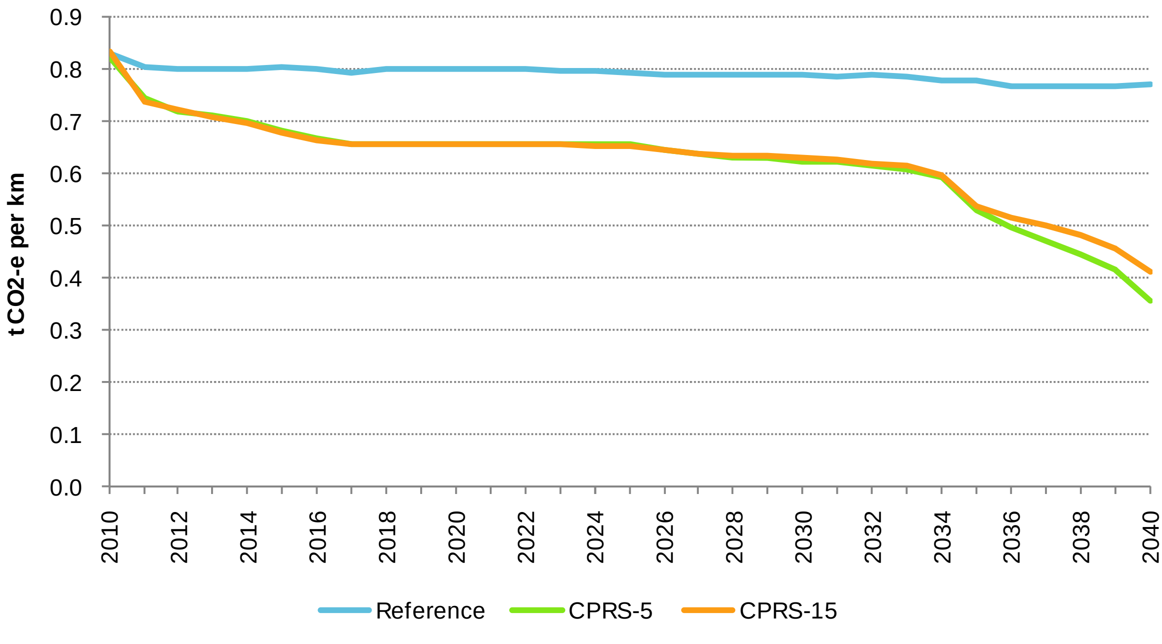
The National Greenhouse Accounts (NGA) Factors recommend an emissions intensity factor of 1.23 kg $CO_2$e per kWh (Scope 2) and 0.14 kg $CO_2$e per kWh (Scope 3) for electricity generated in Victoria.

The greenhouse gas emissions of electric vehicles are dependent on the energy source of the electricity used to power the vehicle. The energy source of electricity is expected to change significantly over the next 30 years. Government policies such as the Renewable Energy Target (RET) and the Carbon Tax/Carbon Pollution Reduction Scheme (CPRS) will provide impetus to this change.

There is general consensus that whatever specific technology mix emerges, it is likely to deliver a progressive decarbonisation of electricity generation by mid-century. This is reflected in the Treasury's forecast of the national electricity grid emissions intensity, as illustrated in **Figure 17**, which have been used in this study (Treasury, 2008). These factors only represent Scope 2 emissions so Scope 3 emissions have been added to this, assuming they remain the same proportion of total emissions.
The carbon policy scenarios specifically modelled are:

- Reference case – no additional emission reduction measures (excludes expanded mandatory renewable energy target);
- CPRS-5 – 5% reduction from 2000 emission levels by 2020; and
- CPRS-15 – 15% reduction from 2000 emission levels by 2020.

**Figure 17 Electricity emissions intensity**




Source: Treasury (2008)

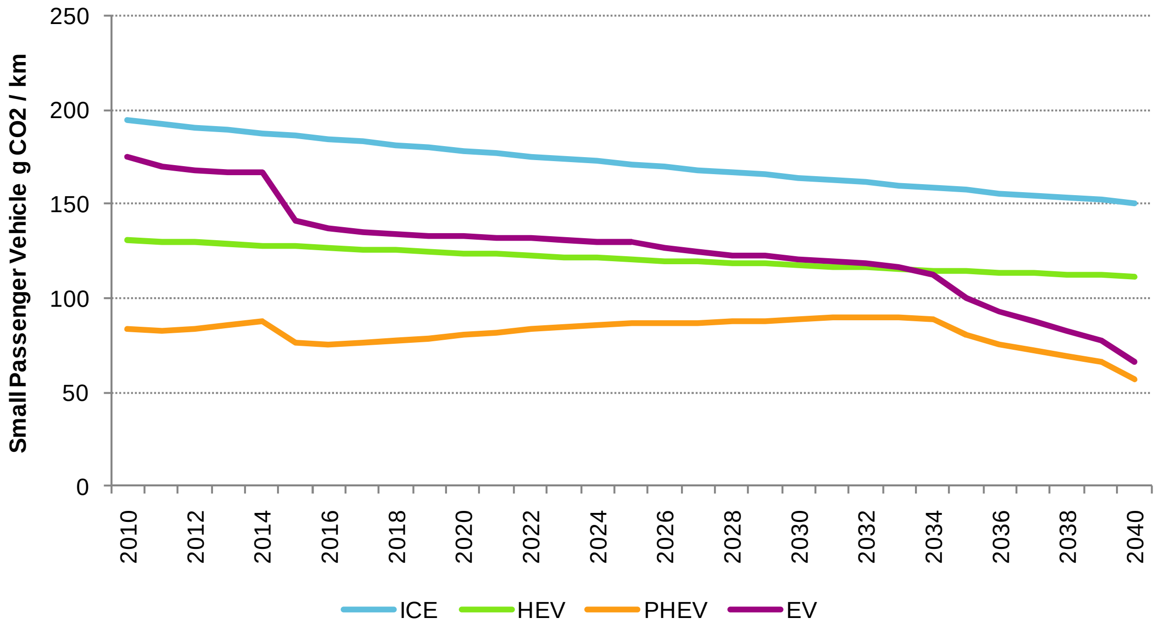
### Greenhouse gas intensities of different engine configurations

**Figure 18** illustrates the greenhouse gas intensities per kilometre travelled for the different engine configurations for a small passenger vehicle. The intensity is dependent on the fuel efficiency and how this changes over time, as well as the greenhouse gas intensity of the different fuel (fossil fuel or electricity). ICE vehicles are the most greenhouse gas intensive per kilometre travelled. HEVs are the least greenhouse gas intensive per kilometre travelled until the late 2020's, when the emissions intensity of electricity falls due to increased renewable energy generation. Around 2027 EVs take over as the least greenhouse gas intensive vehicle. PHEV's track the performance of EVs but are slightly behind due to the proportion of ICE powertrain.

The weighted average passenger vehicle emissions per kilometre are shown in **Figure 19**. Over time, the emissions rate declines from approximately 230 g $CO_2$-e per km in 2010 to around 141 g $CO_2$-e per km in 2040 for Scenario 1. Emissions rates under Scenario 2 and 3 exhibit further improvements declining to 138 and 114 g $CO_2$-e per km in 2040 respectively.

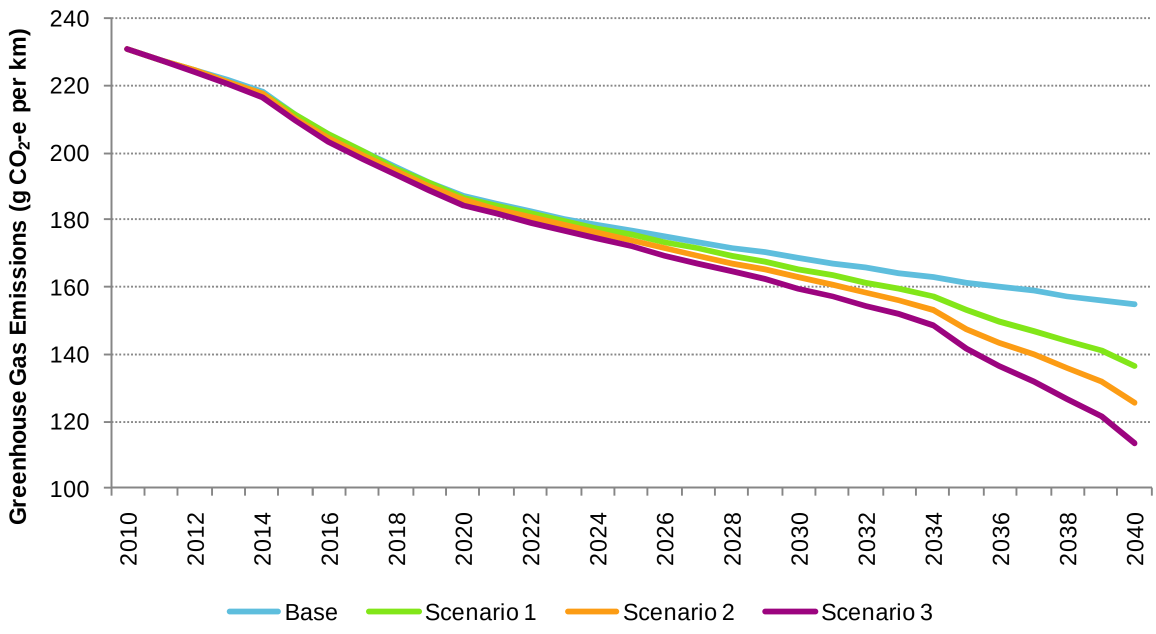
Differences between Scenarios become more prominent from approximately 2025 onwards, as price parity is achieved, supply becomes unconstrained and rising fuel prices encourage take-up of PHEVs and EVs, thereby decreasing the weighted average rate of emissions per kilometre of new passenger vehicles.

**Figure 18 Greenhouse gas intensities per kilometre travelled – small passenger vehicle, low VKT**




Source: AECOM

**Figure 19 Weighted average passenger vehicle greenhouse gas emissions (g $CO_2$-e per km)**




Source: AECOM

### 4.2.2 Value

As discussed in **Section 2.8.2**, the Treasury modelling forecasts of the CPRS permit price have been used in this study to ensure consistency with other CPRS forecasts. These have been adjusted to reflect recently announced policy changes including delaying the implementation of the scheme by a year and a $10 fixed price in the first year.

Although the proposed carbon tax/CPRS is expected to price greenhouse gas emissions that result from petrol/diesel or electricity, AECOM believes further assessment is warranted. The CPRS will be a market price reflecting the value of traded carbon emissions rights given the constraints on supply imposed by the scheme. This, in practice, is often less than the social cost of carbon which seeks to encapsulate the full global cost today of an incremental unit of $CO_2$-e emitted now, summing the full global cost of the damage it imposes over the whole of its time in the atmosphere.

There is a large amount of literature available on the issue of external costs of greenhouse gas emissions. The values vary significantly depending on the approach used and the country in which the analysis is undertaken. International research on the social cost of carbon suggests a figure of around A$50 per t $CO_2$-e. The UK Government recently adopted a value of £25.5 per t $CO_2$-e (2007 prices) that increases by 2% per year to reflect the damage costs of climate change caused by each additional tonne of greenhouse gas emitted. This has been made mandatory for all economic appraisals by the UK Government and was endorsed by the OECD. Recent research on the external cost of greenhouse gas emissions for the European Commission recommends a central value of €25 per t $CO_2$-e (around A$50 per t $CO_2$-e) in 2010 rising to €40 per t $CO_2$-e (around A$80 per t $CO_2$-e) by 2020 (CE Delft, 2008).

Given there is an emerging body of international evidence suggesting the social cost of carbon is around $65 per t $CO_2$-e (2010$), this has been used in this study to value the changes in greenhouse gas emissions. The central case is based on values published by the UK Department of Environment, Food and Rural Affairs, converted to Australian dollars by means of purchasing power parity exchange rates. Given some of the cost of greenhouse gas emissions is priced into the market through the CPRS scheme, the value used in this study will be the difference between the CPRS permit price and the recommended social cost of carbon.

### 4.2.3 Summary

Table 34 sets out the greenhouse gas emissions under each scenario. Compared to the Base Case, Scenario 3 saves around 46.4 million tonnes $CO_2$-e by 2040 with a corresponding present value economic benefit of $500m.

**Table 34 Total greenhouse savings by 2040**

| | Scenario 1 | Scenario 2 | Scenario 3 |
|---|---|---|---|
| Greenhouse gas savings by 2040 (t $CO_2$-e) | 4.3m | 23.0m | 46.4m |
| Economic benefit (Discounted to 2010 at 5%) | $50m | $240m | $500m |

Source: AECOM. Note economic benefits are rounded to nearest $10m.

## 4.3 Summary

**Table 35** summarises the total greenhouse gas and air pollution savings compared to the Base Case under each Scenario.

**Table 35 Greenhouse gas and air pollution emission savings compared to the Base Case (tonnes)**

| Emissions | Scenario 1 | | | Scenario 2 | | | Scenario 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 2030 | 2040 | 2020 | 2030 | 2040 | 2020 | 2030 | 2040 |
| Greenhouse gas | 16,000 | 116,900 | 723,800 | 65,600 | 673,000 | 3,780,200 | 161,700 | 1,437,800 | 7,299,900 |
| $CH_4$ | 10 | 80 | 300 | 30 | 300 | 1,300 | 60 | 700 | 2,500 |
| $N_2O$ | 30 | 600 | 2,600 | 200 | 3,100 | 12,400 | 500 | 6,200 | 24,100 |
| $NO_x$ | 100 | 1,000 | 3,500 | 400 | 4,900 | 19,600 | 800 | 9,900 | 38,300 |
| CO | 1,200 | 20,300 | 81,500 | 6,300 | 90,400 | 354,800 | 14,800 | 182,900 | 684,700 |
| VOC | 30 | 100 | 500 | 100 | 600 | 2,400 | 200 | 1,300 | 4,900 |
| $PM_{10}$ | 20 | 200 | 800 | 70 | 1,000 | 3,800 | 200 | 2,000 | 7,500 |

Source: AECOM. Note values are rounded to the nearest 10 tonnes.

# 5.0 Economic and Financial Results

This chapter brings the model results together to assess the economic and financial viability of an electric vehicle market. The results presented below are based on central forecasts of oil price, electricity price, CPRS policy and the shadow cost of carbon.

## 5.1 Net present value

**Table 36** sets out the present value of the benefits associated with introducing electric vehicles variants into the Victorian metropolitan market compared to the Base Case. The model shows that under all scenarios the electric vehicle market is both economically and financially viable over the long run. The net present value becomes positive after 2031 under all scenarios.

This is largely driven by the high vehicle purchase costs of alternative engine configuration vehicles decreasing over time and the operating cost savings increasing over time. In addition, there are large savings in greenhouse gas and air pollution emissions. Greenhouse gas emission savings total $50m under Scenario 1, $240m under Scenario 2 and $500m under Scenario 3. Air pollution savings total $480m, $2.3 billion and $4.6 bilion under Scenarios 1, 2 and 3 respectively.

The net benefits increase with the level of charging infrastructure as this increases the take-up of EVs. Higher levels of charging infrastructure also bring forward the breakeven year.

The benefits presented below are significantly larger than those forecasted in AECOM's 2009 study for metropolitan NSW. These results arise due to updated parameters (not due to any Victorian-specific characteristics) that act to increase PHEV and EV take-up and hence the economic and financial benefits:

- PHEV and EV price parity at 2025 (compared to 2030 in the 2009 NSW study); and
- Higher crude oil prices as published by EIA.

Applying similar assumptions to the NSW model will result in benefits similar to those presented in this study.

**Table 36 Present value of benefits incremental to the Base Case**

| | Scenario 1 | | | Scenario 2 | | | Scenario 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| NPV ($m) | to 2020 | to 2030 | to 2040 | to 2020 | to 2030 | to 2040 | to 2020 | to 2030 | to 2040 |
| Financial benefits | | | | | | | | | |
| Vehicle purchase | -$550 | -$1,110 | -$1,170 | -$1,170 | -$2,570 | -$2,960 | -$1,940 | -$4,050 | -$4,630 |
| Vehicle operation | $90 | $870 | $2,490 | $410 | $4,090 | $12,070 | $860 | $7,810 | $22,250 |
| Charging infrastructure^ | $0 | $0 | $0 | $0 | $10 | $80 | -$80 | -$70 | $640 |
| *Subtotal* | -$460 | -$250 | $1,320 | -$770 | $1,530 | $9,180 | -$1,160 | $3,690 | $18,260 |
| Externalities | | | | | | | | | |
| GHG emissions | $0 | $10 | $50 | $10 | $60 | $240 | $20 | $140 | $500 |
| Air pollution | $20 | $170 | $480 | $90 | $820 | $2,340 | $200 | $1,680 | $4,600 |
| **Economic benefits** | -$430 | -$60 | $1,850 | -$670 | $2,420 | $11,760 | -$940 | $5,520 | $23,350 |
| Breakeven year | 2031 | | | 2027 | | | 2026 | | |

Source: AECOM. Note: Based on central forecasts of oil price, electricity price, CPRS policy and shadow cost of carbon. All values discounted to 2010 values at 5%.Values are rounded to nearest $10m.

^ Net charging infrastructure is capital cost of charging infrastructure less the premium that customers pay to cover cost of infrastructure.

## 5.2 Sensitivity analysis

As set out in **Section 2.17**, there is considerable uncertainty around the future path of many of the key variables. Whilst the model has been designed to allow extensive sensitivity analysis, this report will focus on the key factors likely to affect the outcomes of this study, including:

- Discount rates.
- Vehicle price and changes over time;
- Vehicle supply into Australia;
- Fuel prices (fossil fuels and electricity);
- Underlying vehicle trends;
- Electric vehicle technology; and
- Availability of EVs and charging facilities.

**Table 37** sets out the present value of the economic benefits under various sensitivity scenarios.

### 5.2.1 Discount rates

Discount rates were varied from the standard rate of 5% for transport projects in Victoria to 3.2% (representing the risk-free 10-year Victorian bond rate) and 10.2% (representing the 10-year bond rate with a 7% high risk premium).

All scenarios remain economically and financially viable under both discount rates; however the 'payback year' (when NPVs become positive) moves forward under the lower discount rate. NPVs increase by around 50-60% under the lower rate, and reduce by 70-80% under the higher rate.

### 5.2.2 Vehicle prices and changes over time

As described in **Section 2.6**, there is considerable uncertainty over future prices of electric vehicles over the next ten years as technologies and markets develop.

A key variable to the model is the rate of convergence of non-ICE vehicle prices to become on a par with conventional ICE vehicles. Various tests have been therefore been undertaken to test these parameters.

Moving the vehicle price parity forward by 5 years (i.e. HEVs reach parity in 2015 and PHEVs and EVs reach parity in 2020) results in a significant increase in benefits and importantly bringing forward the payback year in all scenarios to the early 2020s. A similar but smaller effect is observed if all HEV, PHEV and EV prices are reduced by 10%.

Delaying EV price parity to 2030 (while maintaining PHEV price parity at 2025), does not significantly affect the results as benefits from fuel cost savings are realised in later years anyway. However delaying PHEV price parity to 2030 (while maintaining EV price parity at 2025), acts to lower mid to longer term benefits as additional ICE and HEV vehicles are purchased (instead of more expensive PHEVs) leading to lower fuel and pollution savings.

### 5.2.3 Vehicle supply

Another key constraint in realising the benefits of electric vehicles in Victoria is the supply of vehicles to Australia. Vehicle production worldwide is likely to be restricted in the short-term, as described in **Section 2.15**. EV manufacturers are already focussing sales of vehicles in a limited number of countries.

The central case assumes that Australia will receive 1% of the worldwide production of HEVs, PHEVs and EVs. Increasing this proportion to 5% or removing the constraint decreases NPVs in the short-term. This is because the supply constraint actually delays the purchasing of vehicles that are more expensive in the early years (before price parity). Increased vehicle purchase costs in early years are more significant than operating cost savings in later years due to the effect of the discount rate. The loss in consumer welfare from people not being able to purchase their preferred vehicle is not captured in the model.

### 5.2.4 Fuel prices

Future oil prices are highly uncertain, and changes to future oil price forecasts results in increased take-up of non-ICE vehicles and increases the NPVs to levels similar to that of the reduced vehicle prices described in **Section 5.2.2**. The converse applies if a low oil price trajectory is followed.

The impact of higher or lower electricity prices was less than that of oil prices. This is perhaps due to there being greater stability in electricity markets, and Australia not being reliant on imports or world oil markets in order to satisfy consumer demand. A combination of high oil prices with low electricity prices has a large positive impact on the results.

The impost of the CPRS/carbon tax on vehicle fuels and electricity prices did not have a significant effect on the overall NPVs, since the overall cost to consumers of the tax/policy is relatively small compared to other cost items.

Due to an increasing number of diesel vehicles being sold in Australia, a test was undertaken where the proportion of petrol-engine passenger vehicles was reduced from 80% to 70% and diesel-engine vehicles increased from 5% to 15%. This also only had a very small impact upon the results reflecting that the fuel efficiencies of non-ICE vehicles still outweigh those of diesel cars.

The multi-fuel bonus within the vehicle choice model (described in **Section 2.5.2**) increases the take-up of HEVs and PHEVS compared to EVs; removing the bonus drives take-up of EVs which generate further cost and externality savings.

### 5.2.5 Vehicle trends

Two tests were undertaken on vehicle demand trends by raising the medium to long term demand projections for passenger cars and LCVs. Neither of these tests resulted in any significant change to the central results.

Maintaining the proportion of small, medium and large passenger vehicles at 2010 levels (52% small, 24% medium and 24% large) resulted in increases to NPVs and brought forward payback years to the early 2020s in all scenarios.

Reducing average vehicle lifespans (for example, in response to a vehicle scrappage scheme) causes all results to reduce, since higher levels of consumer expenditure are required to purchase new vehicles each year.

### 5.2.6 Electric vehicle technology

EV battery storage capacity has been assumed to increase by 5% a year (resulting in vehicle ranges increasing by similar levels). Maintaining EV ranges at 2010 levels does not cause a significant change to the results.

Similarly, reducing EV maintenance costs to 50% of those of an ICE (from 70%) also does not realise a significant change.

In the central case, EV charging infrastructure costs (household and public Level 2 chargers and fast chargers/EV service stations) have been assumed to decline by 50% in real terms over the next ten years (and remain constant thereafter). Altering this input to the model such that there is no change to infrastructure costs over the 30-year appraisal period results in a small decrease to NPVs.

### 5.2.7 Electric vehicle charging equipment availability

A number of assumptions have been made in the central case regarding the availability of vehicle charging infrastructure. There are two main effects: the proportion of people who are able to buy a PHEV or EV in each scenario, and an input to the choice model reflecting the availability of EV charging infrastructure relative to the prevalence of conventional service stations.

Making EVs and PHEVs (of all average VKT lengths) available to everyone under Scenarios 1 and 2 results in significant increases in NPVs for these scenarios, bring payback years forward to the very early 2020s. Whilst it is improbable that Level 1 household charging alone would satisfy all consumers, it is highly indicative in Scenario 2 that if appropriate provision of Level 2 public charging infrastructure is in place in the medium term, the economic benefits of EVs can be realised much earlier.

In the central case for Scenarios 2 and 3, the availability of public EV charging facilities has been estimated to be 50% and 75% relative to the number of ICE service stations. Reducing these proportions by 25% results in a small decrease in overall benefits. Increasing the proportions to 100% (i.e. EVs enjoy the equivalent level of coverage of recharging stations as ICE owners have petrol stations) causes a dip in the results in the near-term – as consumers purchase more expensive vehicles – but beyond 2020 this causes Scenario 2 benefits to increase. This indicates that timely supply of charging infrastructure to coincide with the points when EVs become more affordable will increase take-up and maximise economic benefits.

### 5.2.8 Summary

The following factors were found to have greatest influence over the magnitude of the results:

- In the short- to medium term, the level of take-up (and consequential economic benefits) of non-ICE vehicles is highly influenced by the price of these vehicles relative to ICE vehicles. Measures to reduce costs in the short term result in economic benefits being realised earlier.
- Take-up of EVs and PHEVs is sensitive to oil prices, but less so to electricity prices and the carbon tax/CPRS. Should oil prices rise beyond forecasts, then measures to increase the uptake of EVs will produce economic benefits.
- Increasing the availability of charging infrastructure and reducing the ICE captive markets (i.e. reducing barriers to ownership) will encourage take-up of electric vehicles when prices become more affordable and bring forward economic benefits.

**Table 37 Present value of economic benefits under various sensitivity scenarios compared to the Base Case ($m)**

| Economic Benefits | Scenario 1 | | | Scenario 2 | | | Scenario 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | NPV (to 2020) | NPV (to 2030) | NPV (to 2040) | NPV (to 2020) | NPV (to 2030) | NPV (to 2040) | NPV (to 2020) | NPV (to 2030) | NPV (to 2040) |
| Central results | -$430 | -$60 | $1,850 | -$670 | $2,420 | $11,760 | -$940 | $5,520 | $23,350 |
| **Discount Rates** | | | | | | | | | |
| 3.2% discount rate | -$490 | $60 | $3,040 | -$750 | $3,490 | $18,110 | -$1,040 | $7,760 | $35,660 |
| 10.2% discount rate | -$310 | -$200 | $350 | -$500 | $770 | $3,480 | -$720 | $2,010 | $7,180 |
| **Vehicle Prices** | | | | | | | | | |
| Price parity earlier by 5 years (HEVs 2015, PHEVs and EVs 2020) | -$180 | $900 | $2,920 | -$170 | $5,230 | $15,340 | -$130 | $10,650 | $30,060 |
| Price parity delayed by 5 years (HEVs 2025, PHEVs and EVs 2030) | -$450 | -$990 | $750 | -$680 | $80 | $8,390 | -$960 | $1,610 | $17,420 |
| Price parity with ICEs in 2030 for PHEVs only (instead of 2025) | -$480 | -$1,050 | $690 | -$700 | $520 | $9,150 | -$950 | $3,050 | $19,870 |
| Price parity with ICEs in 2030 for EVs only (instead of 2025) | -$430 | -$120 | $1,760 | -$680 | $1,840 | $10,830 | -$980 | $3,960 | $20,800 |
| Price parity with ICEs in 2030 for all configurations | -$440 | -$570 | $1,300 | -$680 | $1,090 | $9,960 | -$950 | $3,260 | $20,140 |
| 10% increase in vehicle prices for HEVs, PHEVs and EVs | -$490 | -$430 | $1,200 | -$740 | $1,520 | $10,090 | -$1,080 | $3,930 | $20,430 |
| 10% decrease in vehicle prices for HEVs, PHEVs and EVs | -$380 | $200 | $2,260 | -$560 | $3,140 | $12,920 | -$740 | $6,700 | $25,250 |
| **Supply constraints** | | | | | | | | | |
| No supply constraint (demand meets supply in all years) | -$1,560 | -$710 | $1,450 | -$2,030 | $2,570 | $12,710 | -$2,600 | $6,410 | $25,590 |
| Supply of HEV, PHEV and EV vehicles into Australia constrained at 5%of global production | -$930 | -$240 | $1,860 | -$1,030 | $2,860 | $12,720 | -$1,190 | $6,550 | $25,230 |
| Supply becomes unconstrained at 2025 for HEV, PHEV and EV | -$360 | $310 | $2,280 | -$560 | $3,370 | $13,050 | -$780 | $7,230 | $25,730 |
| Supply becomes unconstrained at 2020, 2025, and 2025 for HEV, PHEV and EV respectively | -$160 | $720 | $2,690 | -$260 | $3,510 | $12,740 | -$270 | $7,420 | $25,220 |
| **Fuel Prices** | | | | | | | | | |
| Low oil price (20% below EIA reference price) | -$420 | -$140 | $1,560 | -$670 | $1,910 | $10,150 | -$970 | $4,460 | $20,140 |
| High EIA oil price | -$460 | $200 | $2,790 | -$660 | $4,140 | $17,080 | -$840 | $9,140 | $33,990 |

| Economic Benefits | Scenario 1 | | | Scenario 2 | | | Scenario 3 | | |
|---|---|---|---|---|---|---|---|---|---|
| | NPV (to 2020) | NPV (to 2030) | NPV (to 2040) | NPV (to 2020) | NPV (to 2030) | NPV (to 2040) | NPV (to 2020) | NPV (to 2030) | NPV (to 2040) |
| Low electricity price (20% below Treasury forecasts) | -$440 | -$40 | $1,920 | -$670 | $2,540 | $12,160 | -$930 | $5,770 | $24,130 |
| High electricity price (20% above Treasury forecasts) | -$430 | -$80 | $1,770 | -$670 | $2,300 | $11,380 | -$950 | $5,310 | $22,640 |
| No CPRS/carbon tax | -$440 | -$60 | $1,820 | -$670 | $2,440 | $11,630 | -$940 | $5,570 | $23,090 |
| High CPRS/carbon tax (CPRS-15 rate) | -$440 | -$50 | $1,900 | -$670 | $2,510 | $12,060 | -$940 | $5,720 | $23,960 |
| Low oil price and high electricity price | -$420 | -$150 | $1,480 | -$670 | $1,810 | $9,780 | -$970 | $4,230 | $19,420 |
| High oil price and low electricity price | -$470 | $220 | $2,880 | -$660 | $4,290 | $17,540 | -$820 | $9,440 | $34,890 |
| Fuel mix for ICE vehicles changed to 69.5% petrol, 15% diesel | -$440 | -$70 | $1,810 | -$680 | $2,360 | $11,640 | -$950 | $5,410 | $23,120 |
| No multi-fuel bonus (consumers do not get perceived benefit from dual-fuel vehicles) | -$450 | $10 | $1,990 | -$700 | $2,910 | $12,960 | -$1,000 | $6,750 | $26,440 |
| **Vehicle trends** | | | | | | | | | |
| Passenger vehicle growth rate at 1.75% pa to 2040 | -$430 | -$50 | $1,930 | -$670 | $2,450 | $12,070 | -$940 | $5,570 | $23,890 |
| LCV growth rate at 6% pa to 2040 | -$430 | -$60 | $1,850 | -$680 | $2,560 | $12,990 | -$960 | $5,790 | $25,810 |
| Passenger vehicle proportions at 2010 levels | -$460 | $10 | $2,320 | -$720 | $2,940 | $13,840 | -$1,010 | $6,630 | $27,330 |
| Vehicle lifespan reduced to median 10 years | -$440 | -$140 | $1,290 | -$680 | $2,030 | $9,120 | -$960 | $4,760 | $18,400 |
| **EV technology** | | | | | | | | | |
| No growth in EV range | -$420 | -$70 | $1,720 | -$620 | $2,110 | $10,570 | -$860 | $4,680 | $20,220 |
| EV maintenance costs at 50% of EV | -$430 | -$50 | $1,870 | -$640 | $2,550 | $12,070 | -$860 | $5,900 | $24,220 |
| No decline in charging infrastructure costs | -$440 | -$130 | $1,710 | -$690 | $1,840 | $10,520 | -$1,050 | $3,960 | $20,220 |
| **EV charging availability** | | | | | | | | | |
| Non-captive proportions increased to 100% all scenarios (i.e. EVs available to all consumers) | -$500 | $3,810 | $15,540 | -$730 | $5,080 | $21,880 | -$940 | $5,520 | $23,350 |
| Non-captive proportions reduced by 20% | -$370 | -$150 | $1,120 | -$560 | $1,380 | $7,370 | -$790 | $4,450 | $18,740 |
| Proportion of EV recharging infrastructure (relative to ICE service stations) reduced by 25% in Scenarios 2 and 3 | -$430 | -$60 | $1,850 | -$580 | $2,090 | $10,890 | -$800 | $4,540 | $20,880 |
| Proportion of EV recharging infrastructure (relative to ICE service stations) increased to 100% in Scenarios 2 and 3 | -$430 | -$60 | $1,850 | -$1,020 | $3,710 | $15,180 | -$1,140 | $6,740 | $26,700 |

Source: AECOM. Note values are rounded to nearest $10m. All values discounted to 2010 values at 5% except where stated.

## 5.3 Cost per kilometre

**Table 38** sets out the expected lifetime cost per kilometre for the different engine configurations in 2010 and 2040. The total cost of ownership includes the vehicle price, annual fuel[18] and maintenance costs (based on average annual distance travelled as set out in **Table 8**) and insurance. Future costs have been discounted at 5%.

**Table 38 Lifetime cost per kilometre for each engine configuration in 2010 and 2040**

| Engine configuration | Small Passenger | | Medium Passenger | | Large Passenger | | LCV | | Taxi | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2010 | 2040 | 2010 | 2040 | 2010 | 2040 | 2010 | 2040 | 2010 | 2040 |
| ICE | $0.211 | $0.213 | $0.224 | $0.226 | $0.295 | $0.298 | $0.252 | $0.254 | $0.206 | $0.213 |
| HEV | $0.233 | $0.191 | $0.242 | $0.210 | $0.311 | $0.286 | $0.284 | $0.248 | $0.254 | $0.213 |
| PHEV | $0.230 | $0.159 | $0.244 | $0.155 | $0.332 | $0.199 | $0.349 | $0.185 | $0.328 | $0.177 |
| EV | $0.204 | $0.149 | $0.210 | $0.144 | $0.283 | $0.182 | $0.309 | $0.172 | $0.306 | $0.171 |

Source: AECOM. Note the cost per kilometre is non-scenario specific as vehicle and operating costs do not change significantly across the scenarios.

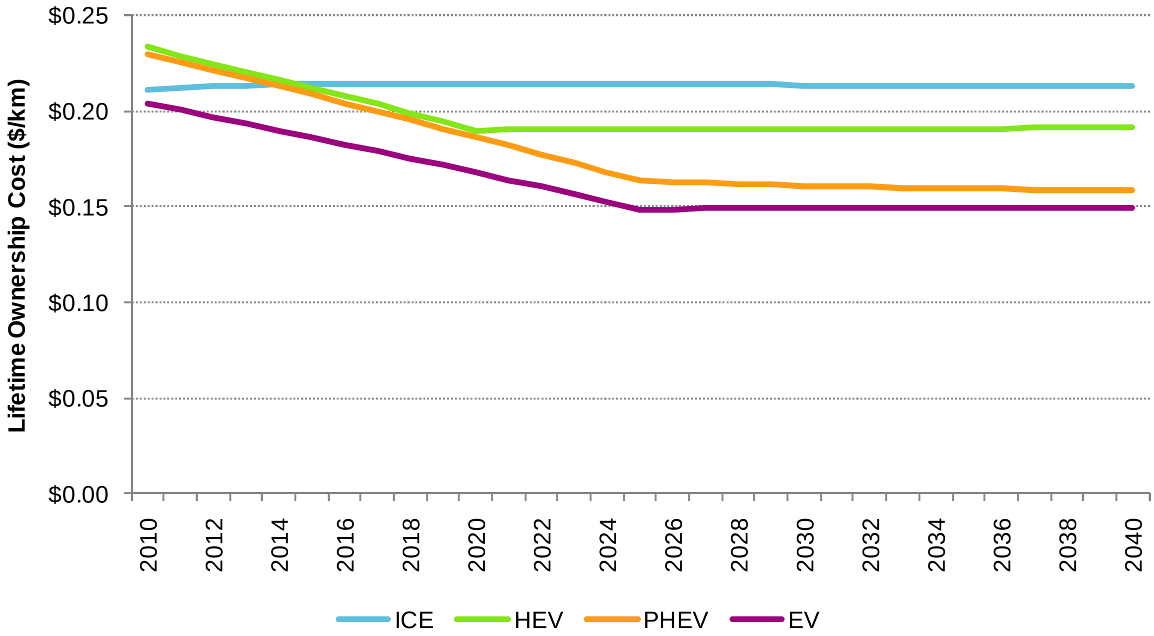
**Figure 20** sets out how the cost per kilometre changes from 2010 to 2040 for a small vehicle. Significantly, despite the high vehicle price, EVs are around the same cost per kilometre as ICE vehicles in 2010 due to large fuel cost savings over the life of the vehicle. The cost per kilometre falls steadily until 2025 when the price of an EV reaches price parity with an ICE vehicle. After 2025, the cost per kilometre of EVs is around 70% of the cost per kilometre for ICE vehicles. HEVs and PHEVS, which do not have the full fuel savings of an EV, take longer to reach a favourable cost per kilometre with an ICE vehicle but both remain significantly below ICE vehicles once vehicle price parity has been reached, at 89% for HEVs and 79% for PHEVs. The cost per kilometre of medium vehicles is similar to small vehicles.

**Figure 21** demonstrates how the cost per kilometre changes from 2010 to 2040 for a large vehicle. Once vehicle prices reach price parity with ICE vehicles there are significant cost savings for large vehicles, which tend to travel larger distances. By 2025, the cost per kilometre for a large EV is 61% of the ICE cost, compared to 70% for a small EV.

**Figure 22** demonstrates how the cost per kilometre changes from 2010 to 2040 for taxis. Unlike large passenger vehicles the high vehicle cost of EVs, PHEVs and HEVs does outweigh the cost savings from fuel in the early years. The fuel savings are not as high as for other vehicles due to the high use of LPG in taxis which is less than half the price of petrol and diesel. Taxis also have a much shorter vehicle life than other vehicles (taxis are not allowed to be older than 6.5 years) which reduces the time available to recoup the fuel savings. The cost per kilometre for Light Commercial Vehicles is similar to large passenger vehicles, although stabilises at 57% of the ICE cost per kilometre due to the larger distances travelled.

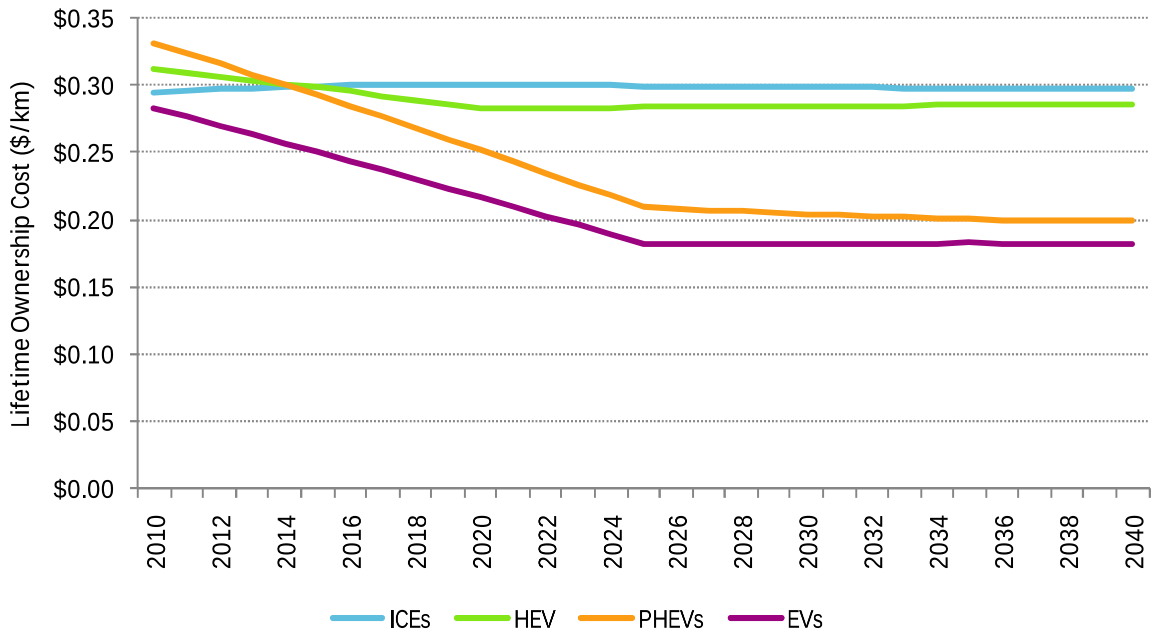
[18] Fuel prices are forecast out to 2040 and are assumed to be constant after this time.

**Figure 20 Lifetime cost per kilometre – small passenger**



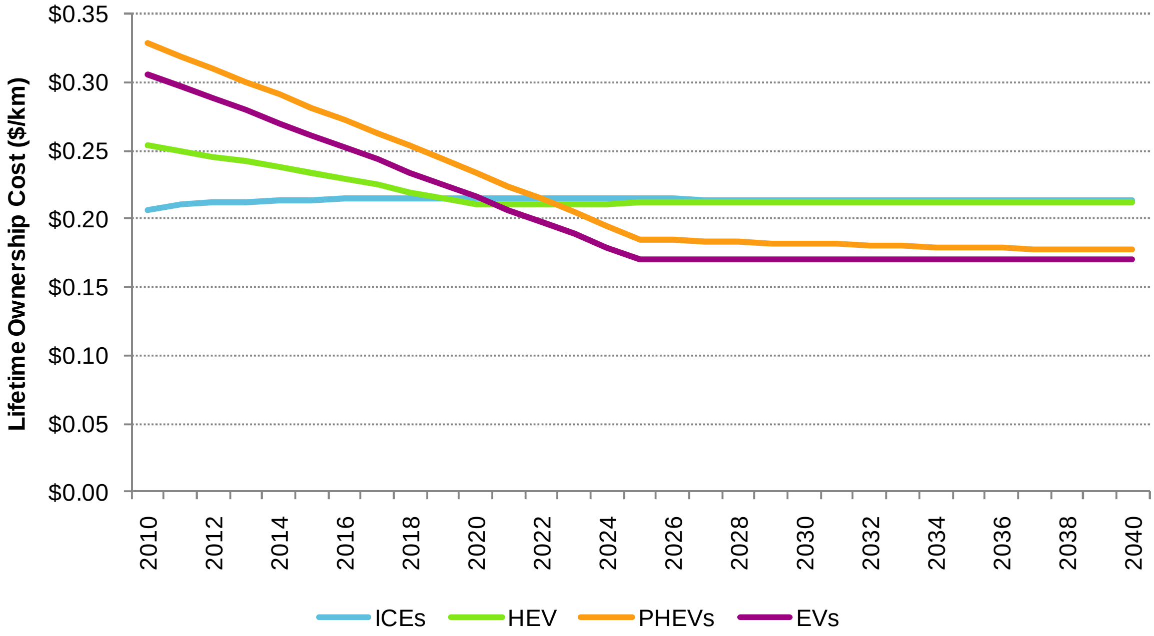

Source: AECOM

**Figure 21 Lifetime cost per kilometre – large passenger**




Source: AECOM

**Figure 22 Lifetime cost per kilometre - taxi**




Source: AECOM

In summary, the cost per kilometre for passenger EVs is already cost competitive with ICE vehicles due to the fuel cost savings outweighing the high up-front vehicle cost. As PHEVs and HEVs only achieve a proportion of the fuel cost savings, it takes longer to offset the higher vehicle cost. Conversely, large passenger vehicles take longer to reach cost per kilometre parity with ICEs due to the high upfront price premium for large EVs, PHEVs and HEVs. However once they reach parity there are savings compared to an ICE due to the larger distances travelled. Taxis take longer to reach a cost per kilometre comparable to ICE vehicles and even with vehicle price parity, the fuel savings are not as high as for other vehicles. This is due to the high use of LPG in taxis and the much shorter vehicle life.

It is important to note that the cost per kilometre measure is complementary to the results set out above. The cost per kilometre uses the same inputs as the vehicle choice model (vehicle price, fuel costs, and maintenance costs) but is not a result of the vehicle choice model and should not be compared with the results.

The cost per kilometre allows a theoretical comparison of the lifetime costs of different engine configurations. However, people make their decisions based on a number of factors including available infrastructure, vehicle range and preference for greener vehicles. They also tend to make decisions based on an average ownership of four to five years. The vehicle choice model tries to include these factors into the analysis.

## 5.4 Conclusions

The model shows that the plug-in electric vehicle market in metropolitan Victoria is both economically and financially viable. However, the economic and financial returns accrue over the longer term. The move towards a plug-in electric vehicle market also generates large savings in greenhouse gas and air pollution emissions.

The vehicle choice model predicts a transition to HEVs in the near term (5-10 years); PHEVs over the medium to long term (10-20 years) and EVs over the long term (15 years plus). In the short term there is increased uptake of alternative engine configurations in the small vehicle category. Significantly, despite the high vehicle price, passenger of all sizes EVs are around the same lifetime cost per kilometre as ICE vehicles in 2010 due to large fuel cost savings over the life of the vehicle. As vehicle prices fall, the vehicle range increases and more charging infrastructure becomes available, owners of larger vehicles and vehicles that travel large distances tend to purchase a higher proportion of EVs. This is due to the fact that operating costs are more important for these vehicle owners.

Higher levels of charging infrastructure (as represented in the different scenarios) significantly increase the take-up of plug-in electric vehicles and hence increase the viability of the market. Other key factors affecting both take-up and viability include the vehicle cost and rate at which it converges with ICE vehicles, fuel prices (particularly higher oil prices), vehicle range and the existence of local supply constraints.

Vehicle costs and vehicle range are expected to converge over time as technology improves and production increases, therefore the removal of supply constraints and the provision of charging infrastructure are the key areas that warrant further attention if the take-up of EVs is to be encouraged.

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Appendix A

# Industry Consultation

# Appendix A Industry Consultation

AECOM consulted with representatives from the automotive and power sectors to inform the update of model parameters with current industry knowledge and to allow industry experts to comment on the soundness of the assumptions. Responses to consultation are anonymous to preserve intellectual property and respect commercially sensitive information. The following five key modelling areas were covered:

- Vehicle prices;
- Charging infrastructure;
- Fuel efficiency;
- Vehicle supply; and
- Maintenance and repair costs.

This report consolidates the responses from industry and reports the values chosen for the model. For each of the areas, this report provides the modelling input required, a description of how the inputs will be used, background information and the values chosen for the model.

AECOM

Victorian Department of Transport
2 July 2010

# Forecast Uptake and Economic Evaluation of Electric Vehicles in Victoria

## Industry Consultation

# Forecast Uptake and Economic Evaluation of Electric Vehicles in Victoria

Industry Consultation

Prepared for

Victorian Department of Transport

Prepared by

**AECOM Australia Pty Ltd**
Level 9, 8 Exhibition Street, Melbourne VIC 3000, Australia
T +61 3 9653 1234 F +61 3 9654 7117 www.aecom.com
ABN 20 093 846 925

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# 1.0 Introduction

## 1.1 Background

In 2009, AECOM undertook a study on the economic viability of electric vehicles for the NSW Department of the Environment and Climate Change. As part of this study, AECOM developed an economic model to assess the economic viability of plug-in electric vehicles (both pure electric vehicles as well as plug-in hybrid electric vehicles) for the NSW metropolitan passenger vehicle, light commercial vehicle and taxi markets. The study identified market and economic conditions under which such vehicles provide a net benefit to society. As part of this study, AECOM developed a vehicle choice model, which was used to model take-up of electric vehicles under different infrastructure scenarios. The vehicle choice model uses inputs on relative prices and preferences to produce projections for the number of new vehicles purchased in each vehicle category. Vehicles were differentiated by size and engine type. The results of the choice model were then used as inputs to the economic and financial viability models. A full copy of the final report can be obtained from: http://www.environment.nsw.gov.au/resources/climatechange/ElectricVehiclesReport.pdf

In February 2010, AECOM was commissioned by the Victorian Department of Transport to undertake a study that builds on the NSW Electric vehicle model. The study consists of two stages:

- Stage 1 involves updating parameter values in AECOM's Electric vehicle model to incorporate the latest available information and Victorian specific data where available. No significant changes to the modelling methodology are planned for Stage 1.
- Stage 2 involves enhancing the model to improve its functionality and incorporate factors beyond the scope of the original NSW study such as fleet purchases and early adopters.

## 1.2 Objectives

The overall objectives of this study are to:

- Understand how different factors such as vehicle prices, fuel prices, charging infrastructure, etc. affect take-up of electric vehicles;
- Test the impact of various policies on electric vehicle take-up and the resulting economic and financial costs and benefits.

## 1.3 Consultation process

AECOM consulted with representatives from the automotive and power sectors to inform the update of model parameters with current industry knowledge and to allow industry experts to comment on the soundness of the assumptions. Responses to consultation are anonymous to preserve intellectual property and respect commercially sensitive information. The following five key modelling areas were covered:

- Vehicle prices;
- Charging infrastructure;
- Fuel efficiency;
- Vehicle supply; and
- Maintenance and repair costs.

## 1.4 Purpose of this report

This report consolidates the responses from industry and reports the values chosen for the model. For each of the areas, this report provides the modelling input required, a description of how the inputs will be used, background information and the values chosen for the model.

Details of the modelling methodology and the assumptions on other economic and financial parameters will be provided in the final report for this study (to be delivered in the third quarter of 2010).

## 1.5 Glossary

The following acronyms and abbreviations are used throughout this report.

| | | |
|---|---|---|
| ICE | - | internal combustion engine |
| HEV | - | hybrid electric vehicle |
| PHEV | - | plug-in hybrid electric vehicle |
| EV | - | electric vehicle |
| CPI | - | consumer price index |
| CPRS | - | carbon pollution reduction scheme |
| $CO_2e$ | - | carbon dioxide equivalent |
| MWh | - | megawatt hour |

# 2.0 Vehicle Supply

## 2.1 Modelling input required

The number of HEV, PHEV and EVs of each vehicle class (small, medium, large passenger cars; LCVs and taxis) available for purchase within Australia each year between 2010 and 2040 need to be input into the model.

## 2.2 Background

A cap is applied within the model upon the number of vehicles of each engine type available for purchase, in the event that demand exceeds supply. AECOM believe that supply of EVs and PHEVs in Australia is likely to be constrained in the near term for the following reasons:

- AECOM are unaware of any plans for PHEVs and EVs to be made locally in Australia, meaning that these will be imported in the near term (until mid 2020s) until such time that there is sufficient demand for domestic production to commence.
- The supply of vehicles into the Australian market will thus be governed by world supply and manufacturing capacity in the near term.
- EV manufacturers may focus their available supply and marketing on countries with suitable infrastructure, consumer preference and driving habits, thus vehicles made overseas may not be distributed to Australia in the same proportions as conventional vehicles.
- In the period from 2015-2020, battery production capacity may be insufficient to meet demand, further restricting the world supply of HEVs, PHEVs and EVs in the near term.

### 2.2.1 World Manufacturing Capacity

A large number of electric vehicle models are expected to be launched in the near future. Deutsche Bank has estimated that at least 120 hybrid, PHEV or EV models will be available worldwide by 2012[1].

Whilst many new models are planned, there is some uncertainty as to how many will be produced and whether this will be sufficient to meet consumer demand.

Currently available electric vehicles are manufactured in relatively small quantities with demand generally exceeding supply. This has resulted in limited availability and customer waiting lists. For example, Tesla Roadsters are currently unavailable in markets outside of North America and Europe and waiting lists within those regions are in the order of 4 to 6 months.

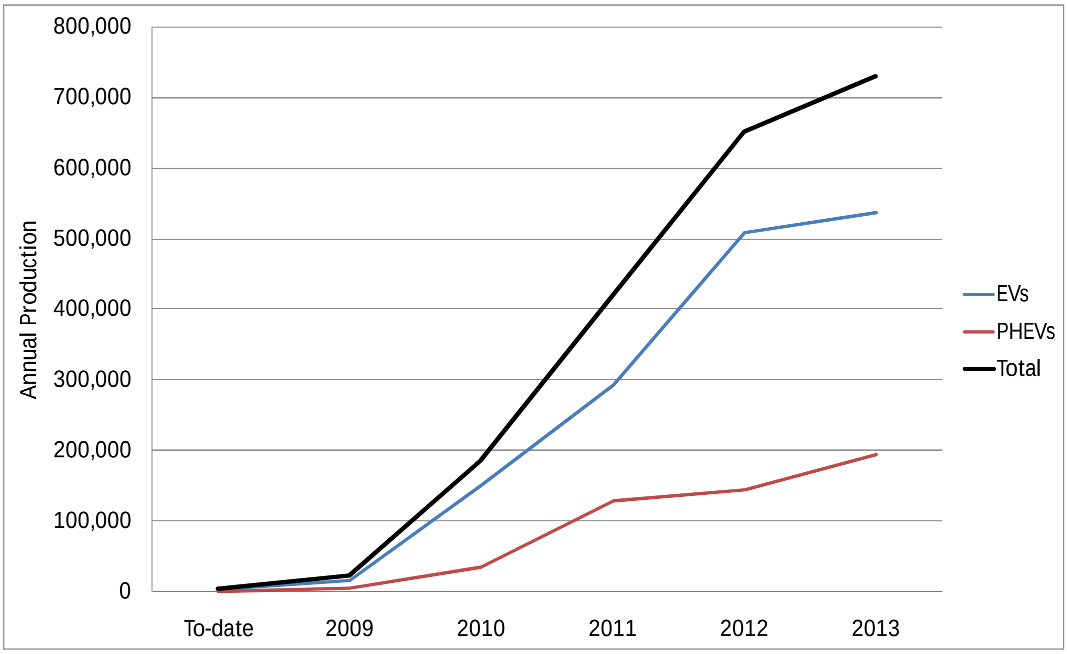
Similarly, Nissan plans to initially restrict availability of the Nissan Leaf electric vehicle to Japan, Europe and the United States when launched in late 2010 before a worldwide release in 2012[2]. Nissan plans to increase electric vehicle production capacity from around 50,000 vehicles per year in 2010 to 500,000 vehicles per year[3].

General Motors believes that when the Chevrolet Volt is launched in late 2010 that there will initially be much greater demand than available supply. However, GM has stated that production can be increased dramatically to meet high demand[4]. It is understood that the Volt Detroit assembly plant is expected to produce 50,000 to 60,000 vehicles per year initially but is capable of producing up to 200,000 vehicles annually at peak production[4].

**Figure 1** charts the projected cumulative volumes for EV/PHEV production using announcements made in the automotive media. These targets should be considered as being at the optimistic end of the spectrum but, if true, would see global production volumes approaching one million plug-in vehicles within five years from now. This is supported by a study from Frost & Sullivan which estimates that the European market for EVs is likely to be about 480,000 units by 2015. The European market currently accounts for around 30% of global production.[5]

[1] Deutsche Bank, *Electric Cars: Plugged In 2*, 3 November 2009
[2] Nissan, *Nissan Will Launch New Season for Mobility in April by Starting Pre-Orders for Nissan LEAF*, 30 March 2010 (available at www.nissan-global.com/EN/NEWS/2010/_STORY/100330-01-e.html)
[3] Reuters, *Nissan to build Leaf electric car in UK from 2013*, 18 March 2010 (available at www.reuters.com/article/idUSTRE62G3TT20100318)
[4] http://gm-volt.com/2010/03/31/first-volt-rolls-off-full-scale-production-line-today/
[5] International Organization of Motor Vehicle Manufacturers (OCIA), global survey of production 2007

**Figure 1: Industry plans for global production of EVs and PHEVs**




Source: Andrew Simpson / AECOM using announcements made in the automotive media

### 2.2.2 Australian Supply

With the exception of some hybrid models (for example, the Toyota Camry hybrid), AECOM is not aware of any current plans by vehicle manufactures to produce electric vehicles in Australia. As such, it is likely that local electric vehicle demand will be required to be met by imports of vehicles manufactured elsewhere.

For the 2009 NSW Study, AECOM assumed that one percent of total world electric vehicle supply would be available for purchase in Australia as per sale of HEVs to date.

However, it is possible that future electric vehicle supply will not be distributed in the same proportions as conventional vehicles.

It is likely that electric vehicle manufactures may focus their available supply and marketing efforts on countries with suitable infrastructure, consumer preference and driving habits rather than simply distribute electric vehicles to different markets in the same proportions as conventional vehicles.

In addition, companies like Better Place have made agreements with vehicle manufactures to ensure the availability of vehicles in locations where infrastructure investments will be made.

Australia has the potential to be an attractive location for electric vehicle manufactures, despite the relatively small market size. Australia is a wealthy, stable country with very high levels of car ownership and car use. Additionally, Better Place has announced that Australia will be one of the first locations in which it will roll out electric vehicle charging infrastructure, further increasing the attractiveness of the Australian market.

As such, it is possible that Australia will receive more than one percent of global electric vehicle production in the near future.

## 2.3 Summary of consultation

- Consultees generally agreed with the finding of the literature review in terms of global vehicle supply, however there was debate over short and long term vehicle supply growth rates. Consultees also expressed differing views over what time period constitutes the “short term” and “long term”. AECOM has assumed the short term to be 2010 to 2015 and the long term to be from 2016 onwards.
- There were also differing views over the size of any supply constraint faced by Australia and when such a constraint is eliminated, either before or after 2020. The modelling will be conducted with a 1% supply constraint and sensitivity at 5%.
- The link between oil prices and take-up of electric vehicle variants was also raised, with higher oil price scenarios generating increased take-up. The model allows for sensitivity on oil prices.

## 2.4 Values chosen for model

The values to be used by AECOM for the model are shown in **Table 1.**

**Table 1 Vehicle supply parameters**

| Parameter | HEV | PHEV | EV |
|---|---|---|---|
| Australian proportion of global market | 1% | 1% | 1% |
| Year of first availability | 2009 | 2012 | 2012 |
| Supply constrained until | 2020 | 2020 | 2020 |
| Initial world supply | 1,000,000 | 150,000 | 500,000 |
| Annual growth in supply:<br>• To 2015<br>• From 2016 onwards | <br>35%<br>35% | <br>20%<br>20% | <br>40%<br>30% |

Given the uncertainty amongst consultees on the supply of vehicles into Australia, AECOM will undertake the following sensitivity tests:

- Australian proportion of global market: 5%.
- Annual growth in supply: (rate to be determined).

# 3.0 Vehicle Prices

## 3.1 Modelling input required

Forecast prices for vehicles considered in the model, distinguishing engine type: ICE, HEV, PHEV and EVs and vehicle size: small, medium and large passenger cars; light commercial vehicles; and taxis.

## 3.2 Background

Vehicle prices need to be included in the choice model since they feed into the vehicle purchase decision process of a consumer, affecting overall take up. Since the electric vehicle market is in very early stages, we expect that reduction in technology costs, namely the battery, will have an important impact on take-up. Price differentials between alternative vehicle technologies will also be important factors in vehicle choice.

For passenger cars, vehicles are distinguished according to size. Distinguishing by vehicle size is important because it will impact on the potential externality emissions. Furthermore, initial market shares of the different vehicle types (in terms of size and technology) considered will impact on the vehicle choice variables such as vehicle price, running costs, tailpipe emissions, availability of recharging infrastructure, amongst others.

Forecast prices will be based on ICE price plus a price premium for electric vehicles. The forecast ICE price is based on current price plus assumed real change. The price premium is based on a survey of current vehicles plus the forecast decline in the price premium.

### 3.2.1 Forecast ICE prices

**Table 2** shows suggested prices for ICE vehicles that are comparable with electric vehicles. Since a large proportion of taxis are Ford Falcons, prices for taxis are assumed to be equal to prices for large passenger vehicles.

**Table 2 New vehicle purchase prices in 2010 (AUD)**

| Vehicle type | ICE |
|---|---|
| Passenger Small | $20,000 |
| Passenger Medium | $27,000 |
| Passenger Large | $48,000 |
| Light Commercial Vehicle | $40,000 |
| Taxi | $48,000 |

Source: survey of prices for new vehicle that are comparable with electric vehicles.

Going forward, it has been assumed that the price of ICE vehicles is constant in real terms.

### 3.2.2 Forecast electric vehicle prices

#### 3.2.2.1 Current prices

New vehicle prices by engine configuration and vehicle size were estimated from a survey of US and global markets. Thirty-four global EV products for the 2009-2012 model years and twenty-eight US hybrids for the 2009-2010 model years were surveyed. **Table 3** sets out the prices assumed in the model for the different market segments and engine combustion types.

**Table 3 New vehicle purchase prices including Australian price premium in 2010 (AUD)**

| Vehicle type | ICE | Hybrid | PHEV | EV |
|---|---|---|---|---|
| Passenger Small | $20,000 | $37,000 | $41,000 | $41,000 |
| Passenger Medium | $27,000 | $44,000 | $51,000 | $51,000 |
| Passenger Large | $48,000 | $66,000 | $113,000 | $113,000 |
| Light Commercial Vehicle | $40,000 | $60,000 | $104,000 | $104,000 |
| Taxi | $48,000 | $66,000 | $113,000 | $113,000 |

Source: Simpson, A/AECOM (2009 study)

An update, based on a smaller sample size of 2010 HEV vehicle available in the US and Australia, indicates that there is a (local) price premium ranging from 30% to 60% for standard hybrid brands such as Toyota and Honda, and an even higher premiums for luxury hybrid brands such as the Lexus. This is likely to reflect a market penalty due to our relatively small market size, distance from large vehicle manufacturing countries, profit margins of local dealers, lack of local manufacturing and other supply constraints of non-ICE vehicles. Supply constraints will be assumed to be similar for PHEVs and EVs.

There is limited information on the expected price of PHEVs. However, a report by the International Energy Agency (IEA, 2008) concludes that electric vehicles will cost around US$10,000 more than a comparable PHEV. Applying this figure to our estimates makes PHEVs cheaper than HEVs which does not seem realistic. As such, it has been assumed PHEVs will be similarly priced to EVs. The basis for this assumption is that the cost reduction from a smaller battery (compared to EV) is offset by the cost of the internal combustion engine.

#### 3.2.2.2 Forecast prices

The cost of the battery pack forms the biggest component of the “cost premium” associated with electric vehicles when compared to internal combustion engine (ICE) vehicles (Irwin cited in Anderson 2009). On top of the battery cost, the premium entangles other components such as the electric motor, a transmission with power split capability (for parallel hybrid architectures), charging electronics (for PHEVs and EVs), amongst others.

Most industry participants expect vehicle prices to remain heavily dependent on the future cost of the vehicle battery. Whilst some expect battery costs to reduce significantly over time (see Nemry 2009, BCG 2010), others only expect marginal decreases in the long term (NAS 2010). Moreover, targets for battery costs have been established at a national level with the United Stated Advanced Battery Consortium setting a cost target of $250 per kWh (BCG 2010). **Table 4** provides a brief overview of the different expectations, focusing on the declines in future lithium-ion battery costs.

**Table 4 Forecasts for battery costs**

| Author/Year | View | Expected evolution (units are US$ unless otherwise stated) |
|---|---|---|
| Boston Consulting Group, BCG, (2010). | Experience and scale effects will decrease the cost of batteries. Automatisation (minimising scrap rates and labour) and cheaper equipment will also have a positive impact.<br><br>Cost target of the USABC by 2020 is unlikely to be attained unless there is a technological breakthrough in battery chemistry that leads to fundamentally higher energy densities without significantly increasing the cost of either battery materials or the manufacturing process. | **2009:**<br>-*Supplier's cell cost:* \$650 to \$790 per kWh.<br>-*Cost to an OEM:* \$990 to \$1220 per kWh.<br>-*End user price* (assuming an average margin): \$1400 to \$1800 per kWh.<br><br>**2009 to 2020:**<br>-*Cost to an OEM:* Decreases by 60 to 65% per kWh, to \$360 to \$440 per kWh, respectively.<br>-*End user price*: Falls to \$570 to \$700 per kWh.<br><br>Underlying falling prices is a parallel decline in the cost of cells, to \$270 to \$330 per kWh. Decline of the cost of cell is less rapid because around 30% of cell costs are independent of production volume. |
| Deutsche Bank (2010). | Lower lithium ion battery prices in the future. | The price of lithium-ion batteries are likely to decline by 25%-50% over the next 5-10 years. There are already bids of 400 \$/kWh for large volume EV batter contracts in the 2011-12 time period, implying a reduction of 30% |
| Nemry et al. (2009). | | **Short term:**<br>-Citing Kalhammer et al 2007: Lithium ion battery cost will fall as low as \$395 per kWh and \$260 per kWh for a PHEV10 and PHEV40, respectively (assuming 100,000 of units produced).<br>-Citing Aderman 2008: The range of \$600 to \$700 per kWh is seen as more realistic.<br>-Citing Anderson 2009: Under the optimistic scenario by 2015, the cost of a battery would be around 370 \$/kWh and by 2030 of around \$250 \$/kWh. Under the pessimistic scenario, values are around \$790 for 2015/30. |
| National Academy of Science (2010). | Lithium ion battery technology has been developing rapidly but costs remain high and there is limited potential for further significant reductions.[6] | Assembly packs currently cost about \$1700 per kWh. Costs are expected to decline by about 35% (to 1105 \$/kWh) by 2020 but more slowly thereafter, |

[6] This conclusion has been challenged by the Electrification Coalition who note that the National Research Council overestimated both current battery prices and that future prices in comparison with several other studies.

| Author/Year | View | Expected evolution (units are US$ unless otherwise stated) |
|---|---|---|
| Pike Research (2009) | Lower lithium ion battery prices in the future. | Price of lithium-ion batteries will decline from around $1000 per kWh today to $810 in 2011, and will continue to drop to $470 in 2015. |
| Bosch (2009) | Reduction in the production of lithium ion batteries will be possible and significant. | Battery pack to cost about 350 euros per kWh by 2015 (66% of current cost). |
| Powertrain (2010) | Large capital investment, experience and economies of scale will render to the reduction of battery costs. | Battery costs will decline from 475 euros per kWh in 2010 to 200 euros per kWh in 2020. |

As **Table 4** shows, estimates of current and future costs of batteries vary widely and are further complicated by a lack of clarity about which cost, precisely, is being estimated (e.g. the cost of a cell, the cost of a battery pack for an original equipment manufacturer). However, there seems to be a stronger consensus that in general the price of lithium ion batteries will decline in the future and most likely by a significant amount.

In its previous report, AECOM assumed that prices for electric vehicles would eventually converge to ICE vehicle prices, that is, price premiums would go to $0. However, some reviewers have commented that price premiums would not go to $0, but would reflect a lower bound battery price.

## 3.3 Summary of consultation

- Consultees generally agreed with the literature review.
- It was recognised that electric vehicle prices will be influenced by battery costs, however it was also noted that retail prices will be affected by other factors such as country of sale, market competition and expected rate of investment recovery.
- Luxury branding and markup will be reflected in the high prices of vehicles in the large passenger segment. As most models to be launched in the near term are small passenger and LCV vehicles, this makes it difficult to estimate price premiums for non-luxury large passenger vehicles.
- Electric vehicles are likely to be the first variant to reach price parity as the power train duplication inherent in HEV and PHEV architectures prices will make it difficult for HEVs and PHEVs to reach price parity.

## 3.4 Values chosen for model

The values to be used by AECOM for the model are shown in **Table 5.**

**Table 5 ICE prices by engine type in 2010**

| Car size | ICE | HEV | PHEV | EV |
|---|---|---|---|---|
| **Price premium relative to ICE** | | | | |
| Passenger Small | N/A | $17,000 | $21,000 | $21,000 |
| Passenger Medium | N/A | $17,000 | $30,000 | $30,000 |
| Passenger Large | N/A | $18,000 | $50,000 | $50,000 |
| Light Commercial Vehicle | N/A | $20,000 | $64,000 | $64,000 |
| Taxi | N/A | $18,000 | $50,000 | $50,000 |
| **New vehicle price** | | | | |
| Passenger Small | $20,000 | $37,000 | $41,000 | $41,000 |
| Passenger Medium | $27,000 | $44,000 | $57,000 | $57,000 |
| Passenger Large | $48,000 | $66,000 | $98,000 | $98,000 |
| Light Commercial Vehicle | $40,000 | $60,000 | $104,000 | $104,000 |
| Taxi | $48,000 | $66,000 | $98,000 | $98,000 |
| **Price parity with ICE** | | | | |
| Year | N/A | 2030 | 2030 | 2020 |

# 4.0 Fuel Efficiency

## 4.1 Modelling input required

The following inputs are required for AECOM to model take-up of electric vehicles:

- Fossil fuel efficiency (L / 100km) by vehicle size and by fuel type (petrol, diesel, LPG);
- Electric efficiency by vehicle size (kWh / 100km);
- Annual change in efficiency of hybrid and plug-in hybrid vehicles relative to ICE (% p.a.); and
- Annual change in fossil fuel and electric efficiency (% p.a.).

## 4.2 Background

Vehicle fuel efficiency is required for calculations in three areas of the model:

- **Vehicle operating costs** includes the cost of fuel which requires fuel efficiency in order to calculate the quantity of fuel consumed.
- **Greenhouse gas emission externality costs** also depend on the quantity of fuel consumed.

### 4.2.1 ICE efficiencies

Efficiencies for ICE vehicles were determined for the NSW study from vehicle efficiencies as published by the Commonwealth Government's Green Vehicle Guide[7] and ABS Survey of Motor Vehicle Use. These values are consistent with fuel efficiencies for current vehicles as published by the Green Vehicle Guide.

Changes to ICE efficiencies over time are based on the 2007 CSIRO report *Modelling the Road Transport Sector*[8] which indicated that efficiencies will improve by 30% between 2006 and 2050. This is equivalent to an annual improvement of 0.84%.

**Table 6** summarises the ICE efficiency assumptions.

**Table 6 ICE fuel efficiency by vehicle category in 2010**

| Vehicle Category | Petrol (L/100km) | Diesel (L/100km) | LPG (L/100km) | Annual change |
|---|---|---|---|---|
| Passenger small | 7.8 | 8.6 | 11.7 | 0.84% |
| Passenger medium | 9.7 | 10.8 | 14.5 | 0.84% |
| Passenger large | 13.8 | 15.3 | 20.6 | 0.84% |
| Light Commercial Vehicle | 11.2 | 10.6 | 13.6 | 0.84% |
| Taxi | 13.8 | 15.3 | 20.0 | 0.84% |

Source: Green Vehicle Guide, ABS, CSIRO.

### 4.2.2 Hybrid electric vehicle efficiencies

Efficiencies for hybrids are modelled relative to ICE efficiencies as investments in hybrid technology are expected to generate continued efficiency gains over ICE. However these improvements will decline over time as the potential for improvement gets eroded by improved combustion technologies.

[7] www.greenvehicleguide.gov.au

[8] http://www.treasury.gov.au/lowpollutionfuture/consultants_report/downloads/Modelling_the_road_transport_sector.pdf

**Table 7** summarises the efficiency improvement of HEV relative to ICE in 2010 and 2050 as determined for the NSW study by Simpson (2009). Efficiency improvements decline by 20% between 2010 and 2050, equivalent to an annual change of 0.5%. This is supported by the literature, for example Deutsche Bank find that HEV efficiency gains are in the range of 25% to 40%[9]. For example, in 2010 a small passenger HEV is assumed to be 47% more efficient than the equivalent ICE, yielding a fuel consumption rate of 5.31 L / 100km. The Electric Power Research Institute's study[10] also indicates that fuel consumption for the petrol component of a PHEV will decrease by approximately 18% between 2010 and 2050, equivalent to a 0.45% annual change.

**Table 7 HEV fuel efficiencies relative to ICE fuel efficiencies**

| Vehicle Category | Efficiency improvement relative to ICE | | Annual change (% p.a.) | Fuel consumption in 2010 (L / 100km) |
|---|---|---|---|---|
| | 2010 | 2050 | | |
| Passenger Small | 47% | 30% | 0.43% | 5.31 |
| Passenger Medium | 32% | 15% | 0.43% | 7.35 |
| Passenger Large | 23% | 6% | 0.43% | 11.22 |
| Light Commercial Vehicle | 33% | 16% | 0.43% | 8.42 |
| Taxi* | 23% | 6% | 0.43% | 11.22 |

Source: Simpson, A. (2009)

* Assumed to be the same as large passenger vehicles.

### 4.2.3 Electric vehicle efficiencies

Efficiencies for electric vehicles were identified through a survey of current and planned models for the NSW study. Efficiencies for small passenger vehicles have been revised with data from Nemry et al. (2009) which indicates that efficiencies are approximately 16 kWh / 100km[11]. It has been assumed that the overall efficiency improvement arising from powertrain improvements, increased range and performance is 20% between 2006 and 2050, equivalent to 0.45% per annum based information provided by Simpson (2009) for the NSW study.

**Table 8** shows the assumed efficiencies.

**Table 8 EV electricity efficiency by vehicle category in 2010**

| Vehicle Category | Electricity (kWh/100km) | Annual Change |
|---|---|---|
| Passenger small | 16.0 | 0.45% |
| Passenger medium | 16.5 | 0.45% |
| Passenger large | 21.5 | 0.45% |
| Light Commercial Vehicle | 18.5 | 0.45% |
| Taxi* | 21.5 | 0.45% |

Source: Survey of current and planned EVs

* Assumed to be the same as large passenger vehicles.

### 4.2.4 Plug-in hybrid electric vehicles

The efficiency of a PHEV is dependent on the proportion of distance travelled propelled by the ICE drivetrain or the electric drivetrain. AECOM assumes that PHEVs will use the electric drivetrain for 50% of kilometres in 2012

[9] Deutsche Bank (2008), *Electric Cars: Plugged In*.
[10] Electric Power Research Institute (2007), *Environmental Assessment of Plug-In Hybrid Electric Vehicles Volume 1: Nationwide Greenhouse Gas Emissions*.
[11] Nemry et al. (2009), *Plug-in Hybrid and Battery-Electric Vehicles: State of the research and development and comparative analysis of energy and cost efficiency*, European Commission Joint Research Centre.

increasing to 80% in 2035 based on a report that BITRE and CSIRO prepared or the Treasury on modelling the transport sector for the Treasury's modelling of the introduction of emissions trading in Australia[12]. This corresponds to an annual change of 1.03% (see **Table 9**).This is consistent with the literature, for example the Electric Power Research Institute's study[13] indicates that the proportion of electric drivetrain usage is 49% for a PHEV with 20 mile (32km) range.

Fuel efficiencies in 2010 are therefore equal to the efficiencies shown in **Table 6** and **Table 8** for the ICE and electric components respectively.

**Table 9 PHEV proportions on ICE and electric drivetrains (all vehicles)**

| Year | 2012 | 2035 | Annual Change |
|---|---|---|---|
| % EV drivetrain | 50% | 80% | 1.03% |
| % ICE drivetrain | 50% | 20% | -1.03% |

## 4.3 Summary of consultation

Consultees broadly agreed with the literature review with the exception of:

- Diesel fuel consumption rates which were considered high. It was suggested that diesel fuel consumption is approximately 25% less than that of an equivalent ICE. This value has been adopted for the study.
- Small passenger electric vehicle consumption. There was debate over this value and the methodology by which it was determined; AECOM has therefore proposed to use the original value of 19kWh/100km as in the NSW model.

[12] http://www.treasury.gov.au/lowpollutionfuture/consultants_report/downloads/Modelling_the_road_transport_sector.pdf

[13] Electric Power Research Institute, *op cit.*.

## 4.4 Values chosen for model

The values to be used by AECOM for the model are shown in **Table 10**.

**Table 10 Fuel efficiency parameters**

| | Petrol (L/100km) | Diesel (L/100km) | LPG (L/100km) | Electricity (kWh / 100km) | Annual Change |
|---|---|---|---|---|---|
| **ICE** | | | | | |
| Passenger small | 7.8 | 5.85 | 11.7 | N/A | 0.84% |
| Passenger medium | 9.7 | 7.28 | 14.5 | N/A | 0.84% |
| Passenger large | 13.8 | 10.35 | 20.6 | N/A | 0.84% |
| Light Commercial Vehicle | 11.2 | 8.40 | 13.6 | N/A | 0.84% |
| Taxi | 13.8 | 10.35 | 20.0 | N/A | 0.84% |
| **HEV** | | | | | |
| Passenger small | 5.31 | N/A | N/A | N/A | 0.43% |
| Passenger medium | 7.35 | N/A | N/A | N/A | 0.43% |
| Passenger large | 11.22 | N/A | N/A | N/A | 0.43% |
| Light Commercial Vehicle | 8.42 | N/A | N/A | N/A | 0.43% |
| Taxi | 11.22 | N/A | N/A | N/A | 0.43% |
| **EV** | | | | | |
| Passenger small | N/A | N/A | N/A | 19.0 | 0.45% |
| Passenger medium | N/A | N/A | N/A | 16.5 | 0.45% |
| Passenger large | N/A | N/A | N/A | 21.5 | 0.45% |
| Light Commercial Vehicle | N/A | N/A | N/A | 18.5 | 0.45% |
| Taxi | N/A | N/A | N/A | 21.5 | 0.45% |
| **PHEV** | | | | | |
| Passenger small | 7.8 | N/A | N/A | 19.0 | 0.84%/0.45% |
| Passenger medium | 9.7 | N/A | N/A | 16.5 | 0.84%/0.45% |
| Passenger large | 13.8 | N/A | N/A | 21.5 | 0.84%/0.45% |
| Light Commercial Vehicle | 11.2 | N/A | N/A | 18.5 | 0.84%/0.45% |
| Taxi | 13.8 | N/A | N/A | 21.5 | 0.84%/0.45% |

# 5.0 Maintenance and repair costs

## 5.1 Modelling input required

Vehicle operating costs per kilometre driven need to be determined as an input to the economic modelling. Vehicle operating costs have to be developed for the time period 2010 to 2040 and for 20 vehicle types:

- Small vehicle – ICE, HEV, PHEV, EV;
- Medium vehicle – ICE, HEV, PHEV, EV;
- Large vehicle – ICE, HEV, PHEV, EV;
- Light commercial vehicle – ICE, HEV, PHEV, EV; and
- Taxi – ICE, HEV, PHEV, EV.

## 5.2 Background

The vehicle operating costs influence the life cycle costs of each type of vehicle and are an input to the choice modelling. The vehicle operating costs is a relatively small proportion of total vehicle costs but nevertheless has to be included to fully reflect the cost differences between different engine types.

Maintenance costs are generally broken down into engine/brake related, non engine/brake related and tyre related. Austroads[14] publishes vehicle repair and maintenance costs for ICE vehicles four each vehicle type under consideration. **Table 11** provides an overview of the Austroads values for each type of vehicle.

**Table 11 ICE vehicle repair and operating costs**

| Vehicle Type | Repair and Maintenance (cents per km) |
|---|---|
| Small Passenger | 5.81 |
| Medium Passenger | 4.41 |
| Large Passenger | 4.30 |
| Light Commercial Vehicle | 5.06 |
| Taxi | 4.30 |

Source: Austroads[14] adjusted to Dec-09 prices

Electrical components such as traction motors and controllers require very little maintenance. An EPRI study estimates that the maintenance cost of a HEV are around 88% of an ICE and maintenance costs of a PHEV are around 75% of an ICE. These differences are largely driven by a reduction in the frequency of brake pad replacements. For EVs there is little information on vehicle maintenance costs and it is therefore assumed that maintenance costs are around 50% of an ICE vehicle and only include the non/engine/brake related and tyre related costs.

Battery replacement costs are assumed to be negligible as battery life is expected to equal or exceed vehicle life within the near future. Even though there are uncertainties surrounding the life of electric vehicle batteries, it is considered reasonable to assume that any battery replacement costs that do occur are unlikely to occur within the first decade. As a result, battery replacement costs for later years would be discounted and also influenced by economies of scale and industry learning curves.

[14] Austroads, *Guide to Project Evaluation Part 4: Project Evaluation Data*, 2008

## 5.3 Summary of consultation

Consultees generally agreed with the literature review; however it was suggested that EV maintenance costs are around 70% of an equivalent ICE and not 50%. The value of 70% has been adopted for this study; however a sensitivity test will be undertaken with the value at 50%.

## 5.4 Values chosen for model

The values to be used by AECOM for the model are shown in **Table 12**.

**Table 12 Maintenance assumptions**

| | ICE (cents / km) | HEV (cents / km) | PHEV (cents / km) | EV (cents / km) |
|---|---|---|---|---|
| Relativity with ICE | N/A | 88% | 75% | 70% |
| Passenger small | 5.86 | 5.16 | 4.40 | 4.10 |
| Passenger medium | 4.45 | 3.92 | 3.34 | 3.12 |
| Passenger large | 4.34 | 3.82 | 3.26 | 3.04 |
| Light Commercial Vehicle | 5.10 | 4.49 | 3.83 | 3.57 |
| Taxi | 4.34 | 3.82 | 3.26 | 3.04 |

AECOM will undertake a sensitivity test whereby the maintenance costs of EVs are 50% of an equivalent ICE.

# 6.0 Charging Infrastructure

## 6.1 Modelling input required

The following information on charging infrastructure is required for the model:

- Capital Costs
- Economic life
- Expected return on capital
- Utilisation
- Electricity network

## 6.2 Background

As vehicle manufacturers expand their production lines for plug-in vehicles, a number of companies are emerging in parallel to meet the demand for private and public recharging infrastructure. For the purposes of this study charging infrastructure has been defined as:

- Residential charging;
- Public charge unit (car parks, hotels, shopping centres, street parking);
- Commercial station (fast charging or battery swap).

A battery swap system has been developed by California-based company Better Place for electric vehicle users to replace batteries at dedicated battery swap and recharging stations akin to existing petrol stations. Aside from Better Place, other leading providers of charging infrastructure are Coulomb Technologies and Elektromotive. There are also a number of smaller technology providers including Epyon and Plugless Power that are developing alternative charging technologies based on nanotechnology and induction respectively.

Electricity utilities and vehicle manufacturers are also supporting the deployment of charging infrastructure. Companies such as Électricité de France (EDF), Toyota, Renault-Nissan, Volkswagen, E.ON, CLP Power Hong Kong and TEPCO are involved in various partnerships or programs to rollout electric vehicles and/or supporting infrastructure.

**Table 13** provides a summary of the publically available information on the costs of charging infrastructure.

**Table 13 Summary of charging units**

| Company | Costs |
|---|---|
| Coulomb Technologies/ Charge Point (Australia) | Last year the city of Amsterdam announced plans to deploy 200 EV charging stations before 2012. They have appointed California's Coulumb Technologies to install the charging stations at a cost of US$5000 each (approximately AS$6200)[15]. |
| Elektromotive | In 2008, the City of Westminster installed 12 electric vehicle charging points using Electromotive, at £3300/unit (approximately AS$6600) (Westminster Council press release[16]). The charging stations have since been rolled out across London. |
| Toyota | In June 2009, Toyota Industries announced a new public charging station[17]. Toyota developed this unit with Nitto Electric Works and it's designed to feed single phase electric power at 200 V and 16 A. The charging units will cost ¥450,000 or about AS$5,600 at current exchange rates. |
| Tesla Motors | Tesla is a sports electric vehicle manufacturer that also sells charging units for their vehicles which range from USD600 to USD1950. A home charging unit capable of a 4-hour charge sells for USD1950 and a portable unit costs USD1500 but is not capable of achieving as fast a charge as the home unit. A spare connector is also sold for USD600 but is only capable of recharging at approximately 5 miles per hour. |
| Nissan | When Nissan launches the Leaf they will also offer customers a home charging dock. The average cost of the charging dock including installation is US $2,200.[18] |
| Better Place | BetterPlace estimate that it will cost $500,000* to build battery swap stations. |

Source: AECOM

Note: * excludes land costs

## 6.3 Summary of consultation

Consultees broadly agreed with the literature review however two areas for modification were raised:

- Setting the cost of the public charge unit at A$3000 per unit.
- Modelling a reduction in the real cost of charging infrastructure over time. Real costs are assumed to decline by 50% to 2020 and are assumed constant thereafter.

Responses also noted that different business models will affect how infrastructure costs are recovered by infrastructure providers. For example the upfront cost of the infrastructure may be incurred by the vehicle user or covered by the infrastructure provider then recovered through a subscription model.

15 Cleantech.com, NRC Handelsblad March 2009

16 http://www.westminster.gov.uk/councilgovernmentanddemocracy/councils/pressoffice/news/pr-4234.cfm

17 http://www.autobloggreen.com/2009/06/08/toyota-industries-will-sell-electric-car-charging-stations-this/

18 http://www.nissanusa.com/leaf-electric-car/print-news.jsp?item=30

## 6.4 Values chosen for model

The values to be used by AECOM for the model are shown in **Table 14**.

**Table 14 Summary of charging units**

| | Residential charging | Public charge unit | Commercial station |
|---|---|---|---|
| Cost per unit (2010) | A$1500 | A$3000 | A$500,000 |
| Cost per unit (2020) | A$750 | A$1500 | A$250,000 |
| Economic life | N/A | 10 | 25 |
| Expected return on capital | N/A | 7% p.a. | 7% p.a. |
| Utilisation | N/A | 10% | 20% |

# 7.0 Next steps

AECOM are awaiting the following data inputs for vehicle numbers and usage in Victoria:

- Historical vehicle registration data for each of the vehicle categories to be analysed with the model;
- Vehicle usage data (annual vehicle kilometres travelled) for each of the vehicle categories.

It is anticipated that these inputs will be made available in July 2010.

Once these data are input into the model, AECOM will undertake modelling of take-up of all types of vehicle over the next 30 years under three charging infrastructure scenarios. Sensitivity testing will be undertaken upon key input assumptions.

The results and findings of the modelling will be made available to DOT within the third quarter of 2010.

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Appendix B

# Vehicle Choice Model

# Appendix B Vehicle Choice Model

Many models do not estimate take-up of different engine configurations and instead make assumptions based on experience elsewhere. This study has decided to directly estimate take-up for two reasons. Firstly, as this is a new market there is not a lot of information on past experience with which to draw meaningful assumptions about the future of electric vehicles in Australia. Secondly, by directly estimating take-up it will be possible to consider the impact of various potential sensitivities around prices (electricity price, fuel price, vehicle price) and how these affect take-up.

Much of the research on electric vehicles has focused on the US market. Although the US has the lowest retail fuel prices, US motorists have greater exposure to fuel price fluctuations in proportional terms as fuel taxes and excises make up a low proportion of the pump price. Arguably, this trait is a key contributing factor to a relative wealth of research undertaken in the US.

**The Role of Stated Preference**

In the absence of an established market for electric vehicles, research has focused on the collection of stated preference data in order to estimate relative demand for electric vehicles. However, it is becoming increasingly recognised that choice modelling based on stated preference data alone may not accurately predict choices made within a real market. This disparity is mainly attributable to the fact that respondents react differently under hypothetical situations, whereby they may:

- Not completely understand the attributes associated with a new product/service;
- Consider information that may not have had perfect information on or accounted for in a real market; and
- Consider information outside the experiment in making their choices;

Stated preferences may also be subject to various types of biases. For instance, Brownstone et al. (2000) found that respondents tended to choose sports cars and low emission vehicles under a stated preference exercise. By contrast, after reviewing revealed preference data, these respondents were purchasing non-luxury cars and high emission vehicles.

However, without a large scale electric vehicle market in which revealed preference data can be used to calibrate vehicle choice models, stated preference techniques will continue to predominate.

**The Impact of Heterogeneity in Preferences**

In contrast, more progress has been achieved in capturing the heterogeneity in the vehicle decision making process. In terms of *vehicle type*, consumers have a wide range of vehicles to choose from. Vehicle models vary by:

- Size (small, medium, large);
- Chassis (sedan, wagon, ute, 4WD, sports etc);
- Fuel type (petrol, diesel, LPG, CNG etc); and
- Power and acceleration etc.

Not only are there various types of models but the factors that influence the choice of one vehicle type over another are also widely varied. Apart from capital, maintenance and operating costs, vehicle choices may be influenced by:

- Brand;
- Range;
- Fuel economy;
- Emissions; and
- Socio-economic factors (income, gender, age, household size, education).

Hence, in order to capture the large heterogeneity in vehicle choice, vehicle choice models have become increasingly sophisticated, both in terms of the modelling techniques and the range of explanatory variables used.

Nested and mixed logit models have been used to capture heterogeneity in preferences:

- Bunch et al (1993) estimated nested logit models in which a two level nest, electric versus non-electric, was found to be statistically significant.
- Brownstone et al. (2000) estimated mixed logit models and found that alternative specific constant for electric vehicles and alternative fuel vehicles, whilst being negative, had a large range (some people like them whilst many people dislike them).

There is emerging evidence to suggest that sensitivity to various attributes differs by group. Whilst mixed logit provides a possible environment to explore these variations in sensitivity, work undertaken by ANL (2005) and Mau et al. (2008) suggest that early adopters of electric vehicle cars will have different purchasing habits to mainstream purchasers:

- ANL (2005) finds that early adopters have different purchasing habits to the majority (e.g. are less price sensitive or value fuel savings higher)
- Mau et al. (2008) find a neighbourhood effect whereby EV price sensitivity increases whilst EV “bonus” decreases significantly with time as mainstream purchasers enter the market.

**Review of Current Literature**

As a first step towards the development of an electric vehicle choice model, a literature review of key electric vehicle choice models has been undertaken. This literature review uncovered that key factors influencing vehicle choice, be it electrically powered or not, include:

- Purchasing cost;
- Operating cost/fuel costs;
- Availability of refuelling facilities;
- Range; and
- Multi-fuel capacity.

Willingness to pay (in terms of an increase in the purchase price) for improvements in electric vehicle attributes by study is outlined in **Table B1**. All estimates are in 2009 prices and in Australian dollars. Perhaps unsurprisingly, there is quite a wide range of values.

**Table B1 Willingness to Pay (in 2009 $A)**

| **Study** *Country* | **Improvement in fuel efficiency by 1c per km** | **Improvement in range from 100km to 200km** | **Decrease in emissions to 90% of ICE emissions** | **Increase in recharging facilities from 10% to 20% of petrol stations** | **Multi-fuel capacity** |
|---|---|---|---|---|---|
| Bunch et al. (1993) *USA* | $1,800 | $16,400 | $1,200 | $3,600 | $10,400 |
| TRESIS (undated) *Australia* | $500 | $1,900 | | | |
| Brownstone et al. (2000) *USA* | $2,500 | $14,700 | $400 | $400 | |
| Dagsvik et al. (2002) *Norway* | $1,000 | $3,600 | | | |
| Ewing & Sarigollu (1998) *Canada* | | $1,600 | $400 | | |
| Golob et al. (1996) *USA* | $3,300 | $11,200 | | $1,800 | |
| Average | $1,820 | $8,233 | $667 | $1,933 | $10,400 |
| Midpoint | $1,900 | $9,000 | $800 | $2,000 | $10,400 |
| Minimum | $500 | $1,600 | $400 | $400 | $10,400 |
| Maximum | $3,300 | $16,400 | $1,200 | $3,600 | $10,400 |

Source: AECOM

### Model Development

In emerging markets such as electric vehicles, establishing vehicle market shares requires the development of primary data from stated preference surveys.

In the absence of such data, one common practice is to adopt parameter values from previous stated preference studies. In this context, AECOM have chosen to develop a synthetic multinomial logit choice model to forecast future market shares for ICE, HEVs, PHEVs and EVs. Notwithstanding that heterogeneity in vehicle choice is a well established phenomenon, AECOM have chosen to use a multinomial logit structure as it is transparent, easily understood by stakeholders and does not require assumptions on the degree of heterogeneity in choice, which would be required if a more sophisticated choice model were developed.

AECOM's synthetic multinomial logit model uses the following variables in its vehicle choice model, for which AECOM has developed projections into the future:

- Vehicle price;
- Running costs;
- Vehicle range;
- Tailpipe emission;
- Availability of charging infrastructure;
- A multi-fuel vehicle constant; and
- Constants for each vehicle type.

Parameters for each of these variables have been based on judgements on:

- Relative parameter values guided by willingness to pay values extracted from previous studies;
- The scale of the parameter values guided by known elasticises; and
- Initial market shares by existing vehicle classes.

As a first step to developing these parameters, AECOM have assumed a set of willingness to pay values in relation to fuel efficiency, range, emissions, recharging infrastructure and multi-fuel capacity. These assumptions are shown in **Table B2** and are within the bounds estimated in **Table B1**.

In developing this set of willingness to pay assumptions, it should be noted that that there is significant variance in willingness to pay for improvements to vehicle attributes and for conservatism, have assumed lower willingness to pay values. The following points have also guided our thinking:

- Willingness to pay for fuel efficiency assumed that Australians drive on average 15,000 km per annum. A 1 cent per km saving equated to a saving of $150 per annum. A $1,080 upfront payment was equivalent to 10 years of fuel savings, discounted at 7 percent per annum.
- Willingness to pay for vehicle range seemed to be quite high in the US (typical of the long distance driving patterns prevalent in the US). A slightly lower willingness to pay was assumed for Australian conditions – set closer to the Norway figure.

**Table B2 Implied WTP (2010 $A)**

| Measure | Assumed willingness to pay |
|---|---|
| Improvement in fuel efficiency by 1c per km | $1,080 |
| Improvement in range from 100 km to 200 km | $3,090 |
| Decrease in emissions to 90% of ICE emissions | $510 |
| Increase in recharging facilities from 10% to 20% of petrol stations | $2,060 |
| Multi-fuel capacity | $5,140 |

Source: AECOM

After determining the willingness to pay values for each key vehicle attribute, the parameter values for each of the variables in question were derived. As a start, the *absolute* value for the fuel cost parameter was determined given the availability of a fuel elasticity estimate drawn from analysis undertaken by Goodwin, Dargay and Green (2003) and Bruenig and Gisz (2009). Additional assumptions required to solve the fuel cost parameter are shown in **Table B3**.

**Table B3 Fuel cost parameter assumptions**

| Description | Parameter | Value |
|---|---|---|
| ICE fuel price elasticity | $\eta$ | -0.25 |
| ICE fuel cost rate | $X$ | 10 c/km |
| Initial ICE market share | $\rho$ | 80% |

In multinomial logit models, direct price elasticities can be estimated using the values of the beta parameter, price and the market share as shown in **Equation B1**.

**Equation B1 Multinomial logit direct price elasticity**

$$\eta = \beta X(1 - \rho)$$

where $\eta$ is the elasticity, $\beta$ is the response parameter to changes in the variable $X$ (e.g. price), and $\rho$ is the market share.

Rearranging **Equation B1** and using the fuel cost assumptions shown in **Table B3**, gives:

**Equation B2 Estimating the beta fuel parameter**

$$|\beta_{fuel}| = \left|\frac{\eta_{fuel}}{X_{fuel}(1 - \rho_{ICE})}\right| = \left|\frac{-0.25}{10(1 - 0.80)}\right| = |-0.125| = 0.125$$

### Calculating final model parameters

With the absolute value of the fuel cost parameter established, the absolute value of the vehicle price parameter was calculated by rearranging the willingness to pay equation shown as **Equation B3**.

**Equation B3 Calculating the vehicle price parameter**

$$WTP_{fuel} = \frac{\beta_{fuel}}{\beta_{vehicle\ price}}$$

With the vehicle price parameter established, the willingness to pay assumptions shown in **Table B3** were used to establish the *absolute values* for all other parameters.

The values were then given a sign based on the expected effect of positive changes in the variable on utility. For instance, an increase in charging infrastructure should cause an increase in an individual's utility; hence, a positive sign was assigned. On the other hand, an increase in vehicle price should cause a decrease in an individual's utility, hence a negative sign was considered appropriate.

**Table B4** presents the final parameter values used in AECOM's synthetic multinomial logit vehicle choice model. These were then used to calculate utility (and hence probability through the multinomial logistic function) in the vehicle choice model. These utility calculations given for the years 2010 to 2040 were then used to determine the total new vehicle sales for each engine configuration (i.e. ICE, HEV, PHEV and EV). Prior to this however, the vehicle choice model required information on all relevant variables. The following sections discuss this in more detail.

**Table B4 Assumed parameters values**

| Parameter | Units | Value |
|---|---|---|
| Vehicle price | $ | -0.00012 |
| Fuel cost | c / km | -0.12500 |
| Range | km | 0.00358 |
| Tailpipe emissions | Proportion of ICE | -0.59028 |
| Availability of infrastructure | Proportion of ICE | 2.38426 |
| Multi-fuel bonus | Dummy | 0.59491 |
| EV constant | Dummy | 0 |

Source: AECOM