Economic Viability of Electric Vehicles

Department of Environment and Climate Change

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Prepared by

AECOM Australia Pty Ltd
Level 11, 44 Market Street, Sydney NSW 2000, PO Box Q410, QVB Post Office NSW 1230, Australia
T +61 2 8295 3600 F +61 2 9262 5060 www.aecom.com
ABN 20 093 846 925

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Executive Summary

The key objective of this study is to assess the economic viability of plug-in electric vehicles for the NSW Metropolitan region and to identify market and economic conditions under which such vehicles provide a net benefit to society.

AECOM developed an economic model to assess viability and a vehicle choice model to forecast take-up of different engine configurations. The economic model considers the costs and benefits to infrastructure providers, consumers (in terms of vehicle purchase and operating costs) and externalities such as greenhouse gas emissions and air pollution. The financial model considers the costs and benefits only to infrastructure providers and consumers.

The model shows that the plug-in electric vehicle market in NSW 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 Hybrid Electric Vehicles (HEVs) in the short term (5-10 years), Plug-in Hybrid Electric Vehicles (PHEVs) over the medium term (5-20 years) and full Electric Vehicles (EVs) over the longer term (20 years plus). In the short term there is increased uptake of alternative engine configurations in the small vehicle category. However, over the longer term, as vehicle prices fall, the vehicle range increases and more charging infrastructure become 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.

Key factors affecting the take-up of plug-in electric vehicles and market viability in Australia include the supply of infrastructure, the vehicle cost (this is largely driven by battery costs) and the rate at which it converges with Internal Combustion Engine (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.

Background and Objectives

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

This study assesses the economic viability of plug-in electric vehicles (both pure electric vehicles as well as plug-in hybrid electric vehicles) for the NSW Metropolitan[1] passenger vehicle, light commercial vehicle and taxi markets. The study also identifies market and economic conditions under which such vehicles provide a net benefit to society. Analysis of specific business models and financing arrangements were outside the scope of this study.

Current Technology in the Electric Vehicle Market

As of today (2009), lithium-ion EVs are on the verge of commercial viability and mass-production, with PHEVs following close behind. In the next 3 to 5 years, the industry as-a-whole plans to launch more than 30 new EV and PHEV models with global production targets set to reach almost one million units

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[1] The study area is defined as ―Metropolitan NSW" which includes the Sydney Statistical Division, Illawarra Statistical Division and the Newcastle Statistical Subdivision.

annually within this timeframe. Both EVs and PHEVs are currently in commercial production and are expected to be available to Australian motorists by 2012.

The production of EVs/PHEVs is expected to launch in all segments of the light-vehicle market, although manufacturers of EVs are showing an early preference for small vehicles in order to minimise the cost premium (since battery cost scales proportionally with vehicle size/weight, whereas mature ICE costs vary less with vehicle size/weight).

EVs/PHEVs will provide the same functionality and features as traditional vehicles, except for some obvious differences with regards to range per charge and recharging versus refuelling. The high cost of EVs/PHEVs is driven by battery costs which are typically around US$10,000.

The future evolution of lithium-ion batteries will see continuing advances in performance, range and useful life as a result of significant ongoing investment in battery R&D. It is expected that there will be significant cost reductions in vehicle prices through industry learning curves as this is still a relatively new market, and economies of scale achieved through mass-production.

Key aspects of the methodology

Scenarios to be Assessed

The economic model has been built to allow flexibility and sensitivity testing around the key variables. As such, the scenarios to be tested by the model are focused around the different levels of charging infrastructure that may be required to facilitate the electric vehicle market. All scenarios are compared against the Base Case.

Base Case:	Assumes there are only ICEs and HEVs available and no PHEVs or EVs.
Scenario 1:	Household Charging Only (Level 1 - over 3 hrs per 40kms).
Scenario 2:	Household Charging (Level 1 and 2 - 25 minutes per 40kms) plus Public Charging Stations (car parks, hotels, shopping centres, street parking).
Scenario 3:	Household Charging (Level 1 and 2), Public Charging Stations plus Electric Vehicle Service Stations (2.5 minutes per 40kms).

Market Segments

This study focused on eleven market segments: Passenger Vehicles by vehicle size (small, medium, large) and by distance travelled (low, medium and high vehicle kilometres travelled (VKT)); Light Commercial Vehicles (LCV) and Taxis. Vehicle size was considered important because prices and availability of vehicles will vary significantly between vehicle sizes. Distance travelled was considered important because high VKT vehicles benefit more from the cheaper cost of using electricity as a transport fuel.

Vehicle Choice Model

Many studies of this type 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 from which to draw meaningful assumptions about the future of EVs 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.

After an extensive literature review on the factors affecting the decision to purchase a vehicle, a logit model was developed which takes into account the vehicle cost, fuel costs, vehicle range, emissions, availability of charging infrastructure, multi-fuel bonus and an electric vehicle bonus.

Vehicle Prices

New vehicle prices have been estimated from a survey of 34 global EV products for the 2009-2012 model years and 28 US HEVs for the 2009-2010 model years. An equivalent ICE vehicle was used for the price of ICE vehicles to ensure a consistent comparison.

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 is likely to reflect a local market penalty due to our relatively small market size, distance from large vehicle manufacturing countries, volatile exchange rate, and lack of local manufacturing of non-ICE vehicles. It has been assumed that there will be a similar small market penalty for PHEVs and EVs.

HEVs are assumed to reach price parity with ICEs in 2020. PHEV and EV purchase prices are assumed to reach price parity with ICEs in 2030.

Fuel Cost per Kilometre

Fossil fuel prices were estimated using Energy Information Agency (EIA) forecasts for crude oil prices. Their reference scenario forecasts US$74 per barrel in 2010, decreasing slightly and then increasing to US$80 per barrel by 2040. Electricity prices were estimated based on modelling undertaken by the Australian Treasury. The central price scenario sees electricity prices increasing to over 20 cents per KWh by 2040. The following assumptions on fuel efficiencies have been made:

- Efficiency of an ICE vehicle will improve due to platform engineering as well as other efficiencies such as combustion technology improvements;
- HEVs will experience continued efficiency gains over ICE however these improvements will decline over time as the potential for improvement gets eroded by improved combustion technologies;
- EVs will experience improvements in efficiency due to platform engineering and power-train improvements; and
- PHEVs will use the electric drivetrain for 50% of kilometres in 2012 increasing to 80% in 2035.

Supply Constraints

A major issue to the take-up of EVs in the short term (next 5 – 10 years) will be supply constraints. There are expected to be global supply constraints until at least 2012 and these will be exacerbated in Australia which is not seen as a key market for vehicle manufacturers. As such, a supply constraint has been built into the model to ensure it reflects current market conditions.

Cost of Infrastructure

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.

It has been assumed that there will be no requirements to upgrade the electricity transmission and distribution networks. This assumes the use of smart metering (so that households charge during the off peak period) and that significant investments are known in advance so can be built into investment plans with little additional costs. However, an increase in network access cost has been assumed to apply to all electricity consumed through Level 2 household charging to represent the costs of a potentially necessary upgraded household connection to the local distribution network.

The cost of the charging infrastructure will vary by the different scenarios. There are no infrastructure costs associated with Scenario 1 (household charging). The infrastructure costs for Scenario 2 and 3 are as follows:

Scenario 2: Household charging (Level 1 and 2) plus public charging stations:

- $1,000 per household for interface unit installation (equipment cost included as standard item)
- $6,000 per public charging unit

Scenario 3: Household charging (Level 1 and 2) plus EV service station:

- $1,000 per household for interface unit installation (equipment cost included as standard item)
- $6,000 per public charging unit
- $500,000 per charging station

AECOM has not considered the cost of additional generation capacity due to the use of EVs. Under the higher EV take up of Scenario 3, annual electricity consumption for EVs and PHEVs in 2039-40 (8.2TWh) represents an increase of around 10% of 2007-08 total NSW electricity demand (78.3TWh[2]). However, general growth in electricity demand between 2008 and 2040 will reduce the significance of EV electricity demand as a proportion of total demand.

Model Results

Table E-1 sets out the present value of the benefits associated with introducing EVs into the NSW market compared to the Base Case. The model shows that under all scenarios the EV market is both economically and financially viable over the long run. The net present benefit becomes positive after 2030 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 $33m under Scenario 1, $91m under Scenario 2 and $165 million under Scenario 3. Air pollution savings total $261m under Scenario 1, $710m under Scenario 2 and $1,256 million under Scenario 3.

The net benefits increase with the level of charging infrastructure provided because this increases the take-up of EVs. Higher levels of charging infrastructure also bring forward the break-even year.

Table E-1: Present Value of Benefits incremental to the Base Case*

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)
Vehicle Purchase ($m)	-$272	-$1,230	-$1,230	-$415	-$2,010	-$2,313	-$625	-$2,766	-$3,192
Vehicle Operation ($m)	$71	$461	$1,447	$133	$1,020	$4,008	$242	$1,694	$6,756
Net Charging Infrastructure ($m)**				-$1	-$15	-$37	-$3	-$26	-$65
Financial Benefits ($m)	-$201	-$769	$217	-$283	-$1,005	$1,658	-$386	-$1,098	$3,499
GHG Emissions ($m)	$3	$11	$33	$4	$21	$91	$7	$36	$165
Air Pollution ($m)	$11	$82	$261	$21	$182	$710	$40	$319	$1,256

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[2] ABARE Energy In Australia, Department of Resources, Energy and Tourism 2009

Economic Benefits ($m)	-$187	-$676	$511	-$258	-$802	$2,459	-$339	-$743	$4,920
Breakeven year	2035			2032			2031		
*Based on central forecasts of oil price, electricity price and CPRS policy. A 7% discount rate has been used for all present value calculations. ** Net charging infrastructure is capital cost of charging infrastructure minus premium customers pay to cover cost of infrastructure.									

Source: AECOM

Sensitivity analysis highlighted the following:

- Results are very sensitive to the year in which EVs reach price parity with ICE vehicles. Changing the initial price does affect the results but this is not as sensitive as the year in which prices reach parity; and
- Results are sensitive to increasing oil prices but less so to electricity and the Carbon Pollution Reduction Scheme (CPRS) prices. This is mainly due to the improved efficiency of EVs over ICE vehicles. However, the combination of high oil prices with low electricity prices has large positive impact on the results.

Table E-2 summarises the total greenhouse gas and air pollution (CH_4, N_2O, NO_x, Co, BOC and PM_{10}) emission savings compared to the Base Case under each scenario.

Table E-2: Greenhouse gas and air pollution emission savings compared to the base case (tonnes)

	Scenario 1			Scenario 2			Scenario 3		
	To 2020	To 2030	To 2040	To 2020	To 2030	To 2040	To 2020	To 2030	To 2040
CO_2e	169,763	908,201	5,621,115	224,888	1,929,891	17,255,754	361,435	3,462,002	31,307,014
CH_4	4	62	316	9	139	779	18	243	1,343
N_2O	23	500	2,695	61	1,254	7,779	133	2,228	13,739
NO_x	228	1,185	4,065	313	2,314	11,529	466	3,784	20,117
CO	897	15,802	83,345	2,101	37,068	215,836	4,358	65,242	375,086
VOC	45	167	561	57	271	1,336	91	473	2,418
PM_{10}	22	186	822	36	410	2,284	61	701	4,002

Source: AECOM

Table E-3 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[3] and maintenance costs (based on average annual distance travelled as set out in **Table 4-5**) and insurance. Future costs have been discounted at 7%.

Table E-3: Lifetime cost per kilometre for each engine configuration in 2010 and 2040[4]

Engine Type	Small Passenger		Medium Passenger		Large Passenger		Light Commercial		Taxi	
	2010	2040	2010	2040	2010	2040	2010	2040	2010	2040
ICE	$0.263	$0.264	$0.286	$0.287	$0.352	$0.355	$0.277	$0.279	$0.271	$0.275
HEV	$0.299	$0.245	$0.318	$0.272	$0.380	$0.341	$0.299	$0.264	$0.321	$0.264
PHEV	$0.297	$0.217	$0.313	$0.227	$0.469	$0.274	$0.365	$0.214	$0.466	$0.234
EV	$0.260	$0.191	$0.270	$0.199	$0.416	$0.243	$0.318	$0.185	$0.438	$0.220

Source: AECOM

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

[4] The cost per kilometre is non-scenario specific as vehicle and operating costs do not change significantly across the scenarios.

In summary, the cost per kilometre for smaller 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 and LCVs 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 larger 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.

Issues for Consideration

Several issues arose during the study that were not able to be incorporated into the model, but are important in understanding the electric vehicle market and how it may evolve over time. These include:

- Battery issues: There are various battery issues including the evolution towards standardisation of technology; the current high costs which are expected to reduce over time with increasing production resulting in economies of scale and industry learning curves; a lack of industry practices to ensure safe battery disposal; uncertainty about battery life; and the residual value and potential for a secondary market.
- Global supply constraints: A major issue to the take-up of EVs in the short term (next 5 years) will be supply constraints. These are likely to be exacerbated in the Australian market which is relatively small and not a key market for vehicle manufacturers.
- Market structure: The current market structure of vehicle travel is characterised by vertical separation. The business models chosen by providers of electric vehicle infrastructure can have a strong influence on customer decision-making. While this should not change the fundamental cost and benefits of electric vehicle travel, it could change the perception of relative costs and benefits by customers and hence affect their choice of vehicle. It also has the potential to create competition issues.
- Lifecycle Considerations: The lifecycle of batteries and associated electric-drive components will clearly be a determining factor for the overall sustainability of the plug-in vehicle industry. Early efforts to characterise the lifecycle of electric-drive vehicles are revealing some positive indications. However, given Australia‘s current reliance on fossil fuels, the ongoing use of these fuels for manufacturing process energies and electric power generation will be a critical factor, and further lifecycle assessment will be required based on Australia‘s unique local context.
- Electricity issues: The most significant electricity issue arises in respect of how electric vehicle charging infrastructure is priced and how consumers respond. Clearly there is interplay between cost of charging and convenience, which will affect the take-up of EVs.
- The role of government policies: Governments all around the world have developed policies to encourage the take-up of EVs. Some policies are designed to support industry (charging infrastructure, development of technology) whilst other policies are to encourage increased demand through subsidising the purchase and operating costs for consumers. It is important to consider the applicability of government policies in Australia.
- Wider economic impacts: This study is a partial equilibrium model and as such there are a range of other effects that may occur as a result of changes in the vehicle market that have not been considered in this study.

Conclusions

The model shows that the plug-in electric vehicle market in NSW 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 short term (5-10 years), PHEVs over the medium term (5-20 years) and EVs over the longer term (20 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, small 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 (this is largely driven by battery costs), 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.

1.0 Introduction

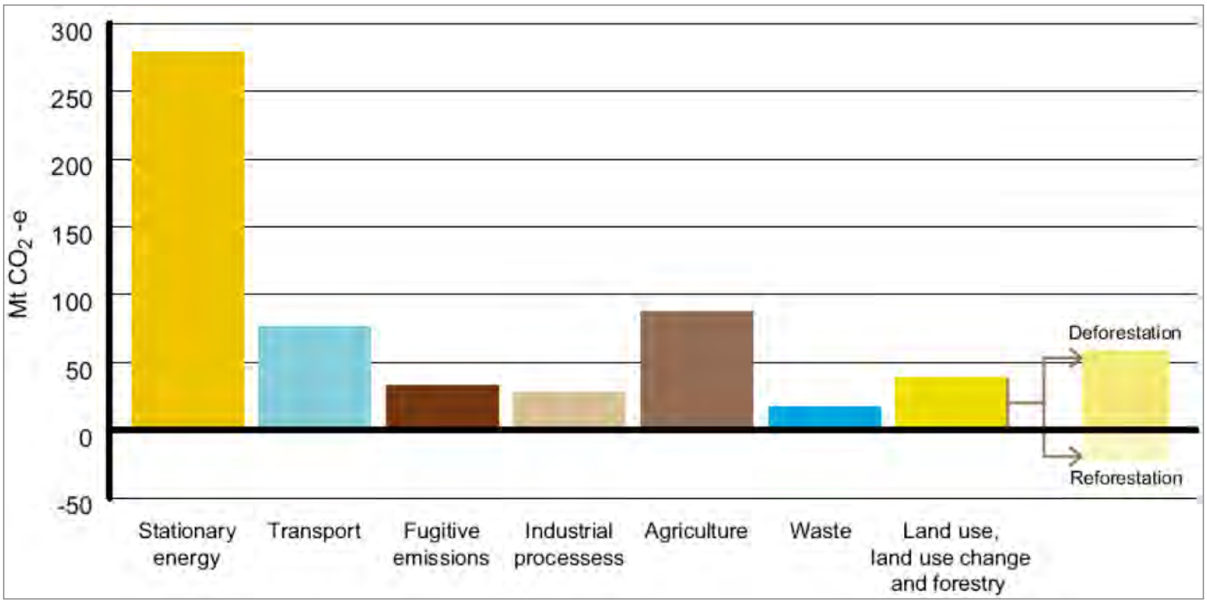
1.1 Background

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

Increasing concerns over climate change has spurred the development of alternative fuel cars in the last decade. The International Panel for Climate Change (IPCC) Fourth Assessment Report in 2007 presents a clear case that climate change exists and it is very likely that greenhouse gas increases related to human activity have caused most of the rise in global mean temperature since the mid-20th century. The Garnaut Review (2008) suggests that emissions are tracking at the upper bounds of the scenarios modelled by the IPCC.

In 2006, Australia‘s net greenhouse gas emissions using the Kyoto accounting provisions were 576 million tonnes of CO2-equivalent (Mt CO2-e)[5]. **Figure 1-1** shows the sectoral breakdown of these emissions. A relatively high level of car ownership in Australia has meant that transport contributes around 14% of Australia's emissions and is the second fastest growing source of emissions[6]. Of this, road travel contributes 89% of total transport greenhouse gas emissions. The use of alternative fuels may help reduce these emissions.

Figure 1-1: Australia’s national emissions profile in 2006



Source: National Greenhouse Gas Inventory 2006, Department of Climate Change

Rising oil prices and the security of fuel supply are other issues that have encouraged alternative fuels and vehicle development. The finite supplies of crude oil which tend to be concentrated in a small number of countries create risks around the security of supply. As oil supplies are run down, fuel prices will rise to reflect the increasingly difficult and expensive extraction process. Thus alternative fuels will become increasingly important to ensure domestic supply and maintain more stable prices.

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[5] Green Paper on the Carbon Pollution Reduction Scheme, Department of Climate Change July 2008

[6] The Future of Transport Fuels: challenges and opportunities, Future Fuels Forum, CSIRO June 2008

Electric vehicles (EV) or plug-in hybrid electric vehicles (PHEV) use electricity as their main energy source. The increased use of EVs or PHEVs is likely to address both the climate change and energy supply problems raised above. The main climate benefit of EV use is that there are no tailpipe emissions at the point of consumption, unlike existing internal combustion engines. Depending on the source of electricity (coal, hydro, wind, etc.), a net emissions reduction for the transport sector could be achievable through the use of EVs.

The development of a plug-in EV market in Australia could face some significant hurdles, including:

- Cost: The competitiveness of all-electric vehicles is dependent on the cost comparison with petrol vehicles. The cost of a vehicle is dependent on the upfront cost of purchasing the vehicle as well as ongoing operating costs (predominantly fuel). The cost of the required battery technology is currently making EVs more expensive to purchase than a comparable petrol vehicle. Whilst electricity is cheaper than petrol resulting in operating cost savings it is not enough to outweigh the high capital costs at present.
- Infrastructure: EVs would also require the support of new infrastructure, such as battery recharge points and changeover stations, or facilities for home charging.

In addition, there are other potential impacts that need consideration, including the impact of EVs on the electricity network.

1.2 Study Objectives

The key objective of this study is to assess the economic viability of plug-in electric vehicles (both pure electric vehicles as well as plug-in hybrid electric vehicles (PHEVs) for the NSW Metropolitan passenger, light commercial vehicle and taxi markets. The study will also identify market and economic conditions under which such vehicles provide a net benefit to society.

Overall, the project aims to develop a model that will help address the following questions:

- What is the current and likely future state of technology for electric vehicles?
- What type of infrastructure is required to support electric vehicles?
- What are the factors that influence the economic viability of electric vehicles, i.e. under which circumstances are electric vehicles economically viable?
- What are the risks and barriers to adopting electric vehicles in New South Wales (more broadly, in Australia) and how might government policy address these?

Analysis of specific business models and financing arrangements were outside the scope of this study.

1.3 Project Scope Issues

This study is primary work in the area of electric vehicle take-up and economic impact in Australia. As such, it is intended to gather information relevant to Australia and provide a base from which further work can be undertaken. There are many factors that will influence the take-up of EVs including technological development, vehicle prices, and government policies on environmental issues. This study has made assumptions using the best available data about these issues to provide an indication of their importance. The model has been designed to be updated as new data becomes available that may affect the future of the electric vehicle market.

1.4 Engine Configuration

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

Table 1-1: Engine configurations

Engine 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 drivetrains typically dependent on vehicle speed (urban/non-urban use). HEVs 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. The batteries in a PHEV are typically larger than those in a HEV 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)	Fully electric vehicles are powered only by electricity stored in batteries. EVs face similar limitations as HEVs 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 2009

1.5 Report Structure

The report is structured as follows:

- **Chapter 2** outlines the current technology in the electric vehicle market and how this is expected to change;
- **Chapter 3** sets out the supply chain and infrastructure requirements;
- **Chapter 4** sets out the methodology for undertaking this study along with the key input variables;
- **Chapter 5** sets out the results of the vehicle choice model;
- **Chapter 6** sets out how the externalities will be quantified and valued;
- **Chapter 7** sets out the key assumptions in this study and the suggested sensitivity analysis;
- **Chapter 8** sets out the economic and financial results;
- **Chapter 9** sets out issues for consideration; and
- **Chapter 10** sets out market failures that may exist in the market now and in the future.

1.6 Acronyms

Below is a summary of commonly used acronyms throughout this report.

- A - ampere
- CPRS - carbon pollution reduction scheme
- EV - electric vehicle
- GST - goods and services tax
- HEV - hybrid electric vehicle
- ICE - internal combustion engine
- kW - kilo watt
- kWh - kilo watt-hour
- LCV - light commercial vehicle
- LPG - liquefied petroleum gas
- PHEV - plug-in hybrid electric vehicle
- VKT - vehicle kilometres travelled
- V - volt

2.0 Current State of Technology

2.1 Commercial History of Plug-in Vehicles

EVs first arose at the end of the 19th century, following the invention of the electrochemical battery. For example, one of the first vehicle prototypes built by Ferdinand Porsche was a battery-powered electric vehicle and, at the turn of the 20th century, EVs were a leading technology candidate for the propulsion of personal automobiles.

Initial interest in the technology stemmed from its –push-button start" capability – which compared favourably with the intimidating hand-crank of combustion engines and slow warm-up cycle of steam engines. Furthermore, since the competing technologies were less mature and also had limited performance, EVs could potentially hold their own. However, combustion vehicles quickly improved to offer greater performance, and once the electric starter motor was invented for convenient starting, electric vehicles lost their key selling point and quickly lost favour in the market.

During the oil shocks of the 1970s and 1980s, there was a resurgence of interest in EVs and a flurry of R&D efforts including the demonstration of many prototypes. However, the next major commercial deployment of EVs came in the 1990s, spurred-on by air quality concerns in California. Controversial legislation – the Zero Emission Vehicle (ZEV) Mandate – was enacted to require a compulsory number of EVs to be sold in the Californian market. These first-generation EVs were mostly equipped with lead-acid or nickel-metal-hydride batteries, offering less performance than the EVs being considered today. Since California was the world‘s largest single automotive market at the time, the impacts of this effort were felt globally. Similar government-led deployments of EVs were also initiated in Asia and Europe. While automakers rushed to meet the ZEV Mandate requirements, they also launched a concerted lobbying effort (in conjunction with oil companies) to roll-back the mandate and alleviate the pressure for them to deliver EVs to market. They claimed that both industry and consumers were not ready to manufacture and buy these EVs (due to a variety of techno-socio-economic factors), and that there were alternative strategies for achieving California‘s air quality goals.

Hindsight has shown that while these arguments may have been partly true, they were also misleading in some ways. The automakers only made available a small number of products to a limited segment of the market. In contrast, there is significant anecdotal evidence to suggest that those customers who did gain access to EVs were extremely receptive to the technology and reluctant to give them up. In any case, the ZEV mandate was not a successful commercial deployment of EV technology. Several thousand EVs were manufactured and sold/leased but all these products had been removed from the market by the end of the 2003 model year.

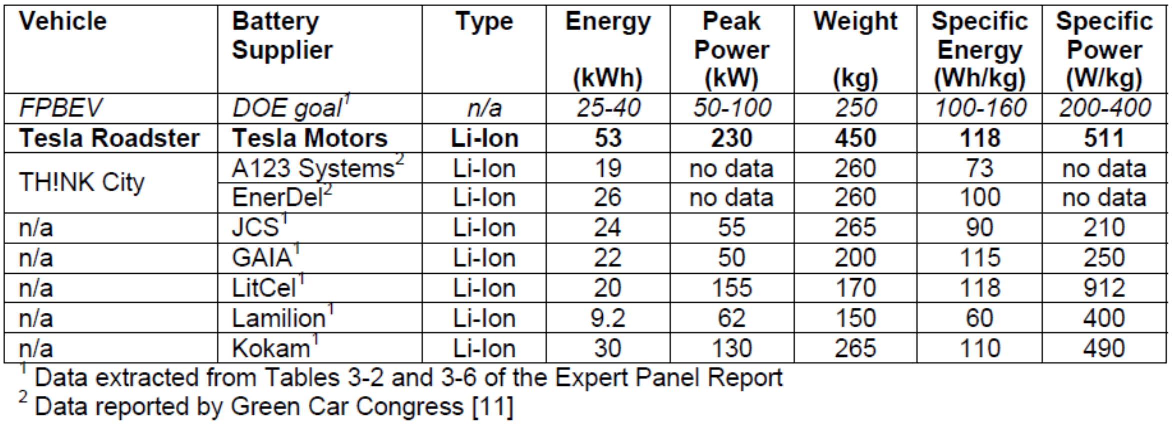
Meanwhile, the industry shifted its focus to non-plug-in hybrid-electric vehicles (HEVs) and then fuel cell vehicles until a new breed of EVs began to emerge in the mid 2000s equipped with next-generation lithium-ion batteries. Furthermore, the commercial success of non-plug-in hybrid vehicles and advances in lithium batteries also enabled the prospect of mass-market PHEVs using component technologies leveraged from these other powertrains. As a result, there are now currently two candidate plug-in vehicle technologies – EVs and PHEVs – that must be evaluated for the future automotive industry.

2.2 Current State of Technology

2.2.1 Lithium-Ion Plug-in Vehicle (EVs and PHEVs) Market Entry

In 2006 the California Air Resources Board (CARB) commissioned an expert panel to determine the market readiness of full-function lithium-ion battery-powered plug-in vehicles. The expert panel concluded positively that ―high energy Li-Ion technology has good potential to meet all performance requirements of EVs with batteries of modest weight…cell and battery technology designed for these applications are likely to also meet cycle life goals.” **Table 2-1** demonstrates several automotive lithium-ion battery packs with targets established several years ago by the US Department of Energy. They were similarly optimistic about the viability of PHEVs. The expert panel did, however, temper their enthusiasm with concerns about battery costs and the likely timeframes for delivery of EVs and PHEVs to market and the scaling of production volumes.

Table 2-1: Specifications for automotive lithium-ion battery packs under development (2006)



Vehicle	**Battery Supplier**	**Type**	**Energy (kWh)**	**Peak Power (kW)**	**Weight (kg)**	**Specific Energy (Wh/kg)**	**Specific Power (W/kg)**
FPBEV	*DOE goal*[1]	*n/a*	*25-40*	*50-100*	*250*	*100-160*	*200-400*
Tesla Roadster	**Tesla Motors**	**Li-Ion**	**53**	**230**	**450**	**118**	**511**
TH!NK City	A123 Systems[2]	Li-Ion	19	no data	260	73	no data
	EnerDel[2]	Li-Ion	26	no data	260	100	no data
n/a	JCS[1]	Li-Ion	24	55	265	90	210
n/a	GAIA[1]	Li-Ion	22	50	200	115	250
n/a	LitCel[1]	Li-Ion	20	155	170	118	912
n/a	Lamilion[1]	Li-Ion	9.2	62	150	60	400
n/a	Kokam[1]	Li-Ion	30	130	265	110	490

[1] Data extracted from Tables 3-2 and 3-6 of the Expert Panel Report

[2] Data reported by Green Car Congress [11]

Source: A. Simpson (2008) ―Response to the CARB ZEV Expert Panel Position on Lithium-Ion Full-Performance Battery Electric Vehicles”, expert testimony on behalf of Tesla Motors Inc. to the California Air Resources Board review of the Zero Emission Vehicle Program, available at: www.arb.ca.gov/regact/2008/zev2008/zev2008.htm, 23 March.

The current rate of advance within the EV and PHEV industry indicates that the CARB‘s expert panel were overly-conservative in their predictions. As of today (2009), lithium-ion EVs are on the verge of mass-production and commercial viability, with PHEVs following close behind. EV products have once again become available in limited volumes supplied by proactive start-up companies. However, in the next 3 to 5 years, the industry as-a-whole plans to launch more than 30 new EV and PHEV models with global production targets set to reach almost one million units annually within this timeframe. **Table 2-2** highlights some of the EV and PHEV products that are already in production or planned for launch in the next few years. This deployment is being further accelerated by the green stimulus packages now being implemented by governments globally. Although the initial supply of EVs and PHEVs may be limited with correspondingly high introductory prices, it is anticipated that the rapid growth in production volumes will allow the industry to drive costs down quite quickly.

Table 2-2: EVs/PHEVs currently in production or planned for launch in the near future

Make	Model	Segment	Type	Elec Range (km)	Battery	Capacity (kWh)
Blade	Electron	small	EV	120	LFP	16
Energetique	evMe	small	EV	200	LMP	40
Ford	Focus	medium	EV	130	Li-Ion	23
Ford/Smith	Ampere	commercial	EV	160	LFP	24
Mini	E	medium	EV	240	Li-Ion	35
Mitsubishi	iMiEV	small	EV	125	Li-Ion	16
Nissan	no data	small	EV	160	Li-Ion	35
Smart	ed	small	EV	115	Zebra	13
Subaru	Stella	small	EV	90	Li-Ion	9
Tesla	Model S	large	EV	260	Li-Ion	42
Tesla	Roadster	large	EV	395	Li-ion	53
TH!NK	City	small	EV	180	LFP	26
BYD	F3DM	medium	PHEV	100	LFP	13
Chevy	Volt	medium	PHEV	65	LFP	16
Daimler	Sprinter	commercial	PHEV	30	Li-Ion	14
Fisker	Karma	large	PHEV	80	Li-Ion	23
Ford	Escape	large	PHEV	50	Li-Ion	10
Toyota	Prius	medium	PHEV	20	Li-Ion	no data
Battery nomenclature: LFP = lithium-ion iron-phosphate LMP = lithium-metal polymer Li-Ion = other lithium chemistries Zebra = sodium nickel chloride						

Source: AECOM study team (Dr Andrew Simpson,) June 2009

The production of EVs/PHEVs is expected to launch in all segments of the light-vehicle market within the next few years. Manufacturers of EVs are showing an early preference for small vehicles in order to minimise the cost premium (since battery cost scales proportionally with vehicle size/weight, whereas mature ICE costs vary less with vehicle size/weight) and in recognition that EV attributes are better-suited to smaller, urban-commuter vehicles rather than larger multi-purpose vehicles. PHEVs are universally applicable across all segments, although EVs are possibly more competitive in the smaller segment. Furthermore, the proliferation of PHEV models may lag behind EVs since PHEV battery requirements are more stringent and PHEV batteries are less-mature and less-proven than EV batteries. In any case, both technologies are currently (as of 2009) in commercial production and are expected to be available to Australian motorists by 2012.

2.2.2 Plug-in Vehicle Functionality and Performance

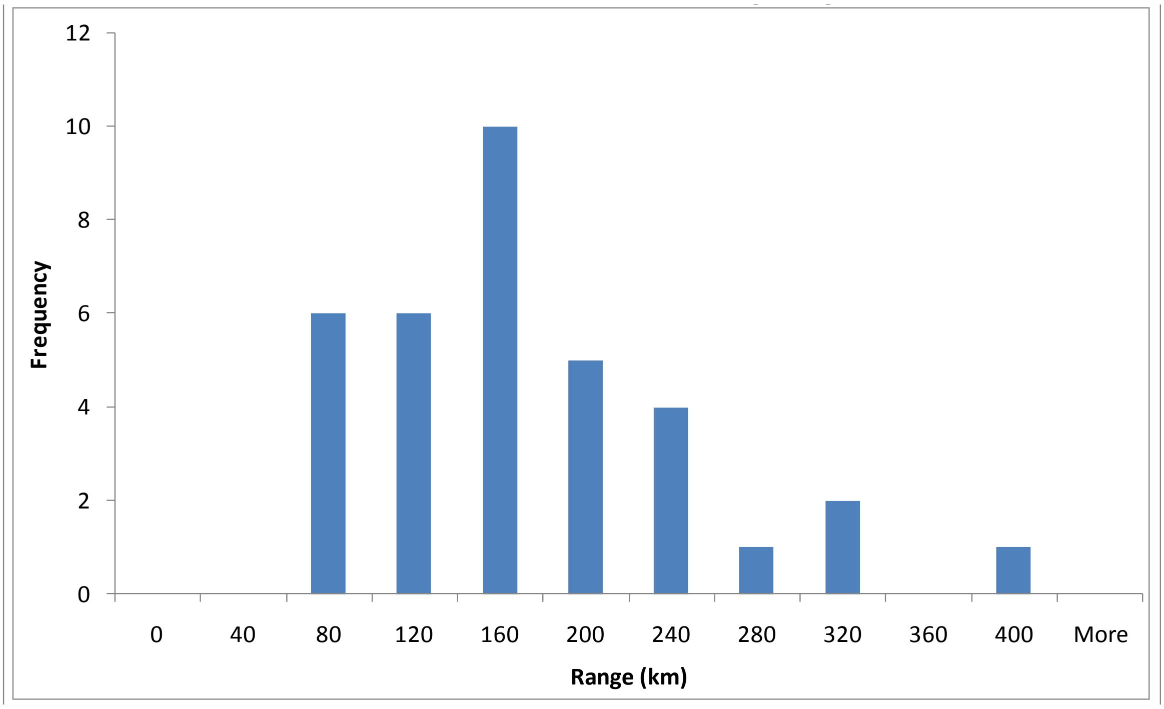
There are some misperceptions regarding the performance of plug-in vehicles with respect to traditional vehicles (e.g. speed and acceleration) but these have arisen largely from the attributes of non-highway-capable EVs (also known as neighbourhood electric vehicles). Highway-capable EVs/PHEVs will provide the same functionality and features as traditional vehicles, except for some obvious differences:

- Range per charge (in the case of EVs as demonstrated in **Figure 2-1**);
- Recharging versus refuelling;
- Novel user interfaces based on unique powertrain components and features;
- Regenerative braking;

- No/less transmission shifting; and
- Less noise during operation (due to engine-off mode or lack of engine, but EVs/PHEVs are definitely not “silent”).

Figure 2-1 highlights the vehicle range of the EV and PHEV products that are already in production or planned for launch in the next few years based on data in **Table 2-2**.

Figure 2-1: Distribution of EV driving ranges based on models in production or planned for release by 2012



Source: Table 2.2, Based on 36 EV and PHEV models

2.2.3 Plug-in Vehicle Maintenance and Reliability

There is little empirical data available to characterise the maintenance schedules and costs of EVs/PHEVs (not including batteries) however it is generally expected that these vehicles will require less servicing and cost less to maintain.

Electric powertrain architectures are generally simpler with fewer moving parts. Many of the consumable items found in combustion engines (belts, seals, filters, sparkplugs, valves and some lubricants) do not exist in EVs. Maintainable parts that are common for EVs include electronics, cooling fluids and radiators, fans and pumps, driveline lubricants, wheel/axle bearings, brake pads and tyres, and air-conditioning systems. For some parts such as brake pads, the maintenance frequency may be reduced. Generally speaking, EV/PHEV powertrain batteries require no maintenance whatsoever and come equipped with charge-balancing and thermal-management systems to maximise their performance and useful life.

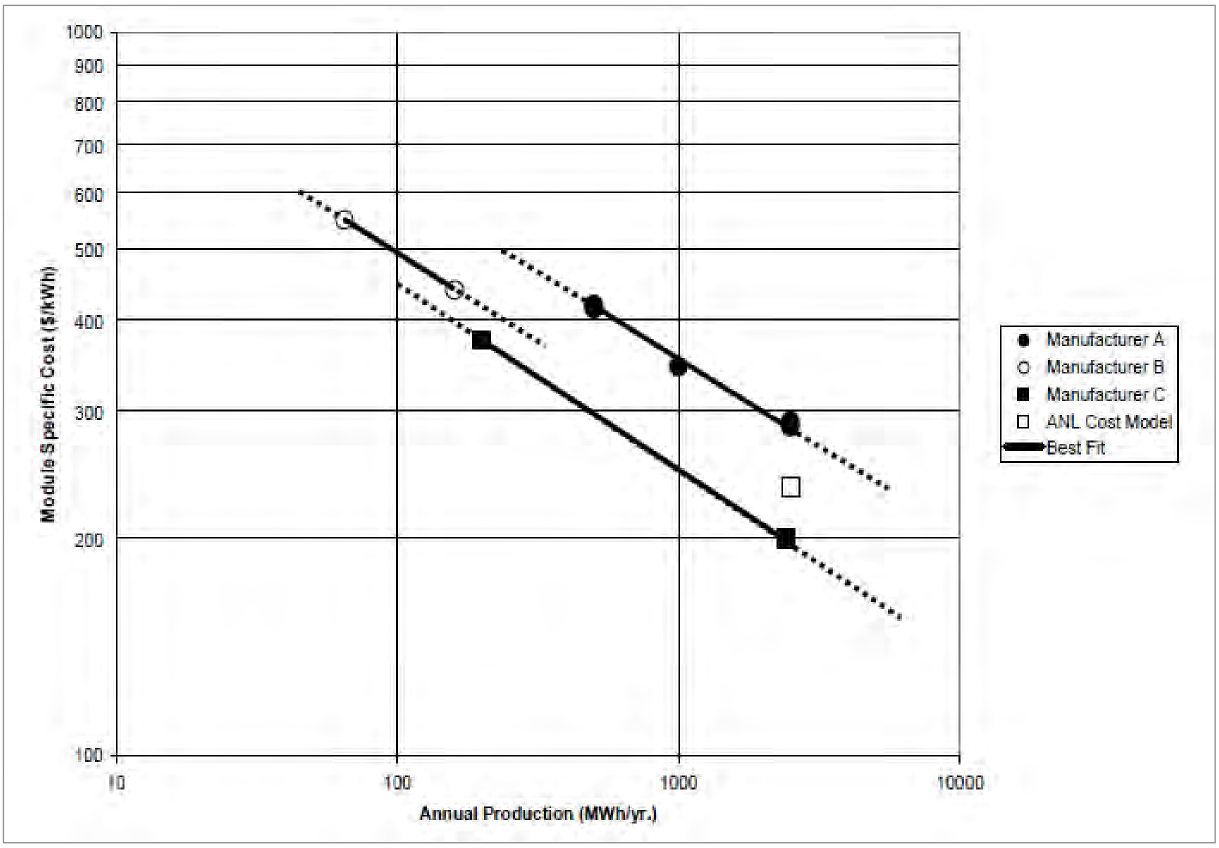
Predicted EV/PHEV battery lifetimes are approaching the life of the vehicle, although the life does still vary widely depending on cell chemistries, cell architectures and methods for pack integration. It should also be noted that the typical “end-of-life” criterion for automotive batteries is 80% of original performance (a substantial amount), and motorists who forgo a battery replacement at this point can expect ongoing utility from the battery even as it continues to decline. Unfortunately, battery lifetimes are difficult to predict without several years of accelerated cell and battery testing – both in laboratories and on the road. For this reason, it is possible that manufacturers will bring EV/PHEV products to market before battery lifetime issues are fully understood and resolved. At this time, there are not enough products on the market to gauge how EV/PHEV powertrain warranties will compare with conventional vehicles. On the other hand, alternative business models are also emerging (such as battery leasing currently offered by TH!NK) to shield the consumer from the responsibility of battery monitoring, maintenance and replacement.

2.2.4 Battery Costs

Since the supply chain for automotive lithium-ion batteries is underdeveloped, the process of estimating battery costs is still a very inexact science. Cost estimation is made more difficult by the fact that the automotive industry holds its proprietary battery costs in strict confidence. Nevertheless, a number of studies and surveys have attempted to quantify and project the cost of automotive lithium-ion batteries now and into the future. A common feature of these studies is the use of industry learning curves to model the reduction of battery costs with increasing production volumes.

The CARB expert panel report included a battery cost model based on data obtained through surveys and interviews with key personnel in the automotive battery industry. **Figure 2-2** shows the learning curves from various battery manufacturers. The raw data was also processed into a scalable, generic battery cost model to predict the costs of various battery configurations at a range of production volumes, as shown in **Table 2-3**.

Figure 2-2: Learning curve of battery manufacturers



Source: Kalhammer F., Kopf B., Swan D., Roan V. & Walsh M. (2007) ~~"~~Status and Prospects for Zero Emissions Vehicle Technology", State of California Air Resources Board, Sacramento.

Table 2-3: Estimated cost of automotive lithium-ion batteries at various production volumes (US $)

Vehicle Type	Battery Capac. (kWh)	Cell Capac. (Ah)	500MWh/year 20k Batteries/year			2500 MWh/year 100k Batteries/Year		
			Product. Rate (MWh/y)	Module Cost ($/kWh)	Battery Cost ($)	Product. Rate (MWh/y)	Module Cost ($/kWh)	Battery Cost ($)
FPBEV	40	120	500 800	285 255	13,680 12,240	2500 4000	195 175	9,285 8,395
Small EV	**25**	**45**	**500** **20**	**380**	**11,875**	**2500** **100**	**260**	**8,150**
PHEV-40	14	45	500 280	380 435	7,075 8,350	2500 1400	260 300	4,850 5,585
PHEV-20	7	30	500 140	435 595	4,305 5,190	2500 700	295 405	2,750 4,025
PHEV-10	4	15	500 80	575 880	3,265 4,990	2500 400	395 605	2,240 3,445
Full HEV	2	7	500 40	805 1,465	2,420 4,395	2500 200	550 1,010	1,650 3,025

Source: Kalhammer F., Kopf B., Swan D., Roan V. & Walsh M. (2007) ―Status and Prospects for Zero Emissions Vehicle Technology”, State of California Air Resources Board, Sacramento.

For each application, the table lists module specific and battery total cost projections for limited production rates (left half of table) and in mass production (right half). For each of these two levels of commercialization, cost projections are given for capacity production rates (MWh/year, upper numbers) and for battery production rates (batteries/year, lower numbers).

FPBEV means a full-performance battery electric vehicle and PHEV-40 means a PHEV whose battery provides 40 miles of all-electric operation before the combustion engine turns on.

Other key technologies that are essential for commercial deployment of EVs/PHEVs include electric drivetrain technologies (electric motors and inverters) and onboard/offboard recharging systems.

2.2.5 Electric Drivetrain Technology

Automotive electric drivetrains are approaching technical maturity and have moved significantly down their industry learning curves and production cost curves. Today‘s electric drivetrain technologies provide very high levels of performance and efficiency with continually-lowering costs and, although there is still scope for further improvement, these components are quite adequate for their task of providing EV/PHEV propulsion. This is largely due to nearly twenty years of development and commercial application in 1st generation EVs, then HEVs, then fuel cell EVs and now lithium-ion EVs and PHEVs. In parallel, a significant Tier-1 supplier base has been established to provide high-volume, high-quality electric drivetrain components to vehicle manufacturers.

2.2.6 Recharging Systems and Charging Efficiencies

Recharging technology has not required as much development to support the coming wave of mass-market plug-in vehicles. Consumer charging systems were developed for 1st- generation EVs and these have been gradually improved upon since. The industry now seems to be converging on common architectures and standards for charging systems that will provide for universal compatibility across the plug-in vehicle fleet. Most notably, the industry seems to have largely abandoned inductive (magnetic) charging systems in sole favour of conductive (electric) charging systems.

Recharging of EVs/PHEVs will require approx 0.15-0.25 kWh/km depending upon vehicle size and powertrain efficiency. Recharging generally varies depending upon the size and weight of the vehicle, as well as its powertrain efficiency and charging circuit topology.

Another positive development has been the definition by the Society of Automotive Engineers of tiered ―levels” of charging capability around which industry is harmonising. These levels are defined in **Table 2-4.**

Table 2-4: Charging levels as defined by the Society of Automotive Engineers

Charger	Circuit Rating	Power	Charging Rate	Charge Time (for 40km)
Level 1	120V/20A (240V/10A for Australia)	2.4kW	0.2 km/min	200mins
Level 2	240V/80A[7]	19.2kW	1.6 km/min	25mins
Level 3	480V/400A 3-phase	192.0kW	16.0 km/min	2.5mins

Source: AECOM / Dr Andrew Simpson

Level 1 charging utilises standard electrical circuits and power outlets and all charging electronics required to support Level 1 can be carried onboard the vehicle. Level 2 charging requires a ―charging interface" to be wired into a building's electricity supply to provide protection from higher voltage/power, and these systems typically involve the use of a specialised plug and socket. Level 2 charging can therefore be performed at home, but only if the appropriate equipment has been installed by an electrician. Level 3 charging greatly exceeds 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.

2.2.7 Plug-in Vehicle Safety

Some lithium-ion batteries can be quite hazardous when mis-handled or poorly engineered, and some instances of this have been observed for certain brands of laptop batteries. Fortunately, the use of large-format lithium-ion batteries in vehicles requires a totally different level of focus on system integration including design for safety, crashworthiness and serviceability. Furthermore, the preferred automotive lithium-ion chemistries (e.g. lithium-ion iron-phosphate) are either less-prone to or unable to go into thermal runaway.

Plug-in vehicles for-the-most-part have been and will continue to be engineered to be just as safe to operate, service and transport as conventional vehicles. Established automakers take their safety requirements very seriously in order to avoid liabilities arising from their products, and they have the engineering know-how and resources to guarantee this safety. However, the industry is also acutely aware of the risk that new, small and inexperienced vehicle providers (with fewer resources) may attempt to market products that are not as safe. The use of lithium-batteries in automotive applications is therefore strictly regulated overseas and their safety is promoted via numerous standards for EV/PHEV design. However, the Australian Design Rules have not yet been brought into line with international standards for plug-in vehicle safety.

2.2.8 Plug-in Vehicle Standards

The existence of standards is another key indicator of the commercial readiness of EVs/PHEVs and these have been established by respected industry bodies in North America, Europe and Asia. While these standards are not yet fully-harmonized, the industry is clearly moving in this direction. Locally, the standards for EVs/PHEVs are currently being considered by Standards Australia and it is expected that these will soon be derived from the existing overseas standards.

For example, EV/PHEV standards exist and continue to evolve in the following areas:

- Range, efficiency and emissions testing and labelling;
- Battery design and testing for safety and durability including destructive testing;
- Safety and serviceability of high-voltage electrical systems;

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[7] Even though Level 2 charging circuits are single-phase by definition, it is possible that these higher power levels might require a 3-phase supply in some circumstances which would require upgrades to the household service and possibly the street.

- Crashworthiness including destructive testing; and
- Cargo transport of lithium batteries – both within vehicles and as standalone components.

2.3 Likely Evolution of Technology

The future evolution of lithium-ion batteries will see continuing advances in performance, range and useful life as a result of significant ongoing investment in battery R&D. These advances will be enabled by new chemistries as well as innovative re-application of existing chemistries (for example, via nano-engineering). It is quite possible that plug-in vehicles will improve to the point that they achieve the same performance (in terms of driving range and recharging rate) as conventional vehicles. Regardless, it has been determined that the current state of technology is sufficient to enable the commercialisation of these vehicles.

Another significant evolution will be the economies of scale achieved through mass-production, which will drive-down component and vehicle costs. It is also expected that there will cost reductions through industry learning curves as this is still a relatively new market (as illustrated in **Figure 2-2**).

2.4 Uptake of Electric Vehicles

The uptake of plug-in vehicles to-date has been relatively low, but this has been constrained in a large part by the limited availability of EV/PHEV products to consumers.

Hundreds (if not thousands) of 1st-generation EVs from the 1990s are still in use in North America, Europe and Asia today. As lithium-ion EVs and PHEVs become available, it is clear that demand will greatly exceed supply. For example, Tesla Motors is still working to fill approximately 1200 backorders for its Roadster and meanwhile has received over 1000 reservations for its Model S sedan prior to its release. There is also a small but vibrant and growing market for aftermarket plug-in vehicle conversion/retrofit systems.

It is too soon to tell if or when the market for EVs and PHEVs will plateau as the customer base shifts from early adopters to mainstream consumers. However, it is very clear that two key factors will determine the rate of uptake of EVs and PHEVs:

1) Consumer acceptance and demand for EVs/PHEVs based on product attributes of performance, cost, emissions etc. There is significant anecdotal evidence to suggest that consumer appeal is not the limiting factor at this time (as of 2009). Also, in most major automotive markets, governments provide significant consumer incentives (e.g. a $7,500 tax credit in the US) for plug-in vehicles in recognition of their many societal benefits (See **Section 9.6** for further information on policies Governments around the world have adopted to increase the take-up of EVs).

2) Growth in production volumes for EVs/PHEVs driven by industry investment in expansion of manufacturing capacity for vehicles and supply chain for components. There is significant anecdotal evidence to suggest that this factor is currently limiting and will continue to limit the availability and supply (thereby increasing the price) of EVs/PHEVs – particularly due to constraints in the battery supply chain. A secure battery supply has been identified as a strategic issue for many automotive economies with the result that government funding via the current economic stimulus packages in the US and Europe are being used to address this issue.

It is important to recognise that plug-in vehicles are coming to market at a time when consumer and government awareness and receptiveness to alternative vehicle technologies is at an all-time high due to concerns about oil depletion, petroleum prices, air pollution and climate change. These motivating factors are likely to encourage a faster uptake of EVs/PHEVs as an alternative compared to the uptake observed for HEVs and other alternatives in preceding decades.

2.4.1 Comparison with Hybrid-Electric Vehicles

For reference, it is useful to understand the historical uptake of HEVs.

HEV market entry occurred in Japan in 1997 and the US in 2000. Today, the current total market for HEVs in the US is approximately 320,000 vehicles sold annually, composed of approximately 20 different HEV models. Globally, as of February 2009, the total cumulative HEV sales by Toyota and Honda exceeded two million vehicles, and these two automakers have been responsible for the vast majority of HEV sales to date.

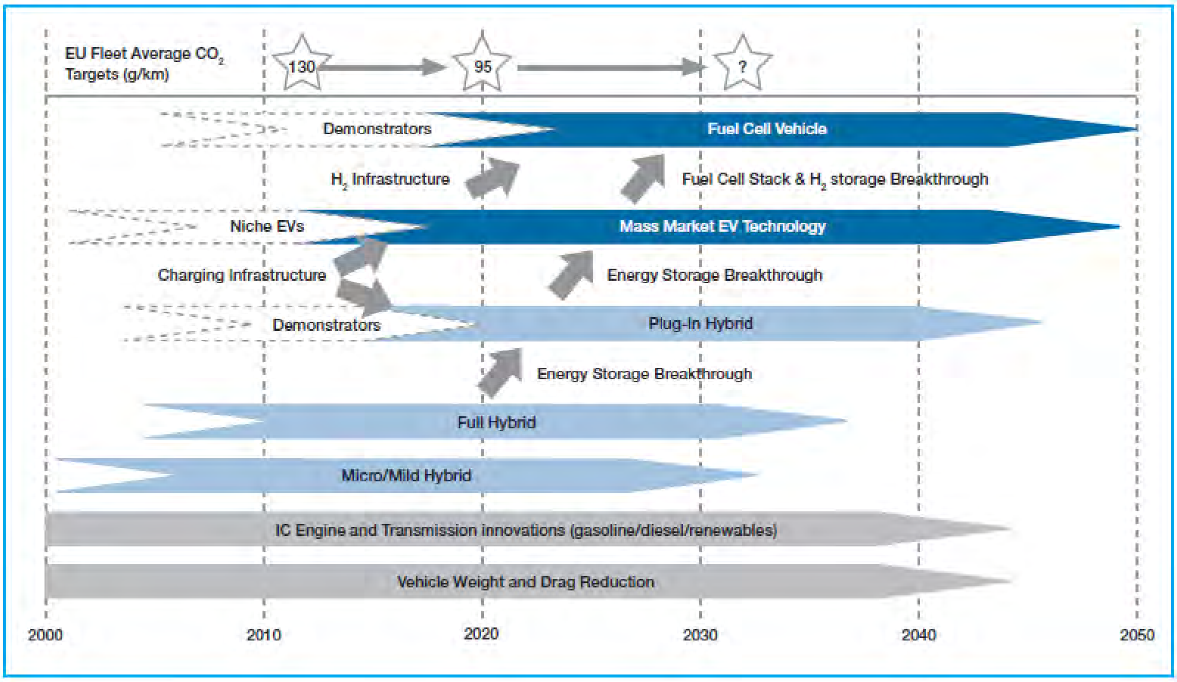
In Australia, almost 12,000 Toyota Priuses have been sold since they were launched here in 2001. The success of HEVs in Australia has been limited by low import volumes and the resulting high price differentials compared to other vehicles.

2.4.2 Other Forecasts of Take-Up of Electric Vehicles

A number of studies have been undertaken to forecast the take-up of EVs. Some recent studies include:

- The UK Government forecast mass production of HEVs by 2010, PHEVs by 2020 and EVs by around 2018 (see **Figure 2-3**);
- Frost & Sullivan[8] estimates that the European market for EVs is likely to be about 480,000 units by 2015 (see **Figure 3-3**);
- Boston Consulting Group forecast that ICE vehicles will remain the dominant technology in 2020. In that year, HEVs, PHEVs and EVs will achieve market penetration rates of between 12-45%, with a steady pace scenario at 28%[9] (Note this relates to total fleet not new vehicles).

Figure 2-3: UK Government expectation of the future of low carbon vehicles in the UK



Source: Ultra–Low Carbon Vehicles in the UK, UK Government 2009

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[8] Concerted Government Support Critical for Powering the Electric Vehicle Market, Frost & Sullivan, May 2009

[9] The Comeback of the Electric Car? How real, how soon, and what must happen next, The Boston consulting Group, 2009

3.0 Nature of the Supply Chain and Infrastructure

3.1 Overview of Supply Chain for Vehicles

3.1.1 Plug-in Vehicle Manufacturing and Prices

The supply chain capacity for mass-market plug-in vehicles is currently building in preparation for the market introduction of more than 30 products within the next 3 to 5 years. The plug-in vehicle manufacturers include both established automakers as well as new brands (a complicated mix of new industry joint ventures and start-up companies). **Table 3-1** summarises a selection of EVs/PHEVs for which production plans and initial pricing have been announced.

Table 3-1: Production plans for various EV/PHEV models in the near team

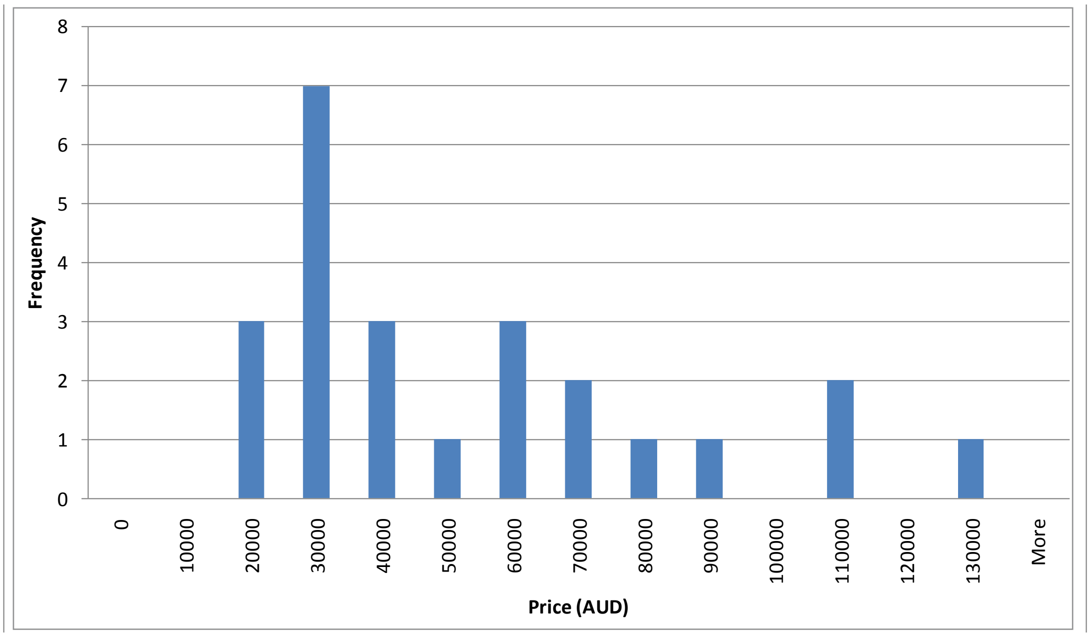
Make	Model	Launch	Initial Pricing	Markets	Production Volumes (Annual)
smart	Ed	2007	US 26,000	EU, NA, Oz	1,000 (pilot)
TH!NK	City	2007	US 44,000	EU, NA	7,000 up to 70,000 in 2012
Blade	Electron	2008	AU 43,000	Oz	200 up to 5,000 in 2011
BYD	F3DM	2008	US 22,000	Asia, EU, NA	6,000 up to 24,000 in 2010
Tesla	Roadster	2008	US 109000	NA, EU	1,500-2,000
Energetique	evMe	2009	AU 70,000	Oz	build-to-order
Mini	E	2009	US 850 p.m.	NA	500 (pilot)
Mitsubishi	iMiEV	2009	US 48,000	Asia, EU, NA, Oz	2,000 up to 30,000 in 2013
Subaru	Stella	2009	US 48,000	Asia	170 (pilot)
Chevy	Volt	2010	US 40,000	NA	10,000 up to 100,000 in 2011
Fisker	Karma	2010	US 88,000	NA	up to 15,000 in 2012
Nissan	EV	2010	US ~30,000	Asia, EU, NA, Oz	50,000
Toyota	Prius PHEV	2010	Unknown	Asia, EU, NA	500 (pilot)
Ford	Focus EV	2011	Unknown	NA	8,000
Renault	Fluence EV	2011	Unknown	EU	40,000 up to 80,000 in 2012
Tesla	Model S	2011	US 57000	NA, EU, Asia	20,000 in 2013
Ford	Escape PHEV	2012	Unknown	NA	5,000
NA = North America, EU = Europe, Oz = Australia and New Zealand					

Source: AECOM study team (Dr Andrew Simpson,) June 2009

The supply of vehicles to Australia could be quite limited in the near term – with vehicles available soon from Mitsubishi and local conversion companies in limited quantities, to be followed by increasing production and other products from Nissan, Smart and other manufacturers. However, the bulk of plug-in vehicles produced in the next few years will be allocated to markets other than Australia. Furthermore, the introductory pricing in Australia for these vehicles will be relatively high – expected somewhere in the range of AU $40,000-$70,000 although for many vehicles Australian pricing has yet to be announced.

Figure 3-1 surveys the announced pricing forecasts across the industry, however it should be noted that these early predictions are frequently subject to change. The prices vary widely from around $20,000 up to over $100,000 reflecting the different vehicle sizes and performance characteristics.

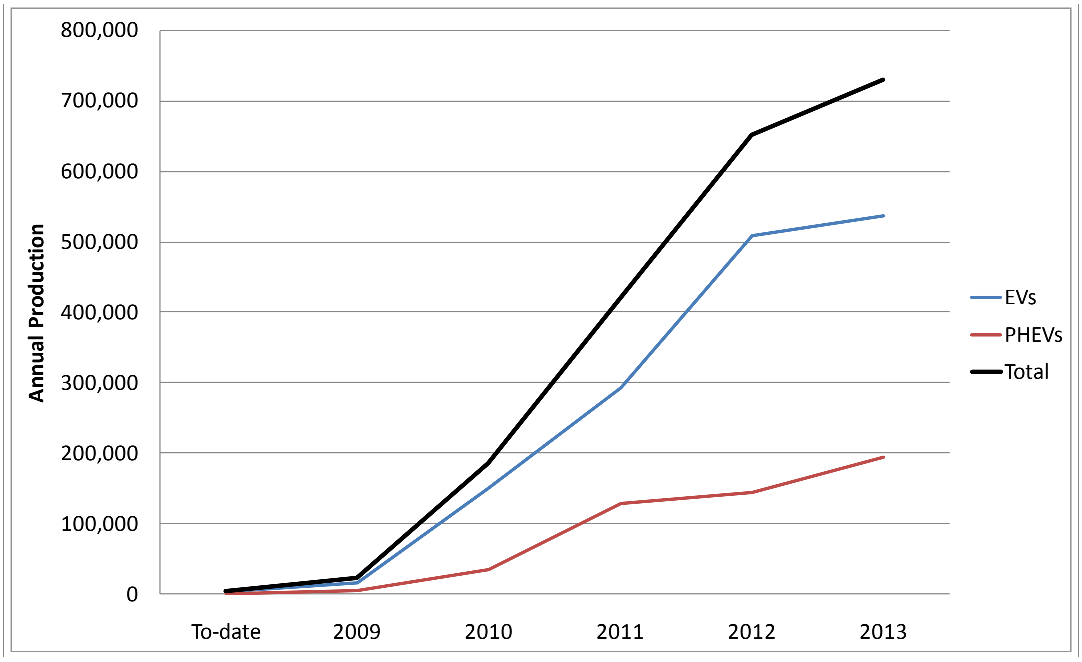
Figure 3-1: Distribution of forecast prices for global production of EVs/HEVs (model launches during 2009-2012)



Source: Table 3.1

Figure 3-2 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.

Figure 3-2: Industry plans for global production of EVs and PHEVs



Source: AECOM study team (Dr Andrew Simpson,) using announcements made in the automotive media

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.[10]

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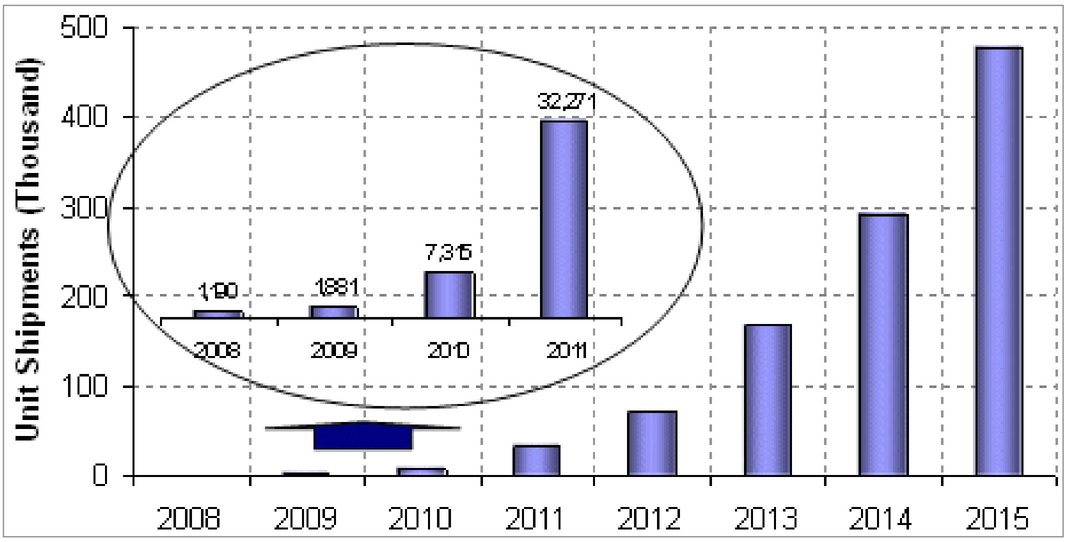
[10] International Organization of Motor Vehicle Manufacturers (OCIA), global survey of production 2007

Figure 3-3: European electric vehicle market forecast, 2008 – 2015



Source: Concerted Government Support Critical for Powering the Electric Vehicle Market, Frost & Sullivan, May 2009

3.1.2 Battery Supply

It was beyond the scope of this study to provide a detailed review of developments in the battery supply chain, however, some general comments should be made.

The majority of today‘s automotive lithium-ion batteries are produced by vendors in Asia (Japan, Korea and China). In most cases, these vendors fall under the umbrellas of the vertically-integrated automotive corporations that is common in the Asian automotive industry. For example, Toyota, Nissan/Renault, Mitsubishi and BYD all effectively assert total control of their battery suppliers – providing them with strategic advantage by denying access to the technologies for their competitors. New battery companies are continually emerging to serve the growing supply-gap, however, these too are often tied-up in strategic joint-ventures with established automakers.

As a result, the variety and quantity of mass-produced automotive lithium-ion batteries available in the open market is actually quite limited. This poses a major barrier for new entrants into the plug-in vehicle industry, and also limits the scalability of aftermarket retrofit plug-in vehicle solutions. The United States has recognised domestic battery supply as an issue of strategic importance and has begun pouring its stimulus funding into expansion of US domestic battery manufacturing facilities.

3.2 Overview of Supply Chain for Charging Infrastructure

As vehicle manufacturers expand their production lines for plug-in vehicles, a number of companies are emerging in parallel to provide private and public recharging infrastructure.

3.2.1 Charging Interfaces

In private locations (residential or commercial), Level 1 charging can occur directly from standard power outlets and specialised charging interfaces are not required, although some customers may choose to install Level 1 interfaces that provide ―smart” charging or other advanced features.

Prominent providers of public Level 1 solutions include Coulomb Technologies (Charge Point) in the US and Australia and Elektromotive in Europe. Each of these companies is currently participating in pilot deployments of plug-in vehicles in North America and Europe. Most PHEVs are equipped to be compatible with Level 1 charging interfaces. The cost of most Level 1 charging interfaces falls in the realm of US$5,000 (for example, Toyota just announced it would begin installing charging stations in Japan at a cost of US$4,560 a piece).

Level 2 options are more limited at this time – and are primarily targeted at EVs with their larger batteries. For example, Tesla Motors provides a Level 2 charging interface as a standard feature in its Roadster (as well as an optional Level 1 charging adapter). Most other EVs come equipped with a Level 2 charging port – although it is not clear which interface solutions will be provided with these products in their commercial deployment, nor is the cost of these Level 2 interfaces well known nor whether they will be included as a standard feature. In terms of open-access infrastructure, Better Place plans for its private/public charge spots to have Level 2 interfaces. With the recent consensus reached in North American and Europe on Level 2 charging standards, there are likely to be many more developments in relation to Level 2 infrastructure in the near future.

Level 3 charging solutions are highly specialised and only exist at the pre-commercial stage. Level 3 charging has been proven in demonstrations by companies such as Nissan, Mitsubishi and Subaru (working with the Tokyo Electric Power Company (TEPCO)) in Asia and Phoenix Motorcars in the USA. Battery swap stations are at a similar stage of pre-commercial development – Better Place recently demonstrated a battery swap station in Japan, but are yet to proceed with their commercial deployment.

Evoasis is a San Diego, California and London, UK based company which develops full service Fast-Charge, EV and PHEV Charging Station Facilities (EVSTAT) for deployment in metro areas and roadway access points in both the public and private sector. 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.

3.2.2 Electric Utilities

Many electric utilities outside Australia are proactively supporting the deployment of plug-in vehicles. Rather than being concerned by the additional load these vehicles might impose on the grid, they see plug-in vehicles as a lucrative new business opportunity. Some of the more-prominent electric utilities in the plug-in vehicle industry include Southern California Edison (SCE), Pacific Gas and Electric (PG&E), San Diego Gas and Electric (SDGE), Xcel Energy in Colorado, Austin Energy in Texas, Electricite de France (EDF) in Europe and TEPCO in Japan. All of these utilities have ongoing participation in pilot commercial deployments of plug-in vehicle fleets, and provide incentives in the form of discounted, plug-in-vehicle-specific tariffs. Most utilities advocate smart-charging technology as a favoured method for managing the charging loads imposed by plug-in vehicles on the grid.

This summary of the benefits of plug-in vehicles to utilities was recently published by Austin Energy:

1. Additional electricity sales
    a) Revenue for the utility or possibly for a third-party service provider.
    b) Higher grid utilization (more energy over same infrastructure) should result in lower rates for customer (also has the potential to impose costs on the utility to enable higher utilization).
2. Distributed resource potential: functioning as either capacity or load
    a) Ancillary services: benefits for both the electric grid and the car owner/customer.
    b) Energy storage: can provide system support or enable a higher penetration of intermittent (solar and wind) generation resources.

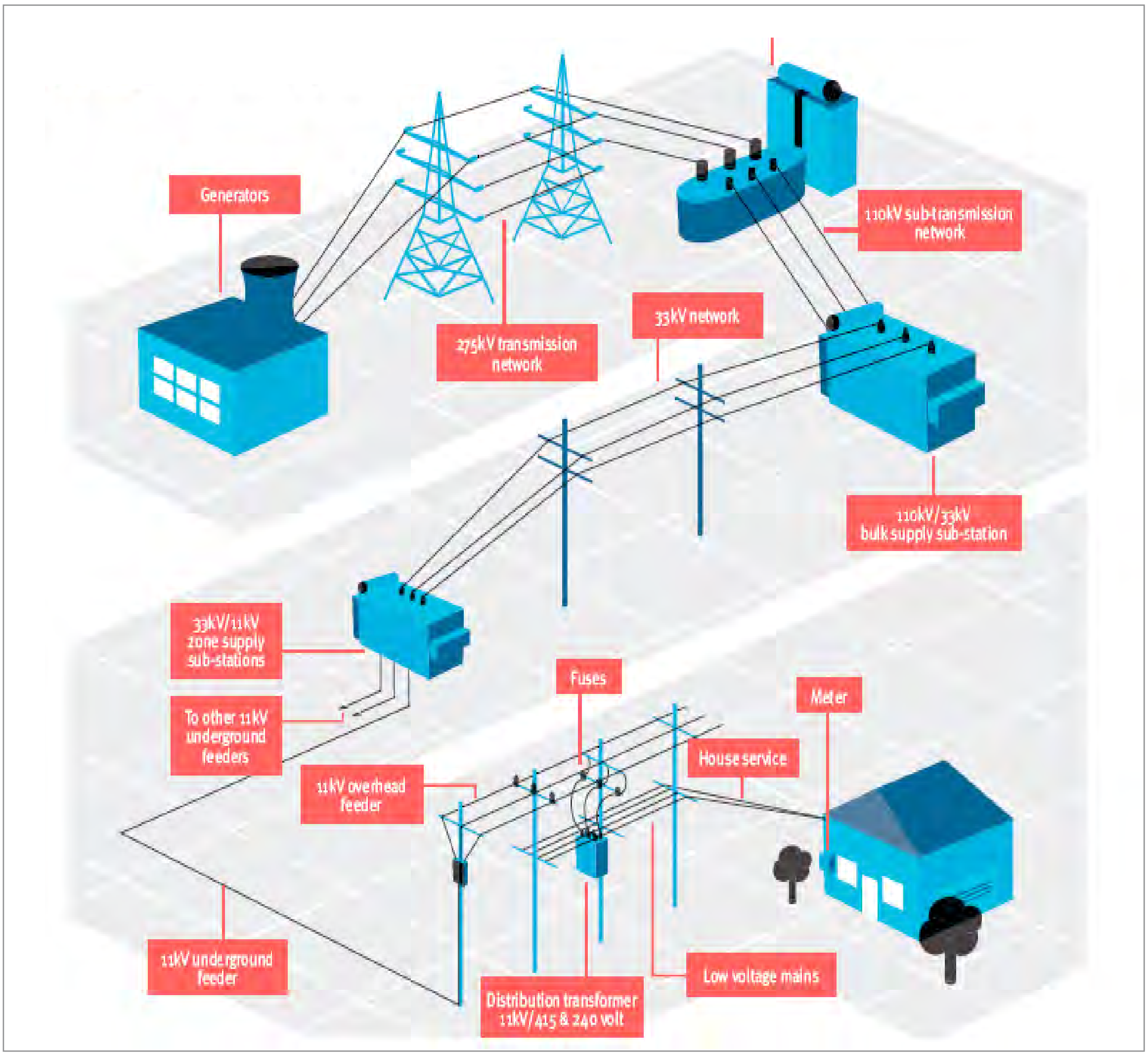
Source: Austin Energy et al (2009) –Testing of Charge-Management Solutions for Vehicle Interaction with the Austin Energy Electric Grid”, technical report, available at: http://www.v2green.com/news/Austin%20Energy%20PHEV%20Trial%20%20Final%20Report%20-Feb%2009.pdf

Electricity distribution network businesses in Australia have a strong interest in possible deployment of EVs. The vital issue is the extent to which the network may need to be strengthened to supply the additional load that might be due to electric vehicle charging (in the medium term) and to accommodate possible feed back into the grid from a distributed battery system.

The electricity supply system in New South Wales has been separated into different components, as illustrated in **Figure 3-4** below. The main components are:

- Internal wiring within premises, which is the responsibility of the owner;
- Meter, which is generally owned by the network although usage is billed by the retailer;
- Distribution network (low voltage in street back to 110 kV subtransmission), which is the responsibility of the distribution business;
- Transmission network (linking subtransmission and generators), which is the responsibility of the transmission business, TransGrid in New South Wales; and
- Generation, which in eastern Australia is managed through the competitive National Electricity Market.

Figure 3-4: Schematic of electricity supply system



Electric vehicle charging will affect different parts of the supply system differently. Services within the premise are likely to be most affected. Upstream services are less likely to be affected provided that diversity of charging behaviour evens out loads rather than adding to peak load. In fact, overnight charging may improve the shape of the system load by increasing the average but not the peak. It will be important to provide strong incentives for charging outside peak periods.

As set out in **Table 2-4** there are three levels of charging capability for EVs.

Current Level 1 charging infrastructure can be provided through a standard 10 amp power point. This should not require any changes to household wiring or to upstream infrastructure. However it may be desirable to add a basic time-clock so that charging happens outside peak periods when prices are higher (for premises that have time-of-use metering).

Level 2 charging infrastructure will require special wiring within the premise because the connection is greater than 10 amp. In fact a 19.2kW / 80A outlet would probably require an upgrade to the supply service connecting to the low voltage network within the street – possibly even 3-phase connection. This may in turn require an upgrade to the wiring in the street and then in turn back to the 33 kV substation. It is unlikely that any upgrade would be required upstream of the 33kV substations. Clearly significant upgrades to the distribution network would be expensive and the question would arise as to whether such costs should be passed on to all customers or only to those customers requiring Level 2 charging. This issue would need to be considered by the Australian Energy Regulator. That said, upgrades that could be incorporated into long term planning would presumably be included in general price determinations rather than charged only to level 2 customers.

Level 3 charging infrastructure will also require special wiring within the premises and an upgrade to the supply service connecting back to 33 kV substations. High charging loads may also require upgrades back to 110kV subtransmission and possibly even back to the transmission network. Clearly such upgrades to the distribution and transmission network would be expensive and such costs should be passed on those customers requiring Level 3 charging. Current approaches to network pricing already allow customer specific pricing for large customers. Depending on the size and timing of loads, changes in generation dispatch and even investment may also be required. However the Australian National Electricity Market is designed to provide appropriate price signals for dispatch and generation.

There has been some discussion about whether electric vehicle owners would prefer to charge with electricity from renewable sources rather than from the standard mix from the NEM. The supply system allows for customers to purchase ‗GreenPower‘, which is accredited as having been matched against production of electricity from renewable sources. However the price is higher than ‗black‘ power that has been used for the modelling in this report and may affect take-up rates.

4.0 Methodology and Assessment Framework

4.1 Overview

As set out in the objectives, the key study aim is to develop an economic model to help address many of the issues surrounding the future of the electric vehicle market. **Figure 4-1** provides an overview of the AECOM methodology. Each of these steps is discussed in more detail below.

4.2 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. 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. 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:	A 7% per annum real discount rate is adopted in the economic evaluation to calculate present values. This study also undertakes sensitivity tests at the discount rates of 4% and 10% (NSW Treasury guidance[11]). As real prices have been used in the financial evaluation the same discount rates were used[12].
Price Year:	All costs and benefits in the evaluation are presented in 2009 constant prices. Where prices were not in 2009 prices they have been adjusted using the ABS Consumer Price Index (CPI)[13].
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 (see Australian Transport Council guidelines[14]).

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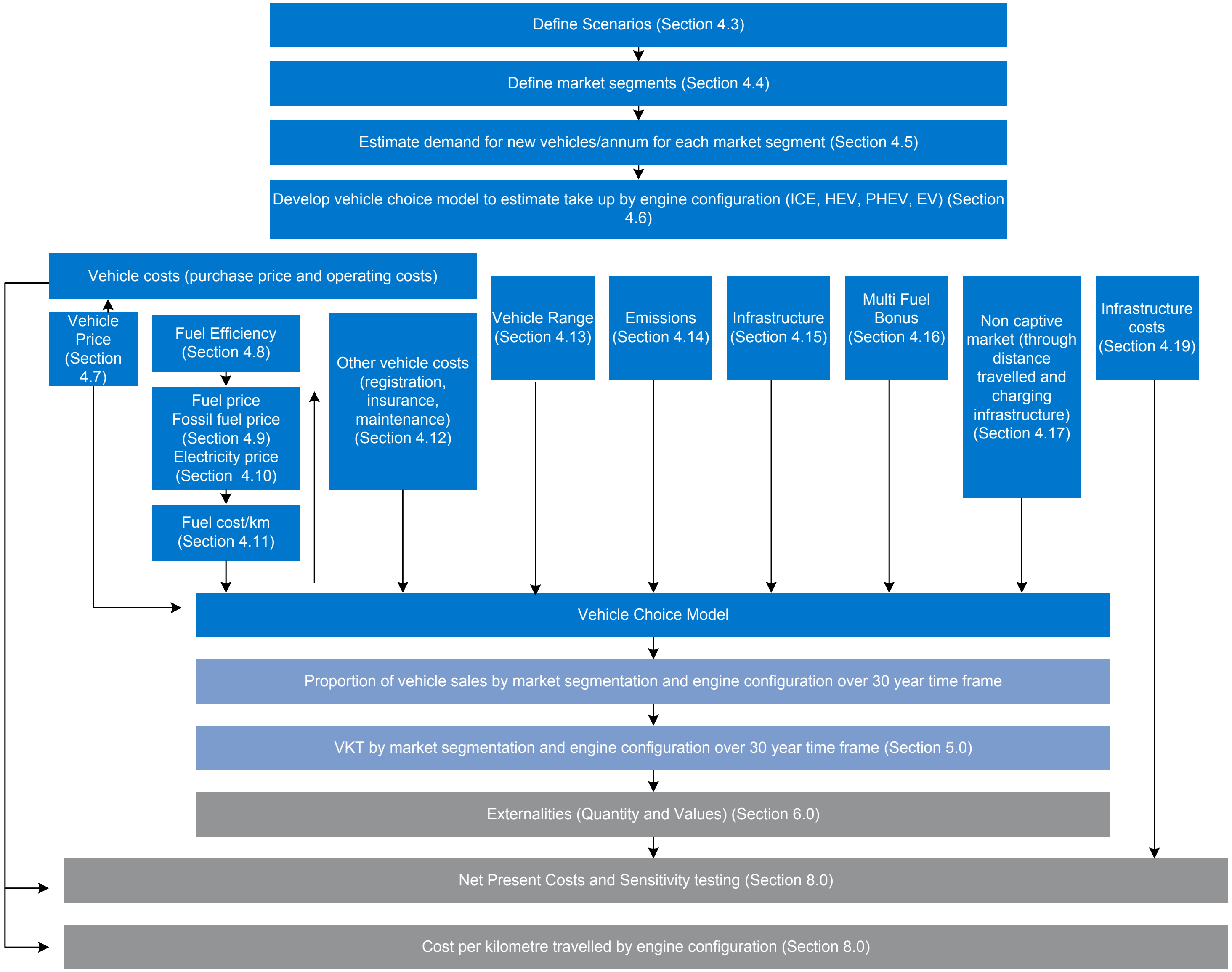
[11] NSW Government Guidelines for Economic Appraisal (TPP07-5), 2007

[12] The Weighted Average Cost of Capital (WACC) was not used as this evaluation considers costs from both industry and consumers. In addition, the charging infrastructure industry is a new market with no comparable WACC benchmarks available.

[13] ABS Consumer Price Index (Cat. 6401).

[14] National Guidelines for National Transport System Management in Australia, 2006, section 3 Appraisal of Initiatives, 2.2.4 Set the appraisal period, p54.

Figure 4-1: Overview of methodology



4.3 Scenario Specification

This section sets out the scenarios to be tested by the economic model. 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 EVs through charging convenience and cost. It will also be a significant factor in the cost side of this cost benefit analysis.

The charging requirements of EVs 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 is in terms of ―kilometres-per-minute". As set out in **Section 2.2.6**, there are currently three different charging levels available for EVs:

- **Level 1** charging only requires a standard power outlet, since all charging electronics required to support Level 1 can be carried on board the vehicle.
- **Level 2** charging requires a ―charging interface" to be wired into a building‘s electricity supply to provide necessary protections from the higher voltages/powers. Level 2 charging can therefore be performed at home, but only if the appropriate equipment has been installed by an electrician.
- **Level 3** charging greatly exceeds 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.

4.3.1 Base Case

The Base Case, is the scenario against which the other scenarios will be compared. The base case will assume there are only ICEs and HEVs available and no PHEVs or EVs.

4.3.2 Scenario 1: Household Charging Only (Level 1)

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

4.3.3 Scenario 2: Household Charging (Level 1 and 2) plus Public Charging Stations

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 1 and Level 2 public charging available within the NSW Metropolitan region[15]. 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 4-2** and **Figure 4-3**. With the recent consensus reached in North American and Europe on Level 2 charging standards, there are likely to be developments in relation to Level 2 infrastructure in the near future.

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

Figure 4-2: **Public charging facilities, California**

Source: Zoomlife, sourced 1 June 2009

Figure 4-3: **NCP car park, London**

Source: Zoomlife, sourced 1 June 2009

4.3.4 Scenario 3: Household Charging, Public Charging Stations plus Electric Vehicle Service Stations

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 NSW Metropolitan region and electric vehicle service stations that offer 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 4-4**);
- In May 2009, the first public high voltage charging station for EVs was installed at the Gateway Center in East Woodland California; and
- Better Place recently demonstrated a battery swap station in Japan, but are yet to proceed with their commercial deployment.

Figure 4-4: Proposed charging stations in London

Source: Zoomlife, sourced 1 June 2009

4.4 Define Market Segmentation

4.4.1 Define Study Area

The study area is defined as –Metropolitan NSW” which includes the Sydney Statistical Division, Illawarra Statistical Division and the Newcastle Statistical Subdivision. As a result, all rural areas are excluded from the analysis.

4.4.2 Define Market Segmentations

The model to assess the cost and benefits of EVs needs to balance practicability and accuracy. In order to ensure accuracy, a number of different market segments have been defined. As CSIRO (2008)[16] observed:

“In theory one could construct a model of the Australian transport sector which included every make of existing vehicle and possible future vehicles. In practice, modellers will always seek to reduce the size of the vehicle fuel/technology set in order to make the model manageable in terms of data, model structure and mathematical solution speed and reliability”. (CSIRO, 2008)

For simplicity, the vehicle market is segmented according to:

- Vehicle type;
- Vehicle size; and
- Distance travelled.

Figure 4-5 provides an overview of the market segmentation. In total, there are eleven market segments and each of these is discussed in more detail below.

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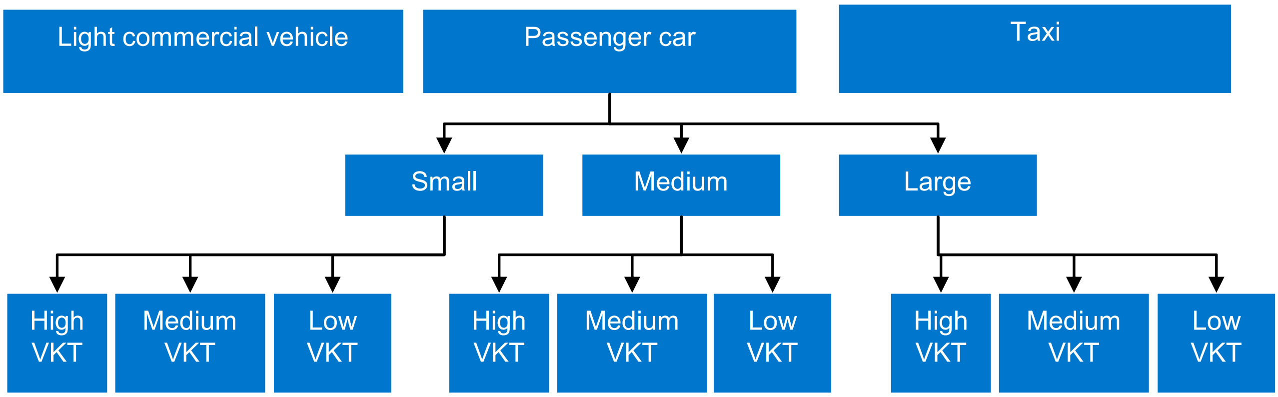
[16] Modelling of the future of transport fuels in Australia – A Report to the Future Fuels Forum, CSIRO 2008

Figure 4-5: Overview of market segmentation



Vehicle Type

This study has focused on three vehicle types where EVs have the biggest potential impact:

- Passenger car;
- Light commercial vehicle; and
- Taxi.

Note that engine size and VKT ranges are not distinguished for light commercial vehicles or taxis. This is considered reasonable as the VKT distribution for these types of vehicles is likely 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.

It has been assumed that in the majority of fleets individuals make the purchase decision instead of the purchaser and most fleet vehicles are taken home at night. As such, fleet vehicles have not been treated separately.

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, as highlighted in Section 2, 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.

While size can be measured by both weight and engine size, for the purposes of the model it was considered more practical to differentiate by engine size. This better captures differences in externality emissions and allows distribution of distance travelled to be modelled. In addition, weight categories do not easily translate to EVs/PHEVs since they are typically heavier than conventional technologies. Three engine sizes are distinguished:

- Small engine – up to 1.8 litres;
- Medium engine – between 1.8 and 3.0 litres;
- Large engine – above 3.0 litres.

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 TDC‘s Household Travel Survey[17] was used to assess the distribution of VKT for each vehicle size. As a result, 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.

4.4.3 Define Engine Configuration

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

- ICE vehicles – internal combustion engines such as petrol, diesel, gas;
- HEV – non plug-in hybrid vehicles;
- PHEVs – plug-in hybrid vehicles; and
- EVs – electric vehicles.

4.5 Estimate Demand for New Vehicles per Annum

4.5.1 Methodology

Demand for new vehicles has been projected from historical new vehicle sales. It has been assumed that future growth in new vehicle sales is consistent with historical growth. Trend estimates for annual growth are calculated from new vehicle sales data spanning 2000 to 2008. Vehicle sales for each vehicle type are then projected forward to 2040 growing from the initial (actual) 2008 value. For the passenger vehicle market, demand for new vehicle sales in individual segments is calculated as a proportion of total passenger vehicle demand based on assumptions for market share by vehicle size and historical VKT.

It is therefore assumed that the decision of whether or not to buy a car is independent of the available engine configuration technologies.

4.5.2 Historic Data and Total Passenger Vehicle Projections

Figure 4-6 provides an overview of total passenger sales of new vehicles for the Sydney, Newcastle and Wollongong metropolitan area. The data provided by the NSW RTA shows large annual fluctuations in vehicle sales.

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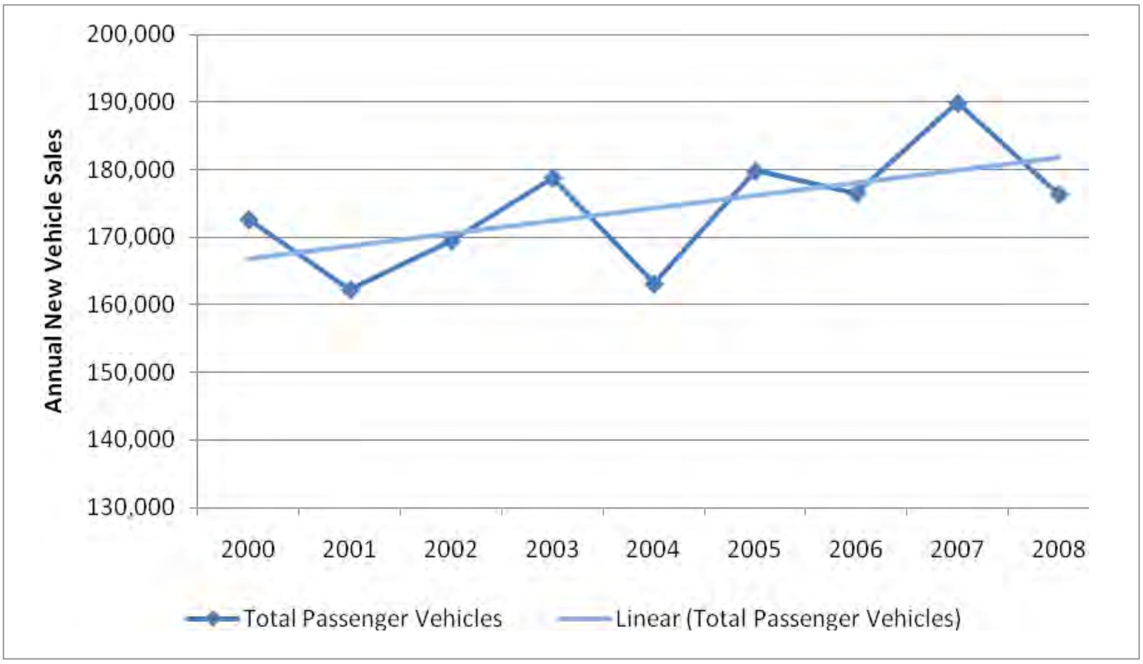
[17] 2006 Household Travel Survey Summary Report - 2008 Release, TDC 2008

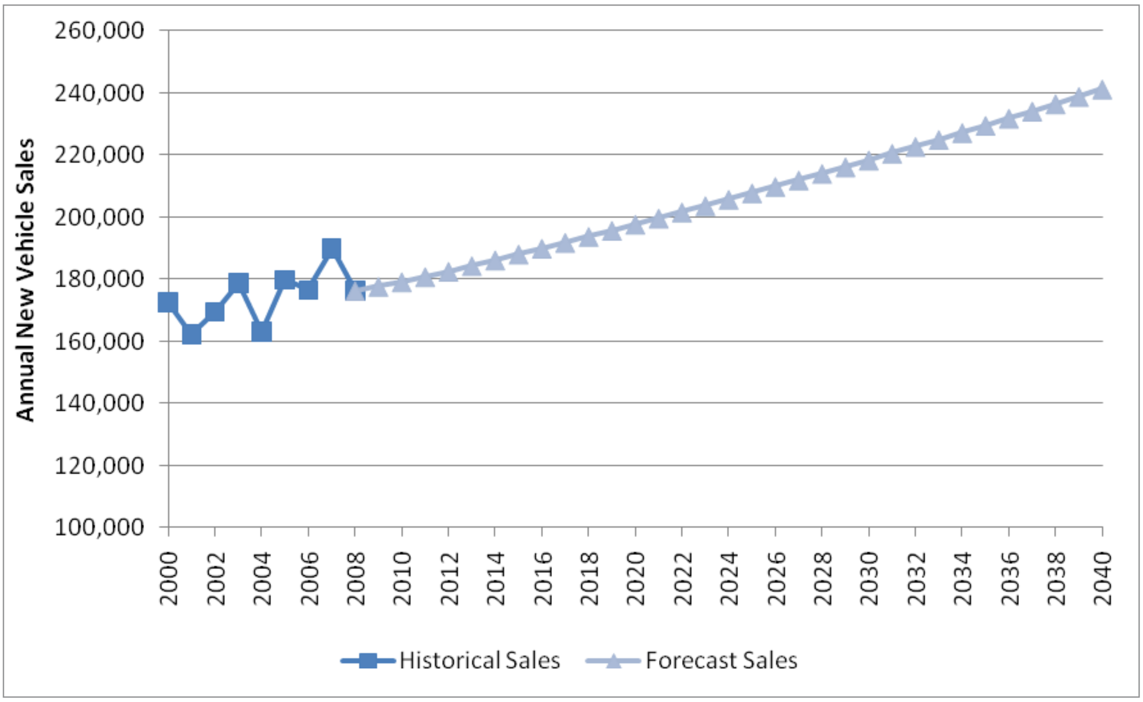
Figure 4-6: Annual new passenger vehicle sales



Source: AECOM calculations based on data provided by RTA.

By analysing the trend in growth of vehicle sales over these nine years it was seen that the growth in vehicle sales was increasing by around 1% per annum It was decided to cap the growth rate at this level as an accelerating rate could not be justified with the limited data available. **Figure 4-7** shows forecast passenger vehicle sales in relation to historical vehicle sales.

Figure 4-7: Forecast Passenger Vehicle Sales



Source: AECOM calculations based on data provided by RTA.

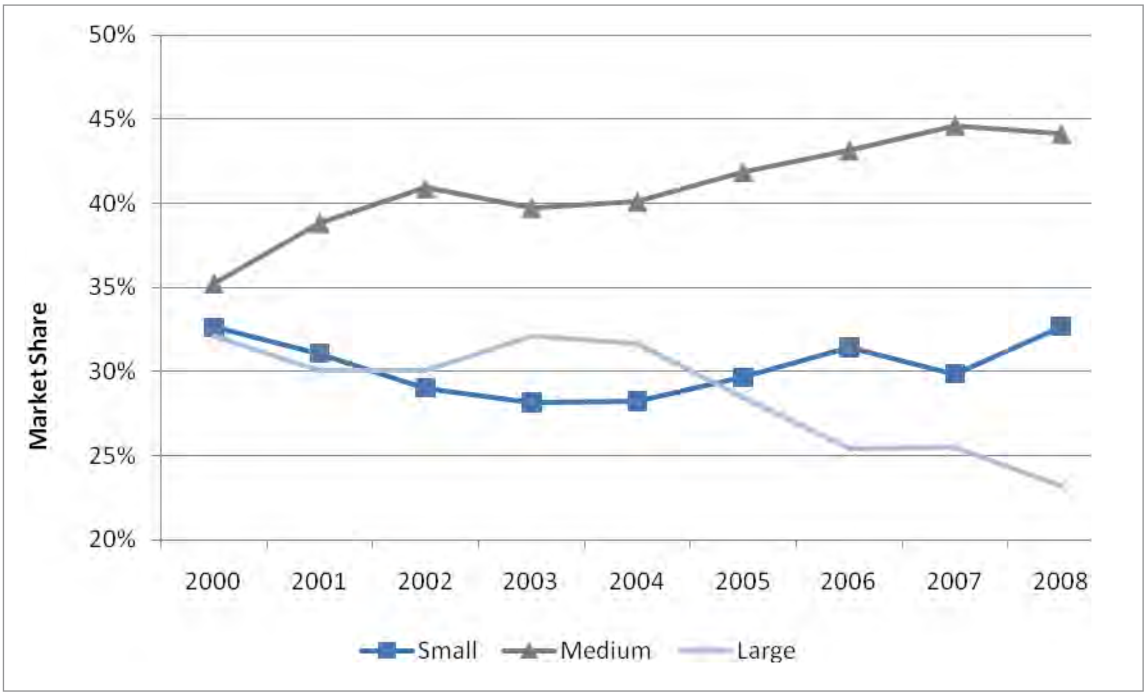
4.5.3 Projections by Size and VKT

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. For example, high VKT vehicles benefit more from the cheaper cost of using electricity as a transport fuel.

Figure 4-8 shows annual vehicle sales by vehicle size. The data shows there has been a shift in demand away from large passenger vehicles to medium sized passenger vehicles in the last decade. 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.

Figure 4-8: Annual new passenger vehicle sales by vehicle size



Source: AECOM calculations based on data provided by RTA.

Extrapolating the current trend in sales away from large vehicles towards medium sized vehicle, the market share in 2020 would be 30%, 55% and 15% for small, medium and large vehicles respectively. 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. **Table 4-1** shows assumptions for shares of the passenger vehicle market by vehicle size.

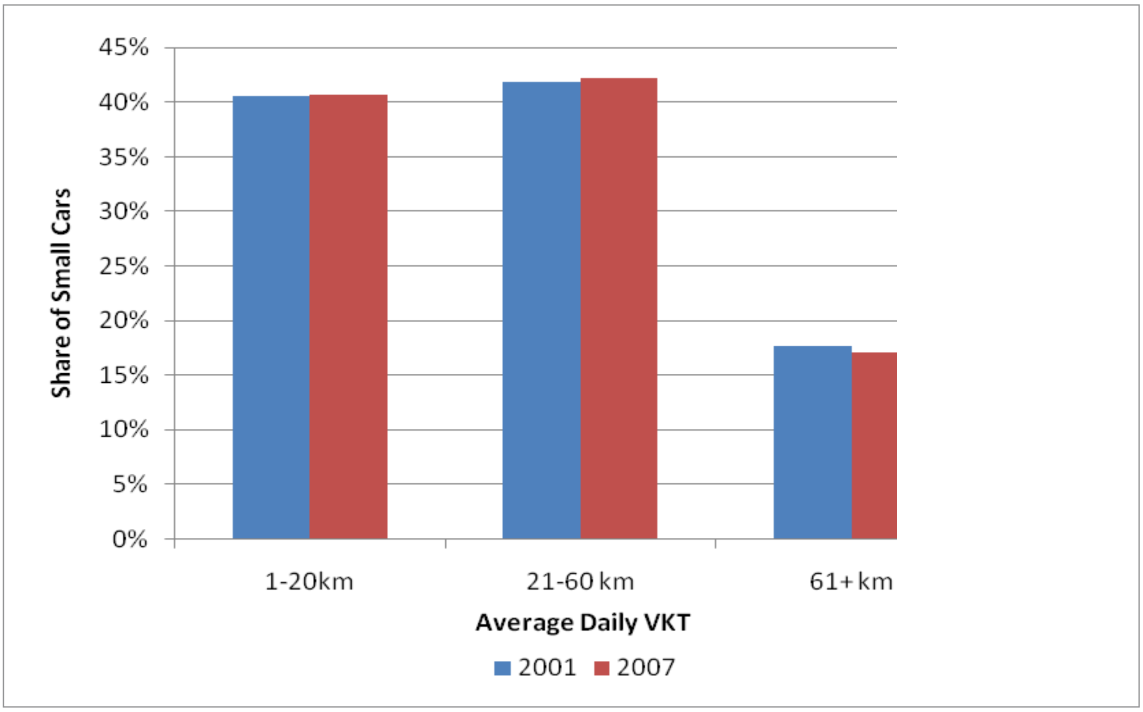
Table 4-1: Passenger vehicle market share by vehicle size assumptions

Vehicle Size	2000	2008	2020	2030	2040
Small	30%	30%	30%	30%	30%
Medium	37%	45%	55%	55%	55%
Large	33%	25%	15%	15%	15%

Source: AECOM

VKT data for each vehicle size was sourced from the Household Travel Survey (Transport Data Centre) for 2001 and 2007. This allowed the three vehicle size market segmentations of the passenger vehicle market to be further disaggregated into low, medium and high daily VKT. For each vehicle size there was no significant change in the share of vehicles in each average daily VKT group. **Figure 4-9** shows the average daily VKT travelled by small cars in 2001 and 2007.

Figure 4-9: Average daily VKT travelled by small vehicles



Source: NSW Transport Data Centre

With historical data showing no clear increase or decrease in the average daily VKT for passenger vehicles, 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 category will increase only with an increase in total number of vehicles, as VKT for individual vehicles is assumed to be constant. **Table 4-2** shows the proportion of VKT ranges in each vehicle category.

Table 4-2: Proportion of VKT ranges in each vehicle size category

VKT range	Small (0-1.8L engine)	Medium (1.8 -3L engine)	Large (greater than 3L engine)
Low (1-20km)	41%	37%	35%
Medium (21-60km)	42%	43%	42%
High (above 61km)	17%	20%	24%

Source: NSW Transport Data Centre

The projections of overall passenger vehicle sales shown in **Figure 4-7** can therefore be combined with the proportions of vehicles in each size and VKT category. It is assumed that VKT proportions will be unchanged in the future. **Table 4-3** provides the projections of new registrations by size and VKT range.

Table 4-3: Projections of new passenger vehicle sales by size and VKT

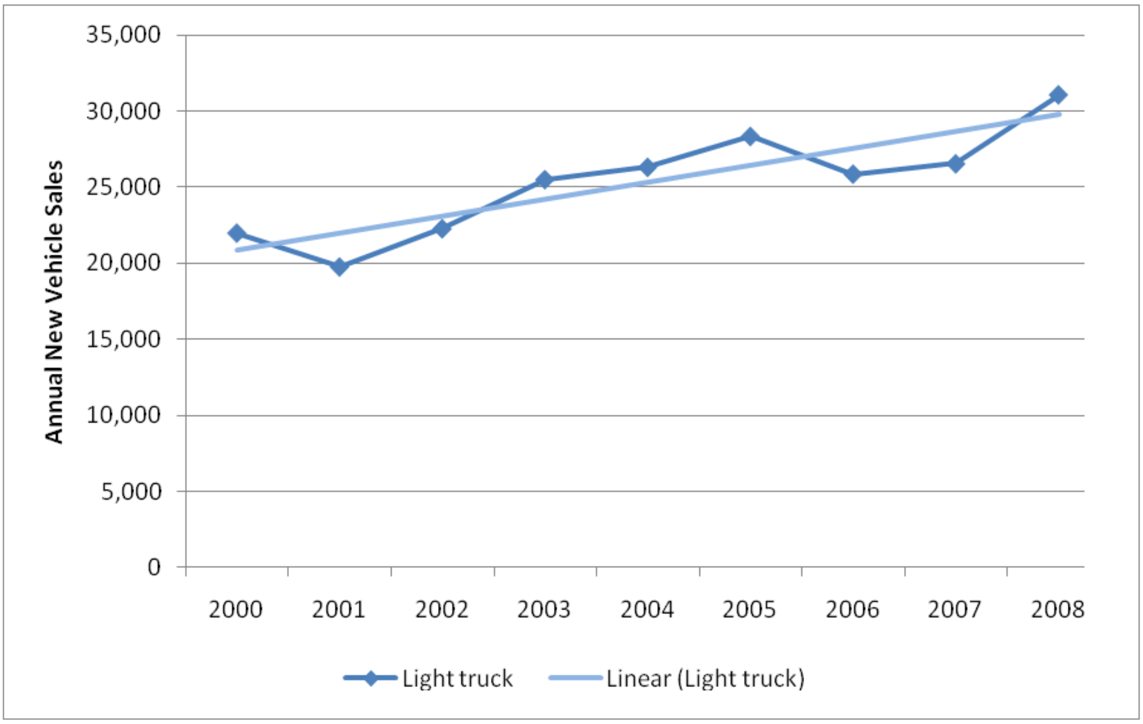
Year	Small (0-1.8L engine)			Medium (1.8 -3L engine)			Large (greater than 3L engine)		
	Low VKT	Medium VKT	High VKT	Low VKT	Medium VKT	High VKT	Low VKT	Medium VKT	High VKT
2010	21,858	22,715	9,181	30,814	36,295	16,509	14,457	17,459	9,893
2015	22,928	23,826	9,631	35,207	41,470	18,863	12,456	15,043	8,524
2020	24,097	25,041	10,122	40,036	47,158	21,450	10,246	12,373	7,011
2025	25,327	26,319	10,638	42,078	49,563	22,545	10,768	13,004	7,369
2030	26,618	27,661	11,181	44,225	52,091	23,695	11,317	13,668	7,745
2035	27,976	29,072	11,751	46,481	54,749	24,903	11,895	14,365	8,140
2040	29,403	30,555	12,351	48,852	57,541	26,174	12,501	15,098	8,555

Source: AECOM

4.5.4 Projections for Light Commercial Vehicles

As with passenger vehicles, projections for demand for new light commercial vehicle sales are estimated from historical sales data. Historical light truck sales are presented in **Figure 4-10.**

Figure 4-10: Historical sales – light trucks



Source: AECOM calculations based on data provided by RTA.

The average annual growth in vehicles sales between 2000 and 2008 was around 5%. This strong growth is expected to continue in the medium to long term. BITRE (2007) observed that

“Annual growth in total VKT by LCVs has averaged between 3 and 4 per cent for well over 20 years, and the base case essentially continues this trend to 2020, with continued (projected) economic growth leading to continued VKT growth. This relatively high level of commercial traffic growth is predicated on the assumption that there will be no decoupling of activity in the freight and service sectors from overall income trends (i.e. GDP per person) during the projection period.” (BITRE, 2007)

As data from the NSW Transport Data Centre shows no significant changes in the average VKT travelled by individual LCVs, the increased total VKT would be related to the increase in the total fleet size. Therefore the growth in LCV sales has been assumed to remain high at 5% per annum, as per the trend for the past eight years, declining annually to 3% per annum by 2030, as per BITRE‘s long run growth projections. Projected sales figures are shown in **Table 4-4**.

Table 4-4: Projections for new light commercial vehicle

Year	LCV
2010	34,193
2015	42,781
2020	52,467
2025	62,919
2030	73,651
2035	85,382
2040	98,981

Source: AECOM

4.5.5 Projections for Taxis

According advice from the Ministry of Transport, there are currently 6,571 taxis licensed to be on the road in NSW. It is estimated that around 80% are in Sydney and 85% are in the Greater Metropolitan Region (GMR). Metro taxis must be replaced when they reach six and a half years.

This has been used to estimate the number of new vehicles per annum. It has been assumed that there will be no growth in total taxi vehicles as the licences are regulated.

4.5.6 Validation of Projections

The NSW Transport Facts 2007 report[18] forecasts new vehicle sales out to 2015 for NSW. Passenger sales for the Greater Metropolitan Region (GMR) have averaged around 71% of total NSW sales since 2000 and light commercial vehicles have averaged around 60%. **Figure 4-11** shows the NSW projections scaled down to the GMR are consistent with the GMR forecasts using the assumptions set out above.

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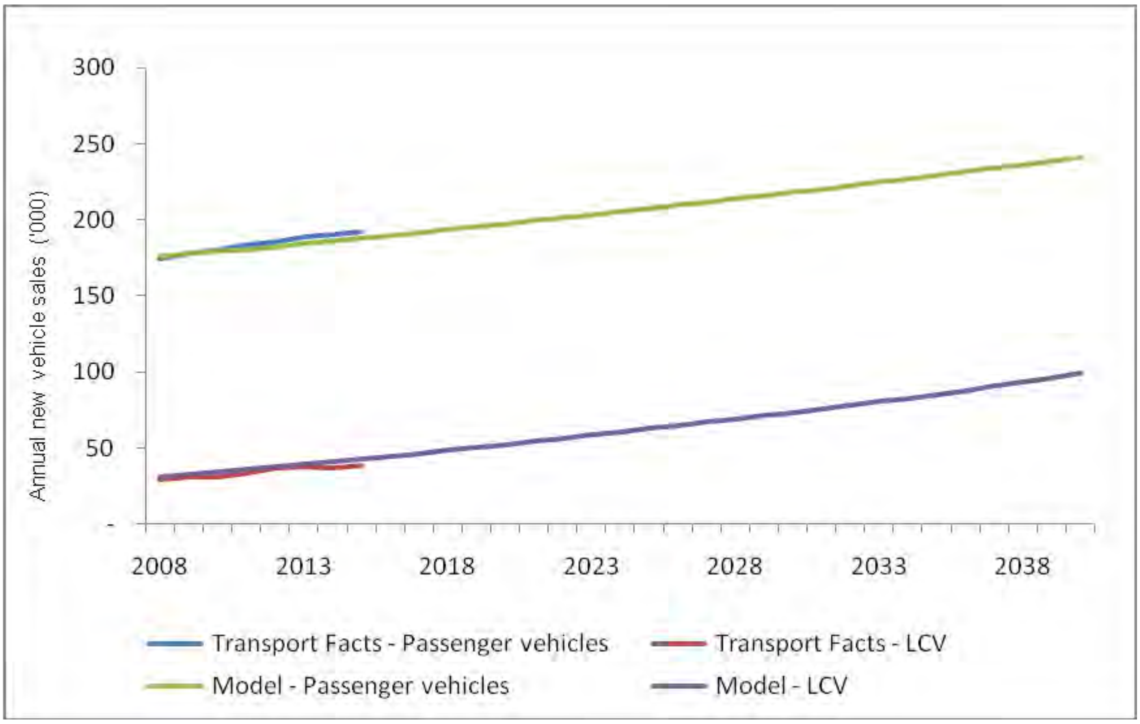
[18] NSW Transport facts 2007, Apelbaum Consulting, April 2007

Figure 4-11: Forecast comparison



Source: NSW Transport Facts 2007, AECOM

4.5.7 Average VKT

In order the derive the total VKT by vehicle type, the projected number of vehicles in each size and VKT category is multiplied by the average annual VKT. **Table 4-5** sets out the average daily vehicle kilometres travelled for each of the market segments.

Table 4-5: Average VKT

	Small Cars	Medium Cars	Large Cars	LCV	Taxi
Average daily VKT					
Low VKT (1-20km)	11.4	11.3	11.6	64.4	356[19]
Medium VKT (21-60km)	39.3	40.3	40.2		
High VKT (61+km)	111.2	116.3	125.7		
Average annual VKT					
Low VKT (1-20km)	4,158	4,132	4,217	23,502	130,000
Medium VKT (21-60km)	14,332	14,708	14,655		
High VKT (61+km)	40,570	42,446	45,875		

Source: AECOM calculations based on passenger and light commercial vehicle data from household travel survey, Taxi data from IPART Review of Taxi fares in NSW

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[19] IPART 2008 Review of Taxi fares in NSW assumes an average VKT of 130,000 in Urban areas.

4.6 Estimate Number of Vehicles Purchased by Type (ICE, HEV, PHEV, EV)

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.

4.6.1 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)[20] 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.

4.6.2 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;

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[20] Brownstone, D., Bunch, D.S. & Train, K. (2000), *Joint mixed logit models of stated and revealed preferences for alternative-fuel vehicles*, Transportation Research Part B, Volume 34, Issue 5, pp. 315-338

- 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)[21] 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)[22] and Mau et al. (2008)[23] 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.

4.6.3 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.

Parameters in multinomial logit models are best interpreted when interpreted as relative values. When parameter values are compared appropriately against a cost parameter, other parameter values can be interpreted as willingness to pay values. These values show the additional vehicle purchase price consumers are willing to pay in order to secure improvements in certain vehicle attributes.

Willingness to pay (in terms of an increase in the purchase price) for improvements in electric vehicle attributes by study is outlined in **Table 4-6**. All estimates are in 2009 prices and in Australian dollars.

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[21] Bunch, D.S., Bradley, M., Golob, T.F., Kitamura, R. & Occhiuzzo, G.P. (1993), *Demand for Clean-Fuel Vehicles in California: A Discrete-Choice Stated Preference Pilot Project*, Transportation Research A, Vol 27A, No. 3, pp 237-253.

[22] Santini, D.J. and Vyas, A.D. (2005), Suggestions for a New Vehicle Choice Model Simulating Advanced vehicle Introduction Decisions (AVID): Structure and Coefficients, Argonne National Laboratory Report ANL/ESD/05-1.

[23] Mau, P., Eyzaguirre, J., Jaccard, M., Collins-Dodd, C. & Tiedemann, K. (2008), *The `neighbor effect': Simulating dynamics in consumer preferences for new vehicle technologies*, Ecological Economics, Volume 68, Issues 1-2, pp. 504-516

Table 4-6: 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)[24] *Australia*	$500	$1,900			
Brownstone et al. (2000) *USA*	$2,500	$14,700	$400	$400	
Dagsvik et al. (2002)[25] *Norway*	$1,000	$3,600			
Ewing & Sarigollu (1998)[26] *Canada*		$1,600	$400		
Golob et al. (1996)[27] *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

4.6.4 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:

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[24] TRESIS (undated), available at http://www.itls.usyd.edu.au/__data/assets/pdf_file/0014/30830/ITS-RR-01_01.pdf

[25] Dagsvik J.K., Wennemo T., Wetterwald D.G., Aaberge R. (2002), *Potential demand for alternative fuel vehicles*, Transportation Research Part B, Vol. 36, Iss. 4, pp. 361-384.

[26] Ewing G.O., Sarigollu E. (1998), *Car fuel-type choice under travel demand management and economic incentives,* Transportation Research Part D, Vol. 3, Iss. 6, pp. 429-444.

[27] Golob, T.F., Torous, J., Bradley, M., Brownstone, D., Crane, S.S. (1996), Commercial Fleet Demand for Alternative Fuel Vehicles in California, Transportation Research A, Vol 31, No. 3, pp 219-233.

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

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

- Relative parameter values guided by willingness to pay values extracted from previous studies;
- The scale of the parameter values guided by known elasticities; 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 4-7** and are within the bounds estimated in **Table 4-6**

Table 4-7: AECOM Willingness to Pay Values for Five Vehicle Attributes (2009 $A)

Measure	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
Value	$1,050	$3,000	$500	$2,000	$5,000

Source: AECOM

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 assumes that Australian drivers clock up on average 15,000km p.a. A 1c/km saving equates to a saving of $150 p.a. A $1,050 upfront payment is equivalent to 10 years of fuel savings, discounted at 7 percent p.a.
- Willingness to pay for range seems to be quite high in the US – typical of the long distance driving patterns that are typical in the US – a slightly lower WTP has been assumed for Australian conditions – set closer to the Norway figure.

As the next step to developing parameters for each variable, the absolute value of the fuel cost parameter was established. In multinomial logit models, direct price elasticities can be estimated using the values of the beta parameter, price (as represented by X) and the market share (as represented by p) as shown in **Equation 4-1**.

Equation 4-1: Multinomial Logit Direct Price Elasticity

$$\eta = \beta X \left(- p\right)$$

Rearranging **Equation 4-1**, the beta parameter can be established as shown in **Equation 4-2**.

Equation 4-2: Estimating the Beta Parameter

$$\beta = \frac{\eta}{X(1-p)}$$

AECOM have made assumptions on current elasticities, current fuel prices and ICE market share to estimate the fuel cost parameter, which are summarised in **Table 4-8**.

Table 4-8: Fuel Cost Parameter Assumptions

Parameter	Description	Value
η	ICE fuel price elasticity[28]	-0.25
X	ICE fuel cost rate	10c/km
p	Assumed initial ICE market share	85%
$\frac{\eta}{X(1-p)}$	AECOM's beta estimate	-0.25 ÷ (10 × (1 – 0.85)) = -0.167

With the absolute value of the fuel cost parameter established, the willingness to pay assumptions shown in **Table 4-7** can then be used to establish the absolute values for all other parameters. Parameter values for the model are highlighted in **Table 4-9**.

Table 4-9: Assumed Parameters Values Based on Table 4-7 Willingness to Pay Values

Parameter	Units	Value
Vehicle cost	$	-0.000159
Fuel cost	c/km	-0.166667
Range	km	0.004762
Tailpipe emissions	Proportion of ICE	-0.793651
Infrastructure	Proportion of ICE	3.174603
Multi-fuel bonus	Dummy	0.793651
EV constant	Dummy	0.000000

The vehicle choice model requires information on all of the above parameters. Each of these is discussed in more detail below.

4.7 Vehicle Price

New vehicle prices, by engine configuration and vehicle size, have been estimated from a survey of 34 global EV products for the 2009-2012 model years and 28 US HEVs for the 2009-2010 model years. An equivalent ICE vehicle was used for the price of ICE vehicles to ensure a consistent comparison.

There was limited information on the expected price of PHEVs. A report by the International Energy Agency (IEA, 2008) concludes that EVs 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

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[28] Based on the median fuel price elasticity in the meta-analysis undertaken by Goodwin, P., Dargay, J. & Hanly, M. (2003), *Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review*, Transport Reviews, Vol. 24, No. 3, pp. 275–292.

combustion engine. In addition, the cost of batteries per kWh is higher for PHEVs compared to EVs. A large proportion of taxis in NSW are Ford Falcons and as such prices for taxis are assumed to be equal to prices for large passenger vehicles.

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 is likely to reflect a local market penalty due to our relatively small market size, distance from large vehicle manufacturing countries, volatile exchange rate, and lack of local manufacturing of non-ICE vehicles. It has been assumed that there will be similar small market penalty for PHEVs and EVs. **Table 4-10** sets out the prices assumed in the model for the different market segmentations and engine combustion types.

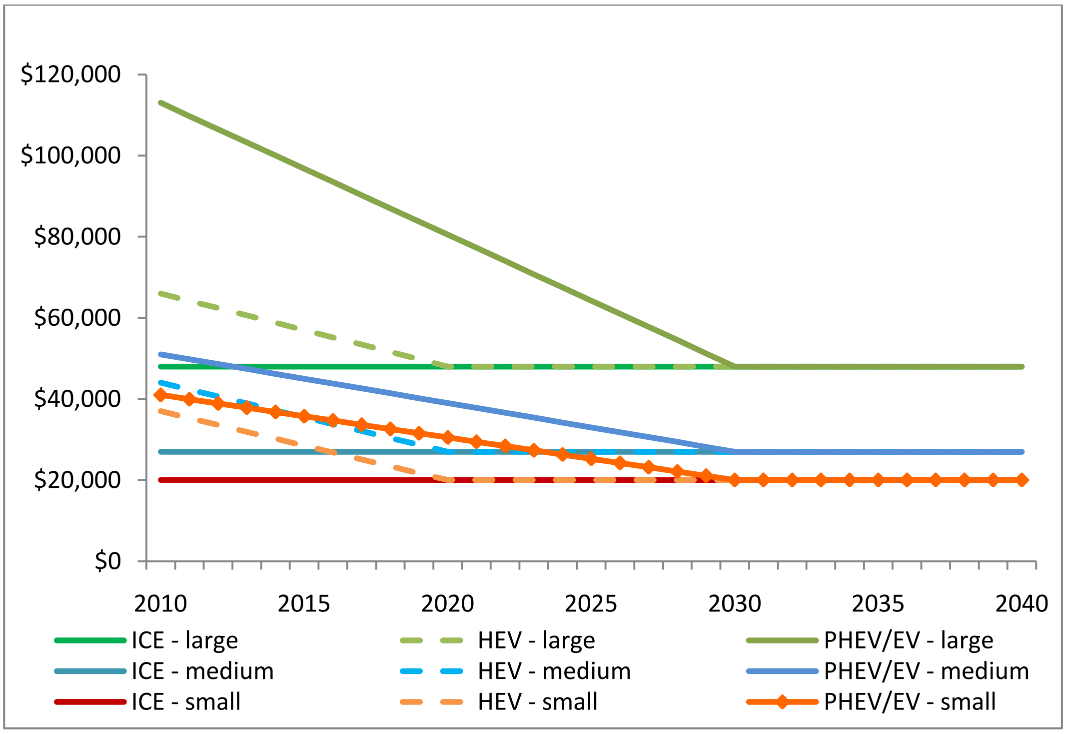
Table 4-10: New vehicle purchase prices including Australian price premium in 2010 (AUD)

Vehicle type	ICE	HEV	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
Commercial	$40,000	$60,000	$104,000	$104,000
Taxi	$48,000	$66,000	$113,000	$113,000

Source: AECOM

Going forward, it has been assumed that there is no real growth in the price of ICE vehicles. Prices for HEV, PHEVs and EVs are estimated relative to the ICE price. HEVs are assumed to reach price parity with ICEs in 2020. This is in line with industry expectations, such as Toyota, that by 2020 HEVs will be the prominent engine configuration type in their fleet. PHEV and EV purchase prices are assumed to reach price parity with ICEs in 2030. Sensitivity analysis will be undertaken on these years**. Figure 4-12** sets out the assumptions on vehicle prices and how these change over time.

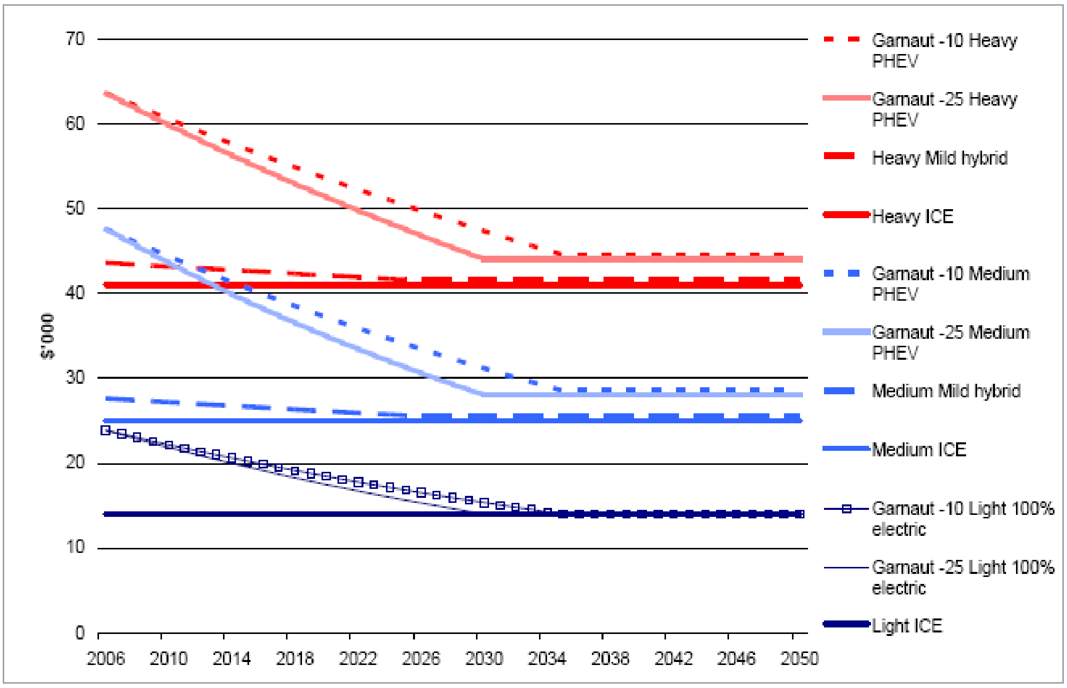
Figure 4-12: Assumed vehicle price for small and large vehicles by different engine configurations



Source: AECOM

Figure 4-13 sets out the assumptions on vehicle prices (and how these change over time) used in the CSIRO/Treasury modelling of the emissions trading scheme. Although our starting prices are higher than the assumptions used in the Treasury modelling the change in prices over time are consistent. The starting prices are different because the market segment definitions are different. Also, the CSIRO study only considers light EVs as a viable option.

Figure 4-13: Vehicle price by different engine configurations – Treasury modelling



Source: Modelling the road transport sector and its response to an Emissions Trading Scheme: A report to the National Emissions Trading Taskforce, CSIRO (2008)

4.8 Fuel Efficiency

BITRE and CSIRO prepared a report in October 2008 for the Treasury on modelling the transport sector for the Treasury‘s modelling of the introduction of emissions trading in Australia[29]. The report reviewed the literature on expected changes to energy efficiency and concluded:

- Fuel intensities for ICEs are expected to decline by up to 37% between 2006 and 2050;
- HEVs will achieve a 5% improvement in fuel efficiency starting in 2006, increasing to 30% by 2050;
- PHEVs fuel efficiency depends on proportion of time using the electric drivetrain. Assumes that the efficiency of the electric drive train will be constant as any improvements will provide for better amenity (room, instruments) rather than fuel savings (see next bullet). Assumes that PHEVs will use the electric drivetrain for 50% of kilometres in 2006, increasing to 80% by 2035 as battery technology improves allowing for longer use of the electric drivetrain. A weighted average fuel efficiency is calculated based on ICE drivetime and electric drivetime; and
- Fully EVs have a fuel efficiency of 0.2kWh/km for light vehicles and this remains constant over time.

This study agrees with some of these conclusions such as the ICE efficiencies and that PHEVs will use the electric drivetrain 50% of kilometres in 2006 increasing to 80% by 2035. However, the latest

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

data suggests that the efficiencies of HEVs and EVs may behave differently. This is discussed below in more detail.

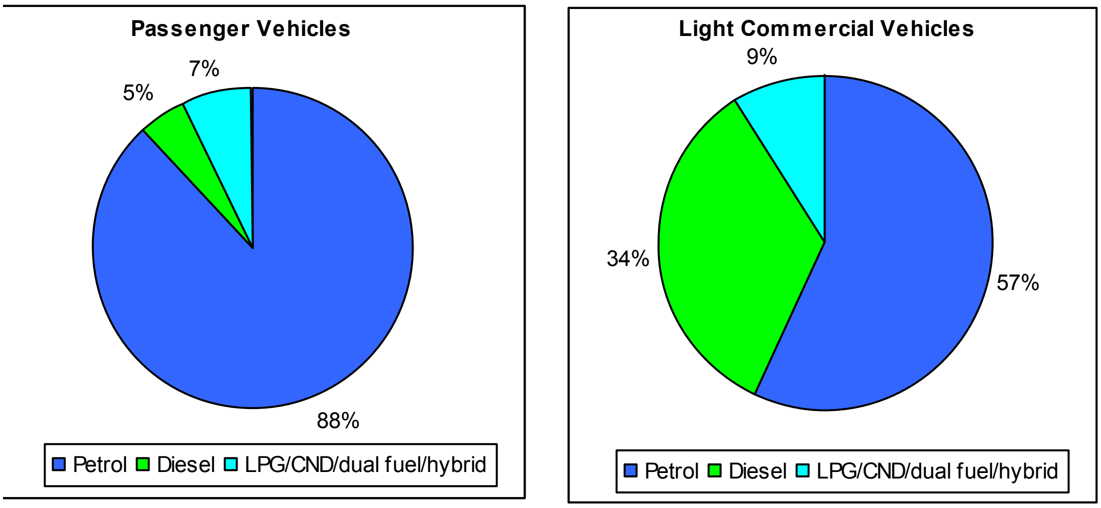
It is worth noting that published fuel efficiencies are traditionally underestimates of real world fuel efficiencies. The test cycle is typically different from how people drive in the real world resulting in lower actual fuel efficiencies. This is true for all vehicle types.

4.8.1 ICE Efficiency

The fuel efficiency for an ICE vehicle depends on the fuel used.

As highlighted in **Figure 4-14**, 88% of fuel used in passenger vehicles is petrol, 5% diesel and 7% other fuel such as LPG/CND/dual fuel and hybrid. These proportions have remained fairly consistent over the past five years. Light commercial vehicles use a lot more diesel with 57% of fuel use being petrol and 34% diesel. IPART undertakes an annual review of taxi fares in NSW. As part of this review it assumes the main fuel type for taxis is LPG. For this study it has been assumed that taxis use only LPG.

Figure 4-14: Fuel usage in Australia



Source: Survey of motor vehicle use, ABS, 2007

The survey of vehicles (used to identify vehicle prices) also identified vehicle fuel efficiencies for petrol vehicles. The ratio of efficiencies between petrol and diesel, and petrol and LPG have been determined from reported ABS values[30] (see **Table 4-11**). These ratios are then applied to the petrol efficiency as identified in the vehicle survey, to obtain fuel efficiencies for diesel and LPG. The taxi efficiency has been taken from the IPART 2008 review of taxi fares in NSW which assumes a fuel efficiency of 5 kilometres per litre of fuel or 20 L/100km[31]. **Table 4-12** shows the fuel efficiencies for ICE vehicles.

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[30] *Survey of Motor Vehicle Use – 12 Months Ended 31 October 2007*. ABS Catalogue 9208.0

[31] http://www.ipart.nsw.gov.au/files/2008%20Review%20of%20Taxi%20Fares%20in%20NSW%20-%20Draft%20Report%20and%20Draft%20Recommendations%20-%20April%202008%20-%20WEB.PDF

Table 4-11: ABS reported fuel efficiencies

Vehicle Category	Petrol (L/100km)	Diesel (L/100km)	LPG (L/100km)	Diesel to Petrol Ratio	LPG to Petrol Ratio
Passenger (all sizes)	11.1	12.3	16.6	1.108	1.495
LCV	13.2	12.5	16.0	0.947	1.212
Taxi	-	-	20.0	-	-

Source: ABS (9208.0), AECOM

Table 4-12: ICE fuel efficiency by vehicle category in 2010

Vehicle Category	Petrol (L/100km)	Diesel (L/100km)	LPG (L/100km)	Weighted Fuel Efficiency (L/100km)
Passenger small	7.8	8.6	11.7	8.1
Passenger medium	9.7	10.8	14.5	10.1
Passenger large	13.8	15.3	20.6	14.4
LCV	11.2	10.6	13.6	11.1
Taxi	-	-	20.0	20.0

Source: AECOM

As in the CSIRO study, it has been assumed that the efficiency of an ICE vehicle will improve by 37% between 2006 to 2050. It has been assumed that 15% of this is due to platform engineering (and hence will apply to the EV) and 22% through other efficiency measures (including combustion technology improvements). This corresponds to an annual change of 0.84%, thereby allowing fuel consumption to decrease over time as shown in **Table 4-13**.

Table 4-13: ICE fuel efficiency for small passenger vehicles over time

Year	Petrol (L/100km)	Diesel (L/100km)	LPG (L/100km)	Weighted Fuel Efficiency (L/100km)
2010	7.80	8.64	11.66	8.1
2015	7.48	8.29	11.18	7.8
2020	7.17	7.94	10.72	7.5
2025	6.87	7.61	10.28	7.1
2030	6.59	7.30	9.85	6.9
2035	6.32	7.00	9.44	6.6
2040	6.05	6.71	9.05	6.3

Source: AECOM

4.8.2 Hybrid Electric Vehicle (HEV) Efficiency

As highlighted above, the CSIRO report concluded that HEVs will achieve a 5% improvement in fuel efficiency starting in 2006, increasing to 30% by 2050.

The evidence on existing HEVs suggests there are currently bigger efficiency gains than 5%[32]. Investments in HEV 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 4-14** shows the expected fuel efficiencies of HEVs over time. Changes in taxi fuel efficiency are assumed to be equal to that of large passenger vehicles.

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[32] The Toyota Prius has a fuel efficiency of 4.4L/100km compared to 6L/100km for the most efficient Toyota Yaris and 7.3L/km for the most efficient Toyota Corolla, with 36% and 66% respective efficiency improvements. (www.greenvehicleguide.gov.au)

Table 4-14: HEV fuel efficiencies over time (L/100km)

Year	Passenger Small	Passenger Medium	Passenger Large	LCV	Taxi
2010	5.31	7.35	11.22	8.42	11.22
2020	5.05	7.02	10.75	8.04	10.75
2030	4.81	6.72	10.31	7.69	10.31
2040	4.59	6.44	9.92	7.37	9.92

Source: AECOM / Dr Andrew Simpson

4.8.3 Electric Vehicles (EV) Efficiency

The fuel for EVs is electricity. Current electricity consumption efficiency values are identified from the vehicle survey of current or planned electric vehicles and presented in **Table 4-15**. Taxi fuel efficiency is assumed to be equal to that of large passenger vehicles.

Table 4-15: EV electricity efficiency by vehicle category in 2010

Vehicle Category	Electricity (kWh/100km)
Passenger small	19.0
Passenger medium	16.5
Passenger large	21.5
LCV	18.5
Taxi	21.5

Source: Survey of current planned EVs

As highlighted above, the CSIRO report concluded that light (small) EVs have a fuel efficiency of 0.2kWh/km which is consistent with this study. However, the CSIRO study assumes that this remains constant over time as any efficiencies will be used to enhance the performance of the vehicle.

This study assumes there will be improvements in efficiency. Consumption efficiency is assumed to improve by 15% due to platform engineering (as with ICEs) and by 10% through powertrain improvements as the technology matures. However efficiency is assumed to decrease by 5% due to increased range and performance. Therefore, there is a total gain of 20% between 2010 and 2050. This corresponds to an annual change of 0.45%, thereby allowing electricity consumption to decrease over time as shown in **Table 4-16**.

Table 4-16: EV electricity efficiency by vehicle category over time (kWh/100km)

Year	Passenger Small	Passenger Medium	Passenger Large	LCV	Taxi
2010	19.0	16.5	21.5	18.5	21.5
2020	18.2	15.8	20.5	17.7	20.5
2030	17.3	15.1	19.6	16.9	19.6
2040	16.6	14.4	18.8	16.1	18.8

Source: AECOM / Dr Andrew Simpson following review of current or planned vehicles

4.8.4 Plug-in Hybrid Electric Vehicles (PHEV) Efficiency

The fuel efficiency for PHEVs is a combination of electricity consumption efficiency and liquid fuel efficiency. It has been assumed that the liquid fuel efficiency is equal to that for ICE petrol, while electricity efficiency is assumed to be equal to that for EVs.

Overall, the efficiency of a PHEV is dependent on the proportion of distance travelled propelled by the ICE drivetrain or the electric drivetrain. We have assumed that PHEVs will use the electric drivetrain for 50% of kilometres in 2012[33] increasing to 80% in 2035. **Table 4-17** shows the annual change.

Table 4-17: 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%

Source: AECOM

4.9 Conventional Fuel Costs

The forecasts of fuel price were estimated using world forecasts of oil price and the past relationship to retail prices for petrol and diesel.

4.9.1 Crude Oil and Liquid Fuels Prices

World published forecasts for crude oil prices have been used from the Energy Information Agency (EIA). There are three crude oil price scenarios, low, medium and high, that have been used to estimate the price of liquid fuels (and are illustrated in **Figure 4-15**):

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

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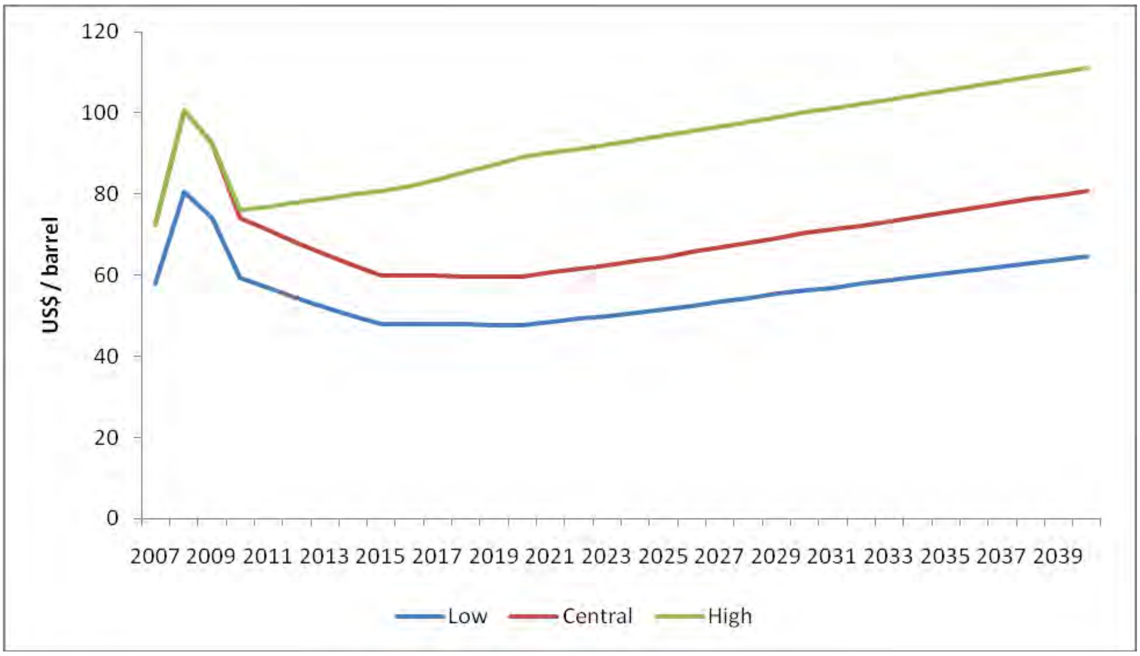
[33] When PHEVS are assumed to be available in Australia

Figure 4-15: Crude Oil price scenarios



Source: AECOM based on EIA oil forecasts

The relationship between crude oil and petrol has been determined by regressing the medium (reference) oil price against historical average metropolitan Sydney petrol prices (at the pump) obtained from FuelTrac for the period 1999 to 2008. This final pump price has then been broken down into components: a base price, excise, Carbon Pollution Reduction Scheme (CPRS) and GST as shown in **Table 4-19** and discussed below.

Base Prices

Base prices for diesel, biofuels and LPG have been calculated as a proportion of the petrol base 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 FuelWatch suggests that LPG prices are approximately 40% of petrol price. The IPART annual review of NSW taxi fares states that LPG prices can vary significantly year to year and they are difficult to estimate too far into the future. 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 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. Excise values are assumed to remain constant.

Carbon Pollution Reduction Scheme (CPRS)

The CPRS is assumed to increase the price of fossil fuels. 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 4.10.1**.

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 no CPRS price effect on fuel for the first three years of its introduction.

Emissions factors (in kg CO2e per litre) for each fuel have been calculated from the energy content and emissions factor (in kg CO2e per GJ) as given by the National Greenhouse Account (see **Table 4-18**). Energy content and emissions factors are assumed to remain constant over time.

Table 4-18: Emission factors for fuel

Fuel	Energy Content Factor (GJ/kL)	Emission Factor (kg CO_2e/GJ)	Emissions Factor (kg CO2e/L)
Petrol/gasoline	34.2	66.7	2.29
Diesel	38.6	69.2	2.69
LPG	26.2	59.6	1.58

Source: National Greenhouse Accounts (NGA) Factors, November 2008

GST

GST has been applied at 10%.

Table 4-19: 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	US$74.03	$0.76	$0.38	$0.00	$0.11	$1.25
2015	US$59.85	$0.65	$0.38	$0.07	$0.11	$1.22
2020	US$59.70	$0.65	$0.38	$0.09	$0.11	$1.24
2025	US$64.49	$0.69	$0.38	$0.11	$0.12	$1.30
2030	US$70.45	$0.73	$0.38	$0.13	$0.12	$1.37
2035	US$75.51	$0.77	$0.38	$0.17	$0.13	$1.45
2040	US$80.88	$0.81	$0.38	$0.20	$0.14	$1.53

Source: AECOM

4.10 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*, 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 (also excludes the expanded national renewable energy target (NRET));

- CPRS-5 – 5% reduction from 2000 emission levels by 2020 (includes NRET); and
- CPRS-15 – 15% reduction from 2000 emission levels by 2020 (includes NRET).

In addition to retail electricity supply costs, the price paid by electric vehicle consumers varies by point of charging under the different scenarios (see section 4.10.4 to 4.10.6).

4.10.1 Carbon Emissions Policy

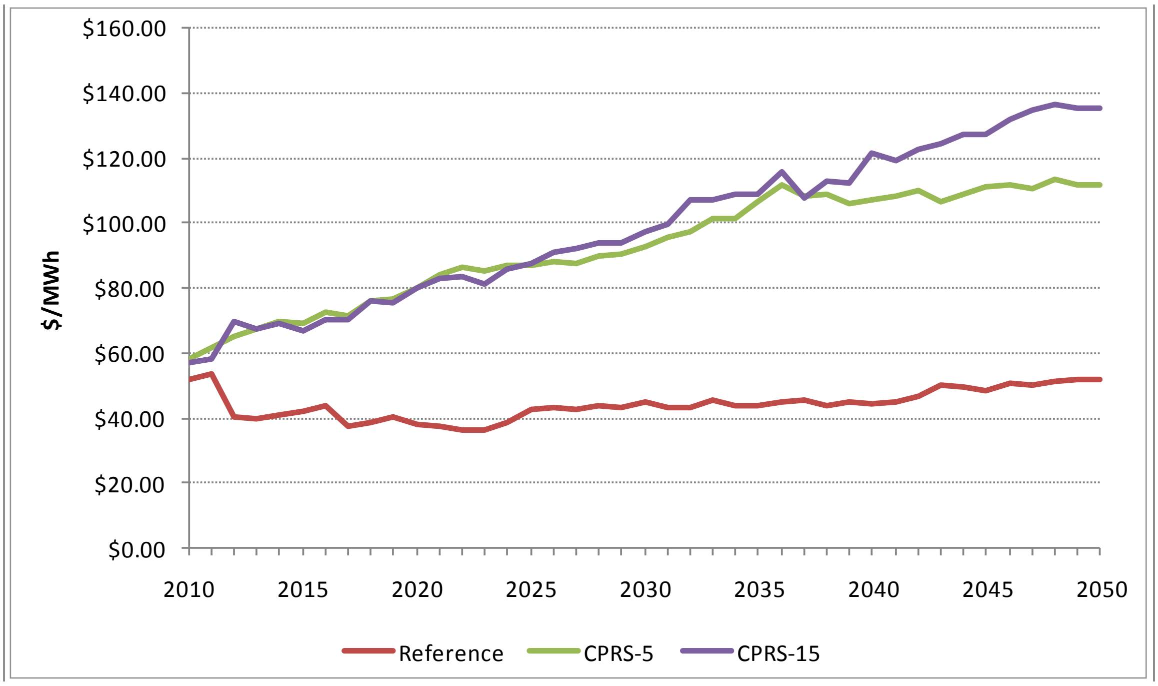
The Government has committed to introducing a Carbon Pollution Reduction Scheme (CPRS) as a key part of its climate change strategy. The Government‘s Carbon Pollution Reduction Scheme will place a limit, or cap, on the amount of carbon pollution industry can emit. It will require affected businesses and industry to buy a ‗pollution permit‘ for each tonne of carbon they contribute to the atmosphere, providing a strong incentive to reduce pollution.

The price of the CPRS 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 Treasury modelling forecasts for all three series, with minor adjustments to account for recent policy announcements including the one year delay to the commencement of the scheme and the $10 fixed permit price in the first year of operation.

4.10.2 Wholesale Electricity Costs

Forecasts of wholesale electricity prices, as detailed in the Treasury white paper[34] are shown in **Figure 4-16**. There is considerable variation in wholesale electricity prices between the reference case (no emission reduction measures) and the CPRS scenarios considered.

Figure 4-16: Forecast Australian wholesale electricity prices (2007$)



Source: Australia‘s Low Pollution Future, The Economics of Climate Change Mitigation, 2008

AECOM have updated the results to 2009 prices[35] 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.

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[34] Australia‘s Low Pollution Future, The Economics of Climate Change Mitigation, 2008
[35] Using CPI

4.10.3 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.

4.10.4 Upgraded Residential Network Connection Charge

To allow for Level 2 charging at residential properties, it is likely 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, a 20% increase in network access charges and retail margin has been assumed for electricity supplied to residential premises with Level 2 charging available. As discussed in **Section 3.2.2**, the Australian Energy Regulator may make a determination on how costs of any network upgrade required for Level 2 charging should be passed on to customers.

4.10.5 Commercial Charging Station Network Charge

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 (192 kW), utilisation or time for which the station is supplying electricity (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 has been estimated at $255 per MWh, or approximately $2 per charge (based on 8 kWh consumed per charge).

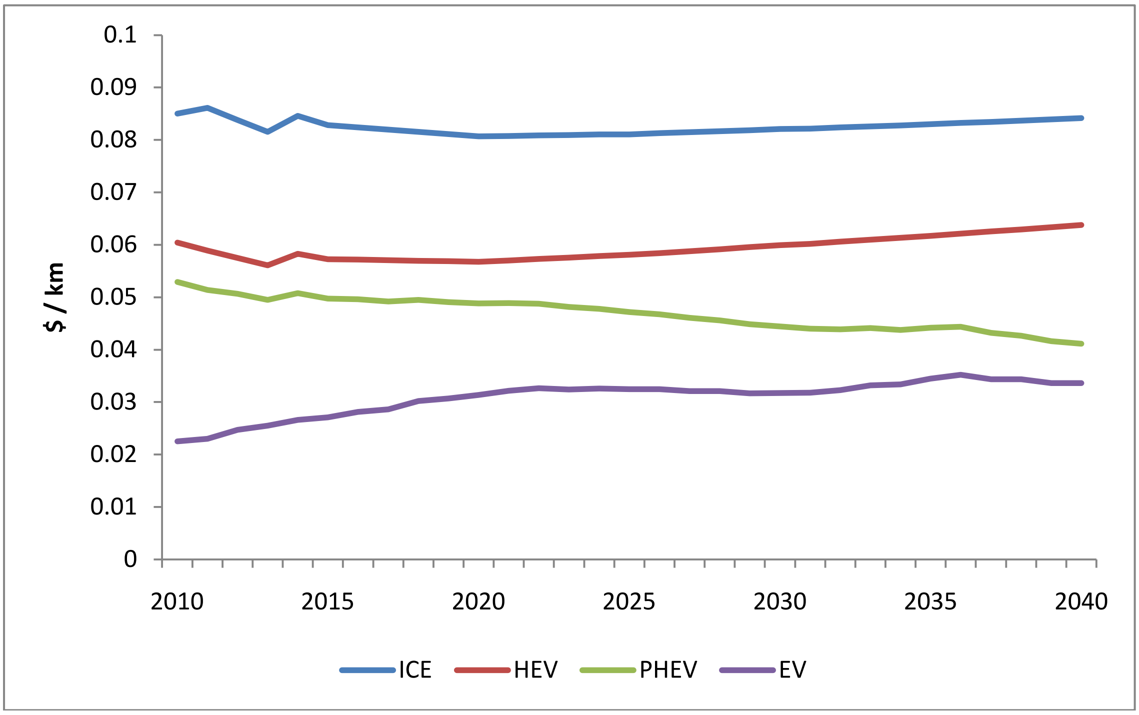
4.10.6 Public Charging Point Network Charge

Similar to commercial charging stations, 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 ($6,000), economic life (10 years), charging capacity (19.2 kW), utilisation or time for which the station is supplying electricity (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 has been estimated at $25 per MWh, or approximately $0.20 per charge (based on 8 kWh consumed per charge).

4.11 Fuel Cost per Kilometre

Figure 4-17 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 4-17: $/KM for different engine configurations – small vehicle, central price estimates



Source: AECOM

4.12 Other Vehicle Costs

Other vehicle costs include:

- Registration;
- Insurance; and
- Maintenance.

4.12.1 Registration

Registration costs were obtained from NSW Roads and Traffic Authority (RTA) website.

Table 4-20 sets out the annual costs by vehicle type and size. It has been assumed that the registration cost will not vary by the engine configuration type. In practice, government policy may reduce registration costs for low emission technologies. However, given registration costs are a small proportion of the total cost of operating a vehicle and there is no policy to distinguish between engine configuration types at the moment it has been assumed to remain the same.

Table 4-20: Registration costs by vehicle type and size

Year	Passenger* ($/annum)			Light Commercial Vehicles ($/annum)			Taxi ($/annum)
	Small	Medium	Large	Small	Medium	Large	
2009	$223	$245	$334[36]	$223 – private use $329 – business use	$245 – private use $336 – business use	$334- private use $507[37] - business use	-
*Car, station wagon or small bus for private use Small = Up to 975 kg; Medium = 976 – 1154 kg; Large = >1155 kg							

Source: NSW Roads and Traffic Authority

4.12.2 Insurance

In order to estimate insurance costs, typical vehicles were defined within each market segment. The typical vehicles focused on the top 3 car sales manufacturers in Australia – Toyota (20% of NSW sales), Holden (19.5%) and Ford (15.4%) who together capture around 55% of total sales in NSW[38]. A small passenger vehicle was classified as a Toyota Yaris, A Ford Fiesta or a Holden Barina. A medium passenger vehicle was classified as a Toyota Corolla, a Ford Focus or a Holden Astra. A large passenger vehicle was categorised as either a Toyota Aurion, a Ford Falcon or a Holden Commodore. A Light Commercial Vehicle was assumed to be either a Toyota Hiace or a Ford Transit.

Greenslip and comprehensive insurance costs for these vehicles were obtained from the websites of the Motor Accidents Authority and NRMA respectively. These costs were then averaged to obtain a common figure for all vehicles within a particular category as shown in **Table 4-21.** It has been assumed that insurance costs do not vary by distance travelled or engine configuration. In reality, they may do but it is a small amount and still a fixed cost. Costs for taxis have been obtained from IPART‘s annual taxi fare review.

Table 4-21: Average greenslip and insurance costs

Category	Greenslip ($ p.a.)	Comprehensive insurance ($ p.a.)
Passenger Small	460	884
Passenger Medium	460	902
Passenger Large	460	762
LCV (business use)	605	958
Taxi	3,697	7,228*

Sources: Motor Accidents Authority; NRMA; IPART

* includes workers‘ compensation insurance of $2228

4.12.3 Maintenance Costs

The Vehicle Operating Cost (VOC) per kilometre represents the cost of operating a vehicle on a kilometre basis and varies with the distance travelled. This includes tyres, oil and maintenance. The RTA Economic Analysis Manual[39] recommends a value of 13.45 cents/km[40].

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[36] RTA also has an extra large category which is combined with the large category in this analysis. The above price is an average of both prices (Large = $275, Extra Large = $393)

[37] RTA also has an extra large category which is combined with the large category in this analysis. The above price is an average of both prices (Large = $415, Extra Large = $599)

[38] NSW Driver and Vehicle Statistics 2007, RTA

[39] RTA Economic Analysis Manual, Appendix B economic parameters for 2007

[40] 2007 prices, converted to 2009 prices for model using CPI

Maintenance costs are generally broken down into engine/brake related, non engine/brake related and tire related. Electrical components such as traction motors and controllers require very little maintenance. AN EPRI study[41] estimate 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, the study assumes maintenance costs are around 50% of an ICE vehicle and only include the non/engine/brake related and tire related costs. These assumptions have been used in this study.

No battery replacement cost was included in the modelling because battery life is expected to equal or exceed vehicle life within the near future. There are, however, still uncertainties surrounding the life of electric vehicle batteries, as discussed in **Section 2.2.3**. Any battery replacement costs that do occur are unlikely to occur within the first decade, which will be discounted, and it is expected that there will be significant cost reductions over the next through years through economies of scale and industry learning curves (see **Section 2.2.4** for more information).

The maintenance costs are summarised in **Table 4-22**.

Table 4-22: Vehicle maintenance costs

Engine Configuration	Cents per km
ICE	13.45
HEV	11.84
PHEV	10.09
EV	6.73

4.13 Range

The vehicle range influences the sales of new vehicles through the choice model. Vehicle range assumptions for 2010 are shown in **Table 4-23**. The electric vehicle range comes from the survey and is supported by the information in **Table 2-2**.

The vehicle range for all vehicles grows over time linked to fuel efficiency improvements. ICEs and HEVs 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‘s 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.

Table 4-23: Vehicle range assumptions (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

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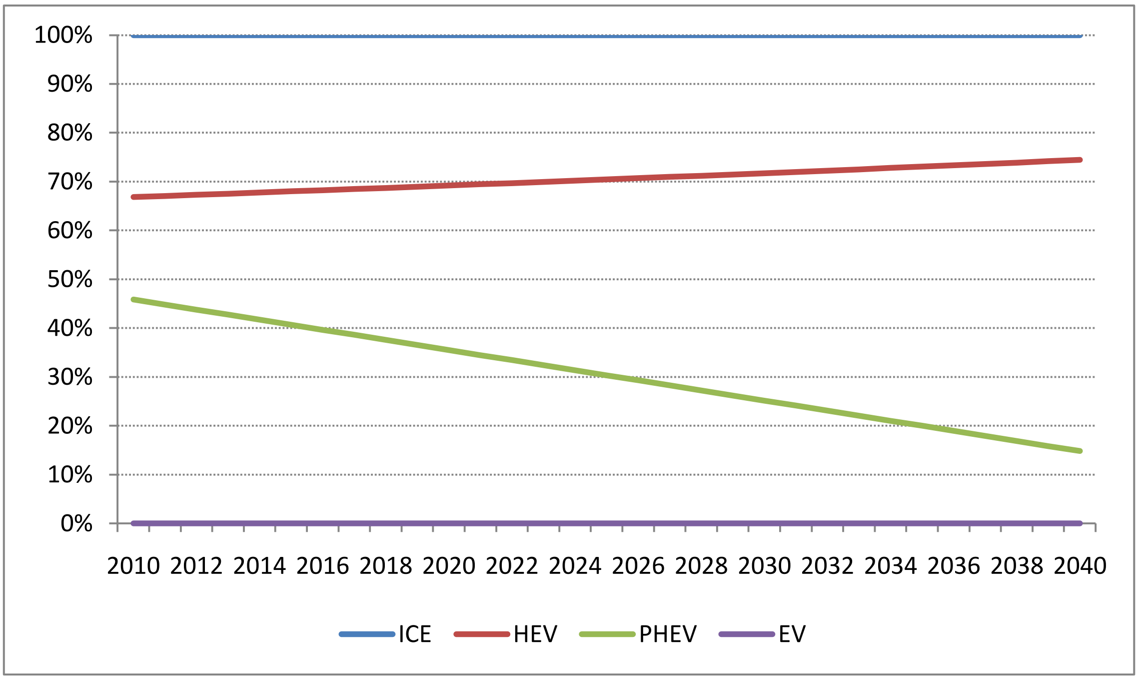
[41] A Technology and Cost-Effectiveness Assessment for Battery Electric Vehicles, Power Assist Hybrid Electric Vehicles, and Plug-In Hybrid Electric Vehicles, EPRI 2004

4.14 Emissions

The tailpipe emissions relative to an ICE vehicle influences the sales of new vehicles through the choice model. **Figure 4-18** 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. The large change for PHEVs is driven by the increased proportion of electric drive time that occurs over time.

Figure 4-18: Tailpipe emissions relative to ICE vehicles – small passenger vehicle, low VKT



Source: AECOM

4.15 Infrastructure

A key factor in the vehicle choice model is the availability of vehicle charging infrastructure relative to ICE vehicles (e.g. service stations). This is linked to the different scenarios modelled. The assumptions of level of infrastructure are summarised in **Table 4-24**.

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.

For EVs, it has been assumed that under Scenario 2, public charging points provide 50% of ICE infrastructure and under Scenario 3, 25% of service stations switch to electric vehicle service stations. Level 1 charging is not considered comparable with ICE charging infrastructure.

Table 4-24: % of 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%

4.16 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.

Sensitivity analysis will be undertaken on the results to determine how sensitive the model is to the size of the multi-fuel bonus.

4.17 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 EVs. 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 4-25** 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 vehicle 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. Further work is suggested to determine the relationship between distance travelled, charging infrastructure and take-up of EVs.

Table 4-25: % of market segment that may purchase an EV or PHEV under different scenarios

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%	50%	100%
Taxi	0%	0%	0%	100%

4.18 Supply Constraints

A major issue to the take-up of EVs in the short term (next 5 to 10 years) will be supply constraints. There are expected to be global supply constraints until at least 2012 and these will be exacerbated in Australia which is not seen as a key market for vehicle manufacturers. See **Section 9.2** for further discussion on supply constraints.

As such, a supply constraint has been built into the model to ensure it reflects current market conditions.

4.18.1 HEV Supply Constraint

It has been assumed that there are around 1,000,000 HEVs currently in global production and these will continue to grow by 35% per annum. Australia will receive 1% of global demand (as per sale of HEVs to date) and supply will be constrained until 2020.

4.18.2 PHEV Supply Constraint

It has been assumed that by 2012 there will be around 150,000 PHEVs in global production (see **Figure 3-2**) and 1% of these will reach Australia. Production will grow at 20% per annum and be constrained until 2020.

4.18.3 EV Supply Constraint

It has been assumed that by 2012 there will be around 500,000 EVs in global production (see **Figure 3-2**) and 1% of these will reach Australia. Production will grow at 20% per annum and be constrained until 2020.

4.19 Cost of Infrastructure

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.

It has been assumed that there will be no requirements to upgrade the electricity transmission and distribution network to cope with Level 1 home charging. This assumes the use of smart metering (so that households charge during the off peak period) and that any significant investments are known in advance so 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. A 20% increase in the network access costs to electricity consumers using Level 2 charging has been assumed to represent this. However, further work on the impact on electricity networks is recommended.

The cost of the charging infrastructure will vary by the different scenarios.

4.19.1 Base Case

There will be no costs under the Base Case.

4.19.2 Scenario 1 (Household Only Charging)

The costs under Scenario 1 are minimal. Level 1 charging utilises standard electrical circuits and power outlets and all charging electronics required to support Level 1 can be carried onboard the vehicle. It has been assumed that every household that has the capacity to charge a vehicle will also have a plug available.

4.19.3 Scenario 2 (Household and Public Charging)

Household Charging

Level 2 charging requires a ―charging interface” to be wired into a building‘s electricity supply to provide protection from higher voltage/power, and these systems typically involve the use of a specialised plug and socket. Level 2 charging can therefore be performed at home, but only if the appropriate equipment has been installed by an electrician. It has been assumed that households will face an additional cost of $1,000 for an electrician to supply and fit a charging interface. The equipment cost of the level 2 interface is expected to be included as standard by the vehicle manufacturer.

A 20% increase in the network access cost component of electricity prices has been assumed to apply to electricity consumed in Level 2 household charging to represent the potential costs of an upgraded household connection to the local distribution network.

Public Charging

There are various public charging stations currently in place in the US and Europe that can provide an indication of cost. Earlier this 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$5,000 each (approximately A$6,200)[42]. In 2008, the City of Westminster installed 12 electric vehicle charging points using charging stations from Electromotive, a UK company, at £3,300/unit (approximately A$6,600) (Westminster Council press release[43]). The charging stations have since been rolled out across London.

In June 2009, Toyota Industries announced a new public charging station that goes on sale in Japan this summer[44]. 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.

All of the above public charging stations are around A$6,000, so a price of $6000 per unit has been used in the model. Most of the charging stations discussed are Level 1 charging stations but there are not expected to be significant cost differences between Level 1 and Level 2 charging infrastructure.

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

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

Another company leading the way in charging stations is Evoasis which develops full service Fast-Charge, EV and PHEV Charging Station Facilities (EVSTAT) for deployment in metro areas and roadway access points in both the public and private sector. 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 6,000 square feet of photovoltaic (PV) panels, further reducing station energy dependency during sunrise-to-sunset operating hours.

It has been assumed that a charging station will cost $500,000 per station to build.

4.19.5 Summary

Table 4-26 summarises the infrastructure costs under the different scenarios.

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[42] Cleantech.com, NRC Handelsblad March 2009

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

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

Table 4-26: Infrastructure costs for each scenario

Scenario	Costs	
	Infrastructure Costs	Electricity Network costs
Scenario 1 (Base Case): No charging infrastructure	None	None
Scenario 1: Household charging only (Level 1)	None	None*
Scenario 2: Household charging (Level 1 and 2) plus public charging stations	$1,000 per household for interface unit installation (equipment cost included as standard item) $6,000 per public charging unit	None*
Scenario 3: Household charging (Level 1 and 2) plus EV service station	$1,000 per household for interface unit installation (equipment cost included as standard item) $6,000 per public charging unit $500,000 per charging station	None*
* Assuming the right incentives are in place to encourage charging in off peak periods. Further work is being undertaken in this area.		

4.20 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.

4.21 Further work

Further work is suggested on refining the vehicle choice parameters.

It is preferred that revealed preference data is used to corroborate the relative shares predicted by a choice model based solely on stated preference data. However, there is no revealed preference data available on electric vehicle take up due to the fact that this is a new market. What revealed preference data is available reflects the behaviour of early adopters rather than mainstream purchasers. Research suggests that early adopters have different purchasing habits to mainstream purchasers and in particular are less price sensitive. Furthermore, the relatively low take up of non-ICE vehicles is likely to reflect the limited supply of these vehicles into the Australian marketplace rather than consumer preferences.

The stated preference data that is available on electric vehicle demand is dated and mainly from the US which does not fully reflect Australian driving conditions. For instance, TRESIS is the only known

Australian study that has estimated electric vehicle demand. However, the TRESIS model is relatively old (uses 1991 RP data) and reflects preferences based on previous generation EVs which typically had lower vehicle performance. The data was also collected at a time when fuel prices weren‘t as high and people were less concerned with environmental issues. Recent vehicle sales data suggest people‘s views on vehicles have changed substantially over the past decade with a clear shift toward smaller, more fuel efficient vehicles. This suggests that the parameters used in this study may not reflect how consumers would respond under current market conditions.

There is also little in the literature on how peoples choices are affected by the distance they drive. As a result this could not be taken account of within the vehicle choice model and separate assumptions were made to capture this impact.

A more up to date stated preference survey would allow for a more robust assessment of demand for electric vehicles under Australian driving conditions, an updated model will allow for a better assessment of the following effects:

- Availability of a broader range of fuel types (e.g. LPG and diesel) in the Australian market;
- Higher ―believability” of electric vehicles as a viable alternative to ICE vehicles;
- Greater awareness of global warming and the environmental impact of ICE vehicles;
- Potential increasing sensitivity to fuel price fluctuations; and
- The multi-fuel capacity and electric vehicle bonuses.

Accounting for the abovementioned effects using new stated preference data will allow for a more precise evaluation of electric vehicle demand and may uncover additional factors that drive vehicle choice.

Moreover, collection of new stated preference data would allow for the estimation of new vehicle choice models which better capture potential heterogeneity in consumer preferences. Compared to the average, different market segments may be more or less cost sensitive and value various aspects of vehicle performance differently, in particular early technology adopters. Other relevant market segments include:

- Different purchasing groups (e.g. private versus fleet)
- Different driving patterns (e.g. distance travelled); and
- Socio-economic groups (e.g. income, age, residential location, existing vehicle ownership).

When properly modelled, heterogeneity in preferences manifests itself in different parameter values and bonuses for different market segments and may lead to marked differences in market shares between different consumer groups (e.g. early adopters). However, accounting for heterogeneity in consumer preferences cannot be accomplished without original stated preference datasets, whether through sample segmentation or by more complex modelling techniques such as mixed logit modelling.

It is also suggested further work is undertaken on understanding the supply constraints in Australia and what drives these and how vehicle use may change in the future (this model assumes similar vehicle use).

5.0 Results of Vehicle Choice Model

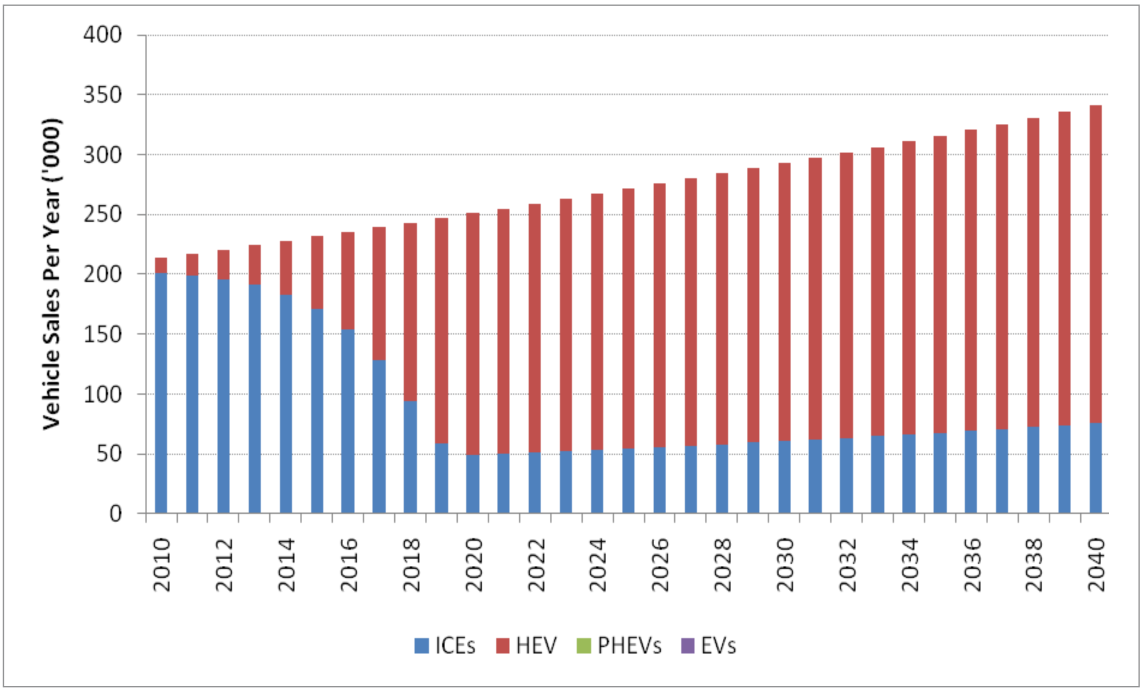
A key part of this study is the vehicle choice model which determines what proportion of new vehicle sales are for the different vehicle types.

The results presented below are based on central forecasts of oil price, electricity price and CPRS policy.

5.1 Proportion of Vehicle Sales for Different Scenarios

Figure 5-1 sets out the proportion of sales for each vehicle type for the Base Case. Under the Base Case there are no sales on PHEVs or EVs. The sale of HEVs starts to ramp up and takes over as the main vehicle type by 2020 once the price of HEVS converges to that of an ICE vehicle and there are no supply constraints. This is consistent with manufacturing expectations. Toyota, expect HEVs to be the majority of their vehicle sales by 2020 and most manufacturers expect to have an equivalent HEV for every vehicle in their range.

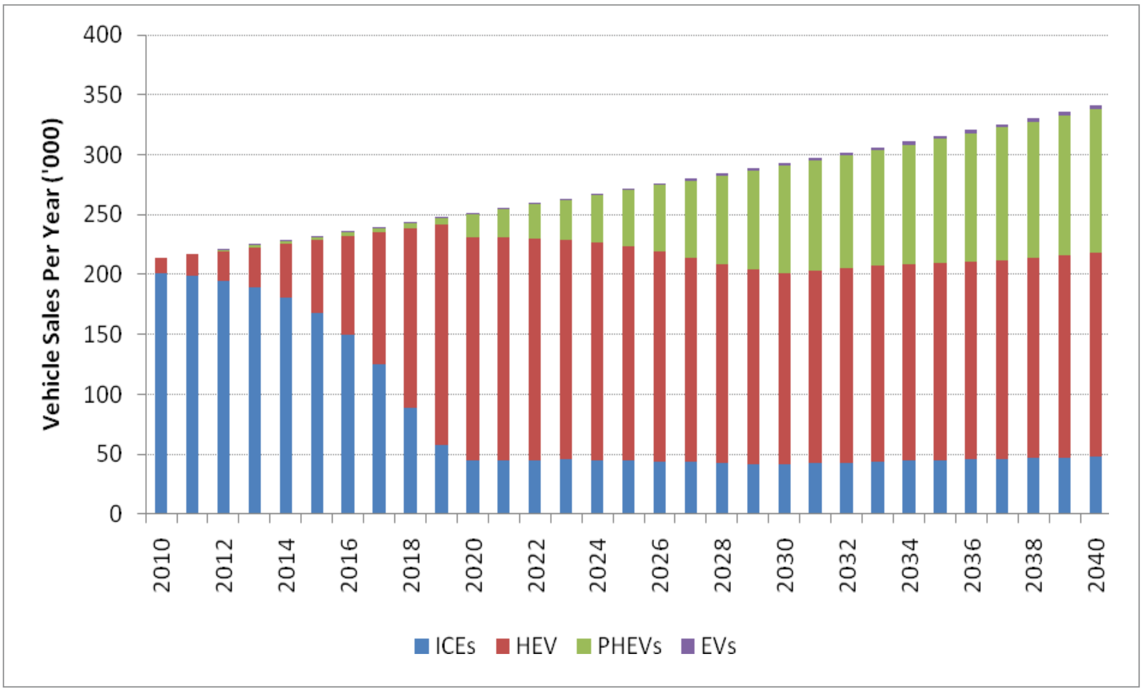
Figure 5-1: Vehicle sales in Base Case



Source: AECOM

Under Scenario 1, **Figure 5-2**, there is a small number of PHEVS and EVS in the market until 2020. After 2020, when supply is no longer constrained PHEVs become an increasing proportion of total sales. EVs remain a small proportion under this scenario.

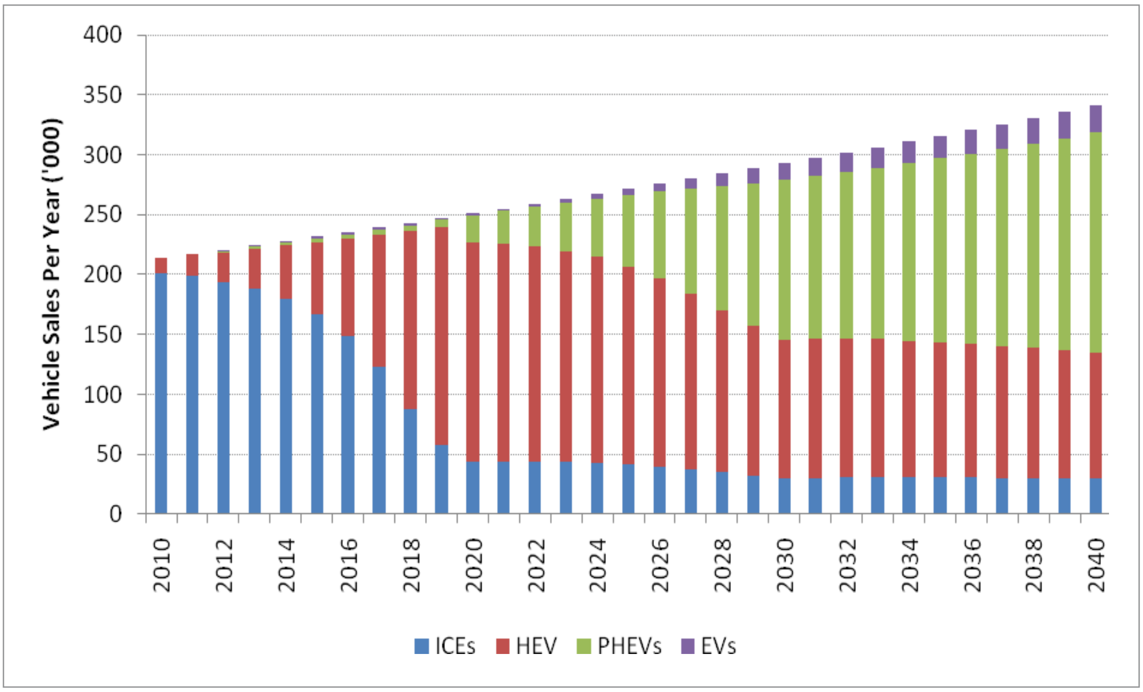
Figure 5-2: Vehicle sales in Scenario 1



Source: AECOM

Figure 5-3 sets out Scenario 2 which has similar proportions to Scenario 1, with an increasing number of EVs in the later years as prices have converged with that of an ICE vehicle.

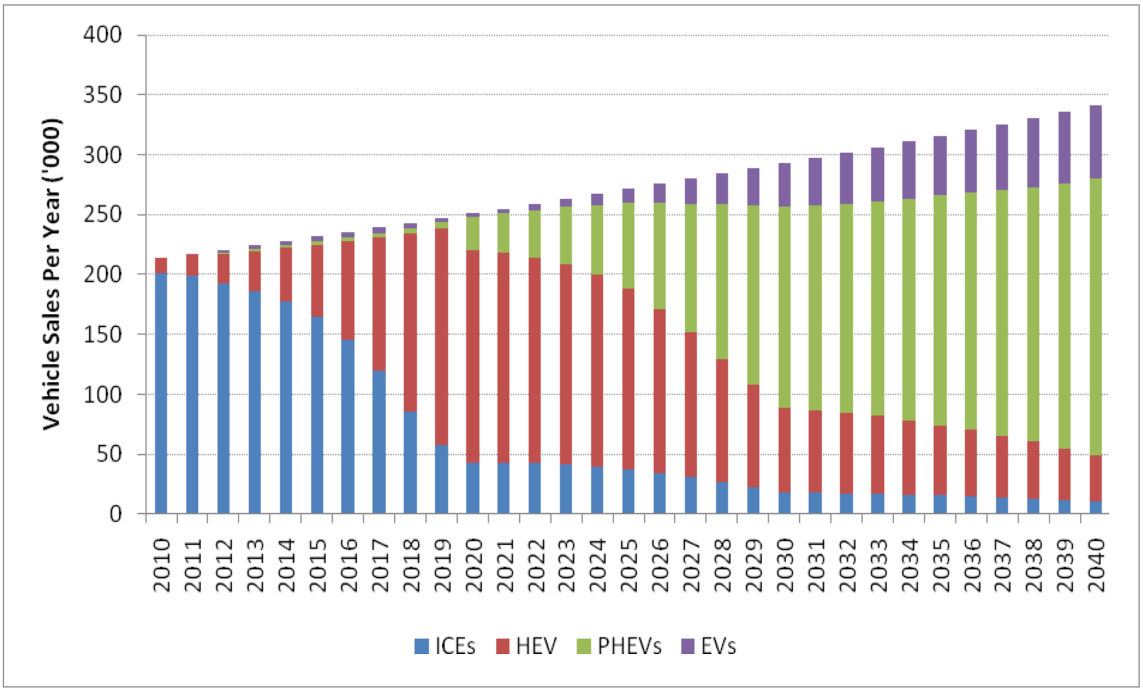
Figure 5-3: Vehicle sales in Scenario 2



Source: AECOM

Scenario 3, **Figure 5-4**, shows EVs and PHEVs taking over as the main vehicle choice from the late 2020‘s as prices converge with ICE vehicles. PHEVs remain the largest proportion of sales in 2040, but pure EVs are becoming an increasing proportion of sales.

Figure 5-4: Vehicle sales in Scenario 3



Source: AECOM

In summary, the take-up of PHEVs and EVs (plug-ins and pure EVs) is highly dependent on when the price converges with conventional vehicle prices and any supply constraints into the Australian market. The supply of infrastructure (as represented in the different scenarios) also has a big impact on the take-up of EVs.

The vehicle choice model takes account of:

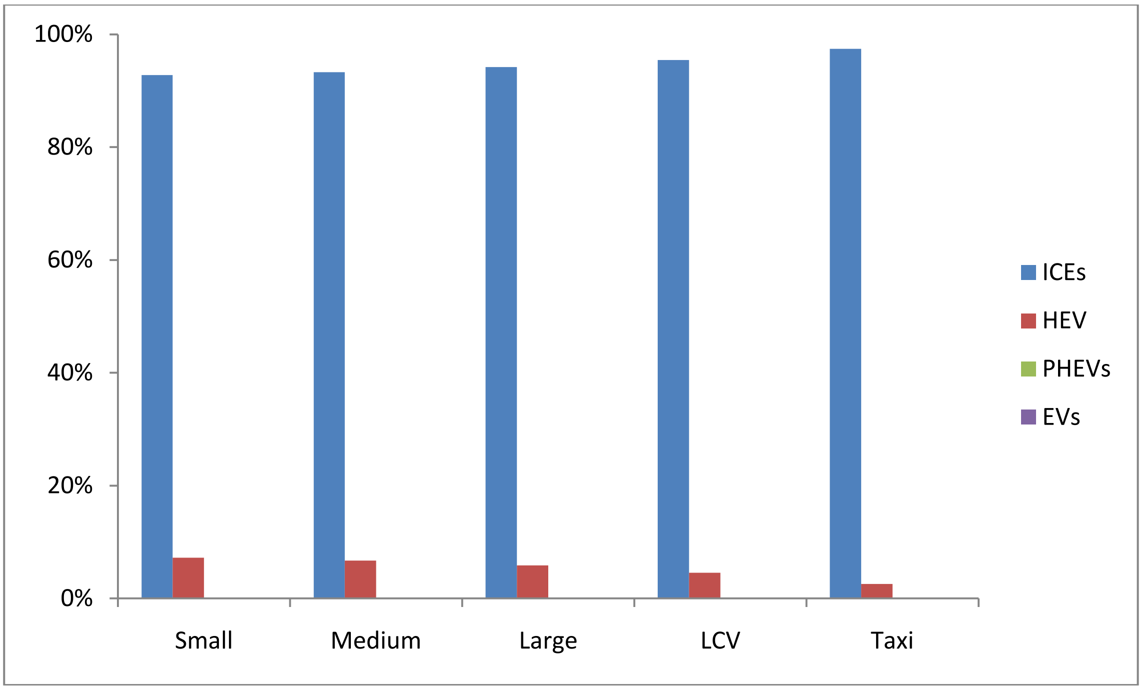
- Vehicle cost;
- Fuel cost;
- Range;
- Emissions;
- Infrastructure and
- Multi fuel bonus

The vehicle price and fuel costs have a large negative impact on the vehicle choice decision, whereas the range and infrastructure have a large positive impact. Emissions and multi fuel bonus are smaller factors in the decision making process. Over time, EVs will become cheaper and their range will increase. Provided charging infrastructure becomes readily available, there will be a shift over time towards EVs.

5.2 Proportion of Vehicle Sales for Different Market Segmentations

As set out in **Figure 5-5**, in 2010, under all Scenarios, new vehicle sales comprise mainly of ICE vehicles, with around 7% of passenger vehicles (small, medium and large) being HEVs, and only 3% of taxis being HEVs.

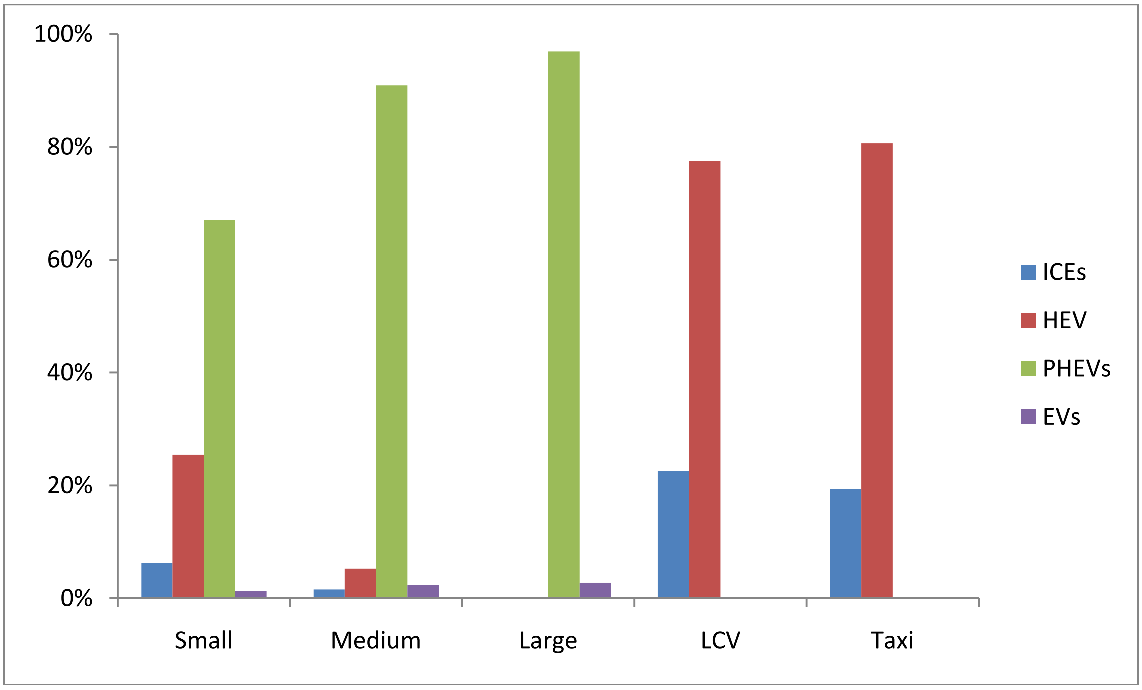
Figure 5-5: Vehicle sales in 2010 (all scenarios)



Source: AECOM

As set out in **Figure 5-6**, under Scenario 1, by 2040 a large proportion of new passenger vehicles are PHEVs with only a small number of EVs. Importantly, small vehicle sales have a higher proportion of HEVs than medium and large vehicle sales, with increasing numbers of PHEVs for larger vehicles. Light commercial vehicles and taxis are predominantly HEVs, with no PHEVs and EVs. EVs sales are very small at 1% to 3% for passenger vehicles.

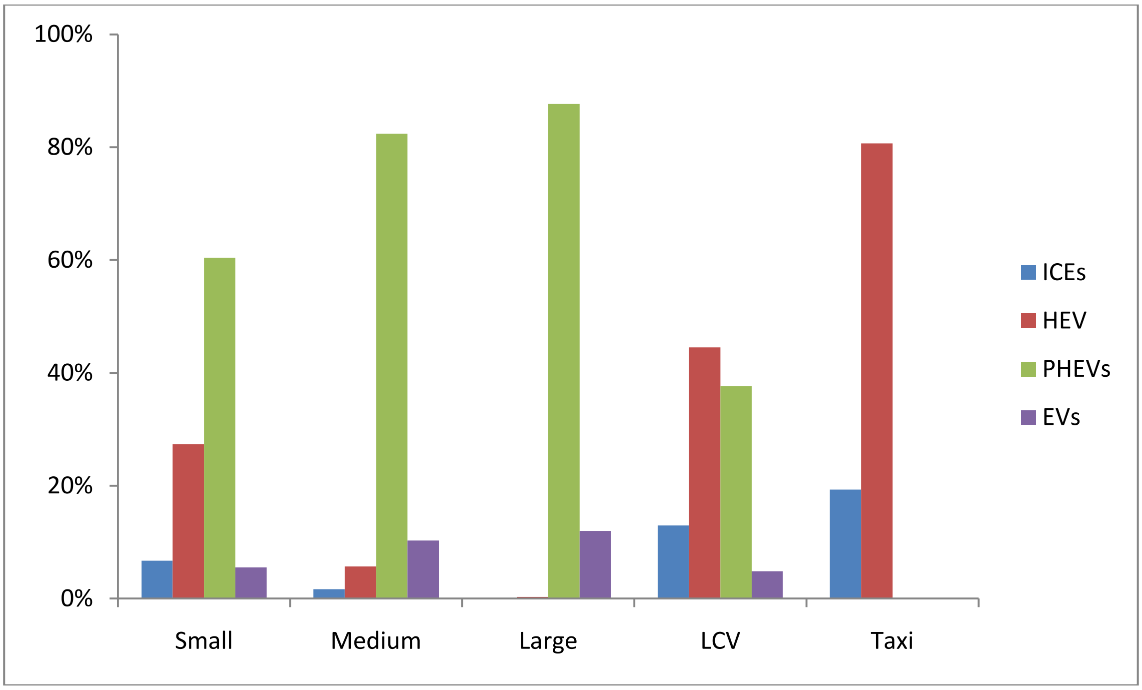
Figure 5-6: Vehicle sales in 2040 (Scenario 1)



Source: AECOM

As set out in **Figure 5-7**, under Scenario 2, by 2040 EVs have a larger proportion of passenger vehicle sales, particularly in the medium to large vehicle sales which account for around 11% to 12% of total sales.

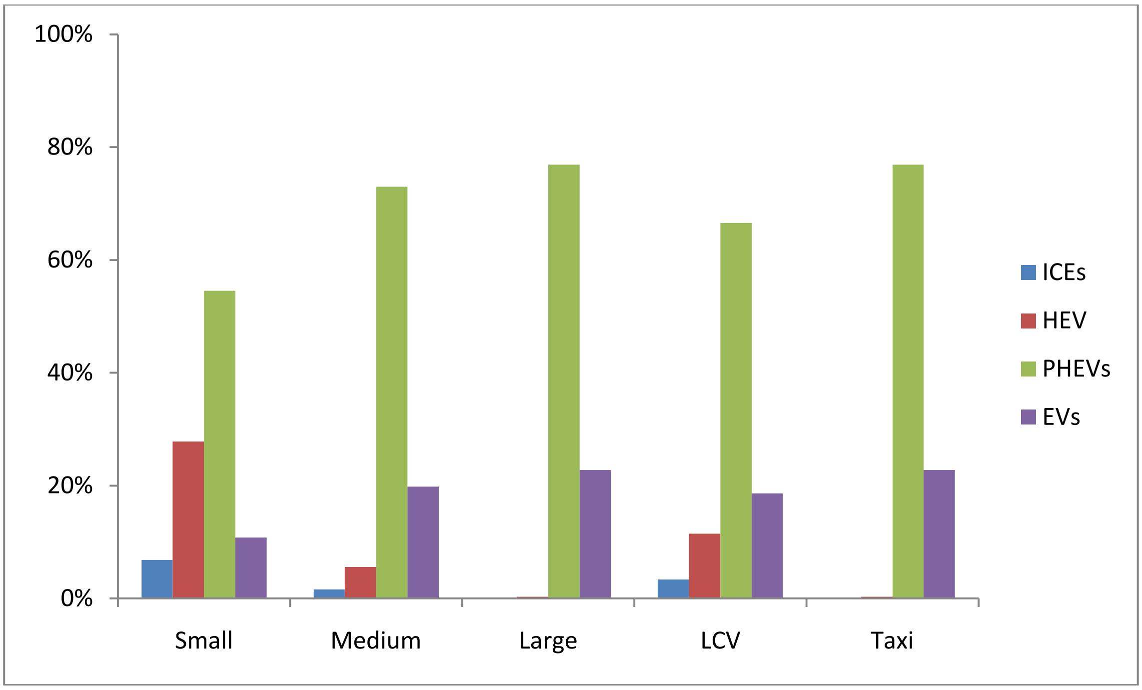
Figure 5-7: Vehicle sales in 2040 (Scenario 2)



Source: AECOM

As set out in **Figure 5-8**, under Scenario 3, with electric vehicle charging stations, electric vehicle sales increase to around 20% of sales by 2040 in most of the categories apart from small vehicles. Small vehicles retain a large proportion of HEVs whereas the other market segments have moved away from HEVs towards PHEVs and EVs. Over time, as the prices converge, the main differences are driven by operating cost savings which are less for smaller cars which typically travel less and have better fuel efficiencies.

Figure 5-8: Vehicle sales in 2040 (Scenario 3)



Source: AECOM

In summary, the vehicle choice model predicts:

- A transition to HEVs in near term (5-10 years), PHEVs over medium term (5-20 years) and EVs over longer term (20 years plus).
- Take-up of HEVs and EVs (plug-ins and pure EVs) is highly dependent on when the price converges with conventional vehicle prices and any supply constraints into the Australian market.
- The supply of infrastructure (as represented in the different scenarios) has a big impact on the take-up of EVs.
- In short term there is increased uptake of alternative engine configurations in the small vehicle category. However, as prices fall, the vehicle range increases and more charging infrastructure becomes available 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 and fuel efficiencies in ICE vehicles tend to be much lower in larger vehicles.

6.0 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 sourced to any particular generation type or location.

6.1 Air Pollution

6.1.1 Quantity

Tailpipe emissions on a per kilometre travelled basis, have been estimated from figures published by the 2007 NSW Transport Facts[45], and are shown in **Table 6-1** and **Table 6-2**.

It has been assumed there will be no air pollution for EVs and for HEVs air pollution will only arise from the proportion of drivetime using fossil fuels.

Table 6-1: Air pollution emissions factors (g / km) – ICE passenger vehicles

Engine Type	CH_4 g / km	N_2O g / km	NO_x g / km	CO g / km	VOC g / km	PM_{10} g / km
Petrol (Euro III)	0.006	0.053	0.070	1.620	0.030	0.014
Diesel (Euro IV)	0.003	0.027	0.270	0.330	0.040	0.041
LPG (Euro IV)	0.005	0.008	0.040	0.830	0.010	0.014
Hybrid (Euro III)	0.006	0.053	0.060	1.620	0.010	0.014

Source: NSW Transport facts 2007, Apelbaum Consulting, April 2007

Table 6-2: Air pollution emissions factors (g / km) – ICE light commercial vehicles

Engine Type	CH_4 g / km	N_2O g / km	NO_x g / km	CO g / km	VOC g / km	PM_{10} g / km
Petrol (Euro IV)	0.002	0.053	0.030	0.850	0.010	0.011
Diesel (Euro IV)	0.001	0.017	0.600	0.210	0.020	0.037
LPG (Euro IV)	0.002	0.007	0.030	0.720	0.010	0.012

Source: NSW Transport facts 2007, Apelbaum Consulting, April 2007

Note: NOx, CO and VOCs are based on a vehicle having travelled 40,000 kms – see Table 5.1-2 in the Apelbaum report.

As vehicle fuel efficiencies improve over time, allowing vehicles to travel increased distance from the same amount of fuel, emissions per km are expected to decrease. It has been assumed that the per km emission factors in **Table 6-1** and **Table 6-2** are applicable to new vehicles in 2010, but will decrease in proportion with fuel efficiency gains in future years.

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[45] NSW Transport facts 2007, Apelbaum Consulting, April 2007

6.1.2 Value

The Australian Transport Council guidelines[46] provide a default value for air pollution externalities of 2.45 cents per vehicle kilometre (2006 prices) for passenger vehicles in urban areas. This value has been assumed to represent emissions for a vehicle of average fuel efficiency. Emissions for each market segments have been scaled by the segment fuel efficiency relative to the average fuel efficiency in 2010, as described in **Section 4.8**.

6.1.3 Summary

Table 6-3 sets out the total air pollution savings by 2040 under each scenario. The savings increase substantially across the scenarios as take-up of EVs increases.

The results presented below are based on central forecasts of oil price, electricity price, CPRS policy and the shadow cost of carbon.

Table 6-3: 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	316	779	1,343
N_2O	2,695	7,779	13,739
NO_x	4,065	11,529	20,117
CO	83,345	215,836	375,086
VOC	561	1,336	2,418
PM_{10}	822	2,284	4,002

Source: AECOM

Table 6-4 sets out the cost savings from air pollution under each of the scenarios compared to the Base Case. By 2040, Scenario 3 results in a saving of around $1.3 billion compared to the Base Case. Scenario 2 has total savings of around $710 million and Scenario 1 has savings of around $261 million.

Table 6-4: Air pollution savings ($m)

	Scenario 1 ($ saved by 2040)	Scenario 2 ($ saved by 2040)	Scenario 3 ($ saved by 2040)
Air pollution cost savings (7% discount rate)	$261m	$710m	$1,256m

Source: AECOM

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

6.2 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.

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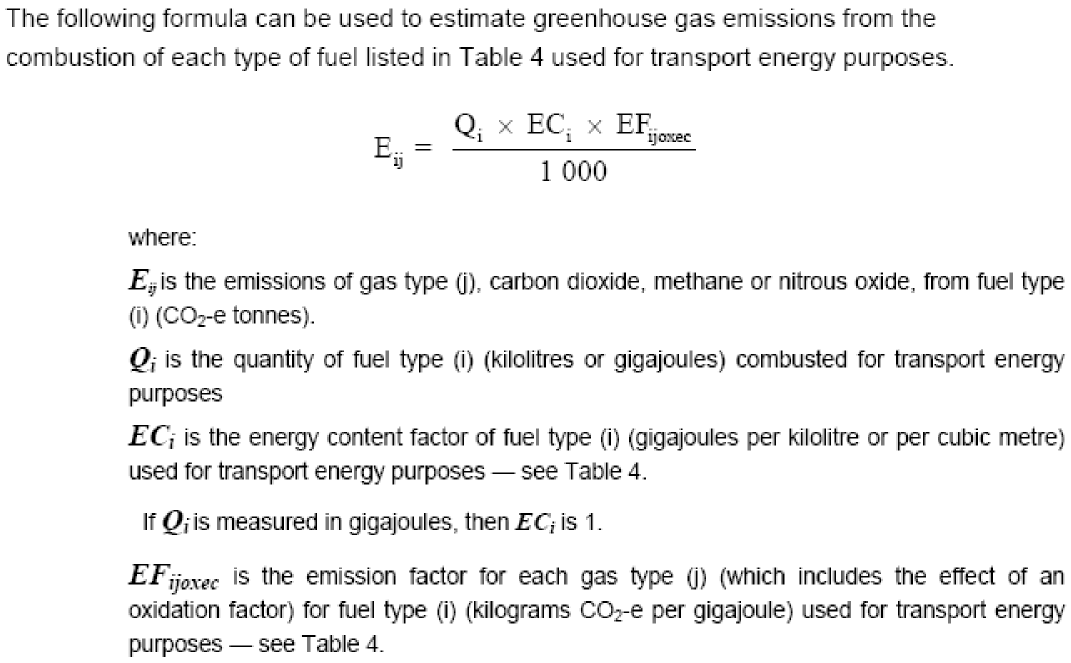
[46] National Guidelines for National Transport System Management in Australia, 2006, section 3 Appraisal of Initiatives

6.2.1 Quantity

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. **Figure 6-1** sets out the guidance from the Department of Climate Change in their National Greenhouse Accounts (NGA) Factors.

Figure 6-1: Australian guidance on greenhouse gas emission calculations from fuel



The following formula can be used to estimate greenhouse gas emissions from the combustion of each type of fuel listed in Table 4 used for transport energy purposes.

$$E_{ij} = \frac{Q_i \times EC_i \times EF_{ijoxec}}{1\,000}$$

where:

E_{ij} is the emissions of gas type (j), carbon dioxide, methane or nitrous oxide, from fuel type (i) (CO_2-e tonnes).

Q_i is the quantity of fuel type (i) (kilolitres or gigajoules) combusted for transport energy purposes

EC_i is the energy content factor of fuel type (i) (gigajoules per kilolitre or per cubic metre) used for transport energy purposes — see Table 4.

If Q_i is measured in gigajoules, then EC_i is 1.

EF_{ijoxec} is the emission factor for each gas type (j) (which includes the effect of an oxidation factor) for fuel type (i) (kilograms CO_2-e per gigajoule) used for transport energy purposes — see Table 4.

Source: National Greenhouse Accounts (NGA) Factors, November 2008

Table 6-5: Emission factors for fuel

Fuel	Energy Content Factor (GJ/kL)	Emission Factor (kg CO_2e/GJ)		
		CO2[47]	CH_4	N_2O
Gasoline	34.2	72	0.02	0.2
Diesel	38.6	74.5	0.01	0.6
LPG	26.2	64.9	0.3	0.3
These figures are for post 2004 vehicles that conform to Euro design standards				

Source: National Greenhouse Accounts (NGA) Factors, November 2008

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 not enough information to model this so it has been assumed to remain constant.

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[47] These emissions factors include Scope 1-3. See the report National Greenhouse Accounts (NGA) Factors, November 2008 for further discussion on the different scopes. http://www.climatechange.gov.au/workbook/pubs/workbook-nov2008.pdf

Electricity

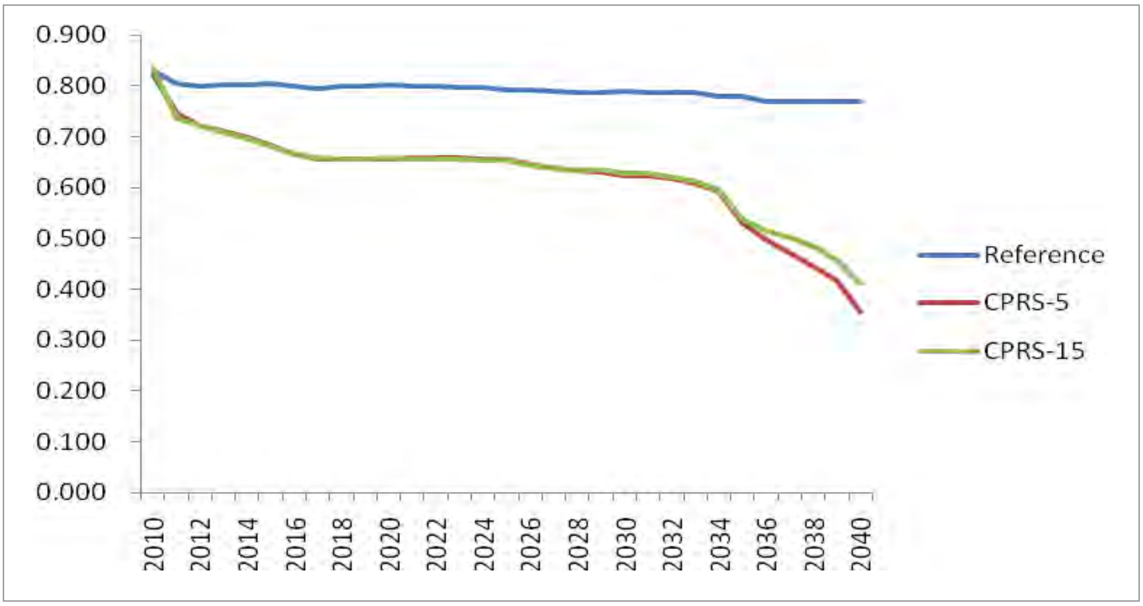
The National Greenhouse Accounts (NGA) Factors recommend a combined emissions intensity factor of 1.085 kg CO_2e/kWh for electricity generated in New South Wales and the Australian Capital Territory. However it should be noted that a National Electricity Market (NEM) operates in eastern Australia, so it is not reasonable to identify where electricity is generated. Rather, the focus should be on mix of generation in the NEM. Going forward the greenhouse gas emissions of EVs is dependent on the mix of the electricity generated and sold to power the vehicle.

The mix of electricity generation is expected to change significantly over the next 30 years. Government policies such as the National Renewable Energy Target (NRET) and the 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 electricity emissions intensity, as illustrated in **Figure 6-2**, which have been used in this study. 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 (also excludes expanded national renewable energy target);
- CPRS-5 – 5% reduction from 2000 emission levels by 2020 and 60% reduction by 2050 (includes NRET); and
- CPRS-15 – 15% reduction from 2000 emission levels by 2020 and 60% reduction by 2050 (includes NRET).

Figure 6-2: Electricity emissions intensity

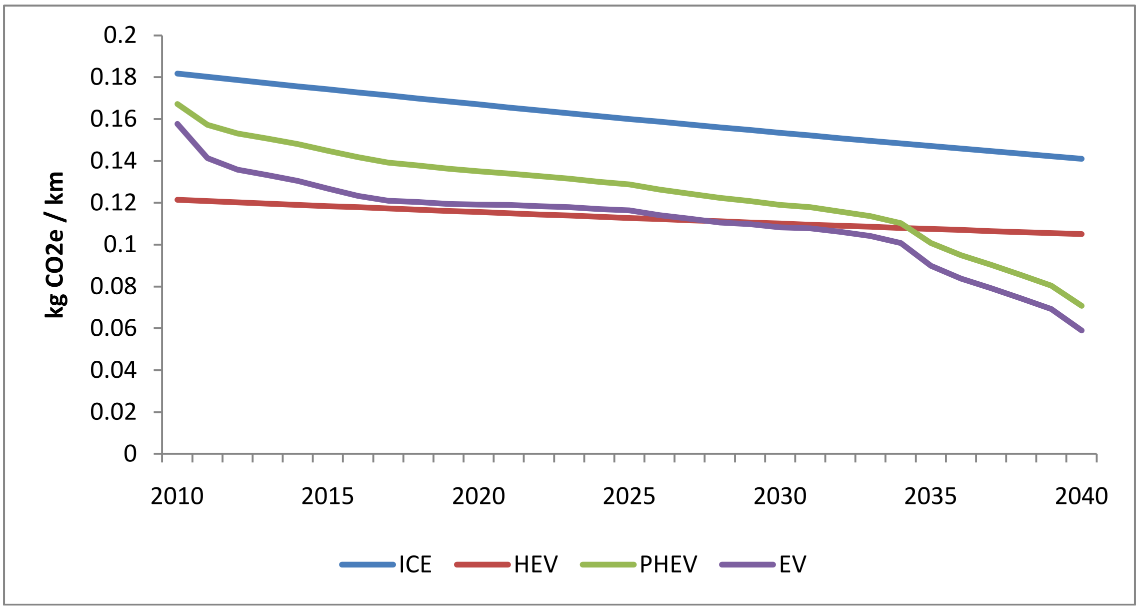


Source: Australia‘s Low Pollution Future, The Economics of Climate Change Mitigation, 2008

Greenhouse Gas Intensities of Different Engine Configurations

Figure 6-3 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. PHEVs track the performance of EVs but are slightly behind due to the proportion of ICE drivetrain.

Figure 6-3: Greenhouse gas intensities per kilometre travelled – small passenger vehicle, low VKT[48]



Source: AECOM

6.2.2 Value

As discussed in **Section 4.10.1**, 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 Pollution Reduction Scheme (CPRS) is expected to price greenhouse gas emissions that result from petrol/diesel or electricity, we feel 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_2e 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/tonne CO_2e. The UK Government recently adopted a value of £25.5/tonne CO_2e (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 (around A$65 in 2009). This has been made mandatory

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[48] Fuel efficiencies as set out in **Section 4.8**

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 /t CO_2e (around A$50/t CO_2e) in 2010 rising to €40 /tCO_2e (around A$80/t CO_2e) by 2020[49].

Given there is an emerging body of international evidence suggesting the social cost of carbon is around $50/t CO_2e, the UK values have 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. The low and high values are ratios of the central case (plus and minus twenty per cent). 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.

6.2.3 Summary

Table 6-6 sets out the annual greenhouse gas emissions under each scenario. Compared to the Base Case, Scenario 3 saves around 31.3 million tonnes CO_2e by 2040.

Table 6-6: Total air pollution savings by 2040

	Scenario 1 (tonnes saved by 2040)	Scenario 2 (tonnes saved by 2040)	Scenario 3 (tonnes saved by 2040)
GHG emissions (tCO_2e)	5.6m	17.3m	31.3m

Source: AECOM

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[49] Handbook on estimation of external costs in the transport sector, CE Delft, February 2008.

7.0 Sensitivity

This study considers a new market for vehicles powered by electricity that could develop over the next 30 years. 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 be easily updated as new information becomes available.

The key areas of sensitivity testing are highlighted in **Table 7-1**.

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 7-1: Summary of key assumptions

Variable	Current Assumption / Suggested Sensitivity
General model assumptions	
Discount rate (economic evaluation)	7% Sensitivity at 4% and 10%
Discount rate (financial evaluation)	7% Sensitivity testing at 4%, and 10%
New vehicle sales assumptions	
Demand for new passenger vehicles	Assume grows at 1% per annum Sensitivity on different growth rates
Projections of new passenger vehicle sales by vehicle type	Currently assume shift from large to medium vehicles continues. In 2008: Small – 30% of new sales Medium – 45% Large – 25% Assume that this changes by 2020 to: Small – 30% Medium – 55% Large – 15% Sensitivity different % shift and different year
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 5% per annum, declining to 3% per annum by 2030 Sensitivity on different growth rates
Taxis	Assume no increase in licences/vehicles
Vehicle price assumptions	
Fixed vehicle price	Prices based on global survey $10,000 premium in Australia compared to US prices No growth in ICE prices HEVs reach price parity with ICEs in 2020 PHEVs and EVs reach price parity with ICEs in 2030 Sensitivity on different prices and growth rates

Variable	Current Assumption / Suggested Sensitivity
Fuel efficiency	
Fuel type	Current fossil fuel mix remains same Passenger vehicles: 88% petrol, 5% diesel and 7% LPG LCV: 57% petrol, 34% diesel and 9% LPG Taxi: 100% LPG
Growth in fuel efficiencies	ICE: 37% between 2006 to 2050 HEVs: relative to ICE See **Table 4-14** EVs: 20% increase to 2050 PHEV: EV 50% of kilometres in 2006 increasing to 80% in 2030
Fuel costs	
Oil price	• High – corresponds to EIA (Energy Information Agency) high price scenario; • Reference – corresponds to the EIA reference scenario; and • Low – equal to a 20% discount from the reference scenario.
Base prices	Diesel 100% petrol price LPG 40% of base petrol prices
Excise	The current fuel excise is $0.381 and is applied to petrol and diesel. LPG tax is scheduled to begin on 1 June 2011 (assumed to be same as petrol excise)
CPRS	Price based on forecast by Treasury modelling Assume no pass through to fuel prices for first 3 years
GST	10%
Electricity prices	
Carbon emissions policy	Prices from Treasury modelling: • Reference case – no additional emission reduction measures (also excludes expanded national renewable energy target) • CPRS-5 – 5% reduction from 2000 emission levels by 2020 and 60% reduction by 2050 (includes NRET) • CPRS-15 – 15% reduction from 2000 emission levels by 2020 and 60% reduction by 2050 (includes NRET)
Residential network charge	Equal to network charge as determined by Treasury Modelling[50]
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 4.10**
Public charging point network charge	Equal to residential network charge plus a premium see **Section 4.10**
Other vehicle costs	
Fuel cost per km	Derived from fuel efficiencies and prices for fossil fuels and electricity
Registration	Fixed registration from RTA. Assumed no growth
Insurance	Greenslip – no growth Comprehensive insurance – no growth
Maintenance	ICE – 13.45c/km HEV – assumed same as ICE (13.45c/km)

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[50] Impacts of the Carbon Pollution Reduction Scheme on Australia's Electricity Markets, Report to Federal Treasury 11 December 2008, McLennan Magasanik Associates (MMA)

Variable	Current Assumption / Suggested Sensitivity
	PHEV – assumed 125% more than ICE (16.81c/km) EV – assumed 50% less than ICE (6.73c/km)
Other assumptions	
Range	ICE and HEV – 500km for small passenger; 550km for all other categories EV – range from 120km to 300km depending on vehicle category. See **Table 4-23** PHEV – range maximum of EV or ICE All grow over time in line with increased fuel efficiencies 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: ICE and HEV – 100% availability for all scenarios PHEV and EV – availability depends on scenario. See **Table 4-24**
Multi-fuel bonus	HEVs and PHEVs receive bonus 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 4-25**
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 **HEV supply constraint** - 1,000,000 HEVs currently in global production, will grow by 35% per annum. Australia will receive 1% of global demand. Supply will be constrained until 2020 **PHEV supply constraint** - By 2012 there will be around 150,000 PHEVs in global production and 1% of these will reach Australia. Production will grow at 20% per annum and be constrained until 2020 **EV supply constraint** - By 2012 there will be around 500,000 EVs in global production and 1% of these will reach Australia. Production will grow at 20% per annum and be constrained until 2020
Cost of infrastructure	Base – no costs Scenario 1 – no costs Scenario 2 • $1000 per household for interface unit • $6000 per public charging unit Scenario 3 • $1000 per household for interface unit • $6000 per public charging unit • $500,000 per charging station Different costs

8.0 Economic and Financial Results

This section 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.

8.1 Net Present Value

Table 8-1 sets out the present value of the benefits associated with introducing EVs into the NSW market compared to the Base Case. The model shows that under all scenarios the EV market is both economically and financially viable over the long run. The net present benefit becomes positive after 2030 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 $33m under Scenario 1, $91m under Scenario 2 and $165 million under Scenario 3. Air pollution savings total $261m under Scenario 1, $710m under Scenario 2 and $1,256 million under Scenario 3.

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

Table 8-1: Present Value of Benefits incremental to the Base Case*

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)
Vehicle Purchase ($m)	-$272	-$1,230	-$1,230	-$415	-$2,010	-$2,313	-$625	-$2,766	-$3,192
Vehicle Operation ($m)	$71	$461	$1,447	$133	$1,020	$4,008	$242	$1,694	$6,756
Charging Infrastructure ($m)**				-$1	-$15	-$37	-$3	-$26	-$65
Financial Benefits ($m)	-$201	-$769	$217	-$283	-$1,005	$1,658	-$386	-$1,098	$3,499
GHG Emissions ($m)	$3	$11	$33	$4	$21	$91	$7	$36	$165
Air Pollution ($m)	$11	$82	$261	$21	$182	$710	$40	$319	$1,256
Economic Benefits ($m)	-$187	-$676	$511	-$258	-$802	$2,459	-$339	-$743	$4,920
Breakeven year	2035			2032			2031		

*Based on central forecasts of oil price, electricity price and CPRS policy. A 7% discount rate has been used for all present value calculations.

** Net charging infrastructure is capital cost of charging infrastructure minus premium customers pay to cover cost of infrastructure.

Source: AECOM electric vehicle model

8.2 Sensitivity Analysis

As set out in **Section 7.0**, there is much 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:

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

Table 8-2 and **Table 8-3** set out the present value of the economic and financial costs under various sensitivity scenarios. In summary:

- Results are very sensitive to the year in which EVs reach price parity with ICE vehicles. Bringing price parity forward/delaying it by five years has a significant impact on the results;
- Changing the initial price does affect the results but this is not as sensitive as the year in which prices converge;

- If the price convergence is delayed and the price increases the viability of Scenario 1 (and Scenario 2 in the financial results) starts to be affected;
- Results are sensitive to increasing oil prices but less so to electricity and CPRS prices;
- Combination of high oil prices with low electricity prices has a large positive impact on the results;
- The multi fuel bonus increases the take-up of HEVs and PHEVS compared to EVs, resulting in less benefits in terms of cost and externality savings;
- The supply constraint makes the overall results better. This is because it delays the purchasing of vehicles that are more expensive in the early years. By constraining supply you prevent people purchasing more expensive vehicles. Increased vehicle purchase costs in early years are more significant than operating cost savings in later years due to the high level of discounting. The loss in consumer welfare from people not being able to purchase their preferred vehicle is not captured in the model.
- Results are sensitive to the discount rate used, when a 10% discount rate is used Scenario 1 becomes financially not viable; and
- The results of all the sensitivity tests are intensified moving from Scenario 1 to Scenario 3.

Table 8-2: Present Value of economic benefits under various sensitivity scenarios (compared to the Base Case)

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)
Vehicle Prices (7% discount rate)									
Price parity with ICEs in 2015 (instead of 2020) for HEVs and 2025 for PHEVs and EVs (instead of 2030)	-$163 m	$19 m	$1,420 m	-$239 m	$505 m	$4,604 m	-$319 m	$1,367 m	$8,502 m
Price parity with ICEs in 2025 (instead of 2020) for HEVs and 2035 for PHEVs and EVs (instead of 2030)	-$217 m	-$923 m	-$265 m	-$277 m	-$1,084 m	$794 m	-$348 m	-$1,146 m	$2,236 m
10% increase in vehicle prices for HEVs, PHEVs and EVs	-$233 m	-$782 m	$358 m	-$293 m	-$951 m	$2,170 m	-$366 m	-$993 m	$4,426 m
10% decrease in vehicle prices for HEVs, PHEVs and EVs	-$135 m	-$530 m	$711 m	-$214 m	-$572 m	$2,856 m	-$287 m	-$338 m	$5,623 m
Price parity with ICEs in 2015 for HEVs and 2025 for PHEVs and EVs **plus** 10% decrease in vehicle prices	-$122 m	$146 m	$1,574 m	-$200 m	$738 m	$4,925 m	-$262 m	$1,797 m	$9,099 m
Price parity with ICEs in 2025 for HEVs and 2035 for PHEVs and EVs **plus** 10% increase in vehicle prices	-$246 m	-$994 m	-$448 m	-$293 m	-$1,156 m	$462 m	-$352 m	-$1,270 m	$1,683 m
Fuel Prices (7% discount rate)									
Low oil price	-$190 m	-$681 m	$393 m	-$256 m	-$839 m	$2,067 m	-$333 m	-$842 m	$4,177 m
High oil price	-$180 m	-$664 m	$767 m	-$262 m	-$703 m	$3,337 m	-$348 m	-$476 m	$6,611 m
Low electricity price	-$186 m	-$676 m	$542 m	-$259 m	-$794 m	$2,559 m	-$341 m	-$720 m	$5,108 m
High electricity price	-$187 m	-$676 m	$481 m	-$258 m	-$811 m	$2,358 m	-$338 m	-$767 m	$4,735 m
No CPRS	-$186 m	-$683 m	$479 m	-$258 m	-$813 m	$2,359 m	-$339 m	-$758 m	$4,736 m
High CPRS	-$186 m	-$680 m	$536 m	-$260 m	-$800 m	$2,553 m	-$343 m	-$725 m	$5,110 m
Low oil price, high electricity price and central CPRS price	-$190 m	-$681 m	$364 m	-$256 m	-$845 m	$1,973 m	-$332 m	-$860 m	$4,004 m
High oil price, low electricity price, central CPRS price	-$180 m	-$663 m	$801 m	-$263 m	-$690 m	$3,451 m	-$350 m	-$441 m	$6,826 m
Without multi fuel bonus	-$199 m	-$628 m	$566 m	-$266 m	-$655 m	$2,903 m	-$349 m	-$459 m	$6,105 m
No supply constraint	-$931 m	-$1,327 m	-$108 m	-$1,097 m	-$1,409 m	$1,932 m	-$1,265 m	-$1,376 m	$4,390 m
Discount Rates									
4% discount rate	-$222 m	-$934 m	$1,552 m	-$305 m	-$1,073 m	$5,792 m	-$396 m	-$907 m	$11,014 m
10% discount rate	-$158 m	-$499 m	$84 m	-$221 m	-$608 m	$983 m	-$293 m	-$604 m	$2,159 m

Source: AECOM electric vehicle model

Table 8-3: Present Value of financial benefits under various sensitivity scenarios (compared to the Base Case)

Financial 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)
Vehicle Prices (7% discount rate)									
Price parity with ICEs in 2015 (instead of 2020) for HEVs and 2025 for PHEVs and EVs (instead of 2030)	-$176 m	-$109 m	$1,056 m	-$265 m	$192 m	$3,575 m	-$373 m	$787 m	$6,640 m
Price parity with ICEs in 2025 (instead of 2020) for HEVs and 2035 for PHEVs and EVs (instead of 2030)	-$230 m	-$1,001 m	-$508 m	-$299 m	-$1,234 m	$213 m	-$387 m	-$1,402 m	$1,221 m
10% increase in vehicle prices for HEVs, PHEVs and EVs	-$245 m	-$862 m	$85 m	-$311 m	-$1,106 m	$1,461 m	-$397 m	-$1,258 m	$3,176 m
10% decrease in vehicle prices for HEVs, PHEVs and EVs	-$152 m	-$639 m	$392 m	-$246 m	-$802 m	$2,022 m	-$352 m	-$757 m	$4,127 m
Price parity with ICEs in 2015 for HEVs and 2025 for PHEVs and EVs **plus** 10% decrease in vehicle prices	-$138 m	$5 m	$1,192 m	-$237 m	$385 m	$3,843 m	-$340 m	$1,132 m	$7,123 m
Price parity with ICEs in 2025 for HEVs and 2035 for PHEVs and EVs **plus** 10% increase in vehicle prices	-$256 m	-$1,055 m	-$661 m	-$308 m	-$1,273 m	-$50 m	-$379 m	-$1,467 m	$793 m
Fuel Prices (7% discount rate)									
Low oil price	-$203 m	-$770 m	$108 m	-$278 m	-$1,015 m	$1,333 m	-$373 m	-$1,147 m	$2,881 m
High oil price	-$196 m	-$765 m	$453 m	-$289 m	-$914 m	$2,508 m	-$400 m	-$856 m	$5,124 m
Low electricity price	-$201 m	-$770 m	$246 m	-$284 m	-$984 m	$1,788 m	-$386 m	-$1,054 m	$3,738 m
High electricity price	-$201 m	-$768 m	$189 m	-$282 m	-$995 m	$1,602 m	-$382 m	-$1,090 m	$3,394 m
No CPRS	-$203 m	-$779 m	$186 m	-$284 m	-$1,001 m	$1,596 m	-$386 m	-$1,088 m	$3,370 m
High CPRS	-$200 m	-$769 m	$263 m	-$283 m	-$981 m	$1,848 m	-$386 m	-$1,044 m	$3,858 m
Low oil price, high electricity price and central CPRS price	-$204 m	-$769 m	$82 m	-$278 m	-$1,019 m	$1,247 m	-$371 m	-$1,161 m	$2,723 m
High oil price, low electricity price, central CPRS price	-$195 m	-$765 m	$485 m	-$290 m	-$904 m	$2,614 m	-$402 m	-$828 m	$5,324 m
Without multi fuel bonus	-$209 m	-$707 m	$288 m	-$287 m	-$840 m	$2,113 m	-$391 m	-$813 m	$4,623 m
No supply constraint	-$957 m	-$1,445 m	-$432 m	-$1,146 m	-$1,657 m	$1,094 m	-$1,344 m	-$1,791 m	$2,929 m
Discount Rates									
4% discount rate	-$240 m	-$1,078 m	$986 m	-$335 m	-$1,368 m	$4,285 m	-$451 m	-$1,425 m	$8,336 m
10% discount rate	-$170 m	-$560 m	-$76 m	-$240 m	-$730 m	$580 m	-$329 m	-$818 m	$1,444 m

Source: AECOM electric vehicle model

8.3 Externalities

Table 8-4 summarises the total greenhouse gas and air pollution (CH_4, N_2O, NO_x, Co, BOC and PM_{10}) emission savings compared to the base case under each scenario.

Table 8-4: Greenhouse gas and air pollution emission savings compared to the base case

tonnes	Scenario 1			Scenario 2			Scenario 3		
	To 2020	To 2030	To 2040	To 2020	To 2030	To 2040	To 2020	To 2030	To 2040
Greenhouse Gas Emissions	169,763	908,201	5,621,115	224,888	1,929,891	17,255,754	361,435	3,462,002	31,307,014
CH_4	4	62	316	9	139	779	18	243	1,343
N_2O	23	500	2,695	61	1,254	7,779	133	2,228	13,739
NO_x	228	1,185	4,065	313	2,314	11,529	466	3,784	20,117
CO	897	15,802	83,345	2,101	37,068	215,836	4,358	65,242	375,086
VOC	45	167	561	57	271	1,336	91	473	2,418
PM_{10}	22	186	822	36	410	2,284	61	701	4,002

Source: AECOM electric vehicle model

8.4 Cost per Kilometre

Table 8-5 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[51] and maintenance costs (based on average annual distance travelled as set out in **Table 4-5**) and insurance. Future costs have been discounted at 7%.

Table 8-5: Lifetime cost per kilometre for each engine configuration in 2010 and 2040[52]

Engine Type	Small Passenger		Medium Passenger		Large Passenger		Light Commercial		Taxi	
	2010	2040	2010	2040	2010	2040	2010	2040	2010	2040
ICE	$0.263	$0.264	$0.286	$0.287	$0.352	$0.355	$0.277	$0.279	$0.271	$0.275
HEV	$0.299	$0.245	$0.318	$0.272	$0.380	$0.341	$0.299	$0.264	$0.321	$0.264
PHEV	$0.297	$0.217	$0.313	$0.227	$0.469	$0.274	$0.365	$0.214	$0.466	$0.234
EV	$0.260	$0.191	$0.270	$0.199	$0.416	$0.243	$0.318	$0.185	$0.438	$0.220

Source: AECOM

Figure 8-1 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 2030 when the price of an EV reaches price parity with an ICE vehicle. After 2030, the cost per kilometre of EVs is around 72% 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

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

[52] The cost per kilometre is non-scenario specific as vehicle and operating costs do not change significantly across the scenarios.

reached, at 82% for PHEVs and 93% for HEVs. The cost per kilometre of medium vehicles is similar to small vehicles.

Figure 8-1: Lifetime cost per kilometre - small

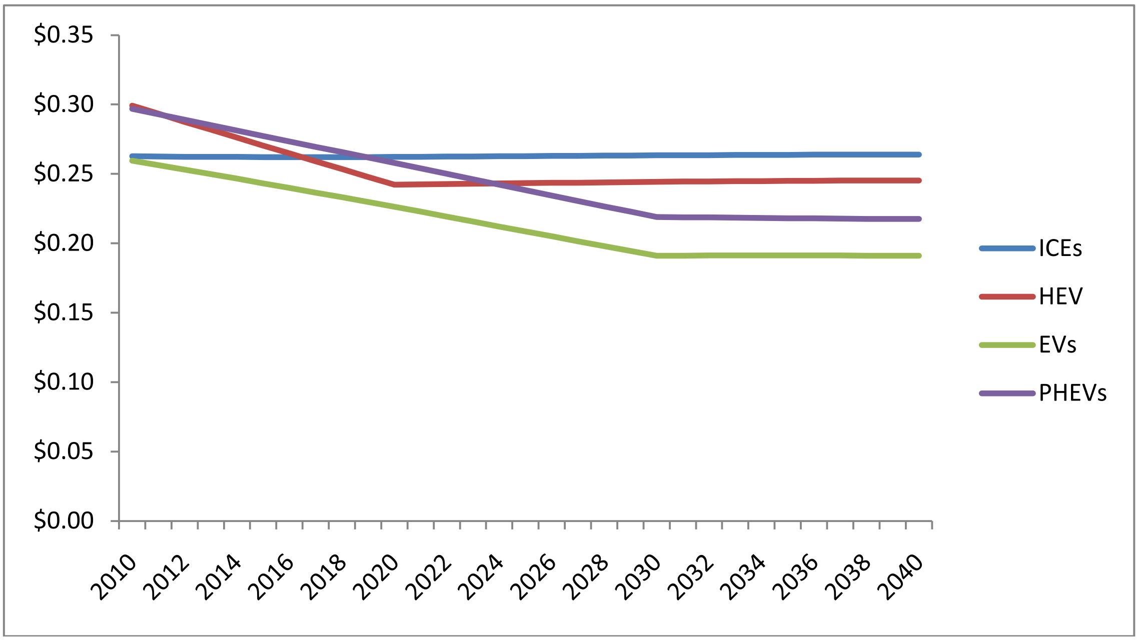


Figure 8-2 sets out how the cost per kilometre changes from 2010 to 2040 for a large vehicle. As highlighted in the review of current or planned EVs (**Table 3-1**) the vehicle price for large EVs is currently high, outweighing the operating cost savings until around 2017. However, once vehicle prices reach price parity with ICE vehicles there are significant cost savings for large vehicles, which tend to travel larger distances. By 2040, the cost per kilometre for a large EV is 68% of the ICE cost, compared to 72% for a small EV. The cost per kilometre for Light Commercial Vehicles is similar to large passenger vehicles, although stabilises at 52% of the ICE cost per kilometre due to the larger distances travelled.

Figure 8-2: Lifetime cost per kilometre – large

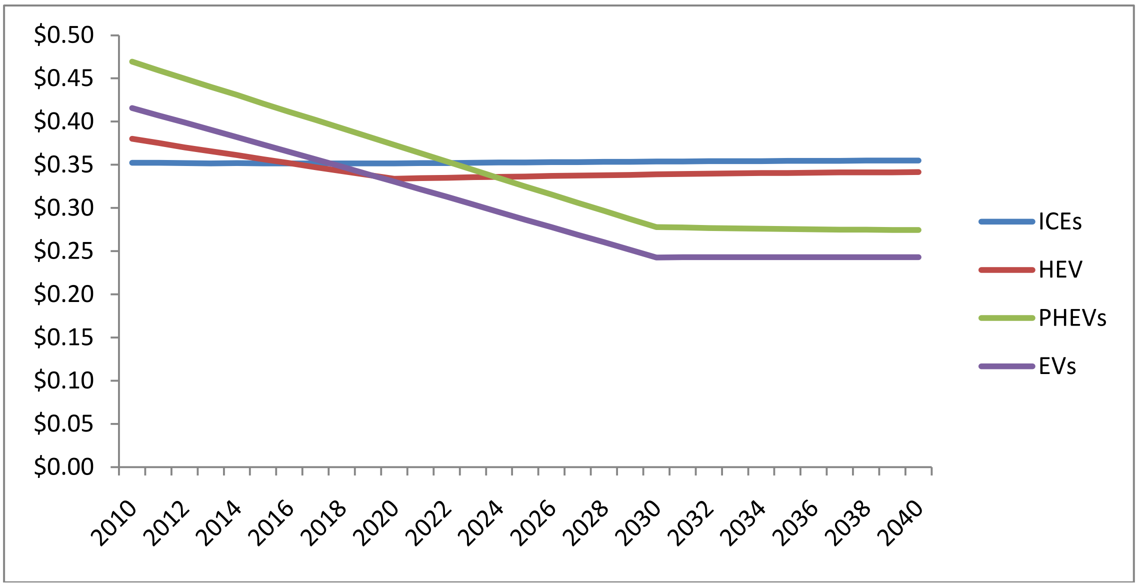
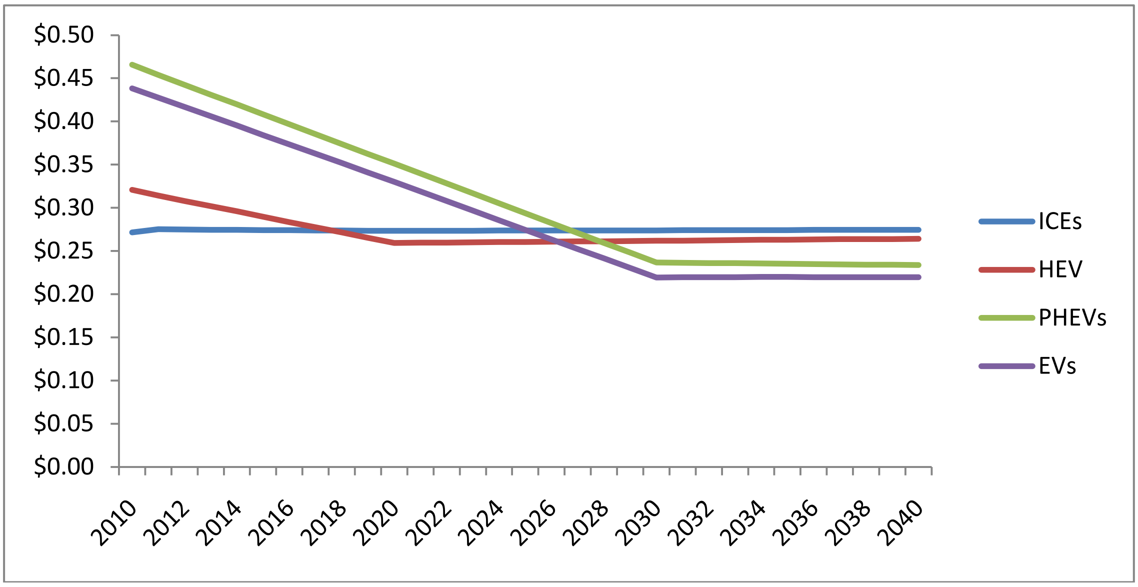


Figure 8-3 sets out the cost per kilometre changes from 2010 to 2040 for taxis. As with large passenger vehicles and light commercial vehicles the high vehicle cost of EVs, PHEVs and HEVs outweighs the cost savings from fuel in the early years. The fuel savings are not as high as for other vehicles due 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.

Figure 8-3: Lifetime cost per kilometre – Taxis



In summary, the cost per kilometre for smaller 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 and LCVs 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 larger 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.

8.5 Model Conclusions

The model shows that the plug-in electric vehicle market in NSW 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 short term (5-10 years), PHEVs over the medium term (5-20 years) and EVs over the longer term (20 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, small 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 (this is largely driven by battery costs), 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.

9.0 Issues for Consideration

In undertaking this study, several issues arose that were not able to be incorporated into the model, but are important in understanding the electric vehicle market and how it may evolve over time. These are discussed below.

9.1 Battery Issues

- **Evolution toward standardisation of technology**: As discussed in **Section 2.3**, the prospects for improvement in plug-in vehicle batteries are quite promising. Today‘s batteries have been deemed ―sufficient" for the commencement of mass-market commercialisation, and as the battery supply industry matures, there will be increasing emphasis to develop standard battery architectures. Standards could define voltages, currents, hardware, software, interconnects, cell and pack form factors, diagnostic systems, etc. Developing standards will be further motivated by increased emphasis on battery compliance regulations for safety, servicing and interchangeability.
- **Cost of batteries**: The cost of batteries will be a critical factor affecting the market uptake of plug-in electric vehicles. **Section 2.2.4** discussed industry expectations are for a reduction of battery costs through economies of scale as production volumes increase and industry learning curves. Without significant increases in production, these cost reductions may not materialise.
- **Environmental issues around batteries (production and disposal)**: While lithium-ion batteries can theoretically be produced and disposed of in an environmentally-sustainable manner, the industry is yet to fully adopt responsible practices as it expands its facilities for manufacturing and recycling.
- **Battery life expectancy and uncertainty**: While the latest expectations for lithium-ion battery life are quite promising and battery technology continuously improving, there is still the possibility that manufacturers will bring EV/PHEV products to market before battery lifetime issues are fully understood and resolved. This is largely a practical issue relating to limited on-road experience with latest-generation lithium battery vehicles and the significant time and resources needed for exhaustive testing. The provision of manufacturer warranties and replacement guarantees will clearly be an important factor in this regard.
- **Value of batteries:** An important consideration will be the residual value of used automotive batteries and the development of secondary markets (e.g. telecoms, backup power). A high aftermarket price for vehicle batteries would make battery leasing more attractive, shifting some of the upfront cost and risk away from the vehicle purchaser,

9.2 Supply Constraints

A major issue to the take-up of EVs in the short term (next 5 years) will be supply constraints. A recent study on the electric vehicle market predicted limited global supply until at least 2012[53]. It is expected that, with the exception of some niche manufacturers like G-Wiz, Tesla, and a few others, only Mitsubishi will have a market ready model available in 2011. Most manufacturers including Nissan, BMW and Renault are currently in the testing phase of their vehicles and are at least 3 years away from mass roll out.

Despite a global slowdown in vehicle sales, the launch of the new Toyota Prius in May 2009 has been hugely successful with early indicators that demand will be much greater than current production plans. Toyota have a sales goal of 400,000 worldwide for the year with half of this in the US. In Japan alone, Toyota received 80,000 orders (20% of total expected global sales) for the car before it went on sale. They sold 110,000 Prius‘ in Japan in May and there is a waiting list of several months. Indications are that the launch of the Prius in the US will face a similar response with some dealers reporting to have been accumulating waiting lists for more than a year. Toyota has three Prius

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[53] Concerted Government Support Critical for Powering the Electric Vehicle Market, Frost & Sullivan, May 2009

manufacturing lines in Japan, which at full capacity are able to make about 50,000 Prius cars a month or 600,000 cars per annum.

Local sales of HEVs suggests global supply constraints are exacerbated in Australia. Toyota has sold more than 1.27 million Prius‘ worldwide since its debut in 1997. In Australia, almost 12,000 Toyota Prius‘ (just under 1% of global sales) have been sold since its product launch here in 2001.

Australia has a relatively small vehicle market and is not a key market for vehicle manufacturers. As highlighted by the recent launch of the Toyota Prius, vehicle manufacturers cannot meet demand in key markets such as the US and Japan. Australia is likely to continue to face exacerbated supply problems until vehicle production increases significantly to meet demand globally.

9.3 Market Structure / Business Model

9.3.1 Current Market Structure for Vehicle Travel

The current market for vehicle travel is characterised by the following:

- **Car manufacturers**: The car manufacturing market is highly competitive with a large number of market players. Car manufacturers produce cars and undertake R&D.
- **Petrol stations**: Oil companies refine oil to produce petrol. They also franchise petrol stations. The market for petrol is dominated by a small number of large players but there are also some independent petrol stations. Importantly, supermarkets and convenience stores have also entered the petrol station market.
- **Independence between car make and petrol station**: At this stage, any car can be filled up at any petrol station. There is no link between the car manufacturer and the petrol station that can be used. However, there are arrangements between fleet operators and petrol stations that bind drivers of fleet cars to use one brand of petrol station only.

The current market structure of vehicle travel is therefore characterised by vertical separation.

9.3.2 Market Structure for Electric Vehicles

In theory the market structure for EVs does not have to differ substantially from the market structure of the current vehicle market. A vertically separated market structure would imply:

- **EVs** would be produced by car manufacturers which are independent from other market participants; and
- **Charging stations** are provided by companies that are independent from car manufacturers.

However, there are a number of business models proposed by private companies that suggest a different market structure from the existing market, and in particular a more vertically integrated market for electric vehicle travel. For example, BetterPlace is proposing a business model that integrates:

- Provision of the vehicle;
- Charging stations as well as charging at home; and
- Battery swapping.

The model is similar to those used for mobile phone contracts. The customer buys a vehicle via BetterPlace and subsequently signs up to a contract for a certain number of kilometres of travel. The customer can recharge at a BetterPlace charging or battery swapping station. This level of vertical integration implies that customer‘s decision-making on whether to drive an electric vehicle is simplified.

The business models chosen by providers of electric vehicle infrastructure can have a strong influence on customer decision-making. While this should not change the fundamental cost and benefits of electric vehicle travel, it could change the perception of relative costs and benefits by customers and hence affect their choice of vehicle.

9.3.3 Implications of Competition Policy

According to the Competition Principles Agreement (1995, updated in 2007):

" […] the Commonwealth will put forward legislation to establish a regime for third party access to services provided by means of significant infrastructure facilities where:

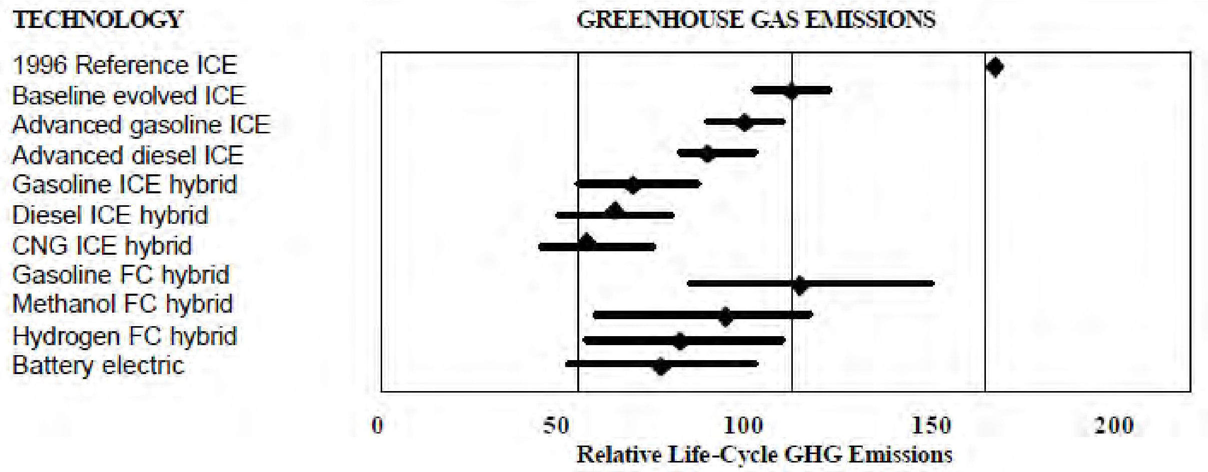
a) it would not be economically feasible to duplicate the facility;
b) access to the service is necessary in order to permit effective competition in a downstream or upstream market;
c) the facility is of national significance having regard to the size of the facility, its importance to constitutional trade or commerce or its importance to the national economy; and
d) the safe use of the facility by the person seeking access can be ensured at an economically feasible cost and, if there is a safety requirement, appropriate regulatory arrangements exist."

Considering infrastructure for re-charging and battery swapping, it is not clear-cut whether it is economically feasible to duplicate facilities. In general, there is sufficient land available for infrastructure charging points to be developed by more than one company. However, if one company establishes charging facilities without any competition at the time, the question of third party access arises. If it is determined that electric vehicle charging infrastructure cannot easily be duplicated, owning such infrastructure leads to significant market power and third party access would need to be regulated in order to prevent any company from charging monopoly rents.

9.4 Lifecycle Considerations

The lifecycle of batteries and associated electric-drive components will clearly be a determining factor for the overall sustainability of the plug-in vehicle industry. Early efforts to characterise the lifecycle of electric-drive vehicles are revealing some positive indications. For example, Toyota has conducted studies using empirical data for their HEV products and some comprehensive, predictive studies have been performed by MIT, EPRI and others. In most cases, electric-drive vehicles have been shown to result in reduced lifecycle emissions of greenhouse gases and other pollutants, as well as potential for reductions in total lifecycle costs. However, given Australia's current reliance on fossil fuels, the ongoing use of these fuels for manufacturing process energies and electric power generation will be a critical factor, and further lifecycle assessment will be required based on Australia's unique local context.

Figure 9-1: Life-Cycle Comparisons of Technologies for New Mid-Sized Passenger Cars



Reference: Malcolm A. Weiss, John B. Heywood, Elisabeth M. Drake, Andreas Schafer, and Felix F. AuYeung (2000) –ON THE ROAD IN 2020: A life-cycle analysis of new automobile technologies", MIT Energy Laboratory Report # MIT EL 00-003, Massachusetts Institute of Technology, Cambridge MA.

9.5 Electricity Issues

The most significant electricity issue arises in respect of how electric vehicle charging infrastructure is priced and how consumers respond. If consumers charge their EVs during peak periods, then there will be an increase in cost of supply due to increase in peak generation and congestion on transmission and distribution infrastructure. If electricity wholesale and network prices rise for all users, the incentive may be too weak to encourage consumers to change their charging behaviour. However prices could be structured to encourage charging outside peak periods with charging infrastructure that does not require major upgrades to networks. Clearly there is interplay between cost of charging and convenience, which will affect the take-up of EVs.

There has been some discussion about the potential for batteries in EVs to act as a distributed storage system — charging during off-peak periods when prices are low and discharging back into the network during peak periods when prices are high. The connection agreements and pricing arrangements for such distributed storage would be challenging to negotiate, based on experience with distributed generation systems such as solar photovoltaics. The impact of such discharges on battery life is also unclear. It is likely to be many years before distributed storage is implemented.

The use of EVs will add to overall electricity consumption and may require investment in additional generation capacity to meet this consumption. This could potentially become an issue should there be large scale shifts from conventional fossil fuel powered vehicles to EVs. Under the higher EV take up of Scenario 3, annual electricity consumption for EVs and PHEVs in 2039-40 (8.2TWh) represents an increase of around 10% of 2007-08 total NSW electricity consumption (78.3TWh[54]). However, general growth in electricity consumption between 2008 and 2040 will reduce the significance of EV electricity consumption as a proportion of total consumption.

9.6 Government Policies

Governments all around the world have developed policies to encourage the take-up of EVs. Some policies are designed to support industry (infrastructure, development of technology) whilst other policies are to encourage increased demand through subsidising the purchase and operating costs for consumers. **Table 9-1** summarises government policies around the world. Most countries have a combination of supply side policies and demand stimulus policies. In summary policies are aimed at:

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[54] ABARE *Energy in Australia 2009* (Department of Resources, Energy and Tourism) 2009.

- Supporting the development of the technology (particularly batteries);
- Supporting the electricity network to adjust to the additional demand from EVs;
- Providing charging infrastructure; and
- Making EVs more attractive to consumers (through subsidising the vehicle and reducing operating costs – free parking, free charging).

Table 9-1: Summary of government policies to support EVs

Country	Policies
US	**Supply side support** *Support to manufacturing industry* In March 2009, US announced the launch of two programmes aimed to support the electric vehicle industry, worth around US$2.4 billion, including: • $1.5 billion in grants to U.S. based manufacturers to produce highly efficient batteries and their components; • Up to $500 million in grants to U.S. based manufacturers to produce other components needed for EVs, such as electric motors and other components; and • Up to $400 million transportation electrification demonstration and deployment projects. *Support to electricity industry* The American Clean Energy and Security Act (ACES), which passed the Energy and Commerce Committee on May 21, 2009, has extensive provisions for electric cars. The bill calls for all electric utilities to, “develop a plan to support the use of plug-in electric drive vehicles, including heavy-duty hybrid electric vehicles”. The bill also provides for “smart grid integration,” allowing for more efficient, effective delivery of electricity to accommodate the additional demands of plug-in EVs. Finally, the bill allows for the Department of Energy to fund projects that support the development of electric vehicle and smart grid technology and infrastructure. *Support for infrastructure providers* In California, the mayors of San Francisco, San Jose, and Oakland have announced a nine-step policy plan to encourage the use of EVs in the Bay Area. The mayors will advance policies to expedite permits for installing charging outlets, create incentives for employers to install charging outlets, secure suitable 110-volt outlets in every government building for charging EVs, develop a plan for installing 220-volt charging outlets throughout each city, and harmonize local regulations and standards to achieve regulatory consistency for electric vehicle companies. The mayors will also establish programs for buying large numbers of EVs at discount rates for government and private fleets. **Demand side support** From 1 January 2009, electric vehicle buyers can receive tax credits varying from $2500 to $7500 depending on the vehicle‘s battery capacity.
European Union	**Demand side support** The European Association for Battery, Hybrid and Fuel Cell Electric Vehicles (AVERE) 55 has a table summarizing the taxation and incentives for EVs in the different European countries. Assistance is mainly on the demand side relating to:

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[55] http://www.avere.org/state_subsidies.pdf

Country	Policies
	• Direct subsidies (e.g. Sweden subsidizes 40% of difference between EV and conventional vehicle; Netherlands subsidizes up to 4,000 Euro per vehicle) • Reduction in VAT and other taxes (e.g. Austria has 50% reduction in VAT, Norway has no VAT) • Reduction in parking and other charges (tolls, highways) (e.g. many countries have free parking and many offer free public charging)
Portugal	**Supply side support** The Government has committed to investing in setting up electric charging stations across the country and in raising awareness of the vehicle's benefits.]
UK	In October 2008 the UK pledged £100 million to support electric, hybrid and other more environmentally friendly car projects over a five-year period to help make Britain "the European capital for electric cars". The funding will be used to support a number of measures, as set out below. **Supply side support** The UK has committed up to £20m, through the ~~-~~Alternative Fuel Infrastructure Grant Program" to support the installation of electric vehicle charging points. The UK Government also has a number of program to support research, development and demonstration of low carbon vehicles. **Demand side support** In April 2009, the UK Government announced financial assistance in the region of £2,000 to £5,000 to purchase EVs and PHEVS when they arrive at the showrooms. There are a range of other national incentives , including: • Vehicle Excise Duty exemption; • Enhanced Capital Allowance; and • Lowest rate of Benefit in Kind /company car tax. There are also a variety of local measures, including Congestion Charge exemption in London and free/reduced price parking in the City of Westminster
Denmark	Denmark is planning to introduce a greater number of battery driven electric cars on the streets - charged on renewable energy from the country's many windmills. Whilst Denmark does not offer direct purchase subsidies the government does offer consumers the incentive of waiving the 180% tax on vehicle purchase for an EV.
China	China's Ministry of Industry and Information Technology (MITI) has offered subsidies of up to around A$12,000 for taxi fleets and agencies for the purchase of an electric car.
Japan	Subsidies will cut 75% of the price premium between an electric vehicle and a conventional vehicle.

It is important to consider the applicability of government policies in Australia. It is worth noting that the limited supply in Australia over the next few years may limit the effectiveness of demand side initiatives. On the other hand, given the current global supply issues, the lack of consumer incentives in Australia may act as a disincentive for manufacturers to bring plug-in products here compared to other markets. It will be important for government to consider these issues if they decide to look further into the role they could play in the electric vehicle market.

9.7 Other Issues

This study is a partial equilibrium model and as such there are a range of other effects that may occur as a result of changes in the vehicle market that have not been considered in this study. These include:

- **Commodity prices:** The large scale use of EVs is likely to affect commodity supplies and prices particularly oil, copper, lithium and other metals prevalent in EVs and batteries.
- **Employment and skills:** The move from conventional vehicles to EVs may impact employment in the petrol vehicle industry (service stations, mechanics) in terms of number of jobs and skills required. The results of this study indicate that the stock of vehicles using petrol does not fall below current levels until after 2030. The long time frame means that capital and labour employed in petrol vehicle industries could relatively easily move across to electric vehicle industries with little industry restructuring costs. For example, service stations could become recharge stations and mechanics could progressively re-skill to service EVs. Local refining of petrol is unlikely to cease, as any reduction in petrol sales after 2030 would mean less refined petrol imports. Currently at least 15% of petrol used in NSW is imported as refined petrol.

10.0 Review of Market Failures

This section highlights market failures that may occur in the electric vehicle market. Importantly, some market failures may be present in the early stage of the electric vehicle market that hinder the development of the market and others may arise once the market is more established. By understanding these market failures Government will be better placed to ensure that they do not hinder the growth and development of the electric vehicle market.

10.1 Impediments to the Development of a Market in Australia

There are a variety of potential barriers and market failures that may hinder the development of the electric vehicle market, including:

- **First mover uncertainty:** The lack of standardisation and regulation in the battery industry may hinder the development of charging infrastructure. On the other hand, the first movers could find themselves in a position of significant market power to dictate the standards to industry.
- **Supply constraints:** The size of the Australian market, relative to other countries, is relatively small, resulting in exacerbated supply problems in the Australian market. Automotive companies seem reluctant to commit to increased production until there is more certainty about the future of the industry.
- **Short time horizon/short-termism:** The literature of vehicle choice decisions suggests that consumers make the decision largely based on the purchase price rather than the life of the vehicle. Given, at the moment EVs have higher purchase price but reduced operating costs there is likely to be distortion away from choosing EVs. This is likely to continue until electric vehicle prices converge with conventional vehicles.

10.2 Market Failures that may arise in the Electric Vehicle Market

There is a variety of potential market failures that may become more serious as the electric vehicle market grows, including:

- **Lack of competition:** The current market structures being suggested by industry may result in increased vertical integration of the industry, with less choice and higher prices for consumers.
- **Barriers to entry:** Setting up electric vehicle service stations is likely to be expensive. Once there is a network set up it may act as a barrier to entry, resulting in a lack of competition (discussed above).
- **Public goods nature of new technologies[56]:** One of the biggest market failures that affects the EVs market is the positive benefits that arise from reductions in greenhouse gas emissions, air pollution and noise emissions. These benefits are largely unpriced in the market at the moment, although CPRS is intended to price some of the greenhouse gas externalities.
- **Information asymmetry:** There may be a certain amount of ambiguity among consumers about the performance and safety of EVs compared to conventional vehicles. For each person to commit resources to researching and assessing the performance of electric vehicles may be too time consuming and costly.

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[56] As defined in the IPART review of NSW climate change mitigation measures, May 2009