WA ELECTRIC VEHICLE TRIAL

Western Australian Electric Vehicle Trial

2010 – 2012

Final Report

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The University of Western Australia — Achieve International Excellence
RAC members are happier
Water Corporation
Government of Western Australia Department of Transport
Department of Environment and Conservation — Our environment, our future
Telstra
City of Mandurah
City of Perth
city of swan
EV WORKS
The West Australian
mainroads Western Australia
CO_2 Smart
LANDCORP

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Executive Summary

Overview

The Western Australian Electric Vehicle Trial (WA EV Trial) was the first EV fleet trial in Australia. The trial involved the conversion of 11 Ford Focus sedans to fully electric operation, and their use in 11 government and private sector fleets in the Perth metropolitan area for a period of two years, commencing in November 2010.

The primary objectives of the trial, as agreed in a Memorandum of Understanding between the trial participants in May 2010, were to:

- Provide a public demonstration of the operating characteristics and environmental benefit of electric vehicles;
- Provide an opportunity for trial participants to assess the suitability of electric vehicles for their specific operation requirements;
- Provide local industry development opportunities in the areas of engineering / design, battery and vehicle management software, recharge and support systems; and
- Identify and assess the technical, regulatory, policy and planning issues with the introduction of electric vehicles in Perth.

The trial was initiated and managed by local Western Australian company CO2Smart, in cooperation with The University of Western Australia's (UWA) Renewable Energy Vehicle Project (REV) team.

As no original equipment manufacturer OEM-manufactured EVs existed in the Australian market at the beginning of the trial, it was decided to use local conversions based on a Ford Focus sedan. The tender for the car conversions was won by Perth company EV Works, who first converted a prototype car belonging to the WA Department of Transport. Following the successful testing of the prototype against agreed performance criteria and the vehicle passing inspection by the Department of Transport's (DoT) vehicle safety examiners, work commenced on converting the remaining ten vehicles.

Fleet participants in the WA Electric Vehicle Trial included City of Mandurah, City of Perth, City of Swan, Department of Environment and Conservation, Department of Transport, Landcorp, Main Roads WA, Telstra, the RAC, *The West Australian* newspaper and Water Corporation. In cooperation with the Australian Research Council (ARC) Linkage Project on electric vehicle charging, led by UWA, all vehicles were fitted with state-of-the-art data recording and telemetry devices (GPS black boxes) to facilitate the research.

Vehicle Performance

This trial had to use locally converted Internal Combustion Engine (ICE) vehicles. The trial proved that conversions can be operated in a fleet environment and are competitive with early release EVs from OEMs in terms of purchase price and driving range (131km road-tested for converted Focus vs. 110km road-tested for Mitsubishi i-MiEV).

However, the WA EV Trial conversions cannot compete with OEM EVs in terms of integrated design, drive experience, reliability and recent price reductions, which were introduced in late 2012.

While the majority of trial participants have indicated an interest in continuing to operate EVs in their fleets, the preference will be to acquire OEM vehicles. Nevertheless, the trial of converted EV has played a valuable role in facilitating the early study of EV driving patterns, infrastructure requirements and public familiarisation of electric vehicles, in preparation for more widespread adoption of EVs in the future. The trial was the trigger for a review of distribution and retail electricity licencing regulations, resulting in an exemption from these requirements for operators of electric vehicle charging stations. Over its two-year duration, the trial of EVs in regular business fleets has successfully demonstrated that EVs can be a viable alternative to petrol cars in a corporate fleet.

Infrastructure Requirements / Charging Station Utilisation

Although the Level 2 charging systems (fast-AC) tested during the trial are more than three times faster than conventional Level 1 charging systems (e.g. standard home or office charging), they still require about three to four hours of charging from completely empty to completely full (as compared to 10–12 hours on Level 1). The collected data confirms that EV charging bays tend to be occupied for most of the day by the same vehicle, so EVs continue to park when the charging operation has finished. This prevents charging stations from being used in an optimal way, because they get a lower vehicle throughput and a lower than optimal utilisation.

These results indicate that a smaller Level 3 (fast-DC) charging station network could be more important than a larger Level 2 network. Level 3 stations typically allow an 80% charge in 20 minutes. As this is much closer to a petrol/diesel fill-up time, an EV driver could be expected to stay with the vehicle (or in an adjacent station store or coffee shop) and immediately move the EV after completion of charging, making space for the next EV.

Web-based statistics as well as smartphone apps have been developed to assist EV drivers with information about their driving behaviour and charging status. This can be extremely helpful when waiting for the completion of a charge cycle before taking the EV for a drive, as well as for monthly statistical evaluations.

The trial reinforced the view that the availability of basic EV charging infrastructure will be an essential factor in the uptake of EVs. While not required on a daily basis by most EV drivers, it is a matter of reassurance to know the infrastructure is in place when needed.

Grid Load / Charging Times

A significant result of this trial is that EV charging times do not concentrate around the early evening hours. As most of the EVs in the trial were used as fleet vehicles, their typical charging pattern was daytime charging with a peak around 9am and a significantly smaller secondary peak around 4pm. As this largely overlaps with the peak power production profile from solar photovoltaic systems, this presents an opportunity to take advantage of PV systems to provide renewable energy for driving, enabling EVs to be a zero-emissions transport option.

Survey

A survey of 43 drivers of trial vehicles indicated satisfaction with EV performance and energy efficiency. Respondents found driving to be little different from that in ordinary cars and most mentioned that EV driving is smooth and quiet. Range was seen as a serious barrier to EV uptake, with almost half of the respondents indicating the need for significant trip planning, particularly for trips greater than 30km. Establishment of a network of charging stations was seen as at least a partial solution to the range problem. With regard to purchase, technology enthusiasts and those with environmental concerns were found more willing than others to buy or recommend EVs but many experiences of technical difficulty would have a negative effect.

Respondents in an expanded sample considered the trade-off between the cost and convenience of charging at work, home, or public charging stations. Given the assumptions that they owned an EV and that charging at work costs money, drivers responded to a set of choices; they were found to be sensitive to cost but on average were willing to pay $1 for each 10-minute reduction in charging duration. Most preferred to charge at home, particularly if they have solar panels, or at work. However those with commitments to collect family members generally preferred public charging stations.

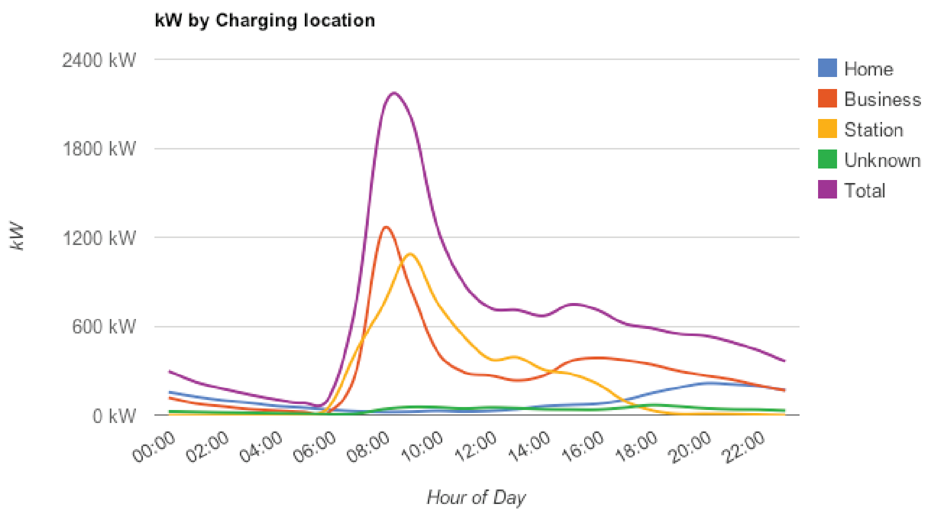


Figure 1: EV charging station usage over time of day for the WA EV Trial

Key trial results

Vehicle range:
- 131km (road-tested);
- 143km (dynamometer), which exceeds the range of the Mitsubishi i-MiEV (110km road-tested).

Average distance:
- 25km average distance driven between charges;
- 22km average daily driven distance, which is lower than the average daily distance for petrol cars (32km).

Vehicle power consumption:
- 197Wh/km (not considering charging losses);
- 242Wh/km including charging losses.

Vehicle recharge time (21kWh out of total capacity of 23kWh):
- Approx. 4 hours on a Level 2 (7kW) charging station or a three-phase power outlet;
- Approx. 12 hours on a single-phase power outlet (or a Level 1 charging station).

Charging station utilisation:
- 82% of all charging events happen at only two different places per vehicle;
- Charging stations were only utilised if they were in a convenient location;
- Charging stations were often occupied for a full working day, while charging only requires a few hours.

Peak charging time:
- 8–10am, with a lower base load from 10am–8pm and very little load during the night.

Driver acceptance:
- Divided. While some embraced the new technology, others felt the limited range a challenge and the charging process tedious.

Challenges and Opportunities

EV Uptake

Considerable costs are involved in establishing and operating EV charging networks and a 'chicken and egg' situation exists where potential network operators are reluctant to invest in the absence of a critical mass of EVs, whereas potential EV buyers are reluctant to purchase vehicles in the absence of a substantial public recharging network. International jurisdictions where this problem has been overcome have generally benefitted from government interventions which have subsidised the availability of EVs and/or underwritten the establishment of public charging facilities.

Some form of short-term government financial support would appear necessary to 'kick-start' the uptake of EVs in Western Australia.

With the recent introduction of OEM EVs into the Australian marketplace, an opportunity exists for government organisations to lead by example by including EVs in their fleets.

Recharging Infrastructure

Data from the trial, supported by overseas data, suggests that most charging will occur at home (for private vehicles) or at work (for fleet vehicles), with only occasional need for an external fast charge. As most of the Level 2 (fast AC) usage during the trial tended to be more for parking than actual charging, its function can be taken over by home charging or office charging using simpler and cheaper 'wall boxes' (simplified charging stations without identification/billing requirements), which are preferred over ordinary power outlets for safety reasons.

A network of Level 3 stations can serve the same purpose as a petrol/diesel station network for conventional internal combustion engine (ICE) cars.

Development of EV charging networks in WA should give priority to:

- Installation of a city-wide Level 3 (50kW) charging network in Perth (compliant with the Combo Type-2 standard for fast DC charging); and
- Implementation of a demonstration 'Electric Highway' project with Level 3 (50kW) charging stations along a route linking Perth to major regional centres (such as Bunbury, Busselton and Margaret River).

Standards

Another challenge encountered during the trial was the absence of standards covering EV recharging infrastructure, particular in relation to plugs and sockets for both cars and recharging stations. Competing standards exist in European, US and Japanese markets and no standards exist in Australia. This meant that the choice of recharging infrastructure for the trial took place in a standards vacuum and may ultimately be incompatible with future standards development. More recently, most of the major international EV industry players appear to have agreed on a new standard.

Agreement on national EV standards in Australia, preferably consistent with international standards, will remove a major barrier to the establishment of recharging networks in this country. Failure to prescribe a particular connector/inlet type could lead to the import of cars and charging stations which are incompatible with one another.

Electricity Network Implications

The introduction of large numbers of EVs and EV charging stations could have significant implications for the management of WA's electricity network. These implications could be positive or negative depending on the response adopted by the network managers. For example, under current arrangements EVs could exacerbate the costs involved with meeting peak network demands but these could be ameliorated, and potentially result in net system benefits, through the introduction of time-of-use tariffs coupled with intelligent ('smart') network protocols which enable better management of vehicle recharging.

It is important that additional research is undertaken to better understand the potential electricity system impacts of EVs and that energy utilities, government policy makers and EV industry participants work collaboratively to maximise the benefits from the introduction of this new transport technology.

Building on our Strengths

The WA EV Trial utilised and expanded the already considerable knowledge and expertise that exists in Western Australia in relation to electric vehicles. Opportunities for retaining and building on this knowledge for the future benefit of the WA community should be explored.

WA universities should consider developing a proposal to establish an EV Centre of Excellence to strengthen and expand WA's leading role in electric vehicle research.

1. Introduction

The WA Electric Vehicle Trial was a prime example of the private sector, State and local governments, as well as The University of Western Australia, an international leader in the field of electric vehicles, joining forces to achieve a common objective—testing the potential for widespread use of electric vehicles.

The trial was one of the first larger-scale tests of electric vehicles in Australia, with the goals of monitoring the performance, environmental benefits, policy, infrastructure and practical implications for the introduction of electric vehicles into fleets. Fleet operators are expected to be an early mass-adopter of electric vehicles.

On 1 December 2010 the WA Electric Vehicle Trial formally commenced with a phased introduction of 11 converted Ford Focuses into a number of leading State government, local government and commercial fleets. The Ford Focuses were especially converted in WA to run 100% on electricity and made use of a specially installed public fast-charge infrastructure (Level 2 AC).

This trial had to use locally converted Internal Combustion Engine (ICE) vehicles, as no OEM-produced EVs were available on the market. Further, the conversion was embraced as a way to gain technology transfer into a leading WA university as well as encourage local industrial development.

Participating organisations were:

- City of Mandurah
- City of Perth
- City of Swan
- CO2Smart (project coordination)
- Department of Environment and Conservation
- Department of Transport
- EV Works (vehicle conversions)
- Landcorp
- Main Roads
- RAC WA
- Telstra
- UWA REV (project coordination and charging infrastructure)
- Watercorp
- *West Australian* Newspapers.

Further details of all trial participants can be found in Appendix C.

Eleven dual stations and one single station (23 fast-recharge bays) were installed around Perth for use by the fleet participants. Of these, five stations (nine bays) were funded by EV Trial participants, six stations (12 outlets) were funded by the ARC Linkage project on EV Charging, and one station (two outlets) were funded by the City of Fremantle. The ongoing ARC Linkage consortium (2010–2014) includes UWA Engineering, UWA Business School, Murdoch University, WA Department of Transport, Australian Electric Vehicle Association (AEVA) and CO2Smart, plus station sponsor Galaxy Resources. All stations were wirelessly connected to a central server where data was collected.

A comprehensive UWA-led research project provided the insights needed to enable the wider introduction of electric vehicles.

1.1 Purpose of the Trial

The purpose of the WA Electric Vehicle Trial is as follows:

- Provide a public demonstration of the operating characteristics and environmental benefits of electric vehicles;
- Provide local industrial development opportunities in a range of areas, as well as gain technology transfer into WA universities for what will be a major new industry;
- Provide an opportunity for trial participants to assess the suitability of electric vehicles for their specific operational requirements;
- Identify and assess the technical, regulatory, policy and planning issues with the introduction of electric vehicles in Perth.

1.2 Why Promote Electric Vehicles?

Electric vehicles have significant potential benefits for the user and the broader community:

- Electric vehicles and electric motorbikes are considered to be zero-emission vehicles when they are charged with electricity from renewable sources, such as solar, wind, tidal or geothermal energy. Transport as a sector contributes a significant part of Australia's greenhouse gas emissions;
- Electric vehicles are ideal for city traffic and commuting in metropolitan areas, even when charged with electricity generated from coal or gas, as, unlike ICE vehicles, they produce no airborne particles which can present a health risk if concentrated in built up areas;

- Electric vehicles are almost silent (although a certain level of warning noise can be added for safety reasons) which helps reduce street noise levels;
- Electric vehicles have significantly less service requirements (as most service costs in conventional cars are associated with combustion engines). This will result in lower maintenance costs;
- Electric vehicles are significantly cheaper to run, as their electricity costs are only a fraction of the cost of petrol or diesel;
- Electric vehicles will reduce Australia's dependence on imported foreign oil, as electricity can be produced locally from traditional power stations and renewable energy sources.

1.3 Getting Started

The WA Electric Vehicle Trial was initially proposed in discussions in early 2009 between UWA, the Department of Transport and CO2Smart Pty Ltd.

In March 2010 the WA Electric Vehicle Trial was launched at UWA by The Hon. Simon O'Brien, MLC, Minister for Transport (2008–2010), in the presence of Donna Faragher, the Minister for Environment; and Professor Alan Robson, UWA's Vice-Chancellor.

In June 2010 a Prototype Agreement for conversion was signed between UWA, Department of Transport and local conversion company, EV Works. It was agreed that once the prototype vehicle conversion was accepted, a subsequent conversion for the trial would be carried out by EV Works. In November 2010 the prototype was completed; it passed all the tests and the two-year EV Trial operational phase was started on 1 December 2010.

The remaining vehicles were completed and commenced operation within the trial during 2011, as per separate Conversion Agreements signed between EV Works and the fleet participants.

In early 2009, UWA had commenced work on an ARC Linkage application to fund research costs related to the trial. The Department of Transport, Gull Petroleum and CO2Smart made a $50,000 research contribution as part of this request. Research partners were UWA Engineering, UWA Business School, Murdoch University and the Australian Electric Vehicle Association (AEVA) Perth Branch. Subsequently, ARC research funds of $280,000 were awarded to UWA to support EV charging and EV movement pattern research.

1.4 ARC Linkage Research

A key support to the WA Electric Vehicle Trial was the research carried out by two groups within UWA, funded by the ARC Linkage grant on 'Analysis and modeling of driving patterns for limited-range electric vehicles' (LP100100436).

The ARC Linkage funding enabled the following:

- Black-box tracking in all converted Ford Focuses, including remote data gathering of all journey and recharge events;
- Automatic data collection and wireless data transmission from all charging stations;
- Implementation of a central data server to aggregate vehicle and charging data at UWA;
- Focus group and household surveys;
- Twelve state-of-the-art recharge stations—available to fleet users and the general public;
- One PhD student located in UWA Engineering and one PhD student located in the UWA Business School;
- In-kind contributions, in the form of labour, from the WA Department of Transport, CO2Smart and AEVA;
- Other research costs arising.

1.5 Budget and Funding

The WA Electric Vehicle Trial is the result of cooperation between the private sector, State and local governments, as well as UWA. As a cooperative project, the basic principal was that each party paid their own expenses.

Below are the total costs expended over the two operating years of the WA Electric Vehicle Trial, which were in the order of one million dollars.

It is important to note that most items (vehicles and recharge stations) are capital items with a life well beyond the trial's two years. Indeed, most participants have leased their trial vehicle.

Item	Cost (ex GST)
Conversion Costs	$364,133[1]
Trial Set Up and Management	$297,000[2]
Donor Vehicles	$184,107[3]
Stations—Participants	$51,000[4]
Additional Ad Hoc Costs—Participants	$16,500[5]
TOTAL	$912,740

In addition, UWA/REV provided the trial participants with free automotive black boxes and telemetry data services free of charge, worth $11,000.

1 Conversion Costs: 11 conversions × average price conversion $33,103 (ex GST) (price as per base conversion agreement).
2 Trial Set Up Costs and Management Fee: $7,000 set up fee + $10,000 annual trial management fee per participant.
3 Donor Vehicles: 11 Ford Focuses x $16,737.
4 Additional Stations—Participants: Six additional stations purchased at average cost $8,500 per station, including installation.
5 Additional Ad Hoc Costs: Each participant incurred an average additional cost of $1,500 over the trial period—additional equipment for car or other items.

Converted Ford Focus fleet at EV Works

2. Vehicle Conversion

The decision to convert a standard petrol or diesel vehicle to electric for use in the WA Electric Vehicle Trial was made for several reasons:

- When the trial commenced there was no electric vehicle from a major manufacturer;
- A key goal of the trial was to provide 'local industrial development opportunities', awarding the conversion contract to a local engineering company served that objective;
- Executing a high-quality conversion, with the involvement of UWA Engineering, was an excellent way to gain technology transfer of emerging electric vehicle technology into a leading WA university;
- It allowed the trial to explore the potential of wider conversion programs aimed at accelerating the adoption of electric technology by converting larger numbers of fleet-based vehicles to electric.

Batteries under the vehicle

2.1 Cost Details for Donor Vehicle and Conversion

The main donor vehicle was a 2010 Ford Focus four-door sedan CL 2.0 manual (5 speed)*. The fleet purchase price of the donor vehicle was $16,737 (ex GST—the discounted price for large fleet purchases).

The conversion cost was $33,103 (ex GST) per vehicle. The following shows the cost breakdown:

Item	Cost (ex GST)
Batteries	$11,945
Components—Electric Drive	$10,325[1]
Components—Standard Vehicle	$1,705[2]
Labour	$7,091
Other (incl. insurance)	$2,037[3]
TOTAL	$33,103

* Ten vehicles are 5-speed manuals; one is an automatic.

1 Components—Electric Drive: Components required to provide electric drive, including electric motor, controller, battery-management software, on-board charger, range gauges and wiring.

2 Components—Standard Vehicle: Components to enable the standard vehicle functions to work as required, including brake booster, air-conditioning and heating unit.

3 Other: Other items including registration, engineer's and crash report, insurance contribution from participants to EV Works.

2.2 Cost Reduction

A cost reduction had been achieved by selling the new petrol motors and all petrol motor related car components, including fuel tank and exhaust system. Since the Ford Focus was a new car model in 2010, there was limited demand for these engines and parts, so a cost reduction of $1,000 per vehicle was achieved.

2.3 Cost Comparison 2010–2013

In order to see how component purchase prices have developed over the last three years, the following table compares conversion prices, not considering donor vehicle, cost reduction through selling of engine and unused parts, black-box instrumentation or items such as insurance and registration costs.

Item	2010 Cost ex GST	2013 Cost ex GST
Batteries	$11,945	$ 9,450
Components	$10,868	$10,707
Labour	$ 7,091	$ 8,195
TOTAL	$29,904	$28,352

Although battery costs have come down significantly, the costs of all other components has stayed about the same, while labour costs have gone up. So overall, there would be a small cost reduction in 2013 for performing the same conversion.

2.4 Key Specifications – Conversion Components

Batteries

Thundersky
45 lithium 160 Ah T/S LiFePO4 Cell 3.2V[1]
22kWh of energy

1 The RAC and City of Mandurah vehicles had an additional four cells fitted.

Electric Motor

Netgain[2]
Impulse 9", Series DC 30Kw continuous, 130Kw peak, 300Nm torque

2 The Water Corporation has a Kostov motor of similar specification.

Controller

Soliton[3]
1000A DC motor, air-cooled[4]

3 The Department of Transport, City of Perth and RAC have Zilla controllers.
4 The Zilla controller is a similar specification, but is water-cooled.

Battery Management

EV Power cell modules
Zeva EVMS

Charger

Protech
30A dual I/P

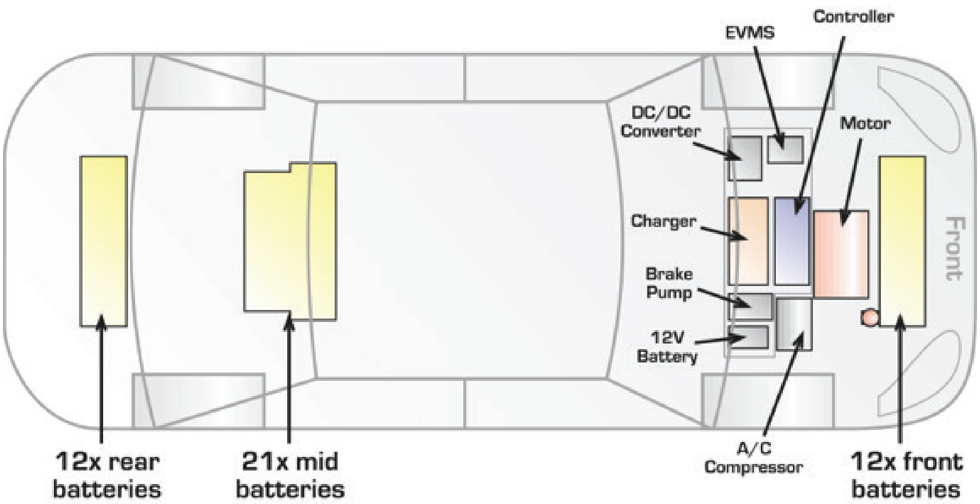


Figure 2: Component placement in converted Ford Focus (diagram by Ian Hooper, EV Works)

Further details on the conversion of the Ford Focus can be found in the research paper by Hooper and Bräunl: ‘Performing battery-electric conversions of passenger cars’, to be published in 2013.

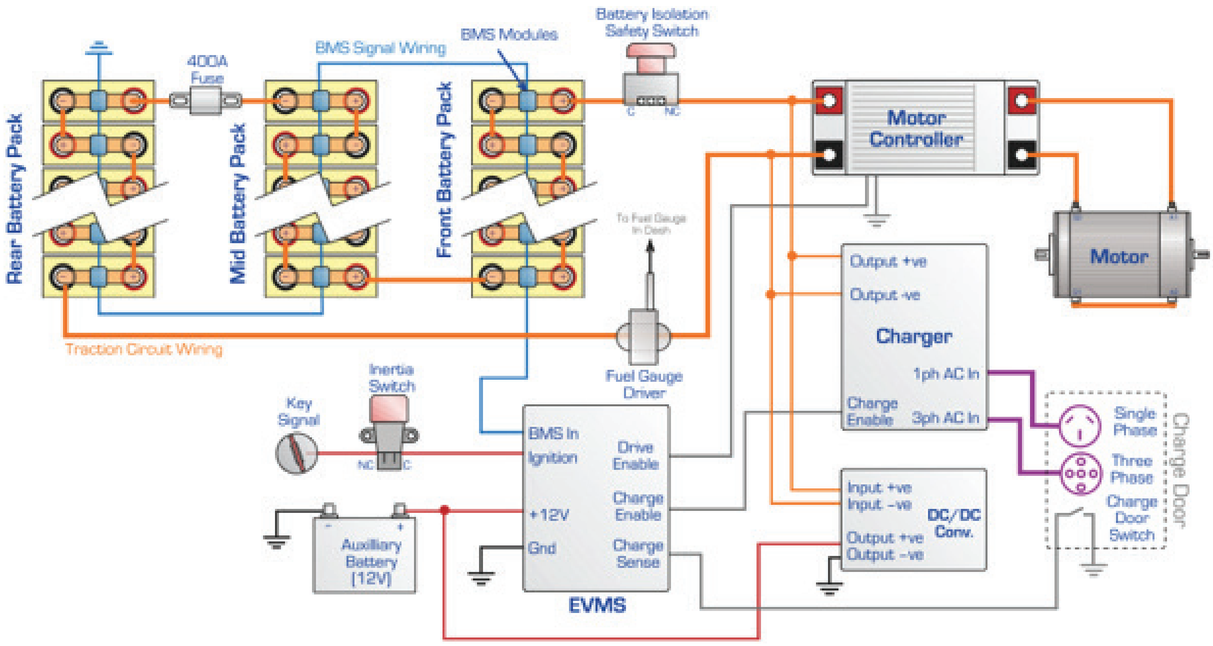


Figure 3: Schematic diagram of converted ≤ (diagram by Ian Hooper, EV Works)

2.5 Comparison of Ford Focus CL (Petrol) versus Converted Ford Focus

	Ford Focus CL (Petrol)	EV Ford Focus
Engine	2.0L petrol	NetGain Impulse 9
Power	107kW	39kW, up to 100kW short-time
Torque	185Nm	233Nm (at 1,000 A)
Batteries		45x160 Ah cells, 144V, 23kWh
Gearbox	5 speed	5 speed[1]
CO_2 Emissions	169g/km	zero *(if charged from renewable sources)*
Economy[2]	12.01c/km	2.24c/km (off-peak)
		3.98c/km (standard)
	ULP[3] $1.43 per l	Power[4] 24.89c/kWh vs 13.97c/kWh
	8.4 l per 100km	0.16kWh per km
Top Speed	200km/h	Tested up to 140km/h
Range	770km	Tested at 131km
Weight	1,280kg	1,390kg

1 Ten vehicles are 5-speed manuals; one is an automatic.
2 Note that these figures to not include the higher servicing costs of the petrol car as compared to the EV.
3 Fuel price according to Australian Competition & Consumer Commission 2012 http://www.accc.gov.au/content/index.phtml/itemId/1092497
4 Energy price according to Synergy tariffs A1 (Synergy Home Plan) vs. SM1 (Synergy Smart Power, 9pm – 7am), 2012 http://www.synergy.net.au/docs/Standard_Electricity_Prices_PDF.pdf

2.6 The Trial Experiences and Challenges

The prototype EV conversion of the 11 Ford Focuses (originally petrol-fuelled) was completed in late November 2010. At the same time, the first public EV recharging station in WA was installed in the RAC headquarter. The Trial Steering Committee used this special occasion to invite the Minister of Transport of Western Australia to attend the official handover of the prototype Electric Vehicle and the launch of the WA's first public EV recharging station. The media event gave the community an opportunity to recognise the potential role that EVs can play as an alternative to fossil-fuelled vehicles. EVs have the potential for reducing carbon emissions and air pollution compared to conventional vehicles, and they can improve energy security.

By the end of May 2011 all converted EVs were handed over to participants. Most EVs were designated as pool vehicles to test the usability of electric vehicles in company fleets and hence were available for business purposes. Two vehicles were used as take-home 'company cars' (one travelling 35,000km within the two years). The vehicles carried logos of the WA EV Trial and the participants' organisation logos, clearly identifying them as electric vehicles.

Throughout the trial, the 11 participating organisations encountered many different challenges, including regulatory barriers, infrastructure issues, as well as operational and technical difficulties. However, all organisations remained positive in regards to the EV trial and the experience. Several of them decided to keep the vehicle beyond the two-year trial duration; continued support is being provided by EV Works. The trial operational experience provided real-world learning about how users of EVs will need to change their expectations of the performance of EVs (specifically range and cost), if EVs and their usage are to become commonplace.

At beginning of the trial there were no OEM-built EVs available for purchase and very little media coverage on EVs in Australia. Therefore, the general public did not fully understand the characteristics of EVs, so the participating organisations used presentations and events to promote the EVs. To encourage a greater use of the EVs in their fleets, all participating organisations introduced EV induction programs inviting staff to undertake familiarisation training that covered converted EV operational peculiarities, including charging, starting, drive characteristics, range limitations and safety protocols. Within a few months, over 200 staff were trained. Each organisation allocated a special EV-only parking bay for their vehicles. Some installed a three-phase power outlet with a monitoring meter in the bay, while others funded fast recharging stations on their premises and in public areas.

Although these early trial experiences represent only a snapshot of the WA EV Trial experience, it is worthwhile to mention that the trial outcomes will assist government in identifying and addressing regulatory barriers, infrastructure issues and practical implications for the future use of electric vehicles in Western Australia.

Benefits	The trial provided staff with an appreciation of the unique issues associated with EVs, such as the need to plan routes and trips to accommodate range. It gave staff opportunities to understand that EVs are an alternative that can help lower dependence on oil and contribute to bettering the environment. Most organisations embrace the view that EVs may offer benefits to the road network. Widespread use would reduce traffic noise, additionally, EVs would improve the air quality on the road network due to no exhaust emissions. Organisations used the trial to promote environmentally friendly initiatives, and were keen to explore and support technology development and also consider investing in further EVs. Operational costs compared with standard petrol vehicles are advantageous.
Performance and Reliability	Some of the converted EVs retained the use of the clutch and gearbox and drove much like a normal manual Ford Focus. Ride was quiet and smooth and normally only two forward gears would be required to cover range of speeds. Generally the vehicles were reliable with the range (120km) and fuel-gauge indication of charge left adequate to alleviate concerns about running out of charge. Acceleration and ability to maintain speeds up to the legal max. of 110km/hr was good. It is a pleasant vehicle to drive and the performance of the EV is surprising with excellent acceleration and the quiet operation enjoyable. Anecdotal evidence suggests that, among those who regularly used the vehicle, satisfaction with it was high, with users finding it smooth, quiet and reliable. Performance was considered satisfactory and almost equivalent to the standard vehicle, the only significant differences being slower initial acceleration due to the automatic transmission being locked in third gear, and a reduced top speed (which was still higher than the State's legal maximum). The prototype vehicle for the trial had experienced a considerable number of breakdowns during the two-year trial period. Major difficulties encountered included controller failure (design faults), battery management system failure (software and manufacturing faults) and overheating (due to heat from the motor warming the engine bay, compounded by a lack of airflow surrounding the charger). As a result, the car was unavailable for staff use for a considerable period of time during the trial (over 100 working days). It was a positive experience for the organisation and the person driving the car as a company car. It proved to be fairly reliable; however, as a trial vehicle, there were a number of issues that needed to be resolved. As one of the vehicles was doing the most mileage, staff experienced a lot of the teething issues before any of the others. EV Works was always on-hand to sort out any issues expediently and professionally. In general the trial was a positive experience for most drivers, although a few intermittent issues with the converted vehicles had an impact on driver confidence and recruitment of new drivers. Some initial problems with reliability may also have discouraged some staff from choosing the electric vehicle instead of a conventional one. The quietness of the vehicle is disconcerting for some drivers and in fact may discourage its use.

Range	Given the fact that the converted EVs were guaranteed for at least 100–130kms, the biggest apprehension was 'range anxiety'. Informal feedback from EV users indicates that in general people are happy with the vehicle performance; however, the range is an obvious barrier to more widespread use. The limited range is the biggest obstacle and the few charging stations available in the metropolitan area results in employees choosing to leave the EV in the pool and instead select a standard vehicle. Staff also preferred standard petrol vehicles as they were more familiar with their driving characteristics. Range anxiety is believed to be one reason the vehicle was used less than expected. It was rare for it to be used to travel anywhere near that distance (90km for auto and 120km for manual). Many staff did not like the idea of having to work out the distance they needed to travel to ensure they had the ability to return without running out of battery power. The limited range and lengthy charging time, as with all current EVs, were challenging issues to face. However, participants got used to these issues and planned their travel accordingly.
Charging	Many employees did not like the idea of having to work out the distance they needed to travel to ensure they had the ability to return without running out of battery power. E.g., when a vehicle was used overnight and returned the following day, the lower charge level occasionally resulted in a booking for that day being cancelled due to a real or perceived lack of sufficient remaining charge. The negative aspect of the vehicle unfortunately is extreme with many employees commenting on the fiddly process of unplugging and charging the vehicle upon return. In relation to the charging station many would like to see a hard-wired plug to simplify the charging sequence. This would allow the driver to simply plug the lead into the EV and press 'lock' to start the charging process. The limited range and lengthy charging time, as with all current EVs, were challenging issues to face. Some of the initial problems were caused by battery management system failures, energy meter inaccuracies, and incorrect or incomplete charging by people not familiar with the EV.

2.7 Conclusions and Recommendations

The key conclusion from the above analysis is that it is possible to convert an ICE vehicle for use in fleets for a reasonable price, but that organisations should be aware of the need for extensive planning, prototype testing over a long period[1] and possible ongoing development.

It is further recommended that considerable technical and development support be put in place to support a conversion program.

1 The trial included the completion and testing of a prototype vehicle, but many issues only arose after delivery of multiple vehicles.

3. Converted Ford Focus Performance Testing

As per the Prototype Agreement, UWA undertook to complete performance testing of the converted Ford Focus, in particular to evidence the important range criteria.

UWA undertook the following performance tests:

- Dynamometer performance testing at Polytechnic West (Bräunl);
- Range testing at RAC DTEC Driving Centre (Pearce, Oakley, Bräunl);
- Range testing on Freeway and urban roads (Pearce, Oakley, Bräunl);
- Dynamometer range testing at Orbital Engines according to ADR 81/02 (Wäger, Bräunl).

3.1 Dynamometer Performance Testing at Polytechnic West

An automotive performance test conducted at Polytechnic West yielded the result of 44.5rwkW maximum power (wheel kilowatts) and a torque of close to 100Nm (see Figure 4).

The ZEVA motor controller originally used for the prototype conversion and in this test was subsequently considered to be of insufficient performance. The ZEVA motor controller was not used in any of the subsequent trial conversions and was replaced in the prototype car. Instead, the more powerful Soliton motor controller has since been used.

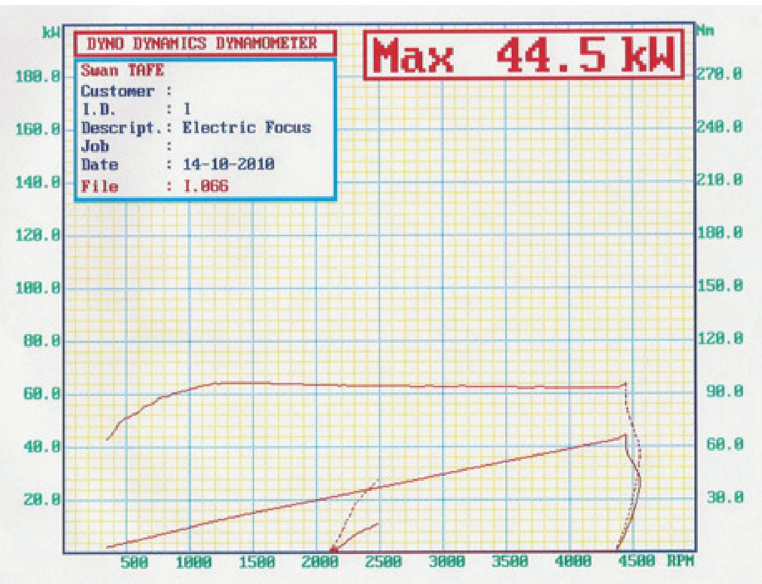


Figure 4: Dynamometer Performance curve for Focus with Zeva controller

Dynamometer testing of electric Focus prototype at Polytechnic

3.2 Range Testing at RAC DTEC Driving Centre

The first range test approach was a manual drive of the Australian Design Rules (ADR) 81/02 on a closed test circuit, trying to match the sequence as accurately as possibly. The car was started fully charged, driven a number of urban or extra-urban cycles, and was then recharged until full. This gave the desired energy consumption per ADR cycle. It should be noted, however, that this on-road test would give higher energy consumption figures than the idealised dynamometer testing, which is used to determine the fuel consumption for all new car models.

A computer program had been written to exactly time and advise the driver of each change in speed and a GPS black box recording unit was used to track the car on the closed circuit.

Unfortunately, it turned out that because of its sharp curves, the RAC DTEC test track was unsuitable to maintain the required speeds even for the urban cycle, let alone the higher speed extra-urban cycle. As such, we were not able to use this method for establishing the car's range.

3.3 Range Testing on Freeway and Urban Roads

A practical on-road test has been conducted by driving the EV Works Ford Focus in regular traffic on Perth roads. In accordance with ADR 82/02, a path of approximately one-third freeway and two-thirds urban driving was selected.

It should be noted that an on-road test in real traffic will give significantly lower range results than an ADR test on a closed test circuit, and even more so compared with a dynamometer ADR test. This should be taken into consideration when comparing the results with range measurements of other (commercial) EVs. On the other hand, an on-road test in real traffic will give much more realistic measurements than any of the other methods mentioned above.

Test Date:	9/9/2010, mid-day/early afternoon
Start Location:	RAC Driver Training and Education Centre, Perth Airport
Finish Location:	EV Works, Kewdale
Total Distance:	131km (odometer)

The on-road range test of the converted Ford Focus was conducted by a driver with no prior experience driving the EV Works Ford Focus. The radio, heater, air-conditioning and headlights were turned off for the entire trip with only the fan set to low. Car windows were left closed and a single person was in the car for the majority of the test. Gears 1, 2 and 3 were used, keeping the engine at between 3000–5000rpm where possible. Throughout the test only a slight decrease in power could be noticed, with the car remaining easily drivable for the entire distance. Driving data has been recorded through a GPS-based black box.

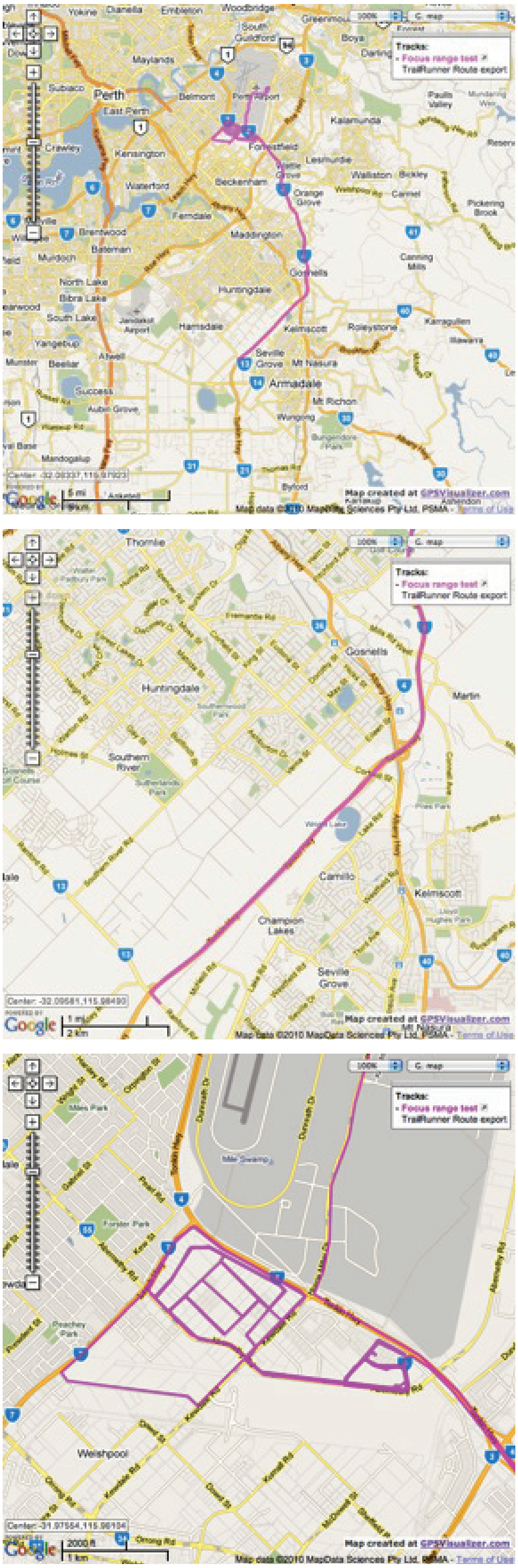


Figure 5: GPS tracks: total (top), highway (cente), urban driving (bottom) (Pearce, Bräunl)

RAC DTEC

The first component of the range test consisted of a circuit around the RAC track with two people in the car. Speeds of up to 85km/h were reached with an average speed of 50km/h over a distance of 2km.

Highway

The highway component of the test consisted of a short distance between the RAC Driving Centre and Tonkin Highway followed by a drive along Tonkin Highway to the Ranford Road intersection, then back along Tonkin Highway to Kewdale. This component had a single person in the car. Speeds of up to 100km/h were achieved with an average speed of 85km/h over a distance of 46km.

Urban

The urban component of the test was made up of stop-start driving through the streets of Kewdale. Most of this component consisted of accelerating from 0 to 50–60km/h. Initially the blocks to the west were circled a number of times, with the blocks to the east, nearer EV Works, driven for the final 30km. Included in this section were two brief stops at EV Works to measure battery conditions. For the final 15km two people were in the car. Speeds of up to 70km/h were reached with an average speed of 30km/h over a distance of 83km.

In summary, the EV Works' Ford Focus EV conversion achieved a range of 131km on a single charge. This was established through on-road testing of roughly one-third highway and two-thirds urban driving in normal traffic conditions on Perth roads.

3.4 Dynamometer Range Testing at Orbital Engines

All dynamometer range testing was conducted at the facilities of Orbital Engines in Balcatta, which provided calibrated test equipment and instrumentation—in particular, a chassis dynamometer with the capability of road load simulation. The test facilities fulfil the requirements for testing motor vehicles according to international standards. The facilities were adapted for electric vehicle testing by installing additional instrumentation equipment as described below.

Dynamometer range testing of electric Focus at Orbital Engines (Wäger)

The computer of the chassis dynamometer contained pre-programmed driving cycles that represent internationally recognised driving cycles. In addition to the existing dynamometer instrumentation system, a custom-made data acquisition system was designed, built and programmed to log additional data, including current, voltage, motor temperature, and brake pedal pressure.

The test method for the energy consumption and range tests was conducted according the United Nations ECE Regulations R101 standard[2]. For the test drive, the vehicle was required to be driven with all auxiliary devices such as heaters or air-conditioner switched off. The test drive required two consecutive New European Drive Cycles (NEDC) with a maximum deviation of +/- 2km/h in the speed profile. After the test the vehicle was required to be recharged and the charge energy E to be measured.

2 United Nations, *Regulation No. 101* 2005 [cited 02/02/2012], available from http://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/r101r2e.pdf

Manual Ford Focus Energy Consumption and Range Test

For the manual converted Ford Focus the energy consumption was measured at 197Wh/km without charging losses and at 242Wh/km including charging losses. The significant difference shows the effect of only measuring energy used by the car versus energy required to recharge the car.

A full NEDC range test was conducted over five hours and 15 minutes of driving. In addition, during the continuous driving, the individual energy consumptions for each driving cycle were recorded. Figure 6 shows the individual energy consumptions over the whole range test. The achieved distance was 143km.

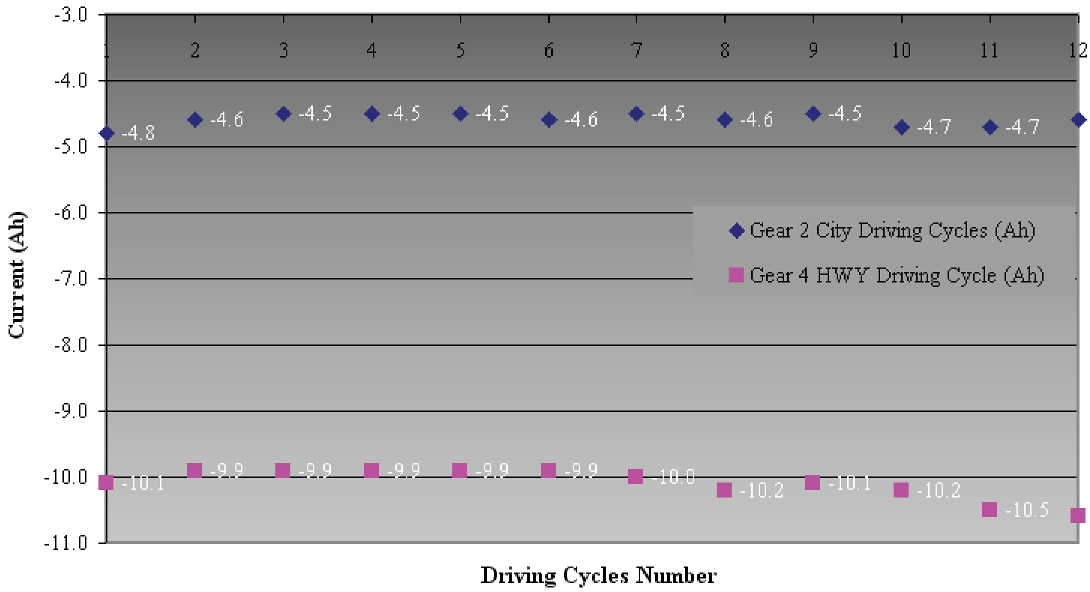


Figure 6: Energy consumption in Ah for each individual drive cycles component for converted manual Ford Focus (Wäger)

Automatic Ford Focus Energy Consumption and Range Test

The energy consumption for the converted automatic Ford Focus was 275Wh/km without charging losses and 338Wh/km including charging losses. A full range test conducted over four hours and 45 minutes of driving achieved a distance of 94.1km.

The range and efficiency of the automatic vehicle was expected to be lower than that of the manual Focus. However, the large discrepancy in the two results comes from the fact that, because of gear shifting problems with the automatic gearbox, only gear 3 is being used when driving in the D position. This is a known issue and is currently being further investigated by EV Works in order to improve the efficiency and the comfort of using the automatic transmission.

Further details on the EV performance testing can be found in the publication: Wäger, McHenry, Whale, Bräunl, *Testing energy efficiency and driving range of electric vehicles in relation to gear selection*, to be published 2013.

4. EV Charging Infrastructure and Standards

Before selecting the appropriate charging infrastructure for the WA EV Trial, we had to look at existing international standards. The following standards sections summarise the technology and terminology of EV charging standards IEC 62196, IEC 61851 and IEC15118.

4.1 Charging Level Standards

The charging level describes the power level of a charging outlet:

Level 1: Home charging, max. 2.4kW in Australia. For a 23kWh EV-Works Ford Focus vehicle, this means about 10 hours charging from empty to full.

Level 2: Fast AC charging, either 7kW (32A single-phase) or 21kW (three-phase).
For the 7kW stations in the WA trial, this means about three hours charging from empty to full.

Level 3: Fast DC charging, up to 50kW.
This means 20 minutes charging from empty to 80% full (in DC charging, the last 20% takes a very long time, so DC charging is usually measured up to 80%).

Elektrobay dual-headed station at The West Australian *newspaper*

4.2 Charging Mode Standards

The charging mode describes the safety communication protocol between the EV and charging station. These standards are identical worldwide.

Mode 1: Home charging from a standard power outlet with a simple extension cord, without any safety measures. Although this is what many (private) EV conversions use today, Mode 1 has been outlawed in several countries as it does not provide basic safety features (e.g. over-current or over-temperature shutdown, although many homes have circuit breakers and RCDs, which provide a level of protection).

Mode 2: Home charging from a standard power outlet, but with a special in-cable EVSE (EV Supply Equipment), aka 'occasional use cable', usually supplied with an EV from the manufacturer. This cable provides:

- in-cable RCD;
- over-current protection;
- over-temperature protection;
- protective earth detection (from wall socket).

Power will only follow to the vehicle if the EVSE has detected that:

- protective earth is valid;
- no error condition exists (over-current, over-temperature, etc.);
- vehicle has been plugged in (detected via *pilot* data line);
- vehicle has requested power (detected via *pilot* data line, usually linked to the car's central locking mechanism).

Mode 2 cables provide a moderate level of safety and are the minimum standard today for charging an EV (already a number of incorrectly wired home/business power outlets have been found by using Mode 2 cables). However, most automotive OEMs accept 'occasional use cables', as the name suggests, only for occasional use, (e.g. when visiting a friend's house) and insist on installing a proper Mode 3 home charging station ('wall box') in the EV owner's garage for continuous use. Some car manufacturers even make the customer sign an agreement confirming installation of a wall box at the time of ordering an EV.

Mode 2 cable for home charging use

Mode 3: Wired-in AC charging station, either in public places or at home, allowing a higher power level than Mode 2. The safety protocol is identical to Mode 2.

UWA/REV Getz charging at EMC Solar station, West Perth

Mode 4: Wired-in DC charging station, either in public places or at home. In DC charging stations, the charger is part of the charging station, not part of the car.

4.3 Connector Type Standards

The type of charging station (or vehicle inlet) describes the actual connector being used. Unfortunately, there are several different world standards and Australia at the time of publication has not yet adopted one of them. The terminology is:

- socket: on charging station
- plug: on cable towards charging station
- inlet: on EV
- connector: on cable towards EV.

Type 1: The connector/inlet pair used in the US and Japan, aka 'SAE 1772' after the corresponding US standard. As the US and Japan do not have a three-phase power grid, this standard is limited to single-phase and a lower power output than Type 2. Also note that for Type 1, the charging cable is permanently fixed to the charging station.

Type 2: The connector/inlet and plug/socket pairs used in Europe, aka 'Mennekes' after the company first proposing this standard. Type 2 supports both single-phase and three-phase charging at higher power rates than Type 1. For this reason it is expected that Australia will eventually adopt the Type 2 charging standard.

For Type 2 charging stations, the charging cable is detachable, so a Type 2 station can charge both Type 1 and Type 2 cars with appropriate charging cables. A Type 1 charging station, on the other hand, can only charge Type 1 cars as the cable is fixed to the station and the usage of adapters is prohibited.

Type 2 (top) and Type 1 (bottom) charging cables

Type 3: France and Italy are campaigning for a different connector/inlet and plug/socket solution, which has 'shuttered contacts', i.e. contacts that are physically covered by a non-conductive cover when not in use. Proponents of Type 1 or Type 2 (both non-shuttered) point out that these are safe without shutters, as current can only flow when an EV connection has been detected by the station.

China: One notable exception because of its large market share is China. While the Type 2 standard continued to evolve and underwent a number of changes in the last few years (Generation 2 at the moment), China decided to freeze an earlier and now incompatible version of the Type 2 standard as the Chinese standard.

It is expected that Type 2 will be the standard in all countries with three-phase power grids, while all countries without them will adopt Type 1. Type 3 is unlikely to be adopted outside France and Italy. The fact that Standards Australia has not made a recommendation for either Type 1 or Type 2 is not ideal, as in the mean time stations and vehicles of either type are being imported into the country, creating a legacy problem.

All charging stations installed at the WA Electric Vehicle Trial and the EV Charging ARC Linkage Project are Level 2, Mode 3, Type 2 stations. They can AC-fast-charge at 7kW (provided the EV has an AC fast charger on board), and can charge either Type 2 cars (all UWA-built cars and EV-Works Ford Focuses), as well as Type 1 cars (including the currently imported Mitsubishi i-MiEV and Nissan Leaf).

4.4 DC Fast-Charging Standards

While the first DC charging standard was the Japanese CHAdeMO, the leading eight automotive OEMs have now agreed to support the new Combo charging standard, which combines AC and DC charging in a single connector/inlet. CHAdeMO, in contrast, is a DC-only standard. So cars with CHAdeMO (such as Mitsubishi i-MiEV and Nissan Leaf) always require two separate vehicle inlets, one for AC and one for DC (in many cases even under separate hatches), which makes the car more expensive than necessary. As Combo is incompatible with CHAdeMO, it is expected that CHAdeMO will be replaced by the Combo charging standard in all countries (including the US) except Japan.

Since Combo inlets are compatible with AC-only charging (e.g. at an AC charging station or by using the AC 'occasional use cable'), the distinction between Type 1 and Type 2 also remains for Combo stations. All DC charging is Level 3 fast charging, however, there are different power levels available from different charging station manufacturers. These range currently from 20kW to 50kW systems.

Combo Type 2 connector for DC fast charging

4.5 Trial Charging Infrastructure

As Level 3 charging was not an option for the converted EVs, we selected Level 2 charging based on IEC 62196 with socket type 2 ('Mennekes') as the charging standard for the trial. Charging stations with Type 2 sockets have two advantages over Type 1: They can use three-phase charging where available to achieve shorter charging times and they can charge EVs with either Type 1 or Type 2 inlets. Both are not possible with Type 1 station sockets.

The complete EV charging infrastructure used for the trial consisted of the following:

- charging network of 12 stations with a total of 23 outlets (Level 2 fast AC);
- industrial three-phase outlets at some organisations' premises;
- standard 10A single-phase domestic outlets.

Six of the 12 EV charging stations were provided by the UWA/REV-led ARC Linkage Project *Analysis and modeling of driving patterns for limited-range electric vehicles* (LP100100436) with partners UWA Engineering, UWA Business School, Murdoch University, WA Department of Transport, Australian Electric Vehicle Association, Gull Petroleum and CO2Smart. The ARC Linkage project took care of maintaining and monitoring all charging stations; conducting data collection from EV black boxes; and developing a web portal with driving/charging information as well as statistical evaluations and billing systems.

DOT three-phase outlets

Standard 10A Single-Phase Domestic Outlets

Capacity and Charge Time

Domestic 3-pin charge: 240V, max. 10A (2.4kW), but limited to 8A (1.92kW) for safety reasons

Capacity of converted Ford Focus battery pack: 23 kWh

Time to charge converted Ford Focus: 23kWh / 1.92kW = 12 hours (not considering charger losses)

Locations

All homes

Most offices (access to car park an issue)

Industrial Three-Phase Outlets

Capacity and Charge Time

Industrial three-phase charge: 240/415V, max 20A (14kW), limited to 5.4kW by in-car charger

Capacity of converted Ford Focus battery pack: 23kWh

Time to charge converted Ford Focus: 23kWh / 5.4kW = 4.25 hours (not considering charger losses)

Locations

Two participants had access to three-phase outlets—Department of Transport and RAC

Fast Charge Network (Level 2)

Capacity and Charge Time

Fast charge capacity (level 2): 240V x 32A = 7.68 kW limited to 5.4kW by in-car charger

Capacity of converted Ford Focus battery pack = 23kWh

Time to charge converted Ford Focus = 23kWh / 5.4kW = 4.25 hours (not considering charger losses)

Using a higher current in-car charger, the charging time could be reduced on the same charging stations to: 23kWh / 7.68kW = 3 hours (not considering charger losses)

Fast Charge Network Selection Process

Three station manufacturers were invited to submit proposals for the provision of Level 2 fast-charge stations for the trial. A number of criteria were established for the eventual selection of a vendor:

- Level 2 fast charging;
- based on emerging international recharge standards;
- data connection from stations to UWA for data gathering;
- UWA Engineering to have access to software code and may develop and operate own applications to operate with station network.

Elektromotive Ltd (UK) was selected to supply charging stations for this trial as well as for the ARC Linkage project, as it was the only provider that could meet all criteria.

4.6 Charging Station Specifications

The dominant station used in the trial was an Elektromotive Elektrobay Dual Outlet Station. The specifications are summarised below (see also Trial Station Specifications).

Capacity Options:	2 x 3kW single phase 2 x 7kW single phase (selected for WA trial) 2 x 21kW three-phase
Standard Options:	IEC 62196-2, Type 2 IEC 60309 (non-automotive)
Mounting Options:	Wall Mount Ground Mount
Dimensions/Weight:	1240mm high 305mm wide 20kg
Networking Options:	GSM Wireless
Software:	EB Connect, allowing controlled access via chip key, energy metering, per driver and station charge event and energy tracking via remote data connection
Display:	Static backlit display

Prior to the arrival of the Elektrobay Dual Outlet Station, two Elektrobay Single Outlet Stations were purchased with non-standard connectors as an interim solution. These stations have now been upgraded to IEC 62196-2, Type 2 (‘Mennekes’).

4.7 Charging Station Locations

- RAC—the first publicly available Level 2 charging station in Australia was installed at the RAC West Perth building on 832 Wellington Street; dual station, two reserved EV bays;
- RAC DTEC Driving Centre—located in the visitor car park at Grogan Road, Perth Airport; single station;
- *The West Australian*—located in the car park at Newspaper House, 50 Hasler Road, Osborne Park; dual station, one reserved bay;
- City of Swan—located at the Middle Swan depot, Bishop Road;
- MainRoads WA—located at the car park of the Don Aitken Centre, Waterloo Crescent, East Perth;
- Water Corporation—located in the car park below the Head Office on 629 Newcastle Street, Leederville;
- The University of Western Australia—located at the School of Computer Science and Software Engineering, UWA Crawley Campus;
- Murdoch University—located at the CREST building, South Street, Murdoch Campus;
- Department of Transport—located at the Public Transport Centre on Summers Street, East Perth;
- City of Fremantle (non-participant station)—located in Queensgate car park; two parking bays allocated for exclusive use by plug-in EVs;
- EMC Solar—located in the company car park at 18 Colin Street, West Perth. This station is directly connected to a solar PV system with sun tracker;
- City of Subiaco—located in the Rokeby Road public car park.

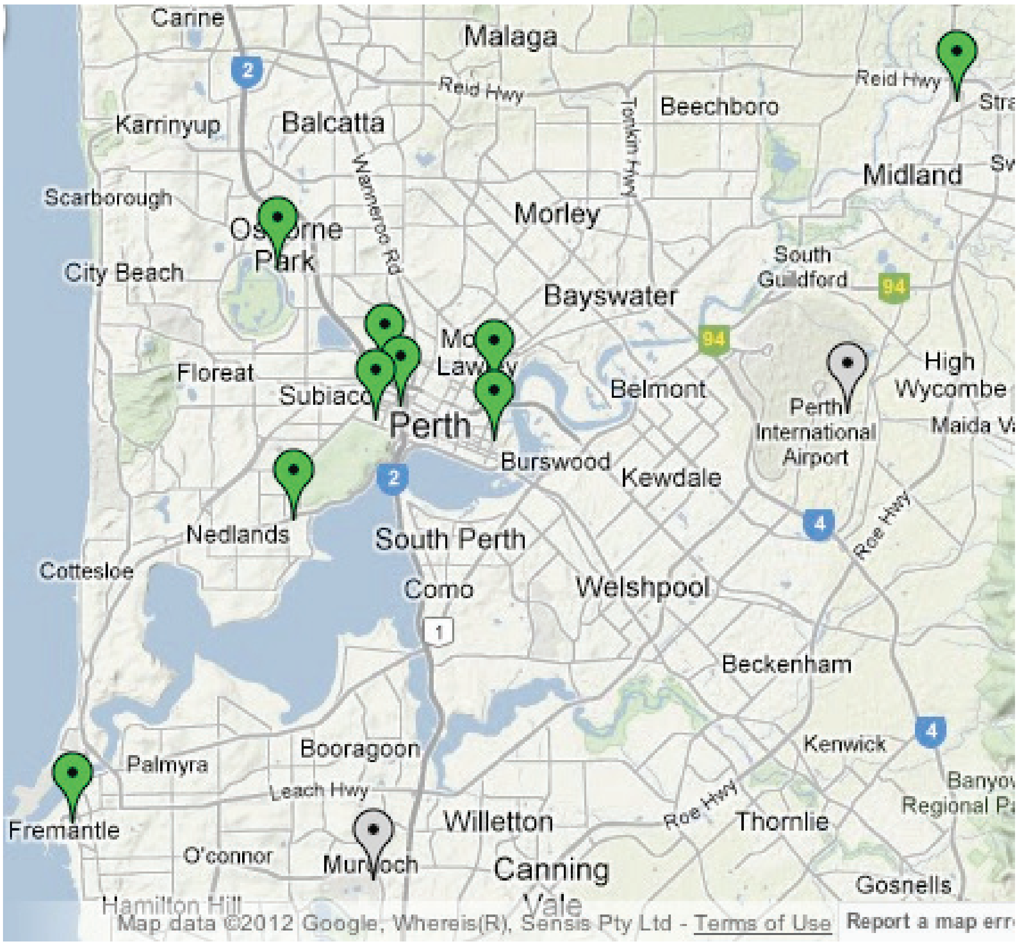


Figure 7: Map of EV charging station locations

The stations at RAC/DTEC, *The West Australian*, City of Swan, Main Roads, Water Corporation and City of Fremantle have been funded directly from these organisations. The stations at UWA, Murdoch University, East Perth Public Transport Centre, EMC Solar, RAC/West Perth and City of Subiaco have been funded through the ARC Linkage project.

4.8 Technical Issues and Installation Challenges

There have been a number of technical issues with the Elektrobay stations which needed to be addressed during the trial:

- inconsistent recognition of some RFID tags;
- inconsistent data connection;
- charge stopping before battery full;
- total failure of one station;
- cable release after end of charge.

A network software (EB Connect) upgrade addressed the issues around inconsistency. One failed station was returned to Elektromotive for repairs.

Station Installation Challenges

The recharge stations used in the trial were the very first recharge stations installed in Western Australia. This meant the trial was faced with a lack of trained and experienced installers. Due to this, it was a slow and gradual process to identify locations, plan for best installation approach and then ensuring the right mix of skills were present on the day of installation. Common challenges faced were:

- finding a location close enough to car bay, but also close enough to a power source;
- ensuring enough (excess) power was available at location to support station;
- digging through hard surfaces;
- routing cables via walls or along roofs.

5. Research

The research team accompanying this EV Trial was headed by Professor Thomas Bräunl from The University of Western Australia and comprised members of UWA's School of Electrical, Electronic and Computer Engineering as well as the UWA Business School. All research team members are co-authors of this Chapter.

UWA Engineering Research Team

Prof. Thomas Bräunl
Engineering Team Leader

John Pearce
Computer Scientist, implementing the first version of vehicle tracker monitoring software and smartphone app, as well as conducting the on-road range tests

Ian Hooper
Mechatronics Engineer, conducting EV drive system studies at UWA, while performing EV conversions together with Robert Mason in their roles as directors of EV Works

Stuart Speidel
Software Engineer, implementing the second version of the vehicle tracker, as well as the charging station monitoring system and statistical evaluation and billing system

Guido Wäger
Renewable Energy Engineer, in cooperation with Murdoch University, conducting the EV dynamometer range tests according to the Australian design rules at Orbital Engines facilities

UWA Business School Research Team

Prof. John Taplin
Business Team Leader

Doina Olaru
Transport Engineer, planning, preparation and supervision of the EV driver survey and EV household survey

Fakhra Jabeen
Computer Scientist, conducting both surveys, as well as performing statistical analyses of both surveys

5.1 Analysis of EV Driving and Charging Behaviour

Data collection was done from two sides: GSM-based GPS-loggers (black boxes) in the cars, and GSM-based data loggers in the charging stations. The vehicle black boxes logged:

- GPS position (and speed derived of that);
- ignition status;
- battery state of charge (analog input from energy gauge);
- charging mode;
- heater status (on/off);
- air-conditioner status (on/off);
- headlight status (on/off).

The available output of the black boxes (e.g. for vehicle immobilisation) was not used because of safety concerns.

The reason for logging heater, air-conditioning and headlights status in addition to the other obvious parameters is that these do represent significant energy consumption and their usage will therefore have a significant effect on vehicle range and recharge behaviour.

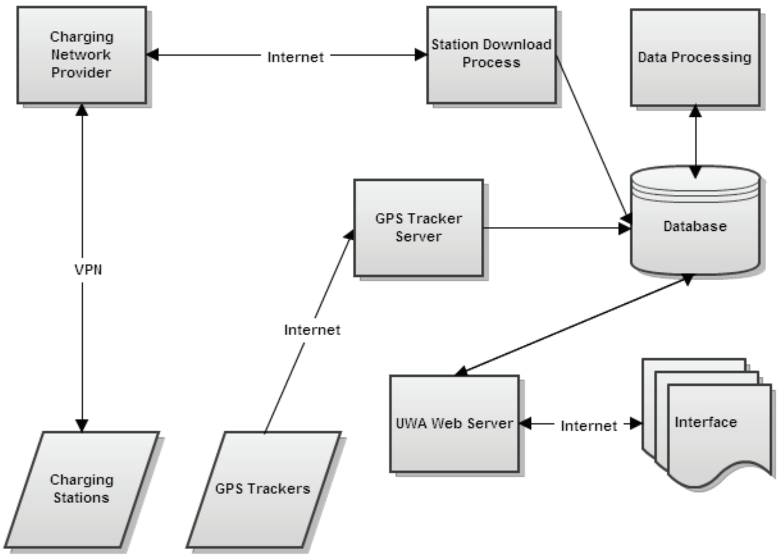


Figure 8: System Diagram (Speidel, Bräunl)

All vehicle data was uploaded onto the UWA server either once every minute or once every ten meters (see Figure 8). For the length of the trial (ending 2012-10-02), 5,284,079 data rows were inserted into the database from the 11 EVs. The data was processed using a batch script and displayed to the trial participants via a web interface that displayed telemetry data, driving and charging statistical heat maps for each and all of the vehicles. The data processing generated journey, charge and parking events. Journeys had a starting time and location, ending time and location, total distance travelled, air-conditioning usage time, heater usage time, headlight usage time and the estimated battery. Journeys were started when the ignition was detected as being on and ended when the ignition was turned off.

Charges had a starting time, ending time, location, distance travelled (between charges), energy used (kWh), time charging and time maintaining charge. The charge events were generated starting when the vehicle had its charging hatch opened (the door covering the charging plugs) and ended when the charging hatch was closed. When an EV was in a location, and did not have its ignition on, a parking event was created from the last journey to the next journey. The parking events were then compared to charging events and if a vehicle charged while parking, the charge was linked to the parking event.

The GPS tracking units log only when they have a GPS fix. A GPS fix is normally obtained when the antenna has an unobstructed view of the sky (Kaplan and Hegarty 2005[3]). Throughout the trial, vehicles were parked on occasions within heavy indoor areas, such as parking structures or underground, and were charged without an active GPS fix. When vehicles had a gap in their data logging of more than 15 minutes and had a battery level increase of more than 10%, a charge event was created for the duration of the data loss. In those cases, the charge event was created entirely by estimation, using the time the GPS signal was lost to the time the GPS was re-established as the start and end times. If a vehicle lost GPS fix while driving, the distance between the point before GPS loss and the point where the GPS was re-established and taken to be the distance travelled during the period.

Data was collected over the two-year trial period. However, there was not a perfect coverage for all cars. Data logging was operational only in a couple of cars during the first few months of the trial and had occasional outages across the EV trial fleet. Consistent data login happened for most cars from September 2009 to November 2012. This is demonstrated in Figure 9, which displays the total number of logging events per month as well as per car and month.

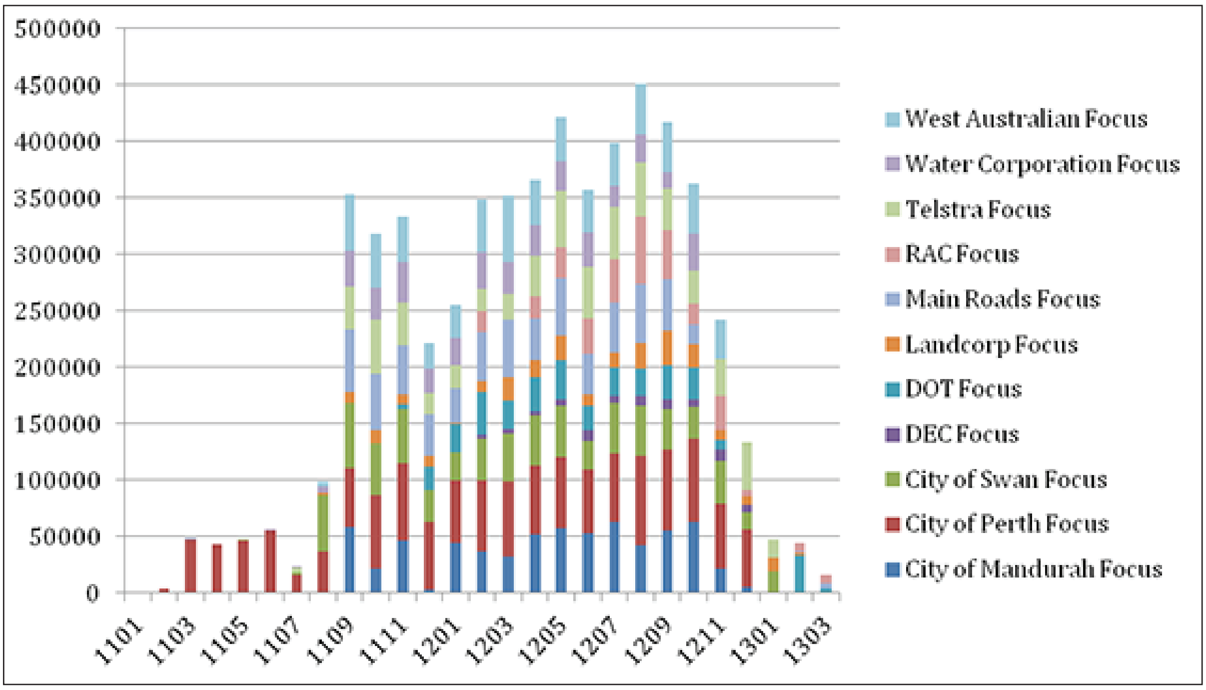


Figure 9: Number of data logging events per month and car (Speidel, Bräunl)

3 Kaplan, E. and C. Hegarty (2005). *Understanding GPS Principles and Applications: Principles and Applications.* Norwood, Artech House Books.

5.2 EV Charging

A total of 23 charging outlets were installed in the form of 11 dual-outlet charging stations and one single-outlet charging station. Each outlet logged the following data items:

- station status (charging or idle);
- customer ID (from RFID tag);
- start date/time of charge;
- end date/time of charge;
- amount of energy used in kWh for potential customer billing.

Charging station data was downloaded via GSM to an external server every four hours. The external server was checked every thirty minutes using a batch process and new charge events were downloaded to the server at UWA.

When an EV was recharged at a charging station, the exact amount of electricity used (kWh) was recorded from the charging station's meter. If an EV charged elsewhere (e.g. at home or at a business), the amount of electricity used was approximated from the battery level of the vehicle, the recharging time, the distance the vehicle travelled before charging, and the level of power supplied. Each vehicle had a 30A charger installed, and the measured power loss from the power socket to the battery pack was 17%.

When the vehicle battery is full, the charger switches to a 'maintain charge' mode, which maintains the batteries at full charge. The trial EV chargers use on average 0.12kW to maintain the charge level. Once the battery charging level is estimated, the vehicle is assumed to be drawing power at that level for the remaining time that it is plugged in. Figure 10 shows the energy drawn from a charging station with the energy meter readings (blue) and the estimated charging kWh (red). Using this information, the vehicle charging profile can be estimated.

Seventy-three percent (2256 of 3096) of the recorded EV recharging events over the length of the trial occurred at 32 locations, with a determined maximum power of 2.4kW, 3.6kW or 7.2kW (10, 15 and 30 Amp sockets/stations at 240V), the latter information being obtained through site visits. The vehicles, when charging at 10 or 15 amp sockets, will draw 1.8kW, and at 30 amp sockets and charging stations will draw at 4.8kW. The vehicles do not draw the full 2.4kW at 10 Amp outlets for additional safety, related to results from audits showing that 20% of Australian households have serious electrical safety faults (MEA 2011[4]).

4 MEA (2011). Switch Thinking – Preventing Electrical Deaths in Australian Homes. Technical Report, Master Electricians Australia. http://issuu.com/master_electricians/docs/switch_thinking_report.

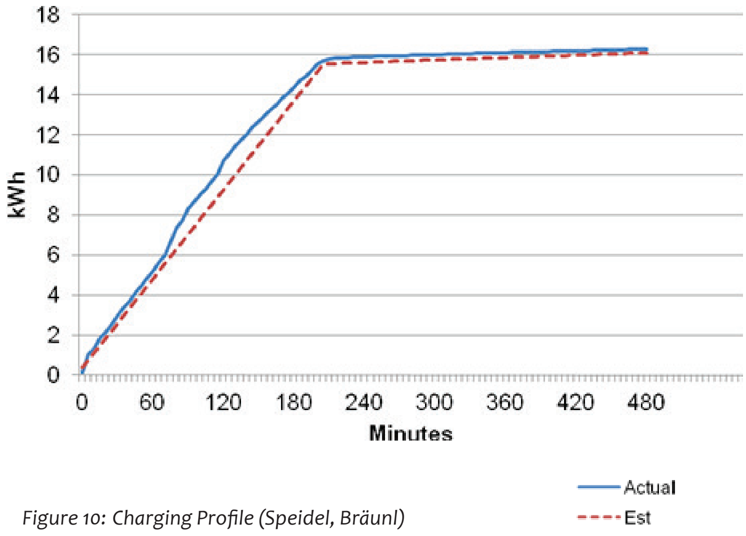


Figure 10: Charging Profile (Speidel, Bräunl)

Each location was also categorised as either:

- home, at a EV user's residence;
- business, at places of business such as work, but not at a charging station;
- stations, at one of the installed charging stations.

If a vehicle was recharged within a certain radius of a known charging station location, it was assumed to be charging at that location. The radius for each charging location was determined by the accuracy of the average GPS fix at that location. The other 27% of charging locations were labelled as unknown and were always assumed to be 2.4kW.

EV Driver Influencers

The trial's electric vehicle drivers reported being influenced by the following factors, which may effect the statistical results:

- All EVs were company fleet vehicles and some organisations had restrictions on their use, such as not taking the vehicle home;
- Some EVs had dedicated drivers, whilst others were shared pool vehicles;
- Most EV drivers were not reimbursed for electricity usage in their homes;
- Four organisations had a charging station installed on their premises, specifically for their vehicle.

5.3 Driving Statistics

In 2010 the average distance a passenger vehicle travelled for business in Western Australia was 11,700km per year or 32km per day (ABS 2011[5]). The average distance the EVs travelled over the length of the trial was 22.3km per day, about two-thirds of *The West Australian's* average (see Table 5.1). Over the time period, the EVs averaged 2.6 journeys per day.

The estimated annual energy usage for the EVs was on average 1.55MWh, driving 22.30km, to a maximum of 3.55MWh driving 50.86km. *The West Australian* business average of 32km per day equates to 2.23MWh per annum. On average the air-conditioner was on 33%, the lights 16% and the heater 3% of the time while driving.

Table 5.1: EV journeys (accumulated over trial period years)

Vehicle	Number of Journeys	Average Journey Time (mins)	Average Journey Distance (km)	Daily Distance (km)	Percentage Air con	Percentage Heat	Percentage Lights
City of Mandurah Focus	250	12.22	5.43	8.01	9%	0%	N/A†
City of Perth Focus	2180	21.31	12.23	50.86	63%	4%	39%
City of Swan Focus	1151	11.00	5.29	15.64	54%	1%	12%
DEC Focus	201	18.43	7.14	26.61	13%	0%	12%
DoT Focus	430	19.63	9.59	13.82	N/A†	N/A†	N/A†
Landcorp Focus	462	19.20	9.22	29.02	N/A†	N/A†	15%
Main Roads Focus	1088	15.05	7.86	14.90	22%	5%	17%
RAC Focus	782	14.32	5.36	29.56	79%	4%	6%
Telstra Focus	856	16.39	7.35	18.69	29%	2%	N/A†
Water Corporation Focus	339	22.16	13.46	11.90	26%	11%	12%
West Australian Focus	1121	13.56	7.77	21.71	19%	0%	15%
Average	805	16.65	8.60	22.30	41%	3%	23%

† Note that for some cars not all events were properly recorded.

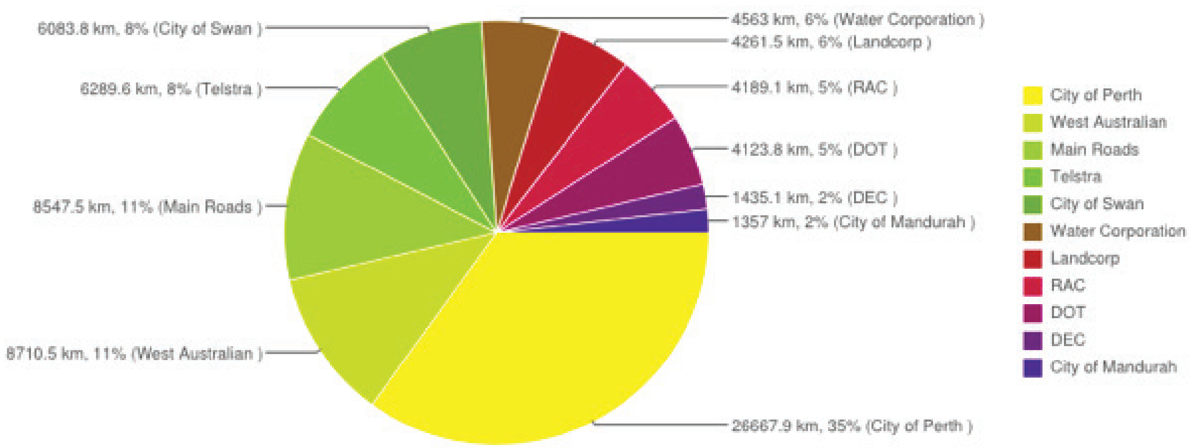


Figure 11: Total number of km logged per EV (Speidel, Bräunl)

5 ABS (2011). Survey of Motor Vehicle Use. Australian Bureau of Statistics.

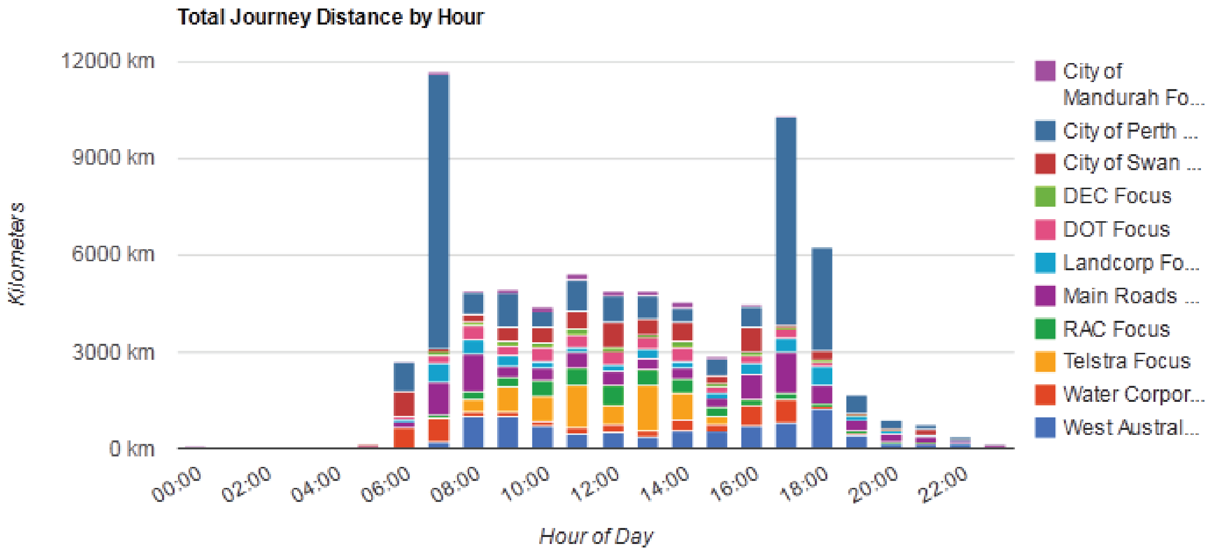


Figure 12: EV travel distance by time of day for each of the 11 vehicles (Speidel, Bräunl)

Figure 12 shows the distance travelled by the hour of day, with 91.31% of the total distance travelled occurring between 7am and 7pm. The peaks of distance travelled are at 7am and 5pm where vehicle 10 (which contributed 35% of the total km driven) arrives at and leaves work. Just under half (48.42%) of the total distance travelled is undertaken between the hours of 9am and 5pm. The results shown in Figure 12 are similar to the number of motorised trips by time of day in Melbourne reported in CSIRO (2011[6]) The vehicles travelled 90.93% of their total distance on weekdays (see Figure 13), with most vehicles not being used on weekends.

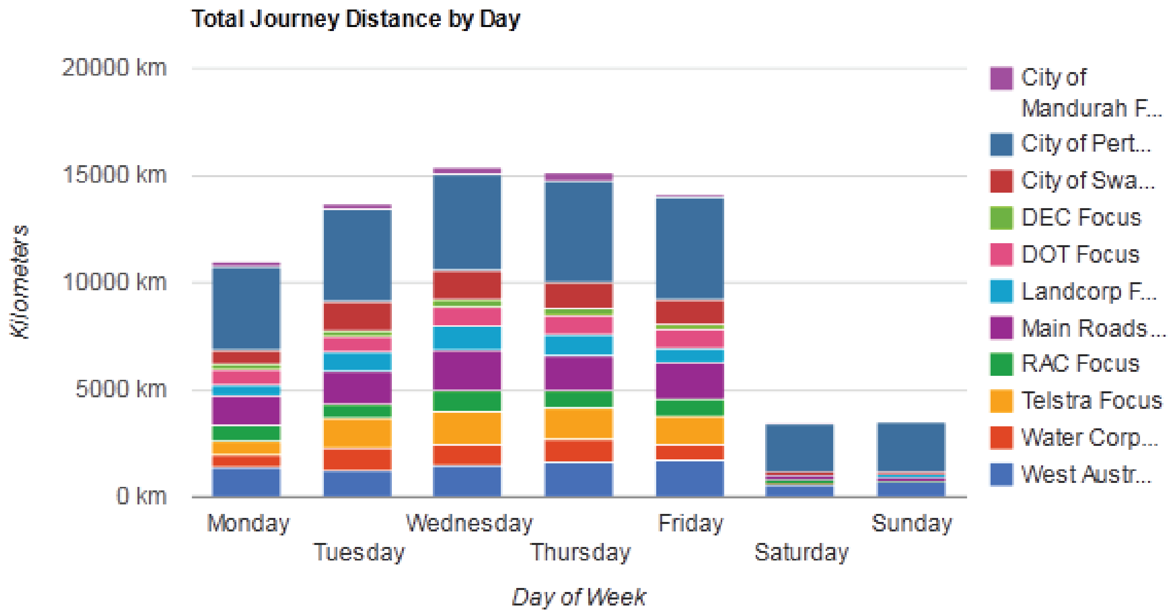


Figure 13: EV travel distance (by day of week) for each of the 11 vehicles (Speidel, Bräunl)

6 CSIRO Electric Driveway Project Plugging in: A Technical and Institutional Assessment of Electric Vehicles and the Grid in Australia Phase 1 Report.

5.4 Charging Statistics

The number of charging events recorded over the duration of the trial was 2917, with 611 (20.95%) charges not charging to full. The charges were made up of 390 home charges, 963 station charges, 1189 business charges and 375 in unknown locations. In these locations 1339 charge events occurred at a high-powered outlet (32A) and 1203 at low-power outlets (10A or 15A), with 375 at an unknown location and socket. Of the number of charges not full, 69 occurred at high-powered outlets (13% of all high-powered charges), 141 occurred at lower power outlet (24% of all low-powered charges) and 26 occurred at an unknown location (34% of all unknown charges).

Table 5.2: Charging amounts and times (accumulated over duration of the trial)

Vehicle	Avg. kWh	Average Charging Time	Average Maintaining Time	Charges at 10, 15A outlet	Charges at 32A outlet	Avg. 10A charge time	Avg. 32A charge time
City of Mandurah Focus	4.32	1:59:14	64:21:01	69*	02	2:07:48	None
City of Perth Focus	8.69	2:28:43	6:27:51	295	301	2:53:19	1:55:16
City of Swan Focus	5.71	1:08:01	4:52:29	92	204	0:18:56	1:26:49
DEC Focus	2.40	1:06:16	55:14:06	80*	0*	1:19:00	None
DoT Focus	9.93	2:08:22	31:06:23	3*	70*	1:35:22	2:15:30
Landcorp Focus	4.01	1:44:42	35:33:06	150	17	2:06:17	0:46:44
Main Roads Focus	4.49	0:59:31	4:42:37	75	370	1:00:59	1:02:15
RAC Focus	8.52	3:55:40	29:00:49	119	0	4:25:46	None
Telstra Focus	13.23	6:06:05	40:55:38	130	0	6:06:34	None
Water Corp.	8.13	1:11:05	38:10:30	27	160	0:14:44	1:17:06
The West Australian Focus	6.11	1:46:57	2:52:04	163	215	2:31:59	1:11:41
Average	6.62	1:55:52	16:20:13	109	122	2:43:09	1:24:45

* Note that possibly not all charging events were properly recorded.

The charging statistics shown in Table 5.2 show the average charging time for an electric vehicle is 1:56 hours, while at a higher-powered socket the EVs are charged in 1:25 hours, and at a lower powered socket the vehicles are charged in 2:43 hours. After the vehicles are charged they remain plugged into the socket for 16:20 hours on average; of the total time parked, on average only 10.57% is spent charging. In Table 5.3 we show that on average the EVs were not being driven for 96.15% of the time, or 23:04 hours per day.

Table 5.3: Vehicle time usage

Vehicle	Logged Time (hrs)	Driving Time per day (mins)	Distance before Charging (km)	Time Driving
City of Mandurah Focus	4067	0:18:02	17.11	4.08%
City of Perth Focus	12584	1:28:37	40.23	6.43%
City of Swan Focus	9336	0:32:32	19.48	2.00%
DEC Focus	1294	1:08:41	10.66	4.33%
DoT Focus	7163	0:28:17	41.19	7.35%
Landcorp Focus	3524	1:00:25	16.91	4.25%
Main Roads Focus	13768	0:28:33	13.63	2.04%
RAC Focus	3401	1:19:03	30.83	5.20%
Telstra Focus	8076	0:41:41	47.85	2.91%
Water Corporation Focus	9206	0:19:35	21.46	1.65%
The West Australian Focus	9631	0:37:52	21.12	4.32%
Average	82052	0:43:09	24.86	3.85%

Table 5.4 shows the parking percentages and charging probabilities in known locations versus unknown locations. A known location is either a charging station, the work location in the organisation where the EV is usually kept and a possible home location for cars that can be driven home by staff members. If multiple staff members got to take the car home and charged it there, some of the 'home charging' events may have shifted to 'elsewhere charging'.

Table 5.4: Parking and charging location type

Vehicle	% Time parked known location	% Time parked unknown location	Charging probab. at home	Charging probab. at work	Charging probab. at station	Charging probab. elsewhere	# Known locations parked	# Known locations charged at
City of Mandurah	96.75%	3.25%	66.67%	52.63%	100.00%	2.29%	9	8
City of Perth	82.03%	17.97%	34.35%	83.97%	0.00%	1.79%	11	8
City of Swan	79.91%	20.09%	75.00%	6.98%	97.74%	2.47%	8	7
DEC	92.22%	7.78%	0.00%	97.00%	75.00%	27.96%	8	7
DoT	83.05%	16.95%	0.00%	59.13%	0.00%	10.69%	13	4
Landcorp	79.51%	20.49%	35.14%	87.14%	52.17%	18.30%	19	13
Main Roads	43.31%	56.69%	37.50%	50.00%	88.71%	23.20%	13	9
RAC	94.81%	5.19%	0.00%	61.11%	0.00%	3.79%	8	2
Telstra	47.58%	52.42%		96.03%	0.00%	0.14%	6	2
Water Corp.	84.04%	15.96%	0.00%	40.00%	94.30%	9.94%	11	7
West Aust.	86.08%	13.92%	23.57%	43.88%	88.57%	4.85%	17	11
Average	77.90%	22.10%	30.86%	60.11%	87.59%	6.80%	11	7

EVs driven and parked at the drivers' homes were recharged only 31% of the 1011 times parked. EVs at the various known businesses locations were recharged 60% of the 1765 times parked and those parking at charging stations charged 88% of the 1015 times parked. EVs were parked at 5058 different unknown locations and charged at those locations 7% of the times parked. On average 78% of an EV's total parking time occurred in 11 different known locations, and on average 90% of recharging time occurred in seven different known locations.

Table 5.5 shows that for all the EVs in the trial, 96% of charges took place in each EV's top three locations, with on average 89% of charging taking place in one location for each EV. This can be interpreted as the EVs having one primary charging location where the majority of power is consumed.

Table 5.5: Percentage of total charging energy (kWh) provided by top three used stations for each EV (each EV has different locations)

Vehicle	Man	Perth	Swan	DEC	DoT	LandC	MainR	RAC	Telstra	Water	West	AVG
Location 1	51%	49%	66%	66%	83%	52%	59%	88%	99%	76%	38%	59%
Location 2	27%	34%	18%	24%	13%	23%	29%	12%	1%	10%	15%	23%
Location 3	9%	6%	6%	4%	2%	6%	9%	0%	0%	9%	15%	7%
Total of 3	**87%**	**89%**	**90%**	**93%**	**99%**	**80%**	**97%**	**100%**	**100%**	**95%**	**68%**	**89%**

Charging Power

The power (kilowatts) drawn by the electric vehicles over time of day is shown in Figure 14. The station and business charging power peaks at 8am and 9am as the electric vehicles are driven from the business the previous day, then returning the next morning and parked to charge for the total distance. At 3pm business power usage also spikes as the EVs are returned back to the businesses. At 8pm the home charging peaks as the vehicles are driven home to slow-charge, and the power used slowly reduces throughout the night until the morning. The business and station charging patterns is similar to the workplace charge load done simulated by Weiller (2011*). Possible grid effects (or the lack of it) have been researched in Mullan (2011†) and (2012‡).

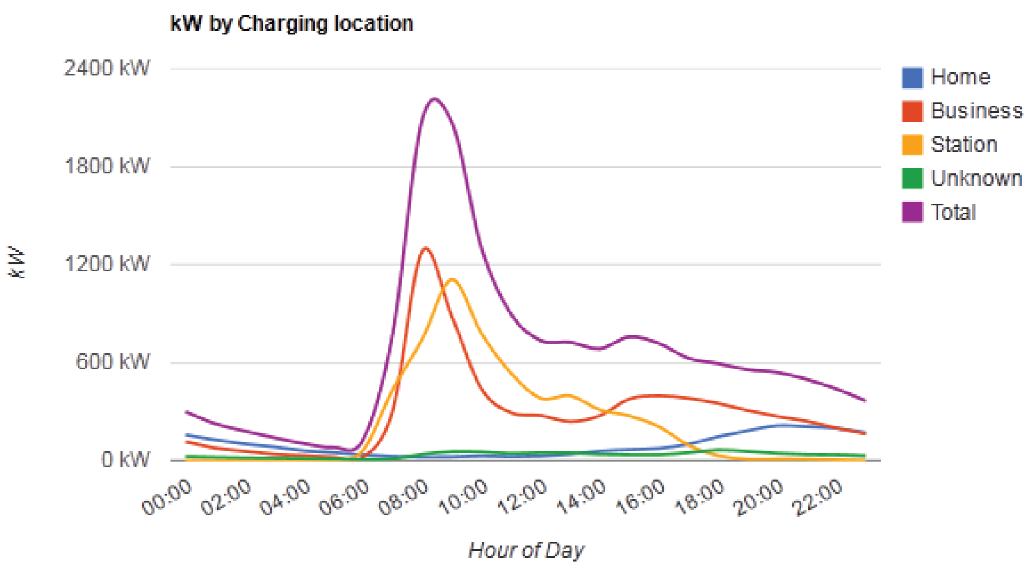


Figure 14: EV charging distribution over daytime, accum. over two years (Speidel, Bräunl)

* Weiller, C. (2011). 'Plug-in hybrid electric vehicle impacts on hourly electricity demand in the United States.' *Energy Policy* **39**(6): 3766–78.

† Mullan, J., D. Harries, T. Bräunl and S. Whitely (2011). 'Modelling the impacts of electric vehicle recharging on the Western Australian electricity supply system.' *Energy Policy* **39**(7): 4349–59.

‡ Mullan, J., D. Harries, T. Bräunl and S. Whitely (2012). 'The technical, economic and commercial viability of the vehicle-to-grid concept.' *Energy Policy* **48**(0): 394–406.

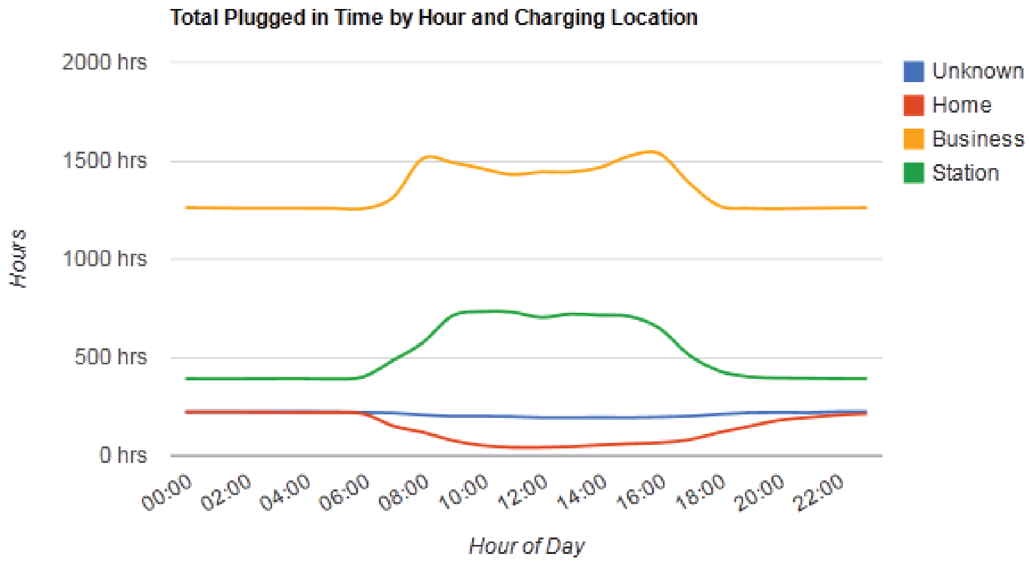


Figure 15: EV plug-in home distribution over daytime, accumulated over two years (Speidel, Bräunl)

5.5 Heat-Maps

Heat-maps are a geographical tool that allows the routes or charging locations to be plotted on a map with colours used to identify the most used ('hottest') routes or places. Heat-maps were generated over all vehicles for the entire trial period, based on the on-board GPS data loggers. The following heat-maps were generated and are shown in subsequent figures:

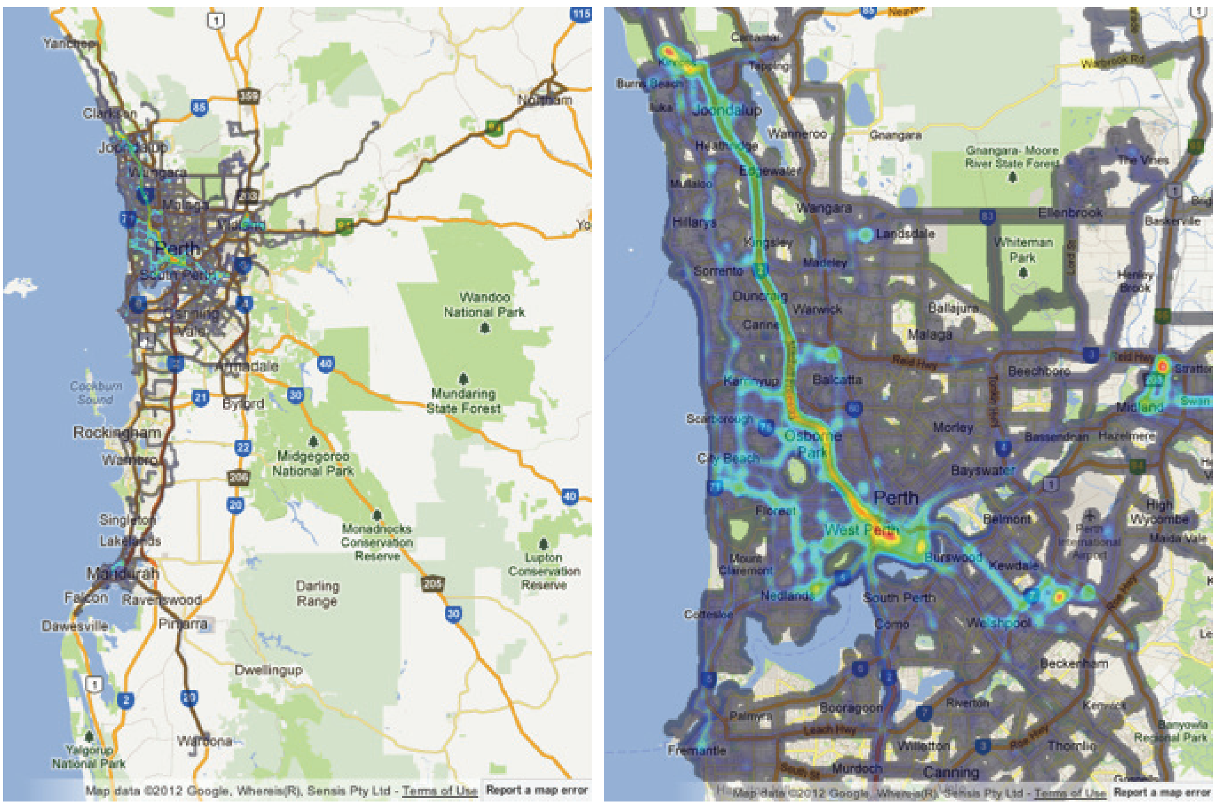


Figure 16: Heat-map of roads driven (Speidel, Bräunl)

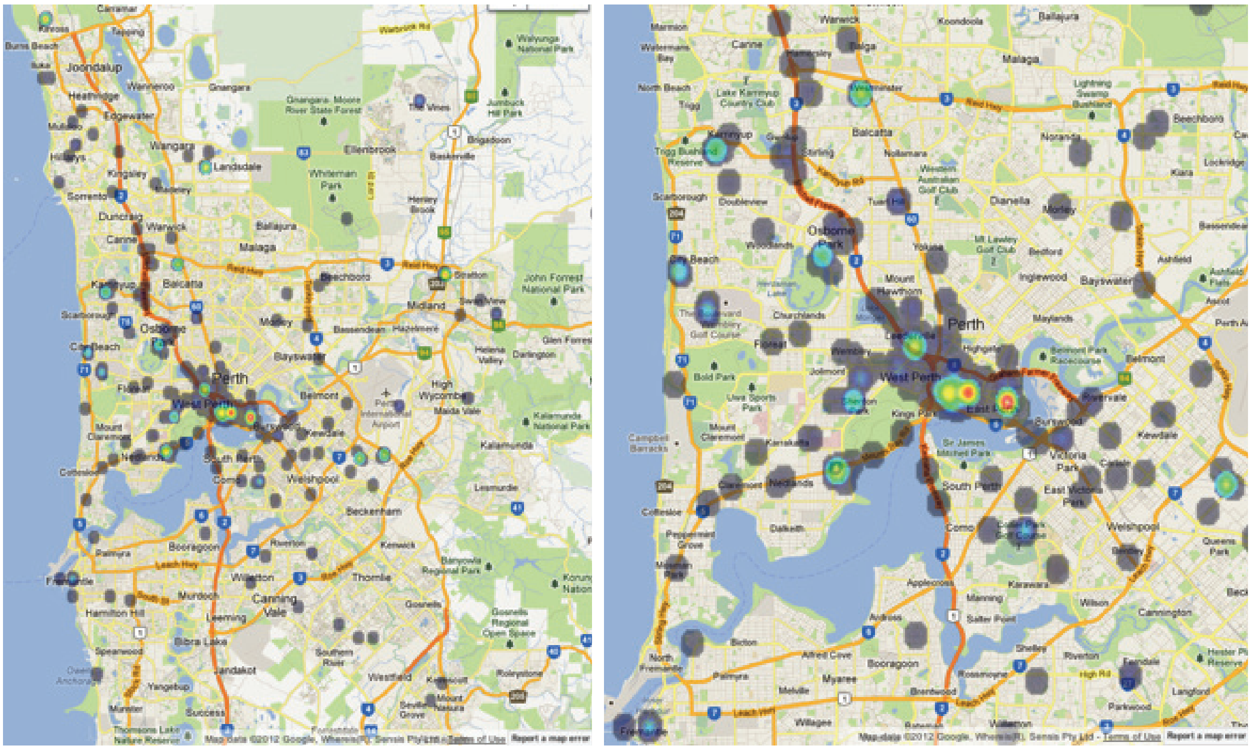


Figure 17: Heat-map of charging hotspots (Speidel, Bräunl)

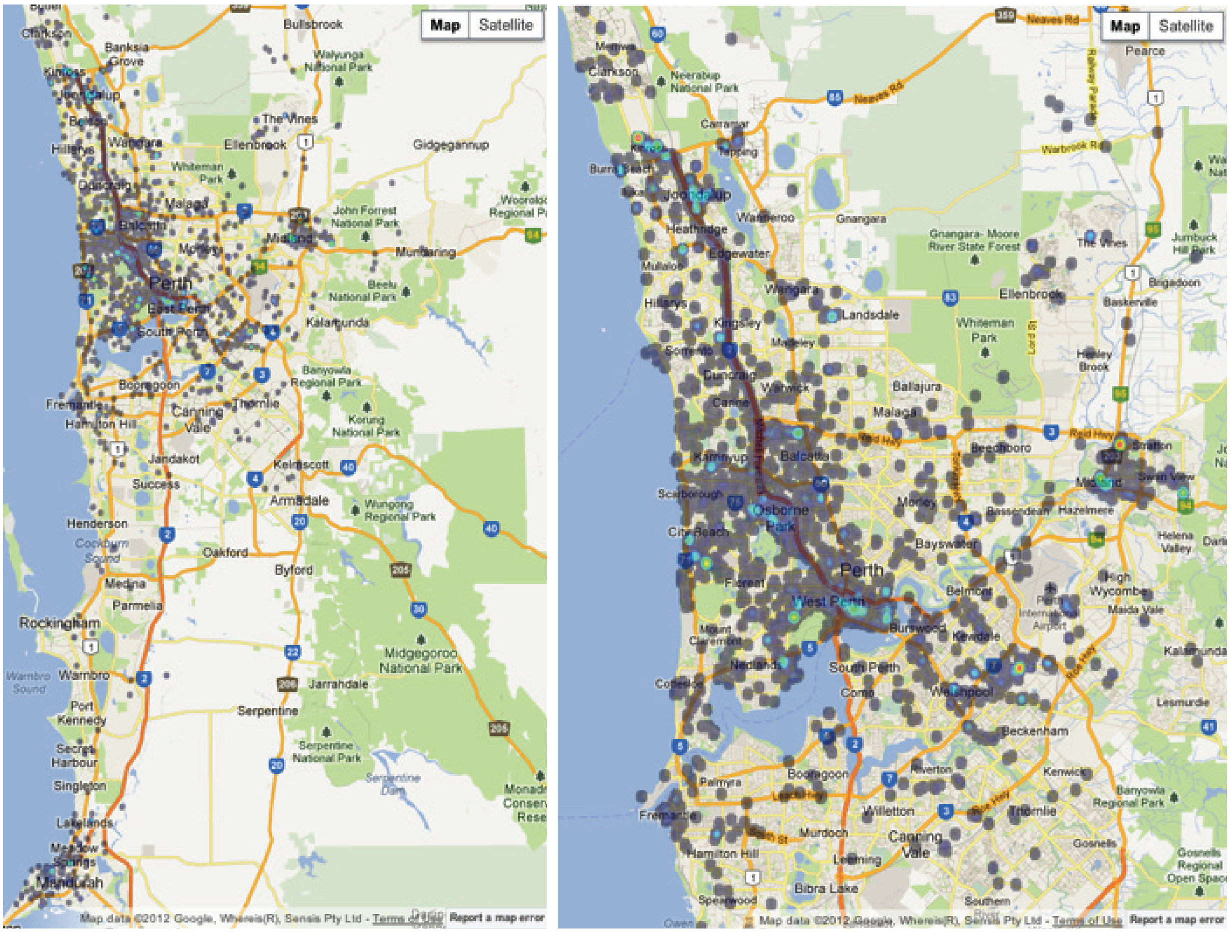


Figure 18: Heat-map for parking hotspots without charging – potential places for new charging stations (Speidel, Bräunl)

Driving Heat-Map

This heat-map shows areas of frequent EV traffic. This shows which roads are frequently driven by the trial EVs. Not surprisingly the most traffic is in the CBD and on the arterial north–south and west–east connections to the city. Most of the traffic was north of the Swan River, which is a consequence of most trial cars being stationed in the northern half of the city.

Charging Heat-Map

The charging heat-map shows the frequency of charging at different points in the city. This includes station charging as well as home or work charging. Most charging stations light up in the graph, as do regular home and work charging places for the individual trial vehicles.

Parking (Non-Charging) Heat-Map

A very interesting heat-map is the one highlighting places of frequent parking without recharging. These hotspots show the opportunity (and possibly a need) for the installation of future charging stations.

Further details of this research can be seen in the publication: S. Speidel, F. Jabeen, D. Olaru, D. Harries, T. Bräunl, *Analysis of Western Australian Electric Vehicle and Charging Station Trials*, 35th Australian Transport Research Forum (ATRF), Perth, Sep. 2012, pp. 12.

5.6 Driver Survey on EV Acceptance

The two techniques used in this study include factor analysis and multiple linear regression. The results of the survey are analysed by testing a set of hypotheses through the regression model. In general, most of the drivers in the WA EV Trial were confident in operating the EV, although 13 participants experienced at least one technical difficulty when driving the converted EVs in the trial. The overall satisfaction with the EV performance is still high with average score being 3.96 out of 5. We explored the drivers' behaviour through a survey with the following aims:

- Identifying drivers' perceptions about EVs, and their willingness to purchase an EV;
- Ascertaining participants' attitudes towards the environment and adoption of new technologies; and
- Informing the research program and assisting in refining the design of the questionnaire for the household survey that will be conducted separately. The EV driver survey serves thus as a pilot, testing two sections of the household questionnaire: a stated choice experiment and household attitudes towards EV.

In the first step, a set of latent constructs were identified through which the acceptability of Plug-in Electric Vehicles by the drivers in the WA EV Trial could be be assessed. The specific questions we explore in this research refer to the direct impact of EV benefits; technical difficulties experienced while driving EVs; and the effects of the attitudes towards environment and technology adoption (measured using latent constructs) on the willingness of the drivers to recommend and purchase an EV. The survey instrument was designed according to the conceptual model shown in Figure 19. While the purpose of the overall research was to test a mediating model (EV benefits and barriers, environmental concern, and technology learning impact on the overall satisfaction while driving an EV, which in turn allows predicting the willingness to recommend and purchase an EV) for this study, we tested a direct model with all predictors affecting the willingness to recommend and purchase an EV. The primary hypotheses of this study include:

H1: Drivers confident in the environmental performance and efficient use of energy of EVs are more likely to recommend and purchase an EV.

H2: Drivers showing concerns for environmental changes are more likely to recommend and purchase an EV.

H3: Drivers ready to adopt and learn about new technologies are more likely to recommend and purchase an EV.

H4: Perceived EV benefits influence positively the willingness to recommend and purchase an EV.

H5: Experienced technical difficulties while driving an EV influence negatively the willingness to recommend and purchase an EV.

H6: Overall, drivers' satisfaction with EVs reflects the willingness to adopt an EV as a future car. For this report the satisfaction with driving an EV is tested as one of the independent variables.

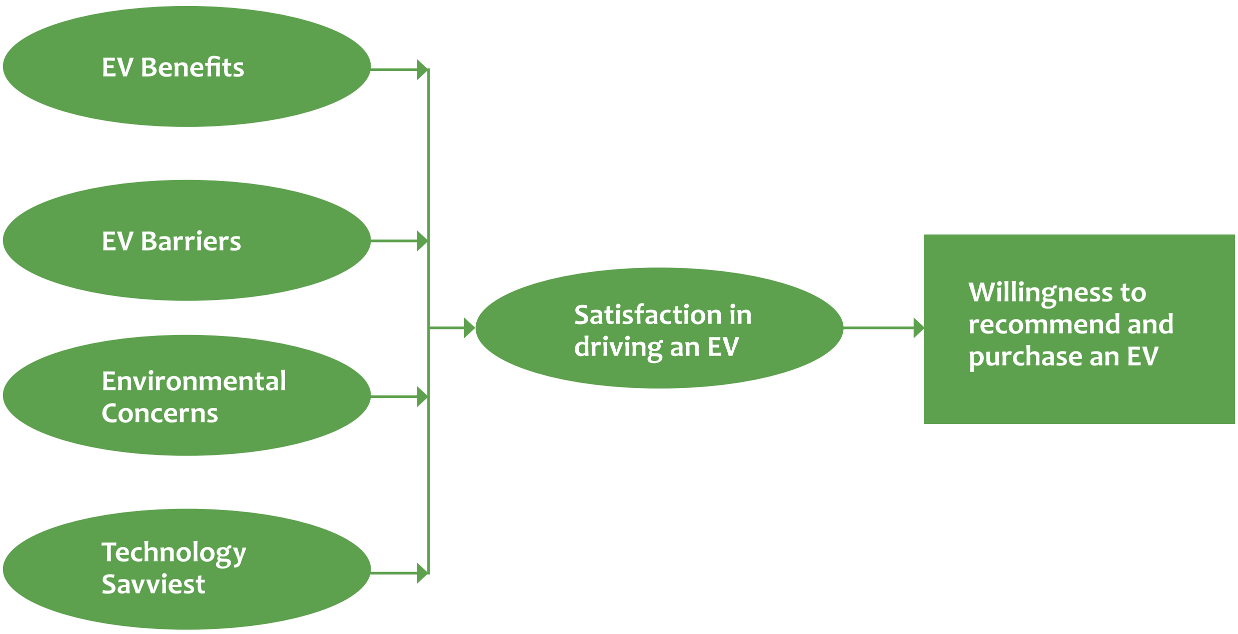


Figure 19: Conceptual Model (Jabeen, Olaru, Taplin)

More than 80% of drivers showed satisfaction in driving EVs, with 34.1% being extremely satisfied. This is a positive indication towards EV acceptance in the WA EV Trial, where 24% of respondents drive more than 50km, 39% drive 21–50km, 27% drive 10–20km, and only 11% drive less than 10km in a single trip.

'Zero tail-pipe emissions' was considered the most desirable feature suggesting that the drivers are concerned about the environment, followed by 'low running cost', then 'reliability', 'low-maintenance', and 'home-charging'. 'Low level of noise' is also suggested as a desirable feature of EVs by the drivers in the trial. In terms of perceived barriers for EV uptake, the respondents indicated the 'limited range' and 'purchase cost' as the most serious limitations, followed by 'recharging infrastructure' and 'recharging time', with 'reliability' the least serious barrier. Forty-two respondents answered this question; 52% respondents indicated 'Power-steering failure', 'no regenerative braking' and 'range indicator errors', while 10 respondents reported other faults related to charging, braking faults, motor overloading, and gearbox problems.

The most important EV benefits identified by respondents included: convenience of home battery recharging and reduced average travel cost per trip. The respondents were also comfortable with recharging their EV at public stations, although almost half of the respondents needed to do a lot of planning of activities when they drive EVs. In regard to EV technical difficulties, only 20% of the respondents believed that EVs have problems with the acceleration; while 29% disagreed that EVs incur significant maintenance costs. None of these two constructs, EV benefits or Technical problems associated with EV had adequate reliability in this sample, and consequently they were not used in this analysis. Satisfaction is a mediator between EV benefits, EV barriers, and technology learning constructs, and the willingness to recommend and purchase an EV.

This research explored the EV drivers' behaviour and their perceptions and attitudes towards new technologies. Experiences of drivers in the trial are useful for exploring the impact of EV benefits and of their technical difficulties on the acceptance of EV. The drivers showed confidence in the EV's environmental performance and efficient use of energy. The range is a serious barrier to EV uptake, however, with almost half of drivers indicating that they require significant trip-planning, especially for trips longer than 30km. The analysis of the drivers' survey also aimed to refine the latent constructs such as technology adoption and environmental concern. With the data from the drivers' survey, the reliability of the constructs was assessed and items with low value of loadings are being revised. The results of this analysis will inform the household survey, and these constructs will be presented with further improvements, in the household survey.

Further details from this survey can be seen in the publication: F. Jabeen, D. Olaru, B. Smith, T. Bräunl, S. Speidel, *Acceptability of Electric Vehicles: Findings from a Driver Survey*, 35th Australian Transport Research Forum (ATRF), Perth, Sep. 2012, pp. 14.

6. The Regulatory Environment

New technologies generally arise ahead of the development of a relevant regulatory environment and this is the case with electric vehicles. In practice, electric vehicles do raise several relevant regulatory questions, which we can expect to lead to various regulatory initiatives.

Currently, and to the best knowledge of trial management, there are no local, state or commonwealth regulations enacted that are focused solely on electric vehicles. However, this will surely change.

Based on the practical experience of the trial, this section seeks to set out in a broad sense where we believe relevant regulations could be required.

6.1 Recharging Standards

As discussed in Chapter 4, various standards ('types') exist for the physical connector between the recharge station and the electric vehicle. Currently there are at least four connector types (including the Chinese standard) and to date Australian regulators have not designated one as the Australian standard. As raised by Bräunl, this means that potentially four connector types can be (and are being) installed around Australia on recharge infrastructure and on vehicles sold, which will create compatibility-related legacy issues.

Based on experience in the trial, the following areas should be monitored by regulators as potential areas for attention.

Regulators should consider setting minimum technical specifications for recharge stations and cables to ensure safe charging. As highlighted in the review of recharging standards, the use of standard domestic cables and outlets has shown to lead to heating fatigue and potential short circuits, which could lead to fires and/or risk of electrocution.

Regulators should weigh the expected benefits of a market developed 'de facto' standard against the potential risks, and be prepared to act to enforce one standard if the negatives look to outweigh the positives. The benefits of a market-based standard is that it leaves the decision to consumers and providers to ultimately settle on one (or several) standards based on the merits as demonstrated in an open market. The negatives are that recharge network providers and automotive manufacturers may hold back on investment based on a concern that they will back the wrong standard. Recharge station networks can cost many millions and this investment will be of nil value if the wrong standard is chosen. A delay in good recharge infrastructure will lead to a delay in the take-up of electric vehicles. We note that most countries are backing a single standard.

6.2 Energy Market Arrangements

Current energy market regulations could be reviewed to ensure they assist, where possible, development of widely available recharge station networks. Currently, recharge network providers have difficulty acting as electricity retailers, which means there is a more limited scope to recoup the investment in recharge stations.

In Western Australia, recharging station operators may be required to obtain electricity distribution and retailing licences in accordance with the provisions of the *Electricity Industry Act 2004*. These requirements could act as a barrier to the establishment of recharging networks. In 2012, the WA Government approved a three-year exemption from the requirements of this legislation for electric vehicle recharging stations. While this removed a barrier for the operation of the trial, a permanent solution is desirable to provide greater certainty for future providers of recharging infrastructure.

6.3 Commonwealth Taxation Arrangements

The Commonwealth Government's carbon tax does not apply to petrol for personal use, whereas the tax does apply to EVs recharging from the grid, even though these vehicles will generally be releasing fewer emissions (and none when charged from renewable sources). This effective subsidy on petrol and diesel vehicle usage acts as a barrier to the uptake of EVs. The carbon tax regime should therefore be reviewed with the aim of removing this distortion.

7. WA Industrial Development Opportunities

One of the key objectives of the trial relates to state industrial development:

'Provide local industrial development opportunities in a range of areas, as well as gain technology transfer into WA universities for what will be a major new industry' (Trial Objectives)

7.1 Technology Transfer into WA Universities

Technology transfer into UWA was achieved in the following ways:

- UWA worked closely with EV Works on the conversion design and execution. EV Works has a long track record in performing commercial conversions. UWA benefitted from the hands-on experience of working with a commercial party;
- UWA gained access to the source software codes for the Elektromotive recharge station system management functions. This allowed direct access to state-of-the-art control and management systems in recharge networks;
- UWA had access to Elektromotive engineers (UK) to answer questions and raise issues;
- UWA was able to attract ARC Linkage funding and appoint two PhD students, which enabled a further focus on electric vehicles and recharge networks;
- UWA research staff attended and spoke at leading electric vehicle conferences, based on the strength of trial research, affording a wider understanding of the issues;
- All the above has built upon the existing work of the UWA Renewable Energy Vehicle Program (REV), establishing a five-year history in electric vehicle technology.

7.2 Industrial Development Opportunities

Conversions—Electric Vehicle Components

Due in part to the WA EV Trial, EV Works is now an Australian leader in the market for the conversion of traditional fuel vehicles to electricity. While the arrival of electric vehicles from major manufacturers has seen new options for fleet and consumers (which they are almost certainly to pursue), the niche market addressed by EV Works in the conversion of older vehicles to electricity will continue.

EV Works has developed further as an Australia-wide provider of electric vehicle parts and systems, including batteries.

Recharge System Software Development

The Elektromotive stations used for the trial utilise an Elektromotive developed software platform called 'EB Connect'. This software facilitates the connection between the station and the central server, and manages the monitoring (stations can be seen via online applications), authentication (swipe card access), electricity usage tracking and billing functions. The system also, in principle, allows analysis per station and per EV driver for the purposes of control and optimisation.

The UWA REV team became aware of significant limitations in the areas of reliability and functionality and developed an own-software platform called 'REView'. This system is designed to be more stable than EB Connect and allows much more sophisticated monitoring and analysis to take place. Elektromotive staff travelled to Perth early 2012 to receive a demonstration of REView. Commercialisation opportunities are being further explored.

Given the considerable knowledge and expertise that has been developed in WA in relation to EVs, opportunities for retaining and building on this knowledge for the future benefit of the WA community should be explored. One way of achieving this would be for the WA government to consider the establishment of an EV Centre of Excellence with participation from all WA universities.

8. Communications and Public Awareness

WA EV Trial participants with Transport Minister Simon O'Brien during recharging station launch at RAC West Perth Headquarters

Promoting the WA EV Trial, and hence awareness of the potential of electric vehicles, was a key objective of the trial. Fleet users, but also the general motoring public, were targeted. To this end a number of strategies were utilised, namely:

- highly promoted WA EV Trial launch event;
- *The West Australian* as participant and 'media partner';
- attendance at relevant events;
- WA EV Trial website;
- participant-led publicity—via each participant's own network or events;
- professional conferences.

8.1 Trial Launch Events

On 11 March 2010 at The University Club (UWA) the WA EV Trial was launched by The Hon. Simon O'Brien, MLC, Minister for Transport (2008-2010). Also in attendance was The Hon. Donna Faragher, Minister for Environment; UWA Vice-Chancellor Professor Alan Robson; and several directors-general and managing directors/CEOs from participating departments or companies.

Three Perth TV channels (7, 9 and ABC) covered the launch, as well as *The West Australian* and local newspapers.

A link to the State Government's media statement can found here:
www.mediastatements.wa.gov.au/Pages/StatementDetails.aspx?StatId=2308&listName=StatementsBarnett

The formal handover of the first trial car (to the Department of Transport) and opening of Perth's first public recharging station at RAC headquarters in West Perth in November 2010 also received significant media coverage.

A copy of Mr O'Brien's media statement can be found here:
www.mediastatements.wa.gov.au/Pages/StatementDetails.aspx?StatId=3382&listName=StatementsBarnett

8.2 *The West Australian* as Participant and 'Media Partner'

The West Australian, the only daily WA newspaper, covered the trial, as well as documenting their own experience—'Living with an EV'.

On 11 June 2011 *The West Australian* included a three-page liftout on EVs, with extensive coverage of the trial. Some of the material can be found here: http://au.news.yahoo.com/thewest/lifestyle/a/-/lifestyle/9624001/plugging-into-the-future/

WA EV Trial participants at The West Australian's *head office in Osborne Park during a recharging station launch*

8.3 Attendance at Relevant Events

The following events were attended in order to promote the trial. Most events included display of a converted Ford Focus:

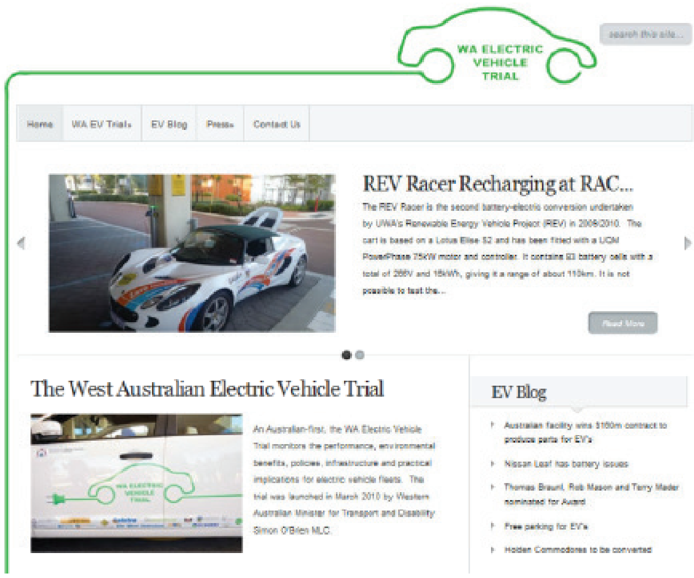
- Perth Motor Show;
- Perth Royal Show;
- Sun Fair;
- various school presentations;
- Perth Christmas Pageant (RAC);
- Curtin Robo Fair;
- WA EV Association Open Day;
- Swan Eco-Fair;
- Mainroads WA Sustainable September;
- Electric Fair, Northbridge;
- Energising South-East Asia, Conference and Exhibition;
- RAC BusinessWise Day;
- WA Sustainability Association Conference;
- Australian Electric Vehicle Conference.

The Perth Motor Show, for example, is the most popular event for the WA motoring industry, and in 2008 it attracted 62,000 visitors and featured world-class displays from well-known brands. The 2011 Perth Motor Show created a stimulus for the market by enabling visitors to view the latest vehicles at their leisure; and was a unique opportunity for exhibitors to present their products to a target audience. One of the trial vehicles was displayed at the show to promote the trial and raise public awareness.

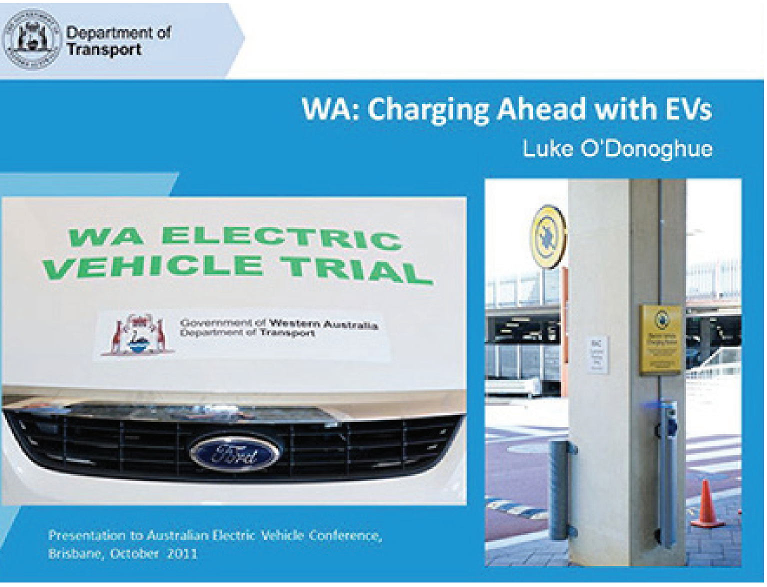
Electric Focus at Perth Motor Show 2011

A dedicated website was another way the trial was promoted. For the period of the trial www.waevtrial.com.au provided a description on the trial, provided contact information as well as information about the participants, an ongoing blog of developments around the trial, as well general news on the EV industry.

Relevant information can now be found at http://therevproject.com/trials/ev-trial.php.



WA EV Trial website



8.4 Participant-led Publicity

Most participant organisations also established their own internal communications processes based on their involvement in the trial. For example, the RAC established a section on their own website, at:

http://rac.com.au/About-Us/Community/Environment/Electric-vehicles-in-the-real-world.aspx

and

http://rac.com.au/About-Us/Community/Environment/Electric-vehicles-FAQs.aspx

8.5 Professional Conferences

Information regarding the trial was presented at the key national conferences:

- Australia EV Conference, Brisbane 2010; and
- Australia EV Conference, Brisbane 2011.

9. Looking to the Future

9.1 Measures to Increase EV Take-up

Electric vehicles have the potential to significantly improve Australia's energy security by reducing dependence on imported fossil fuels, and to reduce greenhouse gas emission associated with transport activity.

Significant barriers must be overcome, however, before EVs become widely adopted in Australia. These barriers relate primarily to the higher cost of EVs, and to the availability and accessibility of appropriate EV recharging infrastructure.

Governments can play a role in addressing these barriers, thereby accelerating the uptake of EVs and the realisation of the benefits that they can bring, as described above. The following measures are expected to increase early take-up rates of EVs. Authorities intending to work to encourage EV take-up would need to complete cost-benefit analysis in order to determine the best option for any given situation.

Electric Vehicle Purchase Subsidies

Purchase subsidies are a complex issue and further debate is required in terms of the Australian situation. In many countries governments provide direct subsidies of between $2,000 and $7,500 to purchasers of electric vehicles. Other subsidies may also apply, such as free parking, deductions on licensing costs, etc. The introduction of such subsidies in the Australian marketplace could significantly accelerate the uptake of EVs.

The inclusion of a moderate number of EVs in government fleets would also demonstrate a commitment towards cleaner transport. It would also introduce more affordable second-hand EVs into the general car market after their lease is expired. Government departments played a leading role in the take-up of hybrids, making a deliberate decision to encourage the market.

Recharging Infrastructure

Fast Charging (Level 3) Networks

Data from the trial, supported by overseas data, suggests that most charging will occur at home (for private vehicles) or at work (for fleet vehicles), with the occasional need for an external fast charge (Level 3). As most of the Level 2 (fast AC) usage during the trial tended to be more for parking than actual charging, its function can be taken over by home charging or office charging using simpler and cheaper 'wall boxes' (simplified charging stations without identification/billing requirements), which are preferred over ordinary power outlets for safety reasons.

A network of Level 3 stations will serve the same purpose as a petrol/diesel station network for conventional internal combustion engine (ICE) cars.

Development of EV charging networks in WA should therefore give priority to:

- Installation of a city-wide Level 3 (50kW) charging network in Perth (compliant with the Combo Type 2 standard for fast DC charging); and
- Implementation of a demonstration 'Electric Highway' project with Level 3 (50kW) charging stations along a route linking Perth to major regional centres (such as Bunbury, Busselton and Margaret River).

Charging Standards

One of the challenges encountered during the trial was the absence of standards covering EV recharging infrastructure, particular in relation to plugs and sockets for both cars and recharging stations. Competing standards exist in European, US and Japanese markets and no standards exist in Australia. This meant that the choice of recharging infrastructure for the trial took place in a standards vacuum and may ultimately be incompatible with future standards development. More recently, most of the major international EV industry players appear to have agreed on a new ('combo') standard.

Agreement on national EV standards in Australia, preferably consistent with international developments, will remove a major barrier to the establishment of recharging networks in this country. Failure to prescribe a particular connector/inlet type could lead to the import of different type cars and charging stations, which will be incompatible with each other.

9.2 The Future of Conversions

On the 6 September 2012 a workshop was conducted titled 'The Future of Vehicle Conversions'. The following were the main conclusions from the workshop:

1) New passenger vehicles converted to run on electricity would be within the price range of current electric vehicles from major manufacturers in Australia, but would offer no cost savings.

Manufacturers' recommended retail prices for electric vehicles inc. GST as of March 2013:

(Note: Sales prices and fleet prices will be well below these figures)

Mitsubishi iMiEV	$54,373 (drive away price) —but fleet prices around $31,000
Nissan Leaf	$46,990 (drive-away price) —but fleet prices around $35,000
Holden Volt	$59,990

Price of EV Ford Focus from EV Works:

Donor car	$16,737
Conversion cost	$33,103
Post-conversion upgrades	$2,000
Payback ICE motor & comp.	$2,000
Total price excl. GST	$49,840
Total price incl. GST	$54,824

2) In reality, even if there was price parity, a vehicle buyer is unlikely to select a new conversion over an electric vehicle from a major manufacturer.

Benefits of an OEM-built electric vehicle over a conversion are:
- improved reliability from more thorough testing;
- the security provided by a major brand— support and service;
- ancillary systems becoming sophisticated—charge and route planning.

3) To have a chance, a conversion would have to be a cheaper economic proposition than a vehicle from a major manufacturer, which is possible if using a second-hand donor vehicle. However, major manufacturers are expected to reduce prices rapidly over the coming two to three years as they reach improved scale.

One way to achieve a lower total cost of conversion is to use a second-hand vehicle. As an example, assuming a suitable second-hand vehicle can be bought for $5,000, then a like-for-like conversion (using EV Works' cost data, without upgrades and assuming a $500 ICE component sale) would mean a second-hand conversion could be offered for $41,363 (inc GST).

However, it was concluded that this price advantage would erode rather quickly (note: Mitsubishi was already discounting iMiEV prices to near this price point).

EV Works pointed out that many people executing conversions are doing so because of an emotional attachment to an older vehicle and that this would not be affected by comparative price advantages.

9.3 IT Infrastructure for EVs

Recharge stations by themselves are not much use unless a) they can be located when you need one, b) are unoccupied, c) access can be gained, and d) usage can be paid for (if required). Further, it would desirable if usage (by a large number of vehicles in a specific area) did not result in the grid being overloaded. An additional benefit would be if one could choose green energy, or choose from a energy metering model that suited one best—for the lowest price and greatest utility. It is the IT Infrastructure that enables these functions—and more. For this reason, IT infrastructure will play a central role in the adoption of EVs. This will include:
- Ex-car: Billing systems for charging at public charging stations;
- In-car: More sophisticated and fully-integrated 'remaining charge' displays;
- Ex-car: Smart phone and PC apps from most automotive OEMs for displaying charge status of EV and notification if a certain charge level has been reached;
- Ex-car: EV portals, displaying EV statistics on distance drive, energy consumption, charging, etc;
- In-car and ex-car: Smartphone, PC (or external embedded device) app allowing setting for smart charging (selection of charging start time and conditions);
- In-car and ex-car: App for reserving a nearby charging station (for a restricted amount of time as allowed by the charging network operator).

In the associated ARC Linkage project, a billing system has been developed that goes significantly beyond a mere listing of charging events at public charging stations. Besides listing the charge events, EV users get a full account of their charging history for the previous month, including home charging, work charging and others. This helps the user to control their overall energy consumption, including at public charging stations, but also the home (or work) energy usage, which will be a part of the home (or work) energy bill.

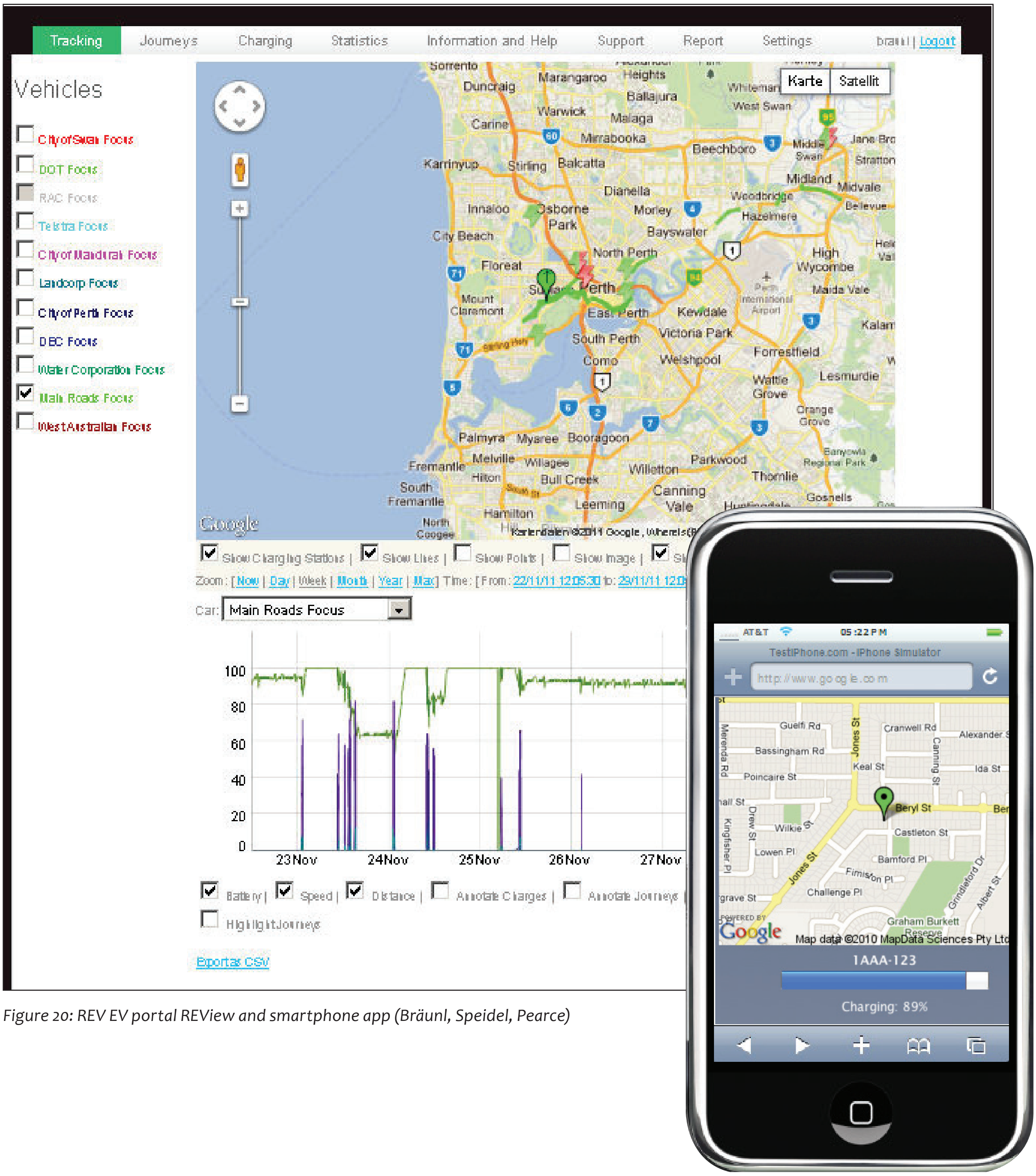


Figure 20: REV EV portal REView and smartphone app (Bräunl, Speidel, Pearce)

APPENDIX A: EV Focus Group

Pros and Cons of Electric Vehicles in Trial (collected mid-trial Nov. 2011)

Pros +	Cons -
Quiet	Where to charge? • This causes distraction
Smooth operating	Range • Lack of range or limited range
Good torque	Time to charge or recharge too long
New technology	Takes time to prepare use of vehicle
Appears as normal car or drives like a normal car	Difficult to find parking with charging points
Resource management and sustainability	Only good for city use
Cheap to run or low running cost	Drivers need to plan their trips
Minimal service costs or no need to go to service stations	Expensive to buy or high cost
No oil or water checks required, minimal maintenance	Vehicle has not been reliable, i.e., blown fuses, batteries, power store
Innovative	Power steering failure—technical
Sustainable mode of transport	No or limited infrastructure to recharge
Good performance and different	Limited by power station efficiency and transmission line loss
Efficiency	Focus reliability not 100% (This is expected to be resolved). Problems include following: • No regenerative braking • No auto – hold on slopes need handbrakes • Insufficient and power for the weight • Sluggish on hills
Reserved parking at work	Comparing with hybrid Prius and Camry still there is a need to recharge Ford Focus
Free parking	Range indicator troubles: • Can't rely on remaining range; wary of remaining distance; the range indicator may not be accurate
No need to queue at petrol station	Barrier to use affects induction process
No need to go service station or to fuel-up	
No emissions	
Clean energy	
Sustainable mode of transport	
Easy to drive	
No loss of boot space	
Standard vehicle share	
Research for better infrastructure in future	
Enthusiasm for EV links us with DEC's mission	
Practical step to reduce emissions	

APPENDIX B: Converted Ford Focus—Reliability and Incidents

Motor Controller

1. Controller Delay

Under normal conditions, there is a small delay of about one second between turning the ignition key and the motor controller being ready. This is required for the motor controller to get pre-charged from the batteries via a special circuitry. However, in cases of accumulating some motor controller error states, which are being stored in the Soliton controller, there will be an additional delay of around 10 seconds between engaging ignition and the controller being ready to accept throttle input. This feature can cause problems with novice drivers, as they may try to press the accelerator pedal harder and harder until the motor controller switches into ready state.

This delay can simply be reset during service, but can reappear over time.

2. Controller Failure

We have tried three different brands of motor controllers in the trial cars. The original controller used in the prototype car proved to be too weak and had to be replaced with more powerful and more expensive versions. But even for this controller model from the US, which is considered one of the best on the market, three units had failed towards the end of the two-year trial (between 10,000 and 30,000 km), which shows that there is still a need for higher quality products.

On one of the initial drives of the City of Swan vehicle, the motor controller overheated and caused a contained fire in the engine bay. Due to the absence of combustible fluids in electric vehicles, the fire burned itself out. No one was injured, but the vehicle was a total loss. Further testing indicated that the component that failed was internal to the controller. The solution was to discontinue the use of the selected controller and replace with another.

Although there were intermittent faults with controllers from other brands, they only reduced power as required and no failures resulted.

3. Jerkiness upon Take-off or Reversing

A further issue with the controller was jerkiness experienced when driving off or when reversing. This was related to controller not providing the correct ramp-up of power when moving from start. The solution to this was found by making adjustments to the controller settings.

4. Radio Interference

Radio reception on some of the converted Ford Focuses (but not all) was poor. This variability was traced to different types of radio fitted. The electrical interference from the additional components in the converted Ford Focus was expected to be the cause. Enquiries with the dealer, and further research, has not resulted in a solution.

One participant resolved this problem by replacing the analog radio with a digital radio, which solved the interference issue. However, there is still limited digital radio coverage in the Perth metropolitan area.

Drive Train

The high torque of electric motors, and the requirement to leave it in one higher gear (due to the wide requirement that vehicles be licensed as automatic), means that the clutch is placed under relative stress. Further, with lack of engine noise feedback, the clutch is challenging to use correctly. These factors resulted in a clutch failure on one occasion. The solution is to leave the vehicle in a higher gear (which due to nature of electric motors works well) and avoid the use of the clutch.

While leaving the vehicle in one higher gear addressed the clutch issue, the result was that other components of the drive train were placed under stress. This resulted in one instance of drive coupling failure. The solution was a change in controller settings to reduce torque loads. No other vehicle has since experienced this failure.

Power Steering

As delivered, the power steering in the converted Ford Focus only operates when the engine is running. This creates a problem for an EV, as the engine is not idling when stationary, so the power steering does not then operate. A small embedded controller had to be inserted to make the Ford's engine control unit (ECU) believe the engine is idling, so that the power steering still operates when the vehicle stops.

Some power steering units had intermittent problems. These were due mostly to not engaging power steering when turning on the ignition, but in one case the power steering cut out during regular operation. The issue was found to be either the embedded tachometer driver or the actual tachometer model.

The measures taken to eliminate these problems were to disconnect the tachometer and to enclose the power steering embedded controller in a water–tight and moisture-resistant container.

Instrumentation

1. Dashboard Engine-warning Light Remains Flashing

The dashboard engine-failure warning lights remain on after switching on the ignition, as the Ford's engine control unit does not receive certain signals from the now missing petrol engine. Solving this problem would have required cooperation by Ford, which unfortunately was not possible. However, EV drivers can simply delete the warning message by pressing a button.

2. Accuracy of Charge-remaining Gauge

There were several incidents of cars getting stranded when they had run out of power. Although all cars were equipped with fuel gauge drivers ('charge-remaining gauge'), which display the remaining charge level in a simple way, these displays were either not accurate, not properly calibrated or in some cases simply ignored.

Commercially available energy meters (TBS Electronics) had been suggested before the conversions were done, but were rejected because of their cost. After some of the cars did run out of power, this addition was strongly recommended to all trial participants, and about half of them had an energy meter installed.

Installing an energy meter also solved the problem of insufficient indication whether or not the car is charging. A dashboard-mounted LED indicates only the status of the fuel hatch (open or closed), but not whether the car is actually charging or not. This information is available either on the installed energy meter inside the cabin (in Ampere mode) or alternatively directly at the charger, which requires opening the car's bonnet and reading the charger's LCD.

Charging

Charging inlet: As neither vehicle power inlets according to norm IEC 62196-2 Type 1 ('SAE J1772') or Type 2 ('Mennekes') were available at the start of the conversions, non-automotive sockets for 10A single-phase and 20A three-phase had to be used together with matching extension leads. These connectors created a number of problems.

1. Single-phase 10A inlet

When using the single-phase power inlet, a poor quality 10A extension lead, significant burn marks did occur on the 10A vehicle inlet, which could, over a longer continued usage timeframe, lead to melting of the socket or even a fire. Also, poor quality 10A extension leads did get warm, due to a smaller wire diameter.

Original single-phase vehicle inlet with burn marks

This is a serious concern, especially when EVs are being on-sold in this condition, as there is no guarantee that the new owner will use a more expensive, higher quality extension lead for charging—especially since poor quality extension leads are available in every supermarket.

2. Three-phase 20A inlet

When using the three-phase power inlet, the connector does not always make good contact with the socket, especially as the screw-in ring of the connector, which is essential for the IP56 rating, had to be removed for space reasons. Besides losing the IP56 rating, this had the negative effect that, in several cases, cars had been plugged in for charging overnight and drivers assumed the car would be fully charged the next morning, when in fact the car did not charge at all because the connector had not made proper contact with the socket.

Several trial participants reported difficulties in correctly plugging in the three-phase connectors.

For those cars in which the single- and three-phase inlets had been replaced by an IEC 'Mennekes' inlet, very favourable reports were received on the ease of plugging-in and unplugging . No plug-in problems have occurred for this IEC 'Mennekes' inlet.

Original three-phase vehicle inlet with rust marks

3. Compatibility with Charging Stations

In the meantime, a network of fast AC (Level 2) EV charging stations were installed by the ARC Linkage project, to be used for this trial. The Linkage project decided to use IEC 62196 Type 2 stations, which are the European standard for EV charging, as Australia like Europe does have a three-phase power grid (Type 1 stations only support single-phase charging). In order to charge the trial EVs, adapter cables had to be manufactured from 'Mennekes' to non-automotive Australian three-phase connectors.

These caused some initial problems with the cable locking mechanism of the charging stations. As the converted EVs were not equipped with data lines (pilot line), they could not signal the end of a charge cycle to the station in order to release the cable. A workaround was implemented on the charging stations in order to release the non-compliant charging cables.

Solution

Once IEC 62196-2 Type, Generation 2 ('Mennekes') vehicle inlets became available, participants were encouraged to replace both non-automotive power inlets with a single 'Mennekes' power inlet. Vehicles could then be charged either from a charging station (using a Mode 3 cable) or from a home power socket (using a Mode 2 cable with built-in RCD, protective earth detection, over-current and over-temperature protection).

About half the trial participants followed this recommendation, which is both a safety upgrade as well as a step to make cars compliant with the IEC norm. On the EVs not performing this upgrade, the slow-charge setting was reduced to 8A charging current.

Note that at this stage (June 2012), Standards Australia has recommended the adoption of IEV 62196-2, but unfortunately without recommending either Type 1 or Type 2 vehicle connectors/sockets.

Converted Ford Focus with IEC 62196-2, Type 2, Gen. 2 'Mennekes' vehicle inlet

4. Charger Operation

A few cases occurred where the in-board charger lost its power settings when hard switched off during a high current charge. The charger is not designed to tolerate a hard shut down and should be signalled to stop a charge cycle instead.

This was achieved by the use of a magnet fitted to the swipe card or a keyring, that when placed at the fuel door sensor of the vehicle turns off the charger.

Brake-assist Performance

Many users reported that the brake performance of the converted Ford Focus was not optimal, requiring significant foot pressure to achieve a stop. EV Works was able to adjust the brake boost setting to correct this problem.

Throttle Setting Error Resulting in Vehicle Unable to Start

In the standard Ford Focus, the throttle sensor needs to send a 'zero' signal to the car's electronics before the vehicle will start. There was one incident in which, related to the conversion, the sensor did not send the required signal. A workaround, involving a manual button to override the sensor, was installed in that vehicle.

12V System Reliability (Non-Lithium)

One converted Ford Focus experienced recurring problems with the non-lithium 12v system. This issue is currently under investigation.

Air-conditioning and Heating Capacity

The standard air-conditioning units on the Ford Focus work only when the vehicle is being driven. When stationary it does not work. During stop–start usage on hot days, the vehicle would not remain cool. The solution, which was taken up by some trial participants, was the optional fitting of an additional auxiliary electric motor to turn over the air-conditioning unit.

The heating in the standard Ford Focus is driven by the internal combustion engine and hence is not usable after conversion. An auxiliary water heating unit has been installed in all converted cars for heating. There have been incidents of the air-conditioning remaining stuck on, or the air-conditioning or heating stopping working.

Performance of Automatic Conversion

The Department of Environment opted to use an automatic car as basis for the conversion. Since the electric motor revs were not available to the Ford engine control unit, this resulted in a jerky gear shift, which the trial participant found unacceptable. To solve this, only gear 3 was used for forward movement, which unfortunately had a significant negative effect on the car's power consumption.

Research is still being done to improve this setting.

Wiring and Relay Issues

A small number of wiring and relay problems needed to be addressed by EV Works.

Engaging Reverse

Drivers of some vehicles with or without a clutch reported that it is difficult to engage the reverse gear if you are not familiar with the conversion. The solution is driver practice.

Motor Mounts

On some of the trial cars the motor mounts showed hairline cracks after around 10,000km of use. Those motor mounts had to be replaced by stronger steel mounts.

High-pitched Noise

Younger drivers report hearing a high-pitched squeal when the electric motor is being driven that is not present when the vehicle is coasting. The squeal was such that one occupant found it necessary to cover their ears when it occurred.

The noise is due to the operating frequency of the motor controller used, which cannot be changed. Some other motor controllers change the frequency depending on motor speed, so to avoid this noise during driving accept for the starting phase. Better sound insulation around the engine bay could reduce this noise problem.

Incident Tracking

Due to the number of incidents needing to be addressed across the fleet, the first year of trial operation was dominated by the work to address these. Since the start of 2012, the majority of these issues have been addressed and more regular fleet operation commenced.

APPENDIX C: Trial Participants and Partners

The following section outlines the parties to the WA EV Trial and their roles.

UWA Renewable Energy Vehicle Project—Research

www.therevproject.com

Professor Thomas Bräunl is Head of the UWA Renewable Energy Vehicle Project (REV) and holds the position of ARC Linkage Lead Researcher. In addition, Professor Bräunl was appointed by trial management as the Technical Director of the WA Electric Vehicle Trial.

REV hopes to 'change personal transport' by building zero-emission vehicles, powered by electricity from renewable sources, charged from any plug point and viable to both the performance and commercial markets. REV is tackling the problems created by rising fuel prices and vehicle pollution directly. The REV team comprises engineering staff and students from The University of Western Australia, working for a sustainable future. REV provides a unique opportunity for students to learn and develop multidisciplinary teamwork plus innovative design, leadership, management, marketing, finance and practical skills.

As per the WA Electric Vehicle Trial Memorandum of Understanding, UWA undertook the following tasks:

- Support the conversion of the first (prototype) vehicle to a fully electric vehicle by providing technical advice;
- Assist to obtain all necessary regulatory approvals for the prototype vehicle to be operated on the Western Australian road network;
- Make all technical specifications and other relevant information for the prototype vehicle available to the contractor selected to undertake the conversion of the remaining trial vehicles;
- Provide technical assistance and advice to the Trial Steering Committee regarding the procurement of appropriate recharging infrastructure for the trial;
- Undertake an agreed research program as part of the trial, and share the research outcomes with the trial participants.

The final task above was shared with the UWA Business School.

Stuart Speidel is the PhD student in the ARC Linkage grant working on 'Optimisation of Electric Vehicle Infrastructure'. In addition, Stuart has worked on the implementation of the technical infrastructure, including black boxes, recharge stations, software and related systems to allow operation and gather data.

Charging Arrangements: UWA had originally installed two 15A power points in an underground car park for charging its two EVs. As part of the ARC Linkage trial, a dual-headed Level 2 charging station (2 * 32A) was installed at two reserved EV-only bays with access to the general public.

UWA Business School—Research

www.business.uwa.edu.au

Professor Emeritus John Taplin is Senior Honorary Research Fellow, Transport and Logistics. In addition, Professor Emeritus John Taplin was ARC Linkage Lead Researcher. The UWA Business School has completed research focused on current fleet users of the converted Ford Focus, a major WA household survey, as well as advisory tasks to the overall trial structure and operation.

Fakhra Jabeen is the PhD student working with the UWA Business School on 'Attitudes to Electric Vehicle Adoption'.

Department of Transport—ARC Linkage Partner, Fleet Participant

www.transport.wa.gov.au

The Department of Transport (DoT) works to provide safe, accessible, sustainable and efficient transport services that promote economic prosperity and enhance the lifestyle of all Western Australians. The Department's Sustainable Transport Energy team has an interest in promoting the development and uptake of alternative fuels and vehicle technologies as appropriate.

The Department of Transport has undertaken the following tasks:

- Part of initial 2009 exploratory discussions with UWA and CO2Smart that lead to initiation of the trial.
- Guidance to UWA and CO2Smart on structure and other matters relating to the successful operation of a trial;

- Prototype Vehicle Testing—purchase of (first) prototype vehicle and provided testing and feedback on performance;
- Regular Trial Participant—purchased and used the converted Ford Focus in a regular fleet setting for period of trial;
- Sponsor ARC Linkage project—financial and in-kind contributor;
- Lead on trial matters relating to (transport) regulatory and policy;
- Financial control via co-signatory of WA Electric Vehicle Trial bank account.

Charging Arrangements: DoT uses a three-phase power outlet in its parking structure to recharge its EV. A dual-headed Level 2 charging station from the ARC Linkage project was installed at the Public Transport Centre on Summers Street, East Perth.

CO2Smart—Trial Management

www.co2smart.com.au

CO2Smart aims to be an integrated electric vehicle services company, working with organisations to lower per-km costs as well as remove vehicle-related CO_2 emissions. This includes correct vehicle selection, the required recharging network and organisational support.

CO2Smart managed the WA Electric Vehicle Trial and undertook the following tasks:

- Initiator of the 2009 exploratory discussions with UWA and DoT that led to initiation of the trial;
- Signing up 11 fleet participants;
- Sponsor ARC Linkage project—financial and in-kind contributor;
- Manager of the WA Electric Vehicle Trial.

As manager of the WA Electric Vehicle Trial, CO2Smart entered into Trial Support Agreements with all participants that set out the following management tasks:

- Trial administration—agenda, chair meetings, minutes;
- Reporting—reporting on trial progress, results and technical problems;
- Issue and risk management—risk plan and addressing issues;
- Legal and contract—lead joint negotiations, drafting and finalising all trial related contracts;
- Financial and audit—maintain accounts, financial reporting and audits;
- Electric vehicles—vendor selection process for vehicle conversions, representing participants in conversion negotiations, monitor conversion process, manage sign-off based on performance benchmarks;
- Fleet management—donor vehicle selection, advice on lease structures, reporting, training and roadside assistance;
- Communications—website, public relations and communications;
- Research—support research program and ensure fleet participants' research questions are answered.

CO2Smart has contracted with UWA for the provision of a number of the above services.

EV Works—Conversion Partner

www.evworks.com.au

EV Works is a leading WA provider of components for electric vehicles as well as a provider of conversion services—converting standard petrol or diesel vehicles to 100% electric. EV Works won a vendor selection process for the conversion of 11 new Ford Focus vehicles to fully electric.

EV Works first completed a prototype vehicle in order to demonstrate the established performance criteria. The Prototype Agreement was signed between EV Works, UWA and the DoT and provided for the following:

- Vehicle to be converted as per set specification.
- Converted vehicle to meet fully all requirements to be licensed;
- Converted vehicle to achieve a minimum range of 100km;
- Converted vehicle to achieve a top speed of at least 120km per hour;
- Converted vehicle to achieve set time-to-recharge.
- Agreed cost of conversion (ex-donor vehicle) of $33,103 (ex. GST) [1];
- Provide a warranty—two years or 30,000km;
- Provide service and maintenance.

Charging Arrangements: EV Works was provided with a dual-outlet Level 2 charging station from the ARC Linkage project. Other than that, EV Works uses three-phase power to recharge cars as well as a self-designed DC charging facility.

1 The base negotiated price of conversion—individual vehicles did vary based on additional requirements or requests.

Telstra—Fleet Participant

www.telstra.com.au

Telstra is one of the largest fleet operators in Australia and has acted where possible to reduce the environmental impact of this fleet. The step towards electric vehicles could provide an additional opportunity to make further improvements and on that basis, Telstra was keen to explore and support the trial.

In the second year of the trial, Telstra sponsored all M2M (machine to machine) GSM connections for data exchange between vehicles and the UWA base station as well as all EV charging stations and UWA, to facilitate collection and statistical evaluation of vehicle and charging data.

Charging Arrangements: An outdoor cabinet, supplying single- and three-phase power was installed at the work depot to charge the EV. Mostly single-phase was used for charging overnight, but occasionally three-phase was used for charging during the day.

Water Corporation—Fleet Participant

www.watercorporation.com.au

Water Corporation is a significant fleet operator in Western Australia and as such has always had a fleet policy that encourages efficiency and lower emissions. Water Corporation has used its fleet as a test centre for new fleet technologies in the past and welcomed the chance to show leadership in the promising technology of electric vehicles.

Charging Arrangements: Water Corporation operates a dual-outlet Level 2 recharge station in order to charge their converted Ford Focus.

City of Perth—Fleet Participant

www.cityofperth.wa.gov.au

Through the City of Perth's strategic planning process the community's expectation became obvious that the capital city should lead in environmental and climate solutions, one aspect of which is access and mobility. A number of programs are in place already in the City's parking portfolio including energy reduction initiatives, carbon sequestration in trees, and sustainable energy sources to reduce carbon emissions.

The most recent example is the construction of a 1050-bay car park in Elder Street, which incorporates smart energy consumption management, solar harvesting and power points for recharging of electric vehicles, although no EV charging stations and no reserved bays for EVs.

The opportunity to be involved with the UWA consortium was taken up with enthusiasm by the City. The City of Perth is an active participant in the ongoing development of alternative mobility that has minimal environmental consequences.

Charging Arrangements: Several three-phase power sockets are being used in various car parks.

City of Swan—Fleet Participant

www.swan.wa.gov.au

The City of Swan was pleased to be associated with the Electric Vehicle Trial Program. It provided valuable insight into the infrastructure and logistical requirements as well as highlighted the future benefits of electric vehicles.

The EV program formed part of the City's strong commitment to supporting environmental improvement and long-term environmental sustainability for our community.

The City of Swan is the largest local authority in metropolitan Perth. It presented a unique opportunity to research the very limits of electric vehicles in terms of range and performance.

Charging Arrangements: The City of Swan operates a dual-outlet Level 2 recharge station in order to charge its converted Ford Focus.

City of Mandurah—Fleet Participant

www.mandurah.wa.gov.au

The City of Mandurah was keen to test the viability of using plug-in electric vehicles as normal fleet vehicles. The trial will enable the City to assess the safety, life-cycle cost, functionality, appeal and environmental impact of the electric vehicle.

The trial contributed towards the City's commitment to be carbon neutral by 2013. This will be achieved by a program of carbon offsets on the electricity source for the car and by using landfill electricity sourced for the car instead of petrol.

Charging Arrangements: City of Mandurah uses either a single-phase or a three-phase power outlet in their workshop, next to the car park, to recharge its converted Ford Focus.

Main Roads WA—Fleet Participant

www.mainroads.wa.gov.au

The recharging and services required by electric vehicles on the main road network was of particular interest to Main Roads WA. The trial will allow an opportunity to reflect on the requirements that may need to be planned for in the future. Main Roads WA also takes seriously the issue of emissions from its own vehicle fleet.

Charging Arrangements: Main Roads WA operates a dual-outlet Level 2 recharge station in order to charge its converted Ford Focus.

RAC—Fleet Participant

www.rac.com.au

The RAC is Western Australia's peak motoring body and will be a key player in educating its members and the wider motoring community about evolving vehicle technology from the internal combustion engine to electric drives.

As the RAC did 100 years ago with the introduction of vehicles, the organisation can play a crucial role on behalf of members by advocating for government policy and the infrastructure required in facilitating the introduction of electric vehicles.

The introduction of electric vehicles also has the potential to significantly affect the services and products offered by the RAC and it was imperative that the organisation be at the forefront of EV development to ensure it can adapt its business to accommodate the new technology and continue to serve and inform its membership in the years to come.

Charging Arrangements: The RAC has been provided, through the ARC Linkage Project, with a dual-outlet Level 2 recharge station at its West Perth headquarters, in order to provide an EV charging service for its members, the general public, as well as to charge its converted Ford Focus. Further, the RAC has purchased a single-outlet Level 2 recharge station for the RAC DTEC Driving Centre at Perth Airport and a single charge point for its new Collier Pass premises in Joondalup, although the latter is for private use only.

The West Australian—Fleet Participant and Media Partner

www.sevenwestmedia.com.au

The West Australian is an important media outlet in WA as well as a key publisher of automobile news and information to the wider community. *The West Australian* will play a key role in shaping public perceptions of sustainable transport options including electric vehicles.

The West Australian also saw the trial as a manner to find direct ways to reduce further the environmental impact of its business.

Charging Arrangements: *The West Australian* operates a dual-outlet Level 2 recharge station in order to provide EV charging service to visitors and to charge its converted Ford Focus.

The Department of Environment and Conservation—Fleet Participant

www.dec.wa.gov.au

The Department of Environment and Conservation (DEC) has the lead responsibility for protecting and conserving the State's environment on behalf of the people of Western Australia. One of the Department's key objectives is to support the development and implementation of strategies to reduce greenhouse gas emissions.

DEC supports initiatives such as this trial of converted electric vehicles to keep Western Australia at the forefront of developments in the field of alternative transport options and to develop the capability within Western Australia to pursue favourable low-emission transport options in the future.

Charging Arrangements: DEC has 15A single-phase wall sockets in underground parking structures at its Perth and Kensington offices.

LandCorp—Fleet Participant

www.landcorp.com.au

LandCorp is Western Australia's land development agency with urban and industrial development projects in the metropolitan and regional areas throughout the State. LandCorp was pleased to be involved in this trial as a demonstration of its commitment to a more sustainable future for all Western Australians.

Charging Arrangements: 15A wall socket.

Trial Management

WA Electric Vehicle Trial Steering Committee

The WA Electric Vehicle Trial Steering Committee was the primary decision-making body of the WA Electric Vehicle Trial. Trial participants and CO2Smart were each entitled to one representative and one vote on the committee.

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