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The transport policy and planning implications of electric cars for Australian cities

Andrew Allan
Barbara Hardy Institute, School of Natural and Built Environments, University of South Australia
Email: Andrew.Allan@unisa.edu.au

Abstract

Mass produced electric cars are about to become a commercial reality in world motoring markets. This phenomenon has been influenced by concerns by policy-makers and the car industry about carbon emissions induced climate change, Peak Oil, and limited non-renewable resources, rather than market demand. In the Australian car market, 2013 potentially marks the beginning of a new era in which Australians will have an unprecedented level of electric or plug-in hybrid car offerings from mainstream car manufacturers, albeit at a considerable price premium over conventionally powered cars. Many of these offerings are plug-in hybrids, however, Tesla, Nissan, Mitsubishi and Renault have or about to launch pure electric cars onto the market, while Holden's Volt, is an electric vehicle with a petrol engine to primarily provide electric current when its battery is depleted. Electric vehicles (including the Volt), pose substantial infrastructure challenges because they potentially require long recharge times or specialised charging infrastructure for fast recharging, their range in pure electric mode is typically 80-90% less than their liquid fuelled equivalents and their energy source (electricity) is derived from the electricity grid rather than from portable liquid fuels. At this stage, there is still considerable uncertainty about how the Australian market will respond to the availability of electric vehicles, but unless some of the infrastructure challenges are addressed, the take up of electric cars in Australia could be limited. This paper explores the policy, infrastructure planning and investment implications of transforming Australia's car fleet to an electric car fleet, using Adelaide as a case study. The findings of this paper provides infrastructure investment and policy suggestions on the changes that need to occur to transform Australia's car fleet to an all electric car fleet.

Key words: electric cars, Infrastructure, policy, parking, renewable energy

1 Introduction

In the Australian passenger car market, electric passenger cars (EVs) are currently a novelty with only the Mitsubishi iMiEV and Tesla Roadster available for purchase. However, given that modern lithium battery powered EVs (passenger cars) have been available to motorists in the United States since late 2011, albeit at a significant price premium, and most mainstream European automotive groups have production ready EVs, it would seem that it is only a matter of time before EVs become a dominant passenger vehicle option in the automotive market, given the political pressure to reduce carbon emissions, oil resource depletion and rising oil costs. However, there are significant technical and practical challenges to overcome before EVs become commonplace which relate to cost, range and

EV recharging. This paper examines the history in bringing EVs to market, what would be involved in transitioning urban automobility in Australia to EVs and the broad policy and institutional changes that would need to take place in order to realize a feasible and enduring EV future.

2 Methodology

This main methodology applied in this paper is that of a review of secondary sources from published documents, literature and other publicly available information from the relevant providers of technologies related to EV. This is then used to generate hypothetical scenarios of future automobility based on assumptions derived from what we know of the technical attributes of current EV technology. The technologies associated with EV, batteries and charging is sufficiently mature to allow reasonable estimates of the kinds of electrical infrastructure transformations that cities with 100% EV will undergo. Nevertheless, the nature of this paper is somewhat speculative, because ICE (engines) are becoming more efficient and the phenomenon of peak oil is delayed as alternative sources of costly oil are exploited, such as Canada's tar sands, coal to oil conversion and oil reserves under the Artic icecap. Projections of what future improvements in EVs is not included in this paper's discussion, however, a doubling of EV battery performance would have dramatic implications for investing an EV future.

3 The Battle to Establish Electric Vehicles (EVs)

In 2012 the private and commercial vehicle fleet in Australia is almost exclusively dominated by either petrol, diesel or LPG powered vehicles, accounting for 99.9% of registered motor vehicles (ABS 2010; ABS 2011). Australia's all-weather road system in its cities and rural regions is generally designed for motor vehicles that are not reliant on road based infrastructure for their operation (electric trams being the exception). It has been a long standing implied assumption in road transport design that road vehicles can carry their own energy source allowing continuous uninterrupted independent vehicle operation over distances ranging from 400km to1500km. The infrastructure that has been provided with roads has tended to relate to road lighting, road drainage and road traffic management, rather than in providing energy to directly power motor vehicles using the road.

From an energy distribution perspective, key reasons for this dominance of petrol, diesel or LPG powered vehicles occurred in the first half of the 20th century because no other energy sources could compete with the high energy density, portability, ease of handling, abundance and relative cheapness of liquid and gaseous forms of fossil fuels. From the early 20th century, market demand for petrol and diesel powered motor vehicles, created rapid incremental improvements in engine technology that quickly eclipsed the progress being made with electric vehicles. Whilst early petrol powered vehicles were crude and unreliable, their relative lightness and vastly superior range found favour in the market place, despite electric motor vehicles being more appropriate as urban vehicles due to their quiet pollution-free operation and greater reliability.

Modern fossil fuel powered vehicles now have sophisticated and complex drivetrains, but given that the fundamental principles of internal combustion engine technology are no different to Karl Benz's 1885 single cylinder petrol powered tricycle, the technological advancements since that time, to use vernacular language, have been more in the form of belts and braces engineering to overcome the inherent shortcomings of using internal combustion engines (ICE) to power motor vehicles (Winfried, 1996). These shortcomings include the low torque and power of ICE powered cars necessitating heavy and complex transmissions to convert the chemical power of the fuel into mechanical energy; the low thermal efficiency of ICE engines (ranging from typically 25-30% for road vehicles to 50% in marine transport applications); the noise associated with exploding fuel inside engines requiring heavy and cumbersome noise suppression in the form of metal exhaust systems and insulation; and the necessity for complicated and sophisticated pollution controls such as catalytic converters to deal with poisonous emissions; and of greatest concern, voluminous carbon emissions. The increasing challenges and costs in sourcing fossil fuels, which are becoming scarcer as the phenomenon of peak oil is approached is a significant shortcoming of fossil fuel dependence, but nevertheless, one that manifests itself with high fuel costs for operating ICE powered vehicles (ICEV) (Anderson & Anderson, 2010).

Electric vehicles (EVs) are not a new idea and a reflection on the history of electric motor vehicles produces almost as a sense of déjà vu. At the conclusion of the 19th century and up until the start of the First World War (1914), it did appear that the future of mechanized independent road based motor vehicles was with electric vehicles. Indeed, the 100km/h speed barrier was first exceeded in 1898 in a French electric car near Paris, in a Jeantaud Duc, setting a new land speed record (Anderson & Anderson, 2010). Numerous makes of electric vehicles quickly appeared on the market, although their high cost limited their widespread adoption in the market place. Interestingly, because paved roads were initially limited to urban areas and most rural road networks were at best rudimentary, motor cars were largely an urban phenomenon, which suited the limited range and low operating speeds of electric cars. The range of early electric cars with their lead acid batteries (80-120km) almost rivalled that of electric cars in more recent times, but this was achieved by restricting their top speed to around 20-25km/h (Anderson & Anderson, 2010). However, by 1908, petrol powered cars such as the Model T Ford undercut the cost of electric cars and their on road performance was far superior, with cruising speeds of 60km/h possible over a range of 300km. Intercity and rural travel thus became feasible as the technology improved in ICE cars, opening up a world of land travel options even if the reality of the road system restricted most motoring to the paved roads of urban areas (Douglas B, 2003). World War 1 (1914-18) was also an incredible catalyst to refining ICE technology as military aviation demanded high power to weight engines that could only be achieved through the use of petrol/diesel fuels in internal combustion engines. With the rapid acceleration of ICE technology from World War 1 that has continued up until the present, investment in electric powered road vehicles lapsed until the 1980s. In the 1990s, General Motors EV1 and the Honda Insight were the first tentative modern EV efforts by mainstream global manufacturers using lead acid batteries and latterly nickel metal hydride batteries. Although these were practical and functional creations, in order to help bring them to the market, they required massive subsidies and a lease only arrangement to offset their fivefold cost premium over an equivalent ICE powered car (Anderson & Anderson, 2010).

It is perhaps relative, but whilst the electric car in isolation is functional and feasible road transport, considerable challenges remain in matching the performance and utility levels of equivalent ICE powered motor vehicles. Originally lead acid batteries (then subsequently nickel metal hydride batteries) were the favoured choice of electric car manufacturers because although the energy density was low, they could be fully drained and yet cope with many recharge cycles with minimal degradation of the battery over a long period of time. Indeed, practically all ICE powered cars still utilize lead acid batteries to run their electrical systems. The newer lithium-ion batteries currently favoured for future electric cars and plug-in hybrid cars provide 4 times the energy storage density of lead acid batteries, but the longevity is severely shortened by as much as 80% from a preferred industry targeted 10 year lifespan if fully discharged in each cycle. The battery temperature also needs to be continuously maintained within a narrow temperature range of between 6C to 38C, even when not being used. In extreme climates, this implies that the greater energy efficiency of such batteries may be compromised by the requirement to heat or cool the battery packs. Sophisticated computers and software are now able to manage these challenging battery management requirements, however, the cost differential between electric cars and their ICE powered equivalents is still a factor of 2-3 times, and driving range is typically 20-25% of what the most efficient contemporary ICE cars are achieving (Miller et. Al, 1999; Gerssen-Gondelach SJ & Faaij APC, 2012)

The economics of battery power are daunting, with each kilowatt hour of electrical storage capacity currently costing about $1000. For an electric car to have the equivalent energy storage of a petrol engine car in the same size class, the costs can be prohibitive. For example, while there is no direct ICE powered equivalent for the Nissan Leaf, ICE powered cars in this size category (small to medium 5 seat hatchback car with an unladen kerb mass of about 1200kg-1400kg) would have a 50 litre petrol or diesel fuel tank able to store approximately 1750MJ of energy, although the relative poor efficiency of ICE engines means that perhaps no more than 40% of that energy can be converted into motive power and to power various vehicle ancillaries such as lights, electronics, ventilation, drivetrain temperature regulation and climate control. A battery that is capable of storing this level of energy, would need to be able to hold 486kW.hr of electrical energy, although because electric cars achieve energy conversion efficiencies of around 85% or better, a battery storage capacity of 229kW.hr could suffice. Unfortunately, the physics complicate the story even further however, because whilst the petrol in a full 50 litre petrol tank would weigh approximately 36kg, a 229kW.hr battery array would weigh a staggering 2.8 tonnes based on an energy density for lithium ion batteries of 12.3kg/kW.hr (the performance achieved by General Motors battery array in the electric-petrol Chevrolet Volt) and a volume of nearly 400 litres (based on a volumetric energy density of 0.6 kW.hr/litre). The cost of such a large battery array based on current economics would be around $229,000. Inexorably, direct engineering attempts to translate the current transport utility of an electric car with their ICE powered cousins, at least in terms of matching range, results in absurdly hefty vehicles. For example, providing a Nissan Leaf with the energy storage capacity to match an equivalent ICE powered car in the same size class would result in an unladen car weighing 4200kg or 3 times the weight of an ICE powered equivalent. The actual energy required to propel such a vehicle would be directly proportionally related to its kerb mass (on a 1:1 ratio), virtually eliminating the energy efficiency gains of electric motor power over current ICE technology. If the power-weight ratio is maintained in attempting to achieve this equivalence in range, then performance may not be degraded, nevertheless, energy consumption is likely to be considerably more given that acceleration is a function of the size of force applied to a given mass (i.e. force=mass x acceleration) (Anderson & Anderson, 2010).

Electric vehicle packaging is also problematical with battery packs requiring 3-4 times the space and weight of ICE fuelled fuel tanks, despite yielding only 20% of the range of their ICE equivalents, meaning that the luggage carrying capacity and passenger space is compromised. There are however, some clever tricks available to stretch the range of electric vehicles such as regenerative braking (which captures the car's kinetic energy when slowing to a stop or coasting down a hill), and managing accessories such as ventilation and air-conditioning to minimize energy consumption (Anderson & Anderson, 2010). The drivetrains in electric vehicles can also be much more compact, with innovations such as compact in-wheel electric motors providing car designers with much greater flexibility in vehicle packaging.

Because of the technology of regenerative braking, EVs achieve their best range and are at their most efficient in terrain that permits considerable coasting on downhill runs or in stop/start driving where there braking has to be applied over regular short intervals (i.e. every 1-2km). These conditions make EVs well suited to low speed grid based urban street networks with numerous intersections. Unfortunately, they are not suited to high speed urban motorways or freeways (with speed limits of 90km/h or more), where the drain on an EV's powertrain is extreme, unrelenting and continuous. Petrol Electric Hybrids Vehicles such as Toyota's Prius are also at their weakest in such conditions because once the battery is depleted, in the absence of regenerative braking, the car becomes completely reliant on its petrol motor for its mobility. This results in even worse energy efficiency because the petrol engine has to carry the dead weight of both the electric drivetrain and depleted battery pack. In practice, however, regenerative braking can be used often and it allows the Prius to achieve an exemplary average fuel economy of around 3.9l/100km 47% better than the ICE powered Toyota Corolla (7.3l/100km), its closest equivalent class of car size (Australian Government, 2012).

With mainstream EV designs such as the Nissan Leaf, Mitsubishi iMiEV, Renault Fluence and Chevrolet Volt (an EV with an ICE generator), the motor vehicle industry has settled on EV characteristics that are the best compromise between daunting economics and minimum performance criterion that ensure that contemporary EVs can compete with their petrol powered equivalents in urban settings (i.e. maximum cruising speeds of 120km/h, a top speed of 140km/h, a range of 120km , an ability to maintain travel at urban speed limits of up to 80km/h in hilly terrain and competitive acceleration up to 80km/h). As at the start of the EV era at the beginning of the 20th century, independent EVs are not viable for long distance travel in rural locations unless they use the range extending technology in the form of an ICE to provide additional electric charging (as does the Chevrolet Volt) (Anderson & Anderson, 2010). For EVs to succeed in the battle to shift consumer preferences away from ICE powered cars, consumer expectations will need to accept the limitations of EVs including their restriction to just urban use. However, unless EVs can be built to provide the same functionality and utility as ICE powered vehicles, at least in urban settings, for an equivalent price, the market place is unlikely to warm to EVs, at least judging by US experience to date with the Nissan Leaf and Chevrolet Volt where sales are trending below the manufacturers' original sales projections (Anderson & Anderson, 2010).

If it is accepted that EVs must have minimal weight, yet be capable of realistic range in an Australian metropolitan setting and at an affordable cost with little or no cost premium over their ICE powered counterparts, then in the absence of a revolutionary improvement in battery technology, there will need to be a considerable investment in EV battery charging infrastructure to compensate for the significant range limitations of EVs. Perhaps motorists' attitudes can be modified to accept the range and performance limitations associated with EVs, however, this cannot be taken as a given, and it would seem that EVs will need designed to be as seamless and easy to use as their ICE powered counterparts. Charging infrastructure would be the way to decouple the energy storage constraints (related to the mass and volume of batteries) from the operation of EVs (Hirshb & Sovacoola, 2009)

A threefold approach to EV infrastructure could be pursued: (1) slow recharging option of EV batteries in stationary settings that is not time limited (i.e. slow low current recharging); (2) a fast recharging option of EV batteries in a stationary setting that is time limited to 10 minutes (i.e. fast high current recharging or battery pack swapping); and (3) a dynamic recharging option for when the EV is in motion (i.e. in a similar manner to how electric current is utilized by an electric train or tram through overhead wires or an electrified surface rail). The International Electrotechnical Commission (IEC) does provide technical standards for four static charging modes but does not take into account induction charging options (*mode 1: conventional standard sockets (16A) to the mains; mode 2: high current (32A) sockets to the mains; mode 3: dedicated EV charging from the mains using a 32A current; and mode 4: high current (400A) dedicated EV charging* (http://en.wikipedia.org/wiki/IEC_62196). Stationary settings would include both off-street and on-street settings. Off-street settings include private homes and businesses with protected and secure access to an electric charging point usually with undercover parking. In on-street settings, the charging point would need to be in a weather-proof housing. Unfortunately, most of the current consideration by government and mainstream car manufacturers has focused on the first approach for EV infrastructure (i.e. slow recharging in stationary settings), although Renault in conjunction with the Better Place company have developed a battery swapping EV that does fulfill the time limit criterion of the second option.

With regard to the third option, the Siemens Company of Germany is currently researching inductive charging, using wires embedded just beneath the road surface of parking areas and roads For larger vehicles such as trucks and buses, electrical power could be accessed via a pantograph mounted on the roof of the vehicle that draws electrical current from overhead wires in a similar set up to electric trams. Overhead wires would prove impractical for small EVs because of the large height of suspended wires above the roadway but for dedicated bus transit routes and intercity freight routes, they could pure electric only operation. Unlike the first option and to a lesser extent the second option for EV charging infrastructure where a switch to EVs is largely determined by the vehicle purchasing preferences of private motorists and motor vehicle manufacturers' EV product offerings, government will need to take a lead role in investing in dynamic electrical charging infrastructure on public roads and in creating a regulatory environment that enforces the motor vehicle fleet to become electrically powered or hybrid electric vehicle-ICE hybrids (HEVICE) (Siemens 2012). One key advantage with the road induction option is that EVs could be made lighter with smaller batteries because range would not be as much of an issue as it is with pure battery EVs. The downside of road induction based EVs with minimal batteries is that the demand for road induction EV electrical power will be instantaneous with limited opportunities for power utilities to manage or control demand as is possible with encouraging EV owners to charge their EV at home overnight during off-peak power demand periods.

A further market based challenge to the take up of EVs is that the purchase, operating, depreciation and disposal costs no worse than that for an equivalent sized ICE powered car. EVs compete well on operating costs but even there, much misinformation abounds in the media of with fanciful efficiency claims being made, and the media not making fair comparisons of minimalistic EVs with the equivalent class size of ICE powered car. The energy running cost advantage in the Australian market for running the Mitsubishi EV over its ICE powered cousin (a 1.1 litre Mitsubishi Colt) is a 46% saving (4.19c/km versus 7.83c/km based on electricity at 26c/kW.hr and unleaded petrol at $1.45/litre). However, if the battery replacement cost is factored into the operational running cost, then the iMiev is likely to cost 20c/km, which considerably undermines its competitive edge over ICE powered vehicles. Given that the Mitsubishi iMieV currently costs about $50,000, a motorist would have to drive over 800,000km to recoup the extra cost of this EV over its ICE powered equivalent (currently a $20,000 car). The purchasing cost handicap of the iMieV or any other EV for that matter, is then likely to manifest itself in depreciation particularly if the batteries require replacement at around 100,000km (currently at least a $16,000 prospect in an EV about the size of the iMieV). Consumers also need to be provided with a better idea of what the lifespan of an EV is when compared to an ICE powered vehicle. ICE powered vehicles generally have a lifespan of 12-15 years in the Australian vehicle market, whereas with EVs, it is 8-10 years if it is dependent on the lifespan of the battery (Mitsubishi, 2012).

If policy-makers are intent on making EVs a significant component of the Australian vehicle fleet, then it will be essential to introduce policies that make the economic argument compelling. With Australian households facing the prospect of rapidly rising electricity costs with the introduction of a carbon tax in 2012 and new investment in renewable forms of power generation and modernisation of electricity networks, it remains to be seen whether EVs can maintain a significant energy operating cost advantage over ICE powered vehicles unless petrol, diesel and Liquid Petroleum Gas (LPG) escalate in price much more quickly than electricity prices. This would mean reducing the upfront price of EVs through grants, placing higher purchase taxes on ICE powered vehicles and providing innovative financial mechanisms such as through leasing to spread the battery costs over the life of the vehicle.

The six main policy challenges facing the introduction of EVs to the Australian vehicle fleet are:

(1) Operating costs and residual vehicle values. This relates to battery longevity and the cost of replacing batteries.

(2) Technical limitations of EVs (essentially revolving around the issue of 'range anxiety').
(3) The charging infrastructure for EVs. Because of EVs limited range, they will need frequent recharging, often away from their home base. Significant public and private investment will be required to provide charging infrastructure in car parks and in roadways to support EVs. Safety standards will also require consideration in high current charging installations.
(4) Upgrading the power grid to cope with the demand form EVs. EVs could in theory add a substantial power demand to the electricity grid. Sophisticated energy supply management may control the peaks, but investment in power generating infrastructure will need to be sufficient to cope with whatever may be demanded in a switch to EVs. Widespread take-up of EVs (i.e. at market saturation level), could result in electricity demand for EVs being instantaneous and therefore occurring during peak electricity demand periods. If on demand road induction charging were adopted, EVs would probably have minimal battery packs (i.e. similar to that of current hybrid cars), which would contribute to uncontrollable spikes in electricity demand from the electricity grid. Power generation capacity would therefore need to be sufficient to cope with a worst case demand scenario to avoid traffic gridlock that could occur from a lack of electricity generation capacity.
(5) Regulation of EVs (registration and taxing of EVs). In encouraging motorists to switch from ICE powered vehicles to EVs, subsidised registration costs may be required. The loss of fuel tax revenue raises particular concern about substitutes for this stream of government revenue.
(6) Educating the public about the advantages of EVs over ICE powered vehicles. Pricing is usually the dominant signal in heralding a change in consumer sentiment. However, if a product is sufficiently innovative and achieves outstanding outcomes (such as having no net effect on the environment while providing competitive performance and utility), then consumers may be prepared to pay a premium. The extraordinary take-up of solar electricity systems by households in South Australian (1 in 6) demonstrates what can be achieved through a combination of technology, government grants and community sentiment about wanting to take action to minimise greenhouse gas emissions (Energy Matters, 2012).

The history of the electric car has shown that society, industry and government have favoured investment in the transport technology that is the most commercially competitive. The preference by the world's automotive industries, governments and consumer markets for ICE powered cars over electric cars during the past century of automotive development has occurred because ICE technology's performance attributes (with the exception of emissions), has appeared to be superior. However, if these aforementioned policy challenges can be solved, then the EV has a much greater chance of displacing ICE powered vehicles on Australia's roads.

4 Transitioning urban automobility towards EVs

Research in Australia on the feasibility of take-up for electric cars has tended to focus on the typical maximum daily commuting distances travelled by car for residents residing in Australia's capital cities and the capacity of the existing electricity grid to cope with switching the motor vehicle fleet from ICE powered vehicles to EVs. The majority of residents in Australia's capital cities could comfortably manage their return trip car commuting requirements from home to work within even the most pessimistic estimates of the current EVs range (around 80-100km) (AG, 2010). The increased demand for electricity would result in a 15% increase in Australia's demand for grid generated electricity from 9396PJ to 10791PJ (using 2008/09 figures as a baseline), which is equivalent to adding 22 new coal fired power stations of 2 GW. Growth in energy consumption in Australia during the period 2000-2009 averaged 1.6% per annum, hence in projecting electricity requirements a decade into the future, in the absence of further growth in the share of renewable power, transport related power demands could escalate to the equivalent of 26 power stations (AG, 2011). Power generated from renewable sources would dramatically change these estimates because thermal power stations have efficiencies of only 30%, which is equivalent to that achieved with the most efficient ICE powered vehicles (Buggea et. al. 2006). However, the intermittent nature of power derived from renewables such as solar photovoltaic systems and wind power may require more installed capacity to cope with this variability. Thermal solar power using molten salt as a heat storage medium can overcome the obvious limitation of the diurnal nature of solar power however there is still variability that occurs in cloudy conditions. This is an extreme estimate of anticipated power demand, and in practice, the transition to an electric car fleet would be more gradual (Medrano et. al. 2010). It should be noted that on demand road induction charging for EVs reduces the options for off-peak EV charging because peak EV electricity demand would most likely occur in peak travelling times which are likely to coincide with peak demands for static electrical power, particularly during hot summer afternoons when air conditioner usage is usually highest. Moreover, if road induction charging were universal, then it is likely that EVs using this system would have minimal battery packs that allow less scope for spreading electricity demand across the day, through encouraging EV recharging during off-peak periods. Some work has been done by the UK Government on predicting the impacts of increased electricity demand from EVs, suggesting that electricity demand management could spread anticipated additional electricity demand from EVs to off-peak periods so that no new electricity generation capacity would be required. However, this UK work based their claim on EVs constituting no more that 12% of the total UK motor vehicle fleet. If the UK had 100% of its motor vehicle fleet as EVs, it is likely that significant new electricity generation capacity would be needed (UKG, 2011).

It has been argued that far from increasing the need for power generation capacity, the battery systems of electric cars can become an active storage system for smoothing out the peak demands for electrical power that characterizes electricity usage (CCES, 2012). This assumes that EVs plugged into the grid for recharging would only do so at night (i.e. between 11pm and 6am) when there is unutilized power generation capacity. It also assumes that EVs would be continually plugged into the grid when they are not used for travelling (i.e. parked). These are somewhat heroic assumptions, because it is predicated on every EV owner being able to plug their EV into the electricity grid at night to recharge and capture off-peak power; that every EV owner can plug into the electricity grid when their EV is away from their home base (e.g. parked at a workplace, shopping area or other facility); that sufficient numbers of EVs will be plugged into the grid to provide an on-demand release of stored electricity from their batteries to feed back into the grid; and that every EV owner would consent to allowing their EVs to release power into the electricity grid. The last assumption is a particularly significant challenge because owners will be aware that the more charging cycles their battery is subjected to, the more quickly their EV battery's lifespan will reduced. Furthermore, because EV battery management (at least for lithium ion batteries), aims to have no more than 60% of the battery depleted, there needs to be sufficient charge remaining in the battery to allow the EV owner to complete their intended trip. With EV range in a Nissan Leaf typically only 120km, an EV commuter intending travel of 60km for the day would require a 'reserve' to protect the battery life of around 50km range, leaving a mere surplus for feeding into the grid of 2-3kW.hr (Alterman, 2009). It is debatable whether EV owners would put up with the risk of coming back to an EV with a partially or fully discharged battery because the electricity utility required its charge to smooth out its peak load electricity demands. The range in current EVs is so limited that it is not practical to assume that motorists will put up with the inconvenience of using their vehicles as an aid in electricity demand management of the electricity grid. The exception to this judgment would be if EV owners were financially compensated to not only cover the expected reduced life of their EV battery from peak power electricity demand management, but the stress of even greater range anxiety than what is normally the case. If battery range for EVs can be sufficiently improved, then the use of EVs as a tool by electricity utilities to control demand management may no longer be such a concern to EV owners, however, there would need to be behavioural research of potential EV owners to determine what tradeoffs in motoring utility EV motorists are prepared to accept in selling their power to the electricity grid.

The other shortcoming in the notion of using EVs to draw power off-peak from the electricity grid at night is that unless the power is wind generated, then it is likely that electrical power for recharging will be sourced from carbon emissions intensive thermal power stations burning either coal or natural gas. More widespread adoption of large scale solar power, particularly in the regions of Australia with a high level of insolation, should mean that EVs have a greater likelihood of being charged with renewable energy rather than carbon emission intensive electricity produced from burning coal or gas.

To ensure that people have confidence in EVs, there needs to be sufficient charging capacity in the electricity grid to ensure that there is on demand recharging of EVs whenever motorists require it. While ICE powered cars do not have universal opportunities to refuel, the large range of ICE powered vehicles (500km-1500km) on a single tank of fuel effectively allows for on demand vehicle operation (AG, 2012). If there is to be a switch to EVs, then early adopters of EVs need to have confidence in the reliability of this mode of transport with range anxiety reduced to an absolute minimum. Unexpected EV battery depletion through the application of electricity demand management practices will not achieve that outcome.

Apart from the high capital outlay and battery life limitations, EV range limitation remains its Achilles heel in considering the level of EV take-up by motorists. Currently, a flat battery in an EV is completely immobilizing, necessitating physical removal of the vehicle to a charging facility. Modern computer electronics, software programming and GPS in the Nissan Leaf, at least in the US market, very cleverly manages this tricky limitation. Because US metropolitan road systems are generally freeway systems with limited access points, Leaf drivers need to be constantly updated of the state of battery charge for their EV with the car's computer providing instructions to avoid the vehicle becoming stranded in a location with no charging facility.

In overcoming the range limitation of EVs, it would be desirable for EV charging infrastructure to be omnipresent. For example, through the use of inductive charging, every parking space could become a charge point. Indeed, the road space could become a battery charging facility. The advantage of this system of EV recharging is that it would be everywhere, providing recharging for when EVs are stationary as well as in motion. It would also allow a decoupling of EV mass associated with heavy battery backs thereby allowing EVs to become almost as light as their ICE vehicle equivalents. The current approach to recharging is to tether a special electric cable to the EV's charging socket, a somewhat cumbersome undertaking and an action that would need to be done whenever the vehicle is parked. While drivers of ICE powered vehicles may only need to 'tether' their car to a fuelling pump once every 600km (or once a fortnight), the EV driver would potentially have to do the same tethering to recharge 4 times a day and 28 times per fortnight (i.e. where either connecting the charge line or disconnecting the charge line each constitute single tethering actions). Siemens (2012) indicate that the transmission losses with inductive charging do not exceed 5% and that there is no risk of people being exposed to dangerous current or electromagnetic radiation when walking over the induction coils that are embedded under the pavement surface. However, this technology is still very experimental in this proposed application of providing electric current to EVs (although the technical principles are well established), and because of this, cost and the willingness of EV motor manufacturers to adopt this technology is currently unknown.

The challenge for the EV sector is in providing a motoring experience that is as seamless and easy to use as conventional ICE powered vehicles. In theory, with the right infrastructure, EVs could be much less trouble to use than that experienced for ICE powered vehicles. For example, universal adoption of induction charging would mean that EV drivers never have to physically connect their vehicle to receive energy in much the same way that householders do not have to think about accessing the power that enters their households. Billing systems for the electrical power used would advise EV owners of their power consumption and usage patterns. The plus of a charging induction system is that it reinforces in the minds of the community that EVs are clean and trouble-free effectively banishing visits to service stations to history. The downside of a non-visible EV battery charging system is that drivers of ICE powered vehicles fail to recognize the new automobility paradigm. Making EV motoring high profile, highly visible and different and appealing to the automotive market becomes a challenging marketing issue.

The company Better Place (BP, 2012), appear to be pursuing a model of electrical energy distribution for EV that attempts to replicate the service station model for ICE powered vehicles through a battery swapping model and a network of strategically located charging posts at public parking spaces around Australian cities. Renault's Fluence Z.E. is an EV passenger sedan currently developed for this system, and it is designed to accommodate a 22kW.hr battery pack of around 250kg in weight providing a theoretical range of 180km. The EV Battery Swapping Stations (EVBSS) for the Renault E.V. resemble the petroleum service station (PSS) model for refueling ICE powered vehicles except that the handling of energy requires considerably more brute mechanical force to transfer the energy from the station to the vehicle (250kg of battery weight compared to 4kg of fuel at a similar energy to weight density and engine efficiency utilisation). The system that Better Place have designed cleverly places the storage facility under the service station parking apron and the EV receives its replacement battery via a service trench that the EV parks over. This system has two key advantages, the first being that it has a high visibility and at least psychologically, will ease the anxiety of motorists in making the transition from ICE powered to EV because there would be no change in mindset; and the second advantage is that the swapping of battery packs is virtually invisible, taking place under the EV with battery pack storage located underground. The drawbacks are in how the battery packs are delivered to the EVBSS. If the batteries are charged in a central location and then trucked to the EVBSS, the relatively low energy density of batteries compared to petroleum based fuels would result in a tenfold increase in energy usage from trucking traffic, unless much higher trucking loads are permitted on urban streets.

A more environmentally sustainable solution would be to charge batteries on site at the EVBSS which would have the advantage of dispensing with the need to transport the battery packs. Interestingly, if fast recharging were incorporated into the EVBSS, with around 10 recharge cycles/battery/day, then the volume of operational area need not be much larger than what underground fuel tanks require for today's petroleum based service stations. There would however, be significant complexity in delivering the 40,000kW.hr of stored electrical charge/day, to provide the recharge power likely to be demanded by the 2000 motorists (equivalent to a busy petroleum based service station) (SSA, 2012). The electrical substation needed to deliver this volume of power, is however, likely to result in an EVBSS being on a considerably larger scale than a petroleum based service station. However, when the scale of total infrastructure needed for refining, shipping and bulk storage of petroleum products is taken into account, EV charging infrastructure may not have any more land take. Currently, Australia has a network of approximately 8,000 petroleum based service stations. A substitution of a network of EVBSS would have to be on a similar scale, indicating the enormity of the transition. It is unlikely that EV charging infrastructure could be incorporated into existing PSS, and instead, the replacement would need to be undertaken as a one for one substitution. From a land use planning perspective, the advantage in a gradual substitution of EVBSS for PSS is that land use planning controls would only require minimal modification to effect this transition. However, a question mark arises over whether Oil Companies would allow PSS to be transferred to operators of EVBSS because it represents a competing technology, unless government policy is able to restrict anticompetitive practices. Massive electricity transmission cables would be needed to connect EVBSS to the electricity grid and in densely developed urban areas, this would pose a significant infrastructural planning challenge.

Over time, the optimum outcome would be a metropolitan wide network of induction coils under all public roadways and in every long stay parking space (both private and public). As with the EVBSS system, there will need to be a program of infrastructure investment on a comparative scale. The roll-out of such a project would have to be staged over at least a decade and it may be dependent on EV manufacturers providing a sufficient supply of EVs suited to this technology. It would be preferable to go the induction coil route for recharging so that direct handling of a charging tether is unnecessary. Because this system is not commercially available at the current time, in the interim, early recharging infrastructure is likely to be home based or have limited numbers of parking spots located around urban areas in the form of charging posts with weather proof charge plug in points. Although companies such as Better Place are currently rolling out this model of charging provision on a limited basis in Australia's largest capital cities, it should not be viewed as the way of the future for EVs. From an urban design perspective, there is already far too much visual clutter in our urban environments, and installing even more poles and charging devices will simply add to the clutter.

Table 1 provides a hypothetical arrangement for gradually transitioning road transport in Australia towards a national passenger car fleet that constitutes 100% EVs. Initially, market penetration would be minor, however, an annual doubling of EVs' sales as a share of total sales would result in 100% market saturation within 10 years. However, the long period that Australians retain their cars for would require an additional 13 years before the ICEV passenger car fleet is retired and replaced with EVs. The rapid take-up of ICE powered vehicles with the release of the Model T Ford in the United States in 1908, culminating in the President Eisenhower's National System of Interstate and Defense Highways that commenced in 1956 and was completed by 1990, provides an indication of the timescale involved in securing major change (Anderson & Anderson, 2010). China's transformation to a personalized motorized society by comparison has only required 15 years with China's automotive sales (OICA, 2011) and national freeway system (Cox, 2011) have recently surpassed what the United States required over 70 years to achieve, admittedly interrupted by the austerity of two world wars and the Great Depression. The rapid take-up of IT technology (for example, mobile or cell phones), demonstrates that if the market recognizes the superior value of a product or service, then take up of the technology can grow as quickly as the product can be manufactured. With EVs, the take-up should not take as long because existing road infrastructure can be used by EVs. Furthermore, people would not have to make major lifestyle changes in adapting to EVs in the way that cities were transformed by private car ownership in the United States during the early 20th century. The installation of induction charging in roadways will be costly and a considerable infrastructure challenge, however, given that many bitumen pavements require resurfacing or even rebuilding every 7-10 years, the timeframe for installing induction charging in roadways need not be as drawn out as the building of the United States' interstate freeway system.

Market dominance of EVs is less likely to be achieved if the charging infrastructure is not upgraded at a commensurate rate. Table 2 illustrates what is likely to happen with a full switch from ICEVs to EVs in terms of the transformation of energy distribution from petroleum fuels to electricity charging infrastructure in the Australian passenger vehicle market. Petroleum based service stations (noted as PSS in the second column) would probably increase to a peak in 2020 in line with the growth in the national passenger car fleet, before declining rapidly over the next 14 years as ICEVs are retired, until effective elimination around 2035. Range extending hybrids that use an ICE as an electrical

Table 1: Phasing out of Australia's ICEV fleet in favour of an all EV fleet

Year	Australian passenger car fleet	Scrapped passenger cars	New vehicle growth	Total sales of passenger cars	New EV sold	% of new cars as EV	EV fleet size	% of passenger car fleet that are EV	ICEV fleet size
2011	12,474,044	748,443	274,429	1,022,872					
2012	12,760,947	765,657	286,903	1,052,560	1,053	0.1	1,053	0.008	12,759,894
2013	13,054,449	783,267	293,502	1,076,769	2,154	0.2	3,207	0.02	13,051,242
2014	13,354,701	801,282	300,252	1,101,534	4,406	0.4	7,613	0.1	13,347,088
2015	13,661,859	819,712	307,158	1,126,870	9,015	0.8	16,628	0.1	13,645,232
2016	13,976,082	838,565	314,223	1,152,788	18,445	1.6	35,072	0.3	13,941,010
2017	14,297,532	857,852	321,450	1,179,302	37,738	3.2	72,810	0.5	14,224,722
2018	14,626,375	877,583	328,843	1,206,426	77,211	6.4	150,021	1.0	14,476,354
2019	14,962,782	897,767	336,407	1,234,174	157,974	12.8	307,995	2.1	14,654,786
2020	15,306,926	918,416	344,144	1,262,560	323,215	25.6	631,211	4.1	14,675,715
2021	15,658,985	939,539	352,059	1,291,598	648,382	50.2	1,279,593	8.2	14,379,392
2022	16,019,142	961,149	360,157	1,321,305	1,321,305	100	2,600,898	16.2	13,418,244
2023	16,387,582	983,255	368,440	1,351,695	1,351,695	100	3,952,593	24.1	12,434,989
2024	16,764,496	1,005,870	376,914	1,382,784	1,382,784	100	5,335,377	31.8	11,429,119
2025	17,150,080	1,029,005	385,583	1,414,588	1,414,588	100	6,749,966	39.4	10,400,114
2026	17,544,532	1,052,672	394,452	1,447,124	1,447,124	100	8,197,089	46.7	9,347,442
2028	17,948,056	1,076,883	403,524	1,480,408	1,480,408	100	9,677,497	53.9	8,270,559
2029	18,360,861	1,101,652	412,805	1,514,457	1,514,457	100	11,191,954	61.0	7,168,907
2030	18,783,161	1,126,990	422,300	1,549,289	1,549,289	100	12,741,243	67.8	6,041,917
2031	19,215,174	1,152,910	432,013	1,584,923	1,584,923	100	14,326,167	74.6	4,889,007
2032	19,657,123	1,179,427	441,949	1,621,376	1,621,376	100	15,947,543	81.1	3,709,580
2033	20,109,236	1,206,554	452,114	1,658,668	1,658,668	100	17,606,211	87.6	2,503,026
2034	20,571,749	1,234,305	462,512	1,696,817	1,696,817	100	19,303,028	93.8	1,268,721
2035	21,044,899	1,262,694	473,150	1,735,844	1,735,844	100	21,038,872	100.0	6,027

Notes:

1. Assumes annual passenger car fleet growth of 2.3% per year in Australia based on the average annual growth rate for 2001-2011.
2. Assumes 6% rate of passenger car fleet scrapping (average passenger car life of 17 years)
3. Growth of EV fleet doubles on an annual basis until 100% dominance of the passenger vehicle market is achieved.
4. EV-Electric Vehicles
5. ICEV-Internal Combustion Engine Vehicle (Diesel, Petrol or LPG) including plug-in hybrids such as the Toyota Prius, but not electric-petrol/diesel hybrids such as the Chevrolet Volt which have an electric mechanical drivetrain with a petrol engine as an electric generator.

Sources: ABS (2012), ABS (2011) and ABS (2010)

generator complicate the picture somewhat because they may extend the life of PSS, albeit in reduced numbers compared to a business as usual scenario with ICEV. Two options are presented. The first option suggests complete dominance of EV Battery Swapping Service Stations as the primary means of EV recharging, whereas the second option suggests induction of road spaces and parking spaces will provide the main form of EV recharging. Both options are ultimately speculative nevertheless, table 2 does illustrate how either types of charging infrastructure would need to be introduced ahead of or at least consistent with the introduction of EVs. The demand for new power stations would be considerable with new power stations having to be introduced progressively in advance of expected demand for new electricity from EVs. Ideally, this new growth in demand should come from carbon neutral energy sources such as solar, wind and geothermal power. The scale of this undertaking is considerable requiring a potentially vast investment from the public sector on a scale not previously experienced in Australia. Because of the level of planning required, early policy decisions will be needed to ensure that the charging infrastructure can cope with the expected demand from future EVs. There appears to be a lack of research on whether road induction for lightweight EVs would be more energy efficient, less carbon intensive and have less overall environmental impact than battery EVs for the total vehicle fleet. Before any major policy decisions are taken, it would be advisable for policy-makers to complete a thorough comparative environmental impact assessment of the two EV approaches.

Table 2: The Phasing Out of Petroleum Service Stations and Progressive Introduction of Electrical Charging Infrastructure to Support an All EV fleet for Australia

Year	No of PSS	PSS as a % of 2013 number of PSS	OPTION 1: Battery Swapping No. of EVBSS	OPTION 2a: Road Induction Roll Out	OPTION 2b: Induction of parking spaces %	Roll-out of new Power Stations (2GW capacity) to meet EV demand
2012	8185	98	3			
2013	8372	100	8	Urban Main roads-CBD		
2014	8561	102	20	Urban Main roads-metro regional centres		
2015	8753	105	43	Urban Main roads-metro regional centres		
2016	8942	107	90	Urban Main roads-metro regional centres		
2017	9124	109	187	Urban Main roads-inner metro route links		
2018	9286	111	385	Urban Main roads-middle metro route links	1	
2019	9400	112	790	Urban Main roads-middle metro route links	2	
2020	9414	112	1,618	Urban Main roads-middle metro route links	4	1
2021	9223	110	3,281	Urban Main roads-outer metro route links	8	2
2022	8607	103	6,669	Urban Main roads-outer metro route links	16	4
2023	7976	95	10,135	Local urban roads-inner metro	24	6
2024	7331	88	13,680	Local urban roads-inner metro	32	8
2025	6671	80	17,308	Local urban roads-middle metro	39	10
2026	5996	72	21,018	Local urban roads-middle metro	47	12
2028	5305	63	24,814	Local urban roads-middle metro	54	15
2029	4598	55	28,697	Local urban roads-outer metro	61	16
2030	3876	46	32,670	Local urban roads-outer metro	68	17
2031	3136	37	36,734	Local urban roads-outer metro	75	19
2032	2379	28	40,891	Primary Rural main routes (Perth-Adelaide-Melbourne-Canberra-Sydney-Brisbane)	81	21
2033	1606	19	45,144	Secondary rural main routes (Adelaide-Darwin; Adelaide-Sydney; Melbourne-Brisbane; Brisbane-Townsville; Hobart-Launceston; Brisbane-Darwin)	88	22
2034	814	10	49,495	Minor Rural routes (secondary regional highways)	94	24
2035	4	0	53,946	Rural local routes (regional linking rural roads)	100	26

Notes:

1. PSS-Petroleum Service Station (assumes 1559 ICEVs served by one station based on 2011 number of service stations.)
2. EVBSS-Electric Vehicle Based Service Station (assumes 390 EVs served by one station)
3. New Power Stations proposed would only meet additional electricity demand for EVs and not meet demand from additional population growth. Renewable sources may offset the need for this scale of infrastructure. The electrical energy required of EVs is based on the 2009 per capita energy take-up of ICEVs in Australia, with adjustments made for the superior energy efficiency of EVs.
   Sources: SSA (2012); AG (2011)

5 Discussion and policy recommendations

Free market proponents are opposed to market interventions to encourage a change in consumer behaviour (Beggs et. al. 1981). With EVs, the high cost premium at 2.5 times that for equivalent ICEV (using the examples of the Mitsubishi iMiEV and Holden Volt (ne' Chevrolet Volt with Holden branding), it is unlikely that cost conscious consumers will willingly opt for EVs, especially with the reduced vehicle utility, added inconvenience of lack of range and the clumsy tethering arrangement for home recharging. Technically, it remains to be seen if EVs will ever achieve the performance of ICEV in terms of the balance between light vehicle weight, mobility flexibility, space, high speed endurance and range. Road induction is the exception, however, because it would allow low weight EVs. The first policy issue that Australia's Federal Government should address is in minimizing the huge price disparity between ICEVs and EVs. In the absence of EV manufacturers reducing the prices to the equivalent of their ICEV counterparts, grants, tax offsets and reduced registration costs will be needed. Parking benefits and EV dedicated transit lanes may also encourage consumers to favour EVs. However, public sector largesse of this nature can discourage EV manufacturers to improve their products, hence and arrangement is needed whereby subsidies are progressively reduced in proportion to the level of market penetration achieved. Legally binding Carbon emission performance targets (as is already occurring in the United States (EPA 2012) and European Community (EC 2012)) will help to push automotive manufacturers to phase out ICEV that cannot produce low or zero emissions. Unfortunately, because Australia is a relatively small market in global terms, its government and regulators are not in a position to force global automotive manufacturers to build products to suit Australian requirements. However, where global automotive manufacturers have affordable EV available and suitable EV recharging technologies, Australian government policy should encourage their inclusion into the Australian motor vehicle market.

Figure 1 is a schematic diagram that illustrates institutional changes and policy actions that would be needed in Australia to achieve a complete transition from a petroleum powered passenger car fleet to an EV passenger car fleet, ideally powered with clean electricity unsullied by carbon emissions. Some policy actions do not require capital investment but simply require regulation. Others, such as investment in EV charging infrastructure, the need to expand the electricity power supply and electricity distribution network upgrades require a substantial commitment in capital funding. Investment in capital works could be staged to respond to indicative sales trends from EVs as the EV fleet reaches certain size thresholds. Table 2 indicated how the introduction of new electrical power generating capacity (i.e. power stations) and either induction charging or EV battery swapping stations could be progressively introduced to match the growing volumes of EV. Where market demand does not run to trend, government could halt a roll-out of infrastructure until demand improves.

What does present a massive political risk to a the government, is where government introduces public institutional structures on the assumption of a massive switch to EVs, but EVs fail to come down in cost and motorists refuse to switch to EVs. If past Australian Governments are an indication, however, this may not be a problem. When Governments change at either the state or federal level or they change focus due to adverse polling, government departments and ministerial portfolios are changed with rapid speed. Nevertheless, a perception of policies derailing and a lack of popularity in polls of voter satisfaction can restructure departments, policies and even unseat prime ministers by their own party as former Prime Minister Bob Hawke and Kevin Rudd discovered. Australian politics rarely encourages a bipartisan approach to dealing with issues of common national concern requiring an obvious singular policy response, and with relatively short 4 year electoral cycles, the suite of policy measures needed to replace ICEVs with EVs in Australia and the long lead time to complete this change across 4 or more electoral cycles would risk a consistent and uninterrupted implementation of policy. Governments may only begin to act with conviction once it is demonstrated that there is market confidence in EVs and market share begins to reach 10% or more.

One super Federal Government Department, an "EV Department", could have responsibility for the raft of policy measures needed to manage the introduction of EVs with their support infrastructure and new regulatory environment. This would include actions such an Authority to decommission Petroleum Based Service Stations, oil refineries and oil storage; a Regulatory Authority in setting technical standards for EVs; an Authority to oversee new electricity power generation capacity, and a network of EV charging systems and electricity distribution to EVs; and an Authority to manage the financing of EV infrastructure and early support for their introduction. Implicit in this approach is that the Federal Government would have to develop the overall strategy for the introduction of EVs and their associated support infrastructure.

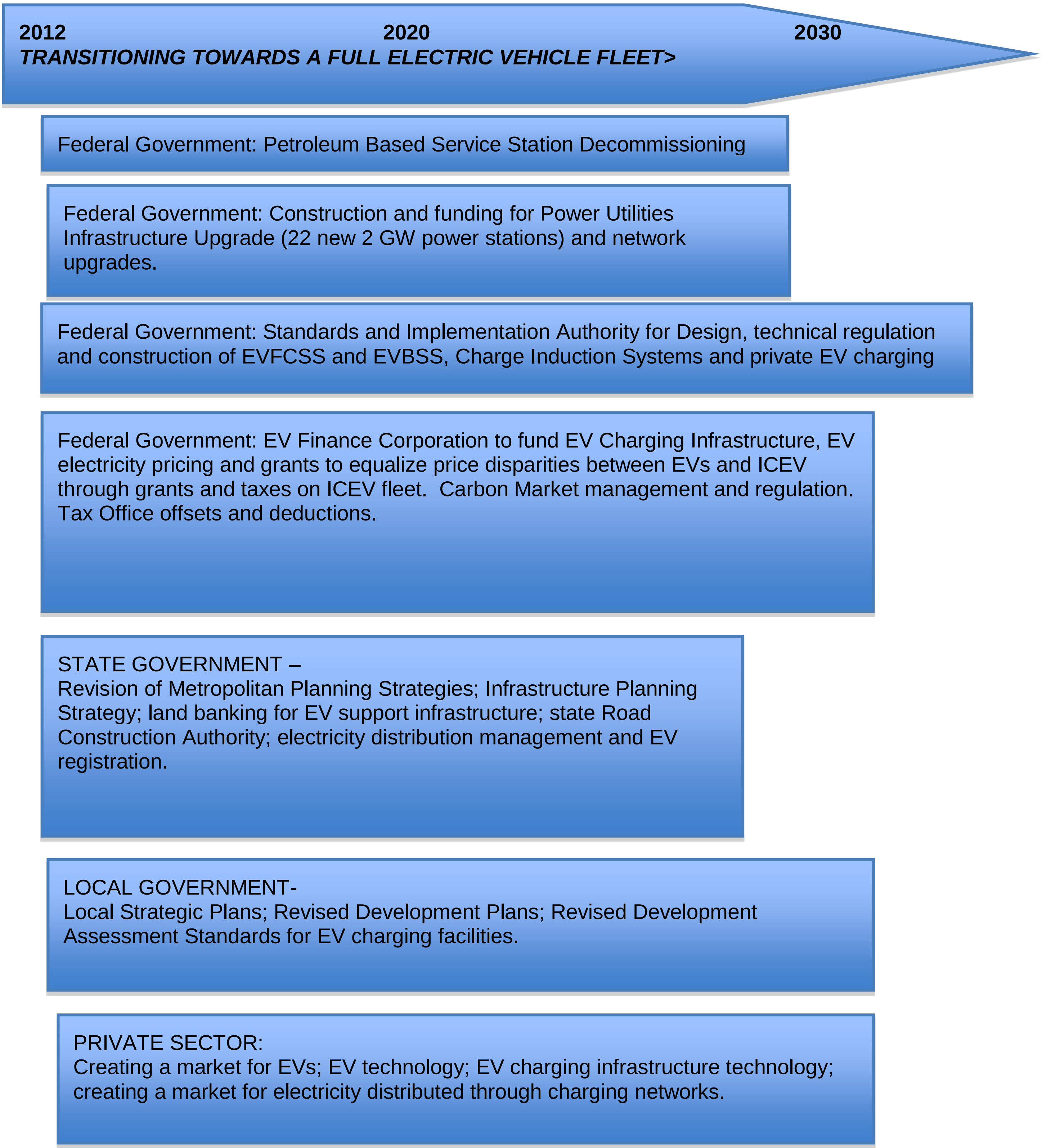

Figure 1: Institutional Changes to Transition to an All EV Fleet for Australia by 2035

Notwithstanding the importance of the Federal Government in initiating a transition to EVs, the role of state and local governments would be critical in strategic planning of infrastructure to support EVs and in ensuring that land use plans are revised in line with the growth of the EV fleet. State Government Transport and Road Departments would also be directly responsible for construction of main roads with inductive charging. Electricity distribution is currently a state government responsibility, however, in this policy model, it is suggested that the Federal Government take over this role to ensure that a consistent national approach is taken to ensuring widespread uptake of EV.

Without the private sector delivering EVs that motorists are willing to buy, Australian government policy will not have much effect in transitioning Australia to an all EV fleet. However, Australia is a substantial motor vehicle market in world terms with over 1 million passenger vehicles purchased annually and 1.7% of world passenger vehicle sales in 2011 (OICA, 2011), hence government can regulate the market to favour EV and low emission vehicles. Unfortunately, with locally produced passenger cars accounting for only 18% of new car sales in Australia in 2011 (OICA, 2011) (ABS, 2012), requiring local manufacturers to switch production to EVs would only have a modest impact on the Australian passenger car market in future. In world terms, Australia's car industry is small and contracting with both its domestic and export markets. Even if innovation amongst local car manufacturers were encouraged, it would not have much impact. From a policy point of view, the challenge for Australian governments is in ensuring that only the best EV technology is adopted. However, not being bound by local industry requirements could be an advantage because Australia is then free to seek out the best EV technology that is globally available.

6 Conclusions and future directions

The Intergovernmental Panel on Climate Change (IPCC, 2012) predicts dire consequences for the world's climate if carbon dioxide emissions from human activities are not dramatically reduced. Since personal automobiles are a major contributor to carbon emissions (15% in Australia (AG, 2011) and up to 25% in the United States(ITF, 2012)), and the world automobile fleet has now surpassed 1 billion cars (HP, 2011), there are compelling reasons to phase out ICEVs in favour of EVs. However, the discussion in this paper has shown that the technical shortcomings (particularly with regard to range) and poor economics that bedevilled EVs at the dawn of the 20th Century continue to create a difficult gestation for EVs relative to ICEV. Rising oil prices associated with Peak Oil and higher costs in extracting future petroleum reserves, may create a stronger economic argument in favour of EVs, however, there is uncertainty when that will be given that the oil industry does not acknowledge that there are any global oil resource constraints into the forseeable future (APEAA, 2012). Projections for full replacement of the Australian ICEV fleet with EVs was discussed, highlighting long period of time involved because EV sales are coming off a virtually non-existent sales base against a mature market for ICEVs. An all EV passenger car fleet for Australia would not be achieved until about 2035 and require substantial investment in electricity recharging, the electricity network and new additional electrical power generation over and above existing normal electricity demand for homes, businesses and industry. There would also need to be significant infrastructure planning, planning amendments and new public sector institutional capacity to manage this transformation to an EV future. Careful management of the economics of EVs, particularly in its early years will be essential in gaining the confidence of prospective motor vehicle consumers that EVs are a practical and affordable alternative to ICEVs. This paper has suggested that under road electrical induction charging of EVs would help make EVs a fuss free alternative to either EVs with swappable batteries or electrical cord tethering recharging systems and rival the high level of mobility flexibility enjoyed by users of ICEVs. Battery technology may improve over time, although it is unlikely to ever achieve the energy density of petroleum fuels, hence investment in electrical induction under roads and parking spaces is likely to be of value to EV users well into the future and allow full cost recovery and ultimately a return on investment.

There are many compelling environmental reasons for EVs to succeed, but it will take a concerted effort by government, the manufacturers of EVs towards better mobility functionality and competitive economics against ICEVs.

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