The Feasibility of Long Range Battery Electric Cars in New Zealand

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ABSTRACT

New Zealand transport accounts for over 40% of carbon emissions with private cars accounting for 25%. In the Ministry of Economic Development's recently released "New Zealand Energy Strategy to 2050" it proposed the wide scale deployment of electric vehicles as a means of reducing carbon emissions from transport. However, New Zealand's lack of public transport infrastructure and its subsequent reliance on private car use for longer journeys could mean that many existing battery electric vehicles (BEVs) will not have the performance to replace conventionally fuelled cars.

As such, this paper discusses the potential for battery electric vehicles in New Zealand, with particular reference to the development of the University of

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Waikato's long range UltraCommuter BEV. It is shown that to achieve long range at higher speeds, BEVs should be designed specifically rather than retrofitting existing vehicles to electric. Furthermore, the electrical energy supply for a mixed fleet of 2 million BEVs is discussed and conservatively calculated, along with the number of wind turbines to achieve this. The results show that approximately 1350MW of wind turbines would be needed to supply the mixed fleet of 2 million BEVs, or 54% of the energy produced from NZ's planned and installed wind farms.

Keywords: Battery electric vehicles, New Zealand

1.   INTRODUCTION

New Zealand (NZ) transport accounts for over 40% of carbon emissions in the energy sector (MED, 2007a) with private cars accounting for about 25% (FRST, 2006). At current growth rates, based on a 'business as usual' scenario, carbon emissions from transport would approximately double by 2050 (MED, 2007b). To counter this predicted growth, the Ministry for Economic Development (MED) has proposed, in its 2007 energy strategy document (MED, 2007c), a number of initiatives for reducing carbon emissions.

The strategy includes the in-principle decision to halve carbon emissions from domestic transport by 2040 and for New Zealand to be one of the first countries to widely deploy electric vehicles. In line with the MED, the Energy Efficiency and Conservation Agency (EECA) have also proposed the wide scale deployment of electric vehicles (BEVs) as a means of reducing carbon emissions

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from transport (EECA, 2007). In a recent Ministry of Transport study it was stated that there were no significant barriers to the wide spread introduction of BEVs in New Zealand. Furthermore, it was recognised that BEVs would reduce carbon emissions, take advantage of NZ's renewable energy sources and finally, that the extra electricity demands on the grid would not be excessive if properly managed (King, 2007).

If the emissions issues are to be addressed, there are several compelling reasons why the BEV warrants further consideration. BEVs have substantially higher well-to-wheel efficiency than ICEVs or fuel cell vehicles and are an optimum solution to urban mobility (Van Mierlo et al, 2006). They can also be charged from electricity produced from renewable sources such as wind, hydro or solar. Hypothetically, the battery capacity of a fleet of 2 million BEVs could be used as a ripple-controlled 'smoothing capacitor' to account for fluctuations in renewable electricity output or, be charged from mains power at off peak times thereby reducing the need for new generation by running the existing system more steadily (Bull, 2007). Such a system could offer the opportunity for grid connected BEV owners to buy and sell their electricity, similar to grid connected PV systems.

Alternatively, automatic battery exchange systems using standardised designs and procedures might be employed to eliminate waiting for battery charging. These could be established in what were previously petrol stations. Another long term possibility is an inductive charging system built into the road network. Whereas there in no existing infrastructure for a hydrogen based transport system,

the basic infrastructure for charging electric vehicles already exists. However, to ensure a reliable system of distribution, extra generating capacity and improved infrastructure will most likely be needed. To reduce carbon emissions from transports, per the requirements of the New Zealand Energy Strategy, it is proposed that any electricity required to charge a fleet of BEVs be offset by at least the same amount of electricity generated from renewable sources.

There are however some issues that need to be addressed when BEVs are considered for wide spread deployment in NZ. Unlike most European Union countries, NZ does not have a well-developed public transport infrastructure; therefore New Zealander's are, and will continue to be for the foreseeable future, far more dependent on their cars for both short and long journeys than for example the UK. Therefore, to achieve a level of comparable mobility, long range BEVs with a performance similar to existing ICEVs will be required to satisfy NZ's ambition of wide spread electric vehicle deployment. As such, this work investigates the technical requirements needed to achieve long range BEVs and the electricity required for a mixed fleet of 2 million in NZ.

Recently the NZ government established the Vehicle Energy and Renewables Group with the aim of promoting biofuels and electric vehicles in NZ. This group recognised that one possibility for NZ to lead in the deployment of electric vehicles is to convince a major automotive company to use NZ as a 'test bed' for their new BEVs. The alternative is that NZ will follow rather than lead and have to wait for used BEVs from Japan. For the latter scenario, it will be many years before BEVs become common on NZ's roads. As an alternative to this, it is

possible that NZ could become a BEV manufacturing nation. Investment capital and plans for a BEV company based in NZ are already in place to exploit the technology used on the UltraCommuter BEV discussed in this paper. A NZ-Australia-UK consortium plans to develop electric cars for initially the low volume BEV market with the aim to move to mass production as demand for BEVs increases (Macrae, 2008).

Aside from the policy driven aspects relating to carbon emissions from transport, another issue facing transport is oil depletion. The NZ energy strategy document comments on this issue, and states the 'main stream' view that the world's oil supplies are sufficient until 2030. Although oil depletion is treated as a secondary consideration relative to carbon emissions in the current NZ energy policy framework, it is likely that this will further serve, even principally, as a driver for the introduction of BEVs. Irrespective of changes being driven by energy policy or oil depletion, the results of this study are equally valid.

2.   ELECTRIC VEHICLES

Electric vehicles can be classified as follows; Hybrid electric vehicles (HEV), Fuel Cell vehicles (FCV) and Battery electric vehicles (BEV). The focus of this paper is BEVs, however the merits of the other types are briefly discussed with regard to their suitability for NZ.

2.1   Hybrid Electric Vehicles

The term *hybrid* generally refers to vehicles that have both an internal combustion engine and an electric drive train. Internal combustion engine hybrid

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electric hybrid vehicles (HEVs) can be more fuel-efficient than comparable internal combustion engine vehicles (ICEVs) and subsequently produce less carbon emissions. In addition HEVs have been the subject of recent attention through their commercial development by Toyota and Honda. The success of these commercial models has led to the production of HEVs by many other leading motor manufacturers.

Efficient HEVs, especially Plug-in Hybrids (PHEVs), could offer NZ a short to medium term solution to reduce carbon emissions from transport and provide motorists with range and performance comparable to ICEVs. Hybrid vehicles however, might also be viewed as an intermediate solution prolonging the use of fossil fuels before FCVs or BEVs are widely available.

2.2   Fuel Cell Vehicles

Fuel cell vehicles (FCVs) represent a specialised form of electric vehicle in which fuel cells convert hydrogen to electricity and stored in batteries for powering electric vehicles. FCVs have received significant attention; particularly in the US where the government is aiming for near independence from oil imports in the first quarter of this century (Whitehouse, 2006). Various organisations are promoting hydrogen FCVs as the replacement for conventional ICEVs, and some have stated that they will be marketed by 2010 (Brooke, 2006).

Many academics researching a hydrogen economy however, have identified many issues that question this assumption. Various reasons are cited why

hydrogen might not be the best alternative transport fuel, including safety, cost and overall efficiency (Shinnar, 2003 and Chalk and Miller, 2006).

Ross (2006) noted that hydrogen storage is one of the major problems facing fuel cell cars and a practical, safe solution faces major technical barriers. Furthermore, hydrogen production from electrolysis would require a significant increase in electricity generation, in fact almost double the existing capacity for the US alone (Grant, 2003). In addition, the overall efficiency of FCVs is much lower when compared with BEV's (Eaves and Eaves, 2004 and Hammerschlag and Mazza, 2005).

Despite the many obstacles and efficiency issues related to hydrogen FCVs the fact that their travel range is comparable to that of conventional ICEVs could make them the preferred long-term option (Chan, 2002 and Chan and Wong, 2004). Even though the overall efficiency of hydrogen fuel cell vehicles is inferior to that of directly charged BEVs, the current high levels of investment mean that this fuel and technology could eventually replace fossil-fuelled ICEVs. However, both GM and Toyota have recently expressed doubts about the viability of FCVs and commented that long range BEVs using Lithium batteries could be a better option (Taylor and Spector, 2008). In this paper it is assumed BEVs and not FCV's will, in the long term replace conventional ICEVs.

2.3   Battery Electric Vehicles (BEVs)

Battery electric vehicles were invented around the same time as internal combustion engine vehicles (ICEVs) and in 1898 the electric 'Le Jamais

Contente' became the first car to exceed 100 km/h. Production models readily competed with early petrol cars because they travelled at an equivalent speed. They were also the preferred choice for many women drivers because they did not require a crank for starting and so the public's perception of BEVs was initially positive. A combination of prolonged battery charging time and developments in internal combustion engine technology (including the invention of the electric starting motor in 1911) meant that by 1915 petrol and diesel engine cars predominated (Schiffer, 1994).

BEVs were thus, and still are, perceived as inferior to ICEVs despite the fact that recent improvements in battery chemistry, electric drive train technologies, and body and component materials mean that the range of a typical production model has increased to an average of 80km on one charge. This meets the average requirements of most drivers in NZ, where for example the mean daily travel distance is less than 40 km (Ministry of Transport, 2008). An issue that current BEVs do not address is that many journeys in NZ are much longer than the daily average and BEVs should be capable of a range far greater than 40km.

2.4 Batteries

A key factor that led to the predominance of the petrol car over the battery electric car is that the energy density of petrol is approximately 300 times greater than that of lead-acid batteries, thus giving the ICEV superior range. This coupled with cheap and abundant oil meant BEVs were relegated to niche markets such as milk delivery floats, golf buggies and mobility scooters.

However, recent improvements in battery performance mean that BEVs could become a mainstream vehicle technology.

Figure 1 shows that the energy density of rechargeable (secondary) batteries has increased significantly since electric vehicles were first introduced. The earliest BEVs used lead-acid batteries, which have an energy density of approximately 30-40Wh/kg. Batteries such as Ni-Cad and Ni-MH have superior energy density but are lower than state of the art battery technologies such as Lithium-ion and Lithium-polymer that have energy densities ranging from approximately 100 - 200Wh/kg. Other technologies such as zinc-air and aluminium-air offer the potential for higher energy density than lithium batteries but are not rechargeable thus requiring a battery exchange system and reprocessing. This latter process however would also require significantly more energy than recharging.

2.5   UltraCommuter - The NZ BEV

The UltraCommuter is is a fully operational two-seat prototype BEV developed by the University of Waikato (UoW) in partnership with HybridAuto Ltd. One of the aims of the UltraCommuter, shown in Figure 2, is to evaluate its performance when compared with conventional ICE cars and thus determine its feasibility as a long range BEV. This was demonstrated when the UltraCommuter was completed and competed in the 2007 World Solar Challenge.

The design of the UltraCommuter incorporated all the elements necessary for high performance battery electric vehicles:

- Low aerodynamic drag

- Low rolling resistance tyres

- Low mass

- High overall transmission efficiency from battery to wheel

- High energy density batteries

The UltraCommuter design incorporates Li-iron-phosphate (LiFePO$_4$) batteries, a lightweight aluminium honeycomb chassis, in-wheel motors with regenerative braking and an aerodynamic body shell. The two motors in the rear wheels could supply a combined power of 100kW but in the first version were limited to 50kW. The top speed is designed to be 120km/h. The range of the car when travelling at 100km/h with a 20.7Wh battery pack is designed to be approximately 250 km. The car also aims to challenge the once 'traditional' image of BEVs as slow, unattractive and having a poor travel range.

3. BEV PERFORMANCE: MODELLING AND TESTING

There are several factors affecting the performance of BEVs and these are investigated to determine if long-range electric vehicles are feasible. In this study, three different purpose-built BEVs are investigated that fulfil specific personal transport roles; single occupant vehicles for short/medium distance travel and commuting, single/dual occupant vehicles capable of short and long distance journeys and a long range family car. A conventional ICE car converted to electric and a standard petrol ICE car are also investigated for comparison.

The single seat BEV was chosen to investigate the use of low power BEVs in particular for commuting as over 70% of commuter cars in NZ are occupied by a sole driver (Sullivan and O'Fallon, 2003). The mean daily driving distance of cars in NZ ranges from 34km for urban residential areas to 51km for rural residential areas as shown in Table 1 (Ministry of Transport, 2008). As mentioned previously, BEVs are currently available with a range of approximately 80km, and can therefore easily achieve the mean daily driving distance. However, Table 1 also shows the statistical breakdown of longer car journeys and for 90th percentile and above, all but one are above 80km. Therefore, to be capable of achieving the 90th percentile of driving distance a BEV must be capable of approximately 100km range, for the 95th percentile over 150km and for the 99th percentile, about 300km. The higher driving distances are, as expected, associated with rural areas and highlight the need to offer longer range BEVs than those currently available.

The power requirements of the five vehicles were calculated when travelling at a constant highway speed of 100km/h. In an earlier study, Simpson et al, (2005) simulated the performance of the UltraCommuter for a range of driving cycles, including the Urban Dynamometer Driving Schedule (UDDS), using the Advanced Vehicle Simulator (ADVISOR) software. From the simulations they predicted the UltraCommuter's urban energy consumption was 67Wh/km. However, at a constant speed, of 100km/h, their simulations predicted a cruising power of 7 kW, equating to an energy consumption of 70 Wh/km. Given that urban driving cycle and a constant speed simulation predict similar energy consumption per kilometre, the simpler constant speed method was used in this

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work. However, it should be noted that for petrol cars, the urban drive cycle typically uses 30% more fuel than highway driving.

The range of each vehicle was then calculated from the stored energy in the batteries or petrol respectively. In addition to investigating the feasibility and performance of long range BEVs, their energy requirements were compared to that of conventional ICEV's and ICEVs retrofitted as BEVs. The investigation of retrofitted ICEV's highlighted the need for vehicles to be designed specifically as BEVs rather than incorporating the technology into existing models.

3.1 Mathematical Model

As discussed earlier, it is satisfactory to use a constant speed simulation rather than the UDDS for predicting the power required for BEVs. As such, the power required to propel a vehicle travelling at constant speed on a straight, flat road with no headwind can be derived from an energy balance, and is given by equation (1). To simplify the analyses, information regarding acceleration, braking, cornering, hills and headwinds were not considered.

$$P_c = \frac{C_d \, A \, \rho \, V^3}{2} + Mg \, RR \, V \tag{1}$$

Where:

$P_c =$ Power to propel car (W)

$C_d =$ Drag coefficient

$A =$ Frontal area (m^2)

$\rho =$ Air density (1.2 kg/m^2)

$V =$ Speed (m/s)

$M =$ Mass (kg)

$g =$ Gravity (9.81m/s^2)

$RR =$ Rolling resistance

3.2 Vehicle Data

The design input data for the mathematical model of the five vehicles is shown in Table 2. For a typical ICEV, specification data was obtained from a number of sources such as Internetautoguide (2005). It was found that the C_d value of a typical ICEV saloon is between 0.3 and 0.4. An ICEV suitable for conversion to battery power was assumed to have a C_d of 0.31, as this would offer the best performance. A computational fluid dynamic analysis of the UltraCommuter BEV predicted a C_d of 0.25. Finally, it was assumed that the C_d of the single seat BEV and five seat family BEV would be the same as that of the UltraCommuter.

Furthermore it was found that the frontal area (A) of a typical ICEV was 2.3 m^2 whereas the UltraCommuter was ascertained to have a frontal area of 1.7 m^2, using CAD modelling software, and the single seat and family car BEV frontal areas were estimated to be 1.2 m^2 and 2.3 m^2 respectively. In addition, it was assumed that a typical ICEV has a curb weight (no fuel, luggage or occupants) of 1150 kg, whereas the mass of the purpose-built BEVs ranges from 200 kg to 700 kg. The total mass of the UltraCommuter (including 270kg LiFePO$_4$ batteries, a passenger and driver - 160kg - and 30 kg luggage) is 860 kg. In the simulation for an ICEV converted to battery power, it was assumed that the same batteries

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as the five seat BEV would be used and that the mass of this vehicle (including batteries, luggage and, occupants) would be 1910 kg.

For all vehicles the rolling resistance (RR) is dependent on tyre type, speed, pressure, road surface and condition and is usually between 0.01 and 0.02 (Bosch, 2004). The RR of a typical ICEV was therefore conservatively assumed to be 0.014. However it was assumed that the BEVs would be fitted with lower rolling resistance tyres with an RR of 0.008. The UltraCommuter used Bridgestone "Potenza" tyres, and although no RR data was available, the test results in the WSC indicated that the RR of 0.008 was a reasonable assumption. It should also be noted that after 2000km driving there was no noticeable wear on the tyre. The RR of 0.008 is much higher than for example a solar racing car tyre that has a quoted RR of 0.0025 but is unsuitable for use on typical passenger cars (Cotter et al, 1999).

3.3   Power and Range Calculations

As discussed earlier, several different types of battery are currently available for BEVs including Pb-acid, NiMH, NiCad and $LiFePO_4$. In this work, commercially available $LiFePO_4$ batteries developed for electric vehicles were used in the analysis. The energy density of the $LiFePO_4$ batteries used in the model was 96Wh/kg. Although this is considered low in comparison with some Li-ion batteries (the energy density of which is claimed to be 180 Wh/kg) the cost of those used in the model was approximately 20% of this latter type. It was assumed that the vehicles would only discharge 80% of the available battery capacity, as a repeated 100% battery discharge would significantly reduce battery

life. One critical issue for the batteries is their cycle life, the number of cycles they can withstand before they need replacing. Manufacturers of LiFePO$_4$ batteries like those used on the UltraCommuter, claim life cycles in excess of 2000 with a depth of discharge of 80%. For the UltraCommuter batteries, this has not been verified, but in 2007, Gu et al, found that when laboratory testing LiFePO$_4$ batteries they completed 1664 cycles at 4.5C discharge rate with negligible cycle fading. They concluded that LiFePO$_4$ were a suitable battery for electric vehicles and their results suggest that it is possible that LiFePO$_4$ batteries could last the life of the BEV.

It was also assumed that the electrical energy for the BEVs was converted to drive by a motor and controller with an overall efficiency of 0.9. Such efficiencies arise from the use of brushless DC motors built into the wheel of the vehicle, thereby eliminating the need for a gearbox and transmission. The inefficiencies that arise from the transmission system mean that a typical ICEV has an overall petrol-to-wheel conversion efficiency of approximately 0.18 (Ahman, 2000). However, in this work an overall value of 0.2 was used to take into account increased efficiency for constant speed driving at 100km/h. Finally, the ICEV converted to battery power was assumed to have an overall efficiency of 0.8 because it would not include brushless in-wheel motors and therefore, losses would be incurred in transmission.

In Table 3 the power calculated to propel the various BEVs, an ICEV and an ICEV electric conversion vehicle at 100km/h is shown, where P_c is the power required by the car, P_a is a nominal auxiliary power required for fans, lights etc.

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and P_s is the power from the supply source, either battery or petrol. In addition the range of the BEVs on one charge (80% battery discharge) and for the ICEV using 40 litres of petrol is also shown.

From these results it can be seen that the UltraCommuter uses only 8.5 kW from the battery compared to 77 kW from petrol for the ICEV. This factor of nine for the UltraCommuter highlights the compounding effect of high efficiency in-wheel motors with no gearbox and transmission losses coupled with low rolling resistance and aerodynamic drag. Similarly, the single seat commuter BEV uses approximately fifteen times less source energy than an ICEV and a five seat BEV about six times less. This highlights the benefits of purpose-designed low energy and high efficiency BEVs. Furthermore, it can be seen that converting a typical late-model petrol car to battery requires almost twice the source energy compared to a specifically designed five seat BEV.

The five-seat family BEV would be capable of over 300km on one battery charge. In comparison, with the same energy input, the ICEV converted to battery only travels 182km. It should be noted that these ranges could be achieved using existing commercially available $LiFePO_4$ batteries. Future batteries will have higher energy densities and subsequently the range of the BEVs will increase proportionately. A range of 500 km for a five-seat BEV of the future should be possible making it comparable to conventional ICEV's.

3.4 UltraCommuter Performance and Model Validation

To validate the simulations undertaken in this study, testing of the UltraCommuter was undertaken during the 2007 World Solar Challenge (WSC), a biennial event where solar powered cars aim to drive from Darwin to Adelaide in the fastest time. The UltraCommuter was entered in the Greenfleet class where new vehicle technologies were demonstrated but not raced. As a condition of there participation however, Greenfleet entrants are expected to complete the route in 6 days, driving approximately 500 km/day. During this event the UltraCommuter drove 2000km of the route from Darwin to Adelaide using stored battery energy only.

For the WSC, the UltraCommuter used three LiFePO$_4$ battery packs each of 13kWh capacity. When 80% depleted the pack would be removed and another fully charged pack installed. This process took about 20 minutes and was carried out three times a day. At the end of a day there were three discharged battery packs that were then charged from camp site power supplies over night. The aim of this system was to give the UltraCommuter a daily range of over 500km in line with the Greenfleet requirements.

The power from the UltraCommuter batteries was measured as the UltraCommuter was being driven on a flat section of road with no turns or noticeable head or tail wind. Before the start of the test run, the battery pack was fully charged and equalised to ensure each of the 45 batteries had the same voltage and state of charge. The UltraCommuter was occupied solely by the driver who kept the vehicles speed constant during the test run. The UltraCommuter was driven until the battery voltage indicated that they were 80%

discharged. At that point the discharged battery pack was removed and another fully charged battery pack installed.

From this testing of the UltraCommuter it was found that the vehicle used only 5kW power at 85km/h. By utilising the parameters of Tables 2 and 3 in equation 1, the predicted power consumption was 5.1kW, or, slightly more than the test result. During the course of the WSC event the UltraCommuter was found to travel approximately 180km on one Lithium battery pack using 10.4kWh (80% discharge of a 13kWh battery) at an average speed of 85km/h. Again, the calculated range at that speed was 174km, therefore showing that the model accurately predicts the UltraCommuter performance for highway driving.

4. ELECTRICITY SUPPLY

Currently, New Zealand has approximately 2.2 million registered cars (Land Transport New Zealand, 2005). For this study it was assumed that if BEVs were to replace ICEVs for personal motorised transport, a similar number would be required. However in a future New Zealand where BEVs replace ICEVs, car travel might be reduced as more people work from home and/or travel by improved public transport, walking and cycling. Single and two person BEV commuter cars similar to those already available might also be widely used. Nevertheless, to illustrate the demands on the NZ electricity supply, in this study a hypothetical mix of 2 million BEVs is proposed. This mix comprises:

- 400,000 single seat BEV commuters each travelling an annual distance of 5000 km

- 600,000 two seat UltraCommuter style vehicles each travelling an annual distance of 10,000 km

- 1 million five-seat BEVs each travelling an annual distance of 15,000 km.

It is recognised that future passenger vehicle requirements are difficult to predict and so these values are hypothetical indicators to enable resource consumption in a range of areas including electricity supply to be estimated.

In line with the MED's aims of reducing carbon emissions from transport, it is proposed that the electricity to charge two million BEVs be offset by renewable energy sources. Wind energy is considered the most likely option as it has the potential to supply over 7,900 GWh/yr by 2015 and 100,000Gwh/yr in the long term (EECA, 2001). Furthermore, it is expected that the batteries would act as a smoothing capacitor for the variable output from wind; however a more in-depth analysis of the generation and load profiles would be needed to confirm this. In New Zealand, well-sited wind farms are a cost effective producer of electricity with a duty cycle of over 40% (WEL, 2006).

From the travel distances and numbers of BEVs given above and the energy model discussed in the preceeding section, the annual source energy required was estimated as shown in Table 4. The fleet of single seat BEVs would require 133 GWh/yr, the UltraCommuter's 507 GWh/yr and the five seat BEVs 1892

GWh/yr. This gives a total of approximately 2500 GWh/yr excluding supply losses. As such, transmission losses were conservatively assumed to be 10%, and the overall Li-ion battery charging/discharging efficiency was estimated in the worst case to be 90%, although the author and other researchers have found it to be to be over 95% (Kennedy et al 2000).

In addition, an arbitrary urban driving factor of 1.3 was included in the energy analysis of the BEVs to account for the probability that the motor/controller will run less efficiently at low speeds. However, has mentioned previously, a simulation of the UltraCommuter predicted an urban energy consumption of 67Wh/km (Simpson et al, 2005) compared to that of highway driving at 70Wh/km. Until testing can resolve the actual energy use of the UltraCommuter BEV for highway and urban driving, it was assumed in this work that urban driving would consume 30% more energy. This figure is in line with the urban/highway fuel consumption ratio of existing petrol cars (Internetautoguide, 2005).

However, unlike conventional ICEVs, braking energy is mostly recouped through regenerative braking (the motor is used as a generator) and the BEV uses no motive energy when stationary. Furthermore, a contingency factor of 1.2 was added to account for issues such as turbine down time through maintenance, or the over estimation of BEV efficiency.

Based on these assumptions, the required energy for charging the mix of two million specifically designed BEVs is conservatively estimated as 4900 GWh

thus equating to 464 x 3MW turbines or 1392MW. There is currently 322MW of installed wind generation, with 173MW under construction and a further 1985MW giving at total of 2480MW (New Zealand Wind Energy, 2008). Therefore the BEV fleet would require 54% of the energy produced from NZ's installed and planned wind farms. As New Zealand generated approximately 40,000GWh of electricity in 2006 (Statistics New Zealand, 2006) the energy needs of two million BEVs equates to 12% of this generation.

It should be noted that while wind energy is the most likely renewable energy supply for the BEVs, other forms of renewable such as projected geothermal programs could supply a considerable proportion. Wind generated electricity has natural fluctuations and seasonal output variance that ultimately limit its penetration of electricity supply. However, a hypothetical analysis undertaken on behalf of the MED found that penetration of about 35% and market share of 20% was possible, based only on technical and operational issues (MED, 2005).

5.   POLICY IMPLICATIONS OF BATTERY ELECTRIC VEHICLES

Some individuals believe that wind energy will only supply a small proportion of New Zealand's future electricity needs and that this will only offset the expected growth in electricity demand (Leyland, 2004). This is questionable however as it assumes continual long-term growth in demand, regardless of the political changes and/or availability of resources. Furthermore, government targets to achieve 90% of electricity from renewable sources by 2025, concerns about climate change and scarcer and more costly energy resources mean that measures to limit and reduce consumption will be inevitable. Examples include the use of

solar hot water heaters, home insulation, double-glazing, low energy light bulbs, low energy vehicles and changes in working and travelling arrangements.

One of the main elements that needs to be addressed, not only for the wide scale deployment of BEVs, but the overall objectives of the "New Zealand Energy Strategy" is the need for investment in the necessary distribution networks. This is particularly pertinent, as a number of potential sites for wind farms lie a considerable distance from the main population centres. This in itself has already become a point of focus, as it has raised issues surrounding resource management and environmental protection.

Alternatively, greater measures need to be taken to reduce consumption, perhaps through the use of greater incentives for the uptake of "energy efficient" devices or by legislative means to remove energy inefficiency. Some examples of how this may be achieved include legislation to replace conventional lighting with energy saving lightbulbs, or, by making the use of gas, solar or heat pump water heating compulsory. Additionally, to remove unnecessary burden on the national grid, steps could be taken to greater encourage, or mandate, the use of onsite generation and higher minimum energy standards for new or refurbished buildings. A number of successful schemes have used feed-in tariffs as well as smart and net-metering to achieve desirable outcomes in this way.

More specifically, perhaps the greatest impediment to NZ being a world leader in the uptake of BEVs is the existing arrangement of importing large volumes of used vehicles from countries such as Japan. Although this results in affordable

transport, it has also resulted in a significantly ageing fleet. Without significant intervention, it is hard to see this market being reduced, principally because BEVs would have a higher initial cost. Drawing parallels with the uptake of solar water heating, EECA (2004) found that the greatest impediment to the use of solar water heaters was the initial cost and it is highly probable that this would occur with the introduction of BEVs.

Whatever solution is reached will need to be carefully balanced to ensure that it achieves not only the technical changes required to reduce carbon emissions, but does not have undue social consequences. It is foreseeable that, if poorly constructed, the implementation of BEVs could result in low income households being penalised for not using BEVs that they may not be able to afford. This would create a somewhat ironic case of "fuel poverty" where families could easily afford the fuel (electricity) but not afford the means of using it (BEV). As such, it could be suggested that in order for BEVs to be successful, there is also a significant need to invest in public transport infrastructure to ensure that there are cost effective alternatives to owning a vehicle.

To initiate the uptake of BEVs, financial incentives could be offered similar to those in London where BEVs are exempt from; London congestion charges, vehicle excise duty and many London Boroughs provide free parking. These incentives enable some BEV owners to repay the purchase cost of the car in 1 year. The London experience highlights the need of financial incentives to stimulate uptake and if BEVs are to be widely deployed in NZ, it is highly likely that similar incentives will be required.

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6. SUMMARY

From this study it is apparent that NZ transport faces a number of challenges in the coming decades if it is to meet the objectives of the "New Zealand Energy Strategy to 2050". Electric vehicles have been identified by the MED as a means of reducing carbon emissions. However, in the past, BEVs have failed due to poor travel range, high battery cost and inappropriate design.

This study showed that BEVs should be designed specifically as electric vehicles rather than being conventional ICEVs converted to battery. They must be lightweight, aerodynamic and have a high battery to wheel efficiency as employed by the Ultracommuter. As such, the UltraCommuter would use approximately one ninth of the source energy compared to a conventional ICEV under the same operating conditions.

As NZ currently lacks the public infrastructure of other developed countries and hence there is a great reliance on private cars. It is likely that most BEVs will need to have a carrying capacity, range and performance similar to existing ICEVs to maintain the mobility of New Zealander's.

Applying UltraCommuter technology to different size BEVs gives similar performance but reduced energy requirements compared to that for conventional ICEVs. High energy density battery chemistry such as Lithium-ion enables well designed BEVs to have a range of 250-300km with existing technology and

double this with improved batteries. It is also possible that the Lithium batteries would last the life in service of the vehicle.

A conservative estimate for the electricity to charge the proposed mix of two million BEVs in NZ is 4900GWh/year. This study suggests that New Zealand has the potential to operate a mixed fleet of 2 million BEVs charged from sustainable energy wind sources, supplied by approximately 450 x 3MW wind turbines. This figure is based on the requirements of a hypothetical fleet of two million battery electric passenger cars comprising 1 million family cars, 600,000 two seat and 400,000 single seat vehicles to address the low occupancy rate of commuter cars.

However, in order for BEVs to be successful in NZ there are a number of issues that need to be addressed in parallel. In particular there is a need to ensure electricity networks are upgraded to satisfy future demands upon it by BEVs. Furthermore, it has been noted that energy efficiency and its implementation needs greater attention. Additionally, it has been suggested that steps be taken to encourage consumers to generate electricity to reduce the load on the national grid.

Finally, it has been recognised that however BEVs are implemented there is a need to ensure that adverse social policy issues are addressed. It has been suggested that this could be avoided, or its effects minimised by also investing in public transport infrastructure as a complement to BEVs and other passenger transport. Furthermore, financial incentives similar to those offered in London

might be required to stimulate the uptake of BEVs and reduce the financial burden on low income households.

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Table 1 km Driven per Day in NZ

Area of residence	Vehicle Type	km/day Mean	km/day Median	km/day 90th percentile	km/day 95th percentile	km/day 99th percentile	km/day max
Residents of Main Urban Areas	All light 4 wheeled vehicles	34.0	20.3	68.3	101.0	260.0	1064.3
Residents of Secondary Urban Areas	All light 4 wheeled vehicles	36.2	15.6	91.8	145.0	302.2	618.2
Residents of rural areas and towns with population <10000	All light 4 wheeled vehicles	50.7	33.9	114.3	156.0	270.5	583.4

Table 2 Vehicle Data

Vehicle type	Mass Without Battery (kg)	Mass occupants (kg)	Mass luggage (kg)	Mass batteries/Petrol (kg)	Mass total (kg)	Frontal area (m^2)	Drag Coefficient C_d	Rolling Resistance RR
1 seat BEV	200	80	20	90	390	1.2	0.25	0.008
2 seat BEV (UltraCommuter)	400	160	30	270	860	1.7	0.25	0.008
5 seat BEV	700	300	100	510	1610	2.3	0.25	0.008
ICEV (battery)	1000	300	100	510	1910	2.3	0.31	0.014
ICEV (petrol)	1150	300	100	30	1580	2.3	0.31	0.014

Table 3 Vehicle Power and Energy Requirements at 100km/h

Vehicle type	Pa Power Aux (W)	Pc Power Car (W)	Battery or Petrol Energy (kWh)	Overall Effic.	Ps Power supply (W)	Range (km)	Annual Distance (km)	One car annual energy (kWh)	Total Number Cars (000s)	Total Energy (GWh)
1 seat BEV	100	4708	6.9	0.9	5331	104	5000	333	400	133
2 seat BEV UltraCommuter	300	7340	20.7	0.9	8456	245	10000	846	600	507
5 seat BEV	500	10904	39.2	0.9	12616	310	15000	1892	1000	1892
ICEV (battery)	1000	16456	39.2	0.8	21570	182	15000	3235	2000	6471
ICEV (petrol)	1000	15197	390.0	0.2	76985	507	15000			

Table 4 Electricity Supply for BEVs

	BEV ELECTRICITY REQUIRED						WIND TURBINES			
Vehicle type	Annual BEV Energy (GWh/yr)	Battery charge efficiency	Trans-mission Efficiency	Urban driving factor	Contingency factor	Total electricity required (GWh/yr)	Rated power per turbine (MW)	Hours per Year (hrs)	Wind turbine duty cycle	Electricity generated per turbine per year (GWh/yr)
1 seat BEV	133	0.9	0.9	1.3	1.2	257	3	8760	0.4	10.51
2 seat BEV UltraCommuter	507	0.9	0.9	1.3	1.2	977				
5 seat BEV	1892	0.9	0.9	1.3	1.2	3645				
Total	2533					4878			Number of 3MW turbines Req'd	464

Figure 1 Energy Density of Batteries

Figure 2 Ultracommuter during testing