

THE EMERGENCE OF BATTERY ELECTRIC VEHICLES: A NZ MANUFACTURING OPPORTUNITY?

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ABSTRACT

Personal passenger transport faces several challenges in the coming decades: depletion of cheap oil reserves, increasing congestion, localised pollution, the need for reduced carbon emissions and the long term goal of sustainability. One way of solving some of these problems could be to introduce comfortable, energy efficient, battery electric vehicles.

Currently, hybrid vehicles have been presented as a means to reducing the transportation related oil demand. New developments in materials and technologies have made them, cleaner and safer as well as more fuel efficient. However, hybrids will only prolong the use of oil until alternatively fuelled vehicles are developed.

One long term alternative is the battery electric vehicle (BEV). A BEV designed to be light, aerodynamic with high efficiency drive train and latest battery technology would have a performance comparable to a typical internal combustion engine vehicle (ICEV). Recent developments in virtual engineering, rapid prototyping and advanced manufacturing might enable low-cost development of niche market BEV's designed and built in New Zealand for export markets.

This work examines the collaborative development of a twin seat BEV using new materials and latest technologies by the University of Waikato's Engineering Department and a group of NZ and foreign companies. The car will be used to research the potential of BEVs and will also compete in the Commuter Class of the World Solar Challenge in 2007.

INTRODUCTION

The use of fossil fuel oil as a source of energy for personal transportation will decrease relative to other fuels during the 21st century. It is difficult to predict the rate at which this will occur, the magnitude of the change or what alternative fuels will replace oil derivatives. Currently, a number of possible alternatives including hybrid electric vehicles, hydrogen fuel cell cars and Battery Electric Vehicles (BEVs) are presented as contenders for the future of transportation.

Hybrid electric vehicles that use a combination of petrol engine and electric motor to improve fuel consumption have experienced recent attention through their commercial development by Toyota and Honda. Hybrid vehicles however, can only be viewed as an intermediate solution prolonging the use of fossil fuels before alternative fuel cell or battery electric vehicles are widely available.

Fuel cells that convert hydrogen into electricity for powering electric cars have received significant attention, particularly in the US where government is aiming for independence from oil imports in the first quarter of this century. A switch from oil to hydrogen for transport is planned to start in 2015 and it is claimed that even though there are still many technical problems, progress is on target (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 significant extra electricity generation, nearly double the existing capacity for the US case (Grant, 2003).

Unlike fuel cell vehicles, which are a relatively new technology, BEVs have a long history and have been

used for more than a century. Battery electric vehicles were invented around the same time as the internal combustion engine started to be developed. 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 and were the preferred choice for many women drivers because they did not require a crank for starting and so public 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 easily meets the requirements of many drivers in NZ for example where the average daily travel distance is approximately 40 km (Charlton *et al*, 2002).

Many automotive manufacturers have stated that the public's poor perception of BEVs means that the potential market would not be large enough to be profitable; however, the results of a Californian study show this not to be the case. This study calculates the initial market for BEVs in California to be between 150,000 and 225,000 p.a. rising to 10 million (EV World, 2001). Using similar criteria, 33% of the 'second' car market, potential annual sales in the UK alone would start at approximately 190,000 rising to a total of 2 million, thus justifying investment in manufacturing plant (Andrews *et al*, 2001).

History shows us that interest in small cars and BEVs has increased when fuel is in short supply, such as during WWII, and/or when oil prices are high, such as was seen in 1956 and the early 1970s (Quandt, 1995). Interest in these types of vehicle has again increased in response to concerns about the environment and economic factors. However in order to appeal to a wide market, the public must be convinced that BEVs can fulfil daily travel requirements. Therefore, BEVs must look as though they can satisfy these requirements. Battery electric vehicles should be at least as aesthetically pleasing as comparable ICEVs and even if they have 'character', like the Smart Fortwo, they need to avoid being seen as an impractical solution to passenger transportation (Andrews *et al*, 1999).

If the transport issues outlined earlier are to be addressed there are compelling reasons why the BEV warrants further consideration. BEVs have substantially higher well-to-wheel efficiency than ICEVs when their electricity supply is taken from low carbon emitting sources such as wind, hydro, solar or gas and are an optimum solution to urban mobility (Van Mierlo *et al*, 2006). BEVs can be charged at home, at a charging stations or use a battery replacement system. The electricity supply should ideally be from renewable sources such as wind, solar and hydro. The infrastructure in NZ already exists to accommodate BEV introduction and could be expanded with the introduction of, for example, wind farms for the required increase in electricity.

A key factor for the predominance of the petrol car over the battery car is the 300 times larger energy density of petrol compared to Pb-acid batteries, thus giving the ICEV vastly superior range. This coupled with cheap and abundant oil meant BEVs were relegated to niche markets such as golf buggies and mobility scooters. However, recent improvements in battery performance present the possibility of BEVs becoming a mainstream vehicle technology.

In Figure 1 it can be seen that rechargeable batteries have risen in power and energy density significantly since the pioneering electric vehicles. It can be seen that standard Pb-acid batteries have an energy density of approximately 30-40Wh/kg. More recent 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 between approximately 100-200Wh/kg. The latest rechargeable Lithium-sulphur batteries claim 350Wh/kg and promise over 500Wh/kg in the near future. This increase in energy density has the potential to give battery electric vehicles the performance, and the range, to compete with conventional ICE cars.

Given the possibilities that emerging battery and other recent technological developments present, there is the opportunity for New Zealand to be an early adopter of BEVs and to demonstrate these technologies on a wider scale. Although it is highly unlikely that NZ will be a major car manufacturing nation there is the potential for NZ to develop high value BEVs for niche markets. Apart from the usual revenue of manufacturing and selling product, the development of such vehicles could lead to Intellectual Property and expertise that might be exported to the established motor manufacturers.

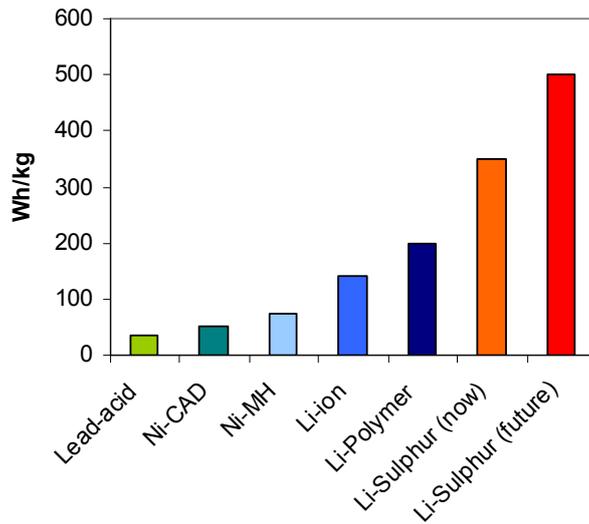


Figure 1: Energy Density of Batteries

A DEMONSTRATION ELECTRIC VEHICLE: NZECO

Given the opportunity presented by electric vehicles, both in NZ and internationally, the University of Waikato and Hybrid Auto, a Brisbane based engineering company, decided to develop a demonstration electric vehicle known as NZeco. NZeco is a long range BEV designed to be lightweight, aerodynamic and energy efficient. The aim of the NZeco, shown in Figure 2, is to demonstrate the potential for such a vehicle by benchmarking it against conventional petrol cars.

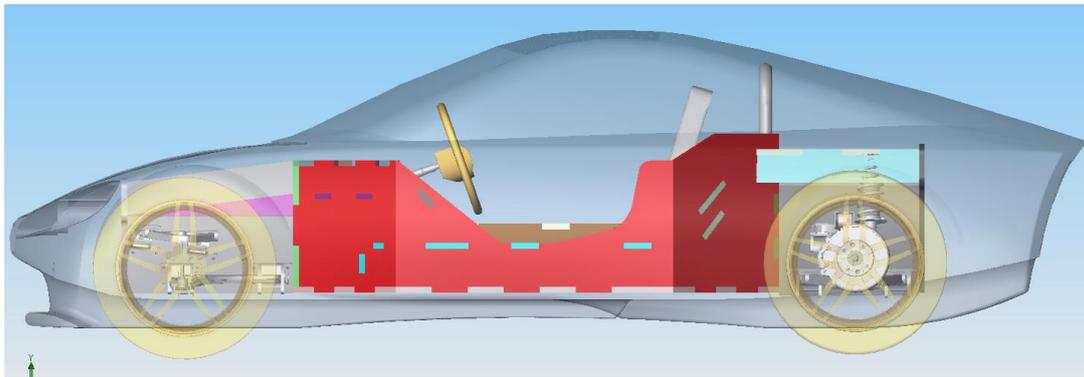


Figure 2: CAD Model of NZeco

The NZeco features Li-ion batteries, a light-weight aluminium honeycomb chassis, in-wheel motors and aerodynamic natural fibre body shell. The two motors in the rear wheels develop a combined power of 100kW and give NZeco a top speed of 170km/h and 0-100km/h in 5 seconds. The range of NZeco when cruising at 100km/h is designed to be 300km. It is apparent that the NZeco aims to challenge the image of BEVs as slow, unattractive and with a poor range. The ground up design of NZeco combined with the latest battery technology is the key to its high specification.

NZeco PERFORMANCE

To investigate the feasibility of high performance BEVs like NZeco an understanding of their energy requirements must be undertaken and compared to conventional petrol cars (ICEV's) and conventional cars converted to battery electric. The latter investigation is required to highlight the need for vehicles to be designed specifically as battery vehicles rather than applying BEV technology to existing car designs.

The energy analysis undertaken in this work is relatively simple. The specifications for the three cars were used to predict the energy required to propel them. The losses incurred through combustion and the drive train were also considered.

Power to Propel Vehicles

The power required to propel the three cars at constant speed was calculated and used to determine the distance they could travel using either the energy stored in the batteries or petrol. To simplify the analysis, information regarding acceleration, braking, cornering, hills and headwinds was not considered. A speed of 100 km/h was used in the analysis to simulate highway driving.

The power required to propel a vehicle travelling at constant speed on a straight, flat road with no headwind is given by equation (1):

$$P_c = \frac{C_d A \rho V^3}{2} + MgRR V \quad (1)$$

Where:

- P_c = Power to propel car (W)
- C_d = Drag coefficient
- A = Frontal area (m²)
- V = Speed (m/s)
- M = Mass (kg)
- g = Gravity (9.81m/s/s)
- RR = Rolling resistance

The input data for the mathematical model of the three vehicles is shown in Table 1. For a typical ICEV, specification data was obtained from number of sources such as (Internetautoguide, 2005). It was found from these sources that a typical ICEV saloon car has a C_d value between 0.3 and 0.4. An ICEV suitable for conversion to battery power was assumed to have a C_d of 0.31. A computational fluid dynamic analysis of the NZeco gave a C_d of 0.25.

Table 1: Vehicle Data

Vehicle Type	C _d	η _{mc} (%)	A (m ²)	M (kg)	RR
NZeco	0.25	92	1.8	600	.008
ICEV (petrol)	0.31	18	2.3	1150	.014
ICEV (battery)	0.31	80	2.3	1150	0.14

Furthermore, it was assumed that the frontal area of a typical ICEV was approximately 2.3m². The NZeco was found to have a frontal area of 1.9m² using CAD modelling. In addition, it was assumed that a typical ICEV has a curb weight of approximately 1150 kg, whereas the NZeco has a mass of 600 kg, including 200 kg of Li-ion batteries and an 80 kg driver. In the simulation for the ICEV converted to battery power, it was assumed that the same batteries as NZeco would be used. Further, it is assumed that the ICEV converted to battery power would have a mass, including batteries and driver, of 1150kg.

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 conservatively assumed to be 0.014. The NZeco was assumed to be fitted with low rolling resistance car tyres with an RR of 0.008, giving it the same RR as those used on the General Motors EV1.

As discussed earlier several different types of battery are currently available including Pb-acid, NiMH, NiCad and Li-ion. 200kg of Li-ion batteries, with an energy density of 143Wh/kg (based on the SAFT HE41), were used in the modelling of the NZeco and ICEV battery conversion. The assumption that the vehicles would only be driven for 80% of the available battery capacity was used in the models as repeated 100% battery

discharge would significantly reduced battery life. With the motors mounted in the wheels the batteries would utilise the space formerly occupied by the IC engine.

It was assumed that the electrical energy for the NZeco BEV is converted to drive by a motor and controller with an overall efficiency of 0.92. Such high efficiencies arise from the use of brushless DC motors built into the wheel of the vehicle. A typical ICEV was assumed to have a petrol-to-wheel conversion efficiency of 0.18 (Ahman, 2000). Finally, the ICEV converted to battery power was assumed to have an overall efficiency of 0.8 assuming that it did not utilise a brushless in-wheel motor.

RESULTS OF MATHEMATICAL MODELLING

Table 2 shows the calculated power required to propel the NZeco an ICEV and an ICEV electric conversion vehicle at 100km/h. P_c is the power required by the car, P_s is the power supplied by the source (battery or petrol). The range of the electric vehicles on one charge (80% battery discharge) and for the ICEV 40 litres of petrol is also shown.

Table 2: Vehicle Power Requirements at 100km/h

Vehicle Type	C_d	η_{mc} (%)	A (m^2)	RR	M (kg)	RR	Energy supply	P_c (kW)	P_s (kW)	Range (km)
NZeco (battery)	0.25	92	1.8	0.008	600	0.008	200 kg Li-ion	7.1	7.7	300
ICEV (petrol)	0.31	18	2.3	0.014	1150	0.014	40 litre petrol	13.6	75.3	490
ICEV (battery)	0.31	80	2.3	0.014	1150	0.014	200 kg Li-ion	13.6	17.0	135

From Table 2 it can be seen that the NZeco uses only 7.7kW from the battery compared to 75.3kW from petrol for the ICEV. This factor of nearly ten highlights the compounding effect of low rolling resistance and aerodynamic drag of the NZeco coupled with a high efficiency in-wheel motors with no gearbox and transmission losses.

Furthermore, it can be seen that converting a typical late-model petrol car to battery would require approximately twice the power from the batteries compared to the NZeco. The range is subsequently affected, achieving only 135km compared to 300km for NZeco. Thus, Table 2 highlights the existing potential for BEVs. However, it should be noted that with battery technologies such as Lithium Sulphur the range of BEVs could at least double and virtually close the gap in performance between BEVs and ICEVs.

POTENTIAL FOR THE USE OF LIGHT ALLOYS IN BEVS

One of the key factors in improving energy efficiency of vehicles is weight reduction. This can be achieved by replacing steel components with metals such as titanium and magnesium alloys. Though expensive compared to steel, their benefits for high value vehicles make them appealing. An example is the use of titanium springs on a Ferrari (Excell, 2004). The springs reduced the un-sprung mass and are corrosion resistant. Vehicles with high sprung to un-sprung mass ratio (greater than 10) have better ride comfort than those with low ratios (Hrovat, 1988).

The NZeco BEV has in-wheel motors and low sprung mass that give it a ratio of approximately 6. To overcome this, the use of titanium and magnesium alloys for suspension components, wheels and brake discs could reduce the un-sprung mass of the NZeco by 40% and hence reduce sprung mass vibration by 24% (Hrovat, 1988). It is widely recognised in the automotive industry that titanium has the potential to become a major automotive metal (Schauerte, 2003).

Furthermore, the use of aluminium honeycomb as demonstrated on the NZeco chassis highlights the potential for low volume manufacture. To the structural ensure the integrity of the NZeco design an analysis of the chassis was undertaken using finite element analysis (FEA) to ensure a stiff strong chassis as shown in Figure 3. Subsequently, sheets of the aluminium honeycomb were water jet cut based on 2-dimensional CAD files. The chassis was assembled as a 3D jigsaw puzzle and glued together. The result is a chassis of total mass under 50kg with stiffness and strength to ensure driver and passenger safety with front and rear impact attenuators.

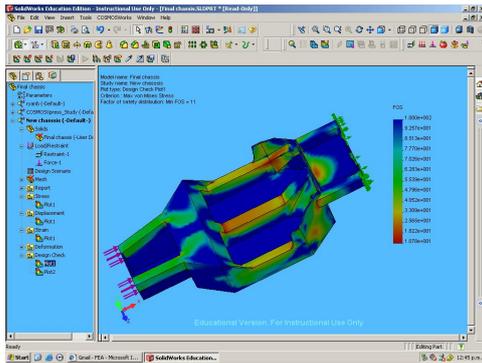


Figure 3: FEA and final chassis assembly

DISCUSSION AND CONCLUSION

This work has mainly dealt with the feasibility of BEVs in relation to performance, materials and manufacture. However, energy and vehicle production, design and cost are important factors that must also be considered. Electricity generation and transmission for BEVs from non renewable sources such as coal or gas undermines their environmental credentials. However, the proposal in this work is this that the NZeco's charge electricity will be offset grid connected PV modules on a house or garage roof. It might also be possible for BEV owners to purchase electricity from wind farms.

Transport faces a number of problems; finite oil reserves, rising petrol prices, congestion, local pollution and green house gas emissions. Alternative vehicle technologies such as BEVs, hybrids and fuel cells need to be investigated for the eventual replacement of conventional ICEVs.

BEVs such as the NZeco are technically feasible today using lithium battery technology. The vehicles can provide the driver with a safe, comfortable, environment with a performance close to a conventional ICE car.

For 15,000km annual travel they use 10 times less electrical energy than an ICEV uses petrol energy. The BEV should be designed and built as a low energy vehicle to have maximum drive train efficiency, low aerodynamic drag, mass and rolling resistance. Converting an ICEV to battery is not recommended as it uses energy inefficiently.

BEVs can be charged from sustainable energy sources such as solar, wind, hydro and biomass. The chassis could be made from aluminium honeycomb and suspension and motor components from light alloys such as Titanium and magnesium. The former ensures a light but strong chassis that is suitable for low volume production. The later gives a low un-sprung mass that provides acceptable vibration characteristics.

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