Transitions in transit: future options for transport energy in New Zealand

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Abstract
Transport contributed 20.1% of New Zealand's GHG emissions in 2009. This, coupled with our current dependence on imported transport fuels provides a strong motivation to examine alternatives. In this paper we examine two conservative policy scenarios for the transition from internal combustion engine powered vehicles to electric vehicles, using transport data from an historic 10 year period. Electrification is an attractive option, but the transition to a largely electric car fleet is shown to be relatively slow. An orderly transition from our existing vehicle fleet is demonstrated to require a consideration of liquid biofuels. The land footprint requirements for liquid and gaseous biofuel production, and of electrification, are revealed and their implications discussed. It is concluded that biofuels will play an important role in moving toward a sustainable transport system, but that complimentary policy measures, including serious attention to transport patterns, will also need to be considered.

Introduction

Transport plays a major part in the New Zealand economy, and way of life. It is dominated by road transport, and in particular the light motor vehicle, due amongst other factors to the "long, skinny" geographic distribution of our main transport corridors, and our relatively low population density. New Zealand's somewhat unique greenhouse gas (GHG) emissions profile, with nearly 50% of emissions due to agriculture, can tend to mask the fact that transport is a significant part of the profile. Transport accounted for 20.1% of total emissions, and 44.2% of non-agricultural emissions, in 2009 (MfE, 2010). Of the total transport emissions, road transport accounted for the overwhelming majority (89.8%), with coastal shipping and domestic aviation accounting for only 2.3% and 6.8%, respectively. Coupled with the long-term rising cost of oil and the prospect of unreliability of supply, plus New Zealand's commitment to a reduction of greenhouse gases of 10-20% on 1990 levels by 2020 (NZ Government, 2009), this draws our attention to the transport sector as an important area to attack in relation to all of these problems.

The adoption of biofuels in place of petrol and diesel, and the electrification of transport, have both been discussed as options for reducing GHG emissions and also gaining security of supply (e.g. PCE, 2010). The disadvantages of "first generation" biofuels have been well documented, whilst the history of the electric car has been long (e.g. Sovacool, 2008), and controversial - particularly in the popular media (e.g. Paine, 2006). In this paper we explore these topics in the New Zealand context, with particular reference to the nature of a transition from today, with a virtually 100% internal combustion engine powered light vehicle fleet, to a future involving biofuels and/or electric vehicles.

Transport energy options

The two major types of road transport vehicles are light vehicles, used for passenger transport and which mostly burn petrol, and heavy vehicles, used for freight transport and which mostly use diesel. The proportions of the two fuels used were roughly equal in 2008, with 111PJ of petrol and 110PJ of diesel consumed (MED, 2009). Some of the substitutions we shall consider are applicable to both types of fuel use and some are applicable only to one. These differences arise because of the different types of engine used to burn diesel and petrol and to the different ways in which the energy storage can be carried on, or brought to, the vehicle.

Reduction in the use of fossil fuels for transport can be made in a number of ways. These include:

1) *Retaining the fuel types but changing the source to a renewable one*. For example, it is possible to generate petrol and diesel from wood pyrolysis products via processes such as the Fischer Tropsch process (Boerighter et. al., 2002; Tijmensen et al 2002; Ehrlich, 2008), with wood grown by sustainable rotation. Current activity in this field is limited to pilot scale production of about 15 million l/yr (CHOREN plant; Ehrlich, 2008), and 656 tonne/y (with 100,000 tonnes/y planned) by Neste-Stora Enso (EBTP, 2010). Laboratory scale work in this area is currently also being carried out.

2) *Changing the fuel type to one that can be used in current vehicle engines and that can be produced renewably*. For example, spark ignition engines that normally run on petrol can, with minor tuning modifications, be fuelled by ethanol produced from a number of organic crops such as beet, sugar cane and wood. Both spark ignition and compression ignition (diesel) engines can be operated on biogas produced from sources ranging from domestic sewage, industrial wastes, and organic waste in landfills (Metcalf and Eddy, 1991; Tchobanoglous et. al., 1993) through to purpose grown crops. This requires a degree of modification of the engine to allow gas fuel induction and a change in the fuel storage on the vehicle so that the gas may be carried in high pressure containers. Producer gas from woody material (e.g. Pfeifer, 2008) is also an option. In this paper we will consider only compressed methane derived from biogas. Although other options such as liquefied biogas and hydrogen (pressurised gas or liquid) have been canvassed, none of these has yet gone beyond the laboratory stage.

3) *Changing the engine to from internal combustion to one that uses an energy form that can be stored on the vehicle and that can be provided from a renewable resource*. The most obvious of these is the electric car in which the energy is stored in an electric battery that can be charged from a stationary generator running on renewable energy such as wind, hydro, or geothermal and transmitted to the wheels via an electric motor. A range of such vehicles (e.g. Nissan Leaf, Tesla, Mitsubishi) are, or soon will be available on the public market. A major transition to electric vehicles may be possible in the future but would, unlike the changes described in the first two paragraphs of this section, depend on the replacement of the whole fleet with new technology vehicles. Moreover it is unlikely, given the characteristics of current electric vehicles, that this change could be used effectively for long distance freight transport by road. Indeed, many of the electric cars that are presently being developed will not have a range suitable for long distance passenger transport. Other energy storage methods such as flywheels and compressed gas (Arrillaga and Bodger, 2009)

have been investigated but these are subject to even more stringent constraints (completely new vehicle technology, short range) than those affecting electric vehicles. Although flywheels were used for a season as kinetic energy recovery devices in formula one racing, no fully flywheel-drive vehicles are available, or likely to be available in the near future. A compressed air storage vehicle is in the development stage, but will not be further considered here.

4) *Changing the ways in which we use transport*. Greater use of low energy personal transport methods such as walking and cycling would reduce fossil fuel consumption in short distance transport. In order for this to occur, city and urban infrastructure needs to be developed to facilitate such activities. Greater use of public transport is also touted as a means of "getting people out of cars". Public transport by underground, rail, light rail (trams) and buses works well in large cities with high population densities providing good accessibility in terms of timetables and routes and reducing vehicle densities on the road. In NZ cities urban transport by diesel bus currently has fuel consumption comparable with cars carrying one to two passengers. Nevertheless we believe that a public transport system for cities based on better use of modern communication technology could achieve significantly greater efficiency of use of fuel and road space.

As the objective of this paper is to examine some options for the replacement of fossil transport energy by renewable energy in both the short and the long term, the remainder of this paper focuses on items 1), 2) and 3) listed above, with particular reference to possible rates of implementation and implications for land use in New Zealand.

Methods

Study period and transport fleet scenarios

Transport fleet composition data for the period 2000-2009 from the New Zealand Ministry of Transport (MOT, 2010) was used for this study. Characteristics of the fleet during this period were:

- Total light passenger vehicles, diesel and petrol, rose from 2,115,776 to 2,574,589;
- On average, 85,845 new cars entered the fleet each year, compared with 131,760 used cars of average age 7 years.

The following two scenarios were then explored to ascertain the change in fleet composition over time using that historic data set:

Scenario 1: all registrations of brand new vehicles from 1 January 2000 to 31 December 2009 were mandated to be electric vehicles, with continued importation of used internal combustion engine powered vehicles permitted. Then, after 7 years, all new registrations into NZ (brand new and used) were mandated to be electric.

Scenario 2: in each year from 1 January 2000 onwards, 10% of all brand new vehicles were mandated to be electrically powered. Thus, in 2000, 10% of brand new cars into New Zealand would be electric, 20% the following year and so on. After 7 years, 10% of used cars were mandated to be electric, and follow the same pattern.

Assumptions used in the analysis were:

- Only petrol/diesel vehicles are scrapped over the period. In reality, some new vehicles entering the country (i.e. electric) would be scrapped due to crash damage;
- Mileage travelled was assumed to be evenly distributed over the fleet. In reality, newer vehicles travel more, and hence consume more energy than older vehicles;
- Electric vehicles were assumed to use one fourth the energy as the equivalent petrol/diesel vehicle.
- Only light passenger vehicles were considered - these comprise cars, vans, “utes” and SUVs less than or equal to a mass of 3500kg.

Land area requirements

Land areas for the production of renewable fuels were calculated using published data for the production per unit area. To incorporate sustainability we have assumed that all energy inputs to the production come from the growing area. This is achieved by multiplying the land area required for the vehicle fuel by a factor (F), based on the ratio Energy Returned On Energy Invested (EROEI). Typical EROEI values are shown in Table 1.

$$EROEI = \frac{energy\ produced}{energy\ expended\ in\ production}$$

F gives the ratio of the effective land area committed to the production over the area’s primary production. At low values of EROEI, F is a steeply varying function, rising from 1.25 at EROEI of 5 to infinity when EROEI falls to unity.

$$F = \frac{EROEI}{EROEI - 1}$$

Land areas were calculated from the total energy consumption required for a particular fuel (EC), the calorific value of the replacement fuel (CV), the productivity of the land (P) and the F factor, which is derived from the EROEI for that particular replacement.

$$Land\ area = \frac{F * EC}{P * CV}$$

Table 1: EROEI values from the literature

Feedstock	Products	Values	Reference
Corn	Ethanol	0.35-2.47	Bisio and Boots (1997)
Sugar beet	Ethanol	2.53-5.70	Henderson (1986)
Wood	Ethanol	3.5-4.5	Hall and Jack (2008)
Wood	Fischer-Tropsch fuels	3.9-5.4	Hall and Jack (2008)
Fruit	Biogas	11.3	Hall and Jack (2008)
Soybeans	Biodiesel	1.45-3.24	Morris (1994)
Rapeseed (Canola)	Biodiesel	1.8 – 2.1	Barber et. al., (2007)

The land areas required for electricity generation were derived assuming purpose grown wood plantations firing a generating station at 25-40% efficiency. Given the fact that some of this electricity would come from wind and hydro, this represents a worst case scenario. Fuel calorific values used in calculations are shown in Table 2.

Table 2: Fuel calorific values[a]

Fuel type	Density (kg/l)	Gross calorific value (MJ/l)
Petrol	0.73	34.5
Ethanol	0.79	23.6
Diesel	0.90	39.1
Biodiesel	0.85	35.6
Methane	0.00064	0.036

[a] Sources: Brown (2003); Metcalf and Eddy (1991)

Results and Discussion

Fleet composition and fuel consumption

Fig. 1a shows the historic petrol and diesel light passenger fleet over the period 2000-2009. Fig. 1b shows the corresponding fuel usage. Figs. 1c and 1d show the petrol and diesel light passenger fleet and corresponding fuel consumption for scenario 1. Figs. 1e and 1f show the petrol and diesel light passenger fleet and corresponding fuel consumption for scenario 2.

Under the two scenarios explored here, incorporation of electric cars into the New Zealand vehicle fleet is shown to be relatively slow, and it is clear that at the end of the 10 year study period, the overwhelming majority of cars would still be powered by internal combustion engines, thus requiring continued supply of liquid or gaseous fuels. The electrical energy requirement is modest and given the composition of the New Zealand electricity generation system would incur quite a small GHG penalty. If GHG emissions are to be substantially reduced therefore, large amounts of biofuels will be required. Based on the reduction in fossil fuel use for scenario 2, there would be an 18% reduction in GHG emissions.

Land areas

The most likely basis for bioethanol production in New Zealand in the short term is beet, from which a yield of about 3855-5000 l/ha.yr can be expected (Brown et. al., 1981; Judd, 2003). The gross productivity is thus 110 GJ/ha.yr. To include the sustainability requirement, this was multiplied by the F factor for sugar beet alcohol which ranges from 1.65-1.21. At the beginning of the study period, 93 PJ of petrol was consumed. Replacement by beet ethanol would have required between 0.93–1.69 million ha. For scenario 1 the land area required at the beginning of the period is as given above, and reduces to 0.76-1.34 million ha at the end of the study period. In the long run, replacement of all current light vehicle road transport by electric vehicles fuelled by wood fired power station(s) at 25% efficiency would require less than half a million ha. The land areas calculated in this way are shown in table 3.

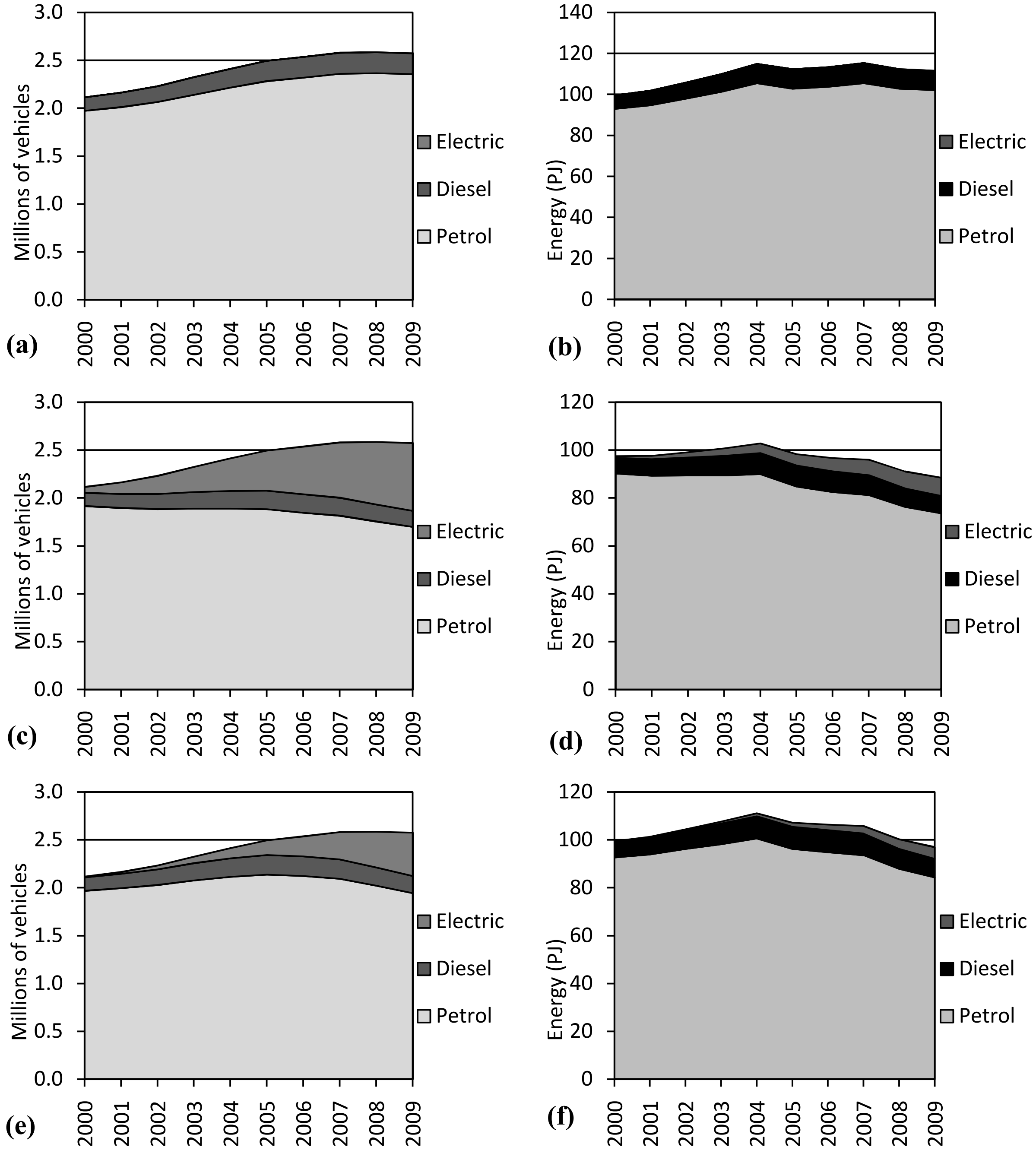

Figure 1. (a) The historic car fleet numbers over the study period; (b) the corresponding energy consumption; (c) the car fleet composition if all car manufacturers switched to producing all electric cars within a year; (d) the corresponding energy consumption; (e) the car fleet composition if car manufacturers took 10 years to switch from producing internal combustion engine powered cars to electric cars; (f) the corresponding energy consumption.

Table 3: Required land areas (million Ha)

	Petrol	Diesel	Electricity	Total
Base case (2000)	0.95-1.69	0.36-0.42	0	1.31-2.11
Base case (2009)	1.05-1.86	0.50-0.59	0	1.55-2.45
Scenario 1 (2009)	0.76-1.34	0.39-0.46	0.09-0.14	1.24-1.94
Scenario 2 (2009)	0.86-1.53	0.42-0.49	0.04-0.07	1.32-2.09

Another option is to utilise compressed biogas, in a manner analogous to previous use of compressed natural gas. Given that all current biogas sources are already usefully employed, we concentrate on the production of biogas from purpose grown crops. The effective use of biogas for vehicle fuelling requires that most of the carbon dioxide be removed and that the remaining methane be compressed and stored on board the vehicle at high pressure. Assuming crop yields about 20 t-DM/ha.y, degradation of 30% of the total solids, and a yield of 0.75 m^3-CH_4/kg-TS removed, this gives a gross energy production of 161 GJ/ha.yr. Assuming an EROEI of 3 (to include agricultural inputs), this gives a net production of 121 GJ/ha.yr. Replacement of all transport fuel by biogas would require 1.83 million ha. The main production of biogas at the moment is from wastewater treatment and the harvesting of landfill gas.

Implications for transition to a low carbon light vehicle fleet

The consequences of ethanol substitution are several. Vehicles would need to be re-tuned. In some cases parts such as flexible fuel hoses might need to be replaced. In a 100% ethanol based system the distribution infrastructure would need to handle roughly 50% more volume of fuel. Current vehicles would have a range of approximately 2/3 of their current range. Given that most cars have a range of about 400-500km, and petrol stations are spaced much more closely than this, the reduced range should not be an inconvenience.

New Zealand currently produces about 20 million litres of bioethanol (energy value 0.47 PJ) from dairy whey (Liquid Biofuels in New Zealand, 2010). An earlier estimate of the energy value gave 0.40-0.44 PJ (Thiele, 2005). Whey ethanol is mostly exported, and used for drinking alcohol and in the production of food and cosmetics. Some ethanol is currently sold as a 10% blend with petrol, at Gull petrol stations in the North Island (40 service stations; Gull New Zealand, 2010). Also, Mobil has E10 available at 7 service stations, and E3 is available at 15 outlets (Mobil New Zealand, 2010).

Full utilisation of tallow has previously been estimated to be able to meet 6-7% of national diesel demand (Judd, 2002), and with inclusion of waste cooking oil, the supply is unlikely to provide more than 10% of demand. Estimates of potential algal oil derived biodiesel amount to another 10%, although a number of issues remain to be solved (PCE, 2010). An increase in biodiesel production therefore either requires greater utilization of by-products/wastes, or growing more rapeseed (Solid Energy, 2009). An analysis on biodiesel production from New Zealand tallow shows it releases 51% of the GHG emissions compared with mineral diesel (Barber, 2007). The decrease in emissions when the biodiesel is derived from rapeseed has been calculated to be 58% compared to mineral diesel (SKM, 2008). In contrast UK produced rapeseed diesel has a 19% reduction compared with mineral diesel (SKM, 2008).

The options discussed so far are ones that use technologies that are available now. They all require quite large areas of land. The total area of arable land in New Zealand is about 13,000,000 ha, with 1,500,000 – 2,000,000 ha needed to feed the current population. Thus the production of biofuels for the transitional scenarios presented here would require diversion of 15-23% of total arable land for this purpose, or major developments in the production of biofuels from cellulosic forestry crops. While such processes currently exist at the experimental level, their large-scale application remains to be proven. In either case the imperative for immediate and concerted action is strong if New Zealand is to achieve security of supply. If not, then considerable increases in biofuels production abroad will be required.

Are there options that could be available in the medium future that would take us towards sustainability with the commitment of less land? Firstly, there is the electric car – but as we have shown the transition time is likely to be long under the assumptions made in this paper. We conclude therefore that rather more drastic policy measures than explored here will be required if electrification of transport is to make a major impact on New Zealand's GHG profile in a timely fashion. Secondly, our analysis has incorporated historic travel patterns. A major shift to the use of public transport, cycling and walking would decrease fuel consumption and hasten the transitional phase to a low-carbon transport system. This requires cultural as well as technical transformation.

Conclusions

The rate of conversion of New Zealand's road fleet from internal combustion engine powered vehicles to electric vehicles under two conservative policy scenarios was shown to be relatively slow. Thus after 10 years, the majority of the fleet remained powered by internal combustion engines. Any future rate of transfer will be conditioned by the production and cost of electric cars and the rate of retirement of our current fleet.

It is technically possible to fuel New Zealand's road fleet from indigenous renewable sources. However, this would take a large part of our arable land, thus impinging on other aspects of our agricultural economy, unless cellulosic ethanol production from woody biomass can be developed. Replacement of a proportion of fossil fuel consumption by biofuels is capable of making a significant contribution to the desired GHG reduction and will be a vital part of the transition under our scenario assumptions. Given the half life of the internal combustion engine fleet, and the likely rate of increase in the cost of fossil-oil, it would be wise to begin a programme of conversion immediately.

In the long run it would appear that a full change to electric vehicles for passenger transport would be able to make significant contribution to the reduction in GHG and self sufficiency in transport fuels. However this should be accompanied by serious attention to altering current transport patterns.

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