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Avenues to sustainable road transport energy in New Zealand

Geoffrey D. Kelly
University of Wollongong, gdkelly44@gmail.com

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Keywords

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Avenues to Sustainable Road Transport Energy in New Zealand.

Geoff Kelly

Sydney Business School,
University of Wollongong
Wollongong NSW 2500

Tel.: + 61 242213850.
Email address: geoff_kelly@uow.edu.au

Abstract

Reduction of the energy use and emissions associated with the provision of transport services is one of the most challenging areas of energy policy. This arises both from the pervasive nature of transport use in modern society, and its dependence on the most limited of fossil fuels. Advances in renewable energy utilisation offer an avenue by which this may be addressed, including the possibility of achieving fully sustainable transport energy supply. The paper considers what potential exists for sustainable road transport energy in New Zealand. That country already has high renewable energy utilisation, but also a high per capita transport demand, and limited domestic hydrocarbon resources. Three main routes for renewable fuel supplies are examined, with the conclusion that two (the production of biofuels from forest products, and the amplification of electricity supply from renewable energy sources for use in electric vehicles) offer technically feasible pathways towards a fully sustainable transport energy system. Cost and confidence in investment remain the principal barriers to this development.

Keywords

Renewable energy
Transport
New Zealand
Forest resources
Biofuels
Electric vehicle
Externalities

1. Introduction

In worldwide efforts to replace fossil energy with sustainable energy forms, one particular area offers major challenges - that of transport energy. Many initiatives are under way to develop alternative energy sources for what is, particularly in developed economies, a most pervasive energy use. A common motivation is pursuit of the 'energy policy triad' - where policymakers seek to simultaneously address issues of economic energy supply, the enhancement of energy security and most significantly, the reduction of damaging emissions associated with fossil fuels (Ringel, 2006). Renewable energy (RE) is increasingly seen as an important step towards these objectives (Czeberkus, 2013). In economic terms, RE sources are seen as a long-term preferred alternative to non-renewable sources, their cost being less driven by pure scarcity, and less volatile in price terms. In regard to security, RE may be derived from a broad range of sources and so, for many countries without major fossil energy endowments, can offer a reduction in dependence on other countries and international markets for essential energy supply. Last, and commonly the most important of the three, RE provides an avenue whereby the emission of greenhouse gases from fossil fuels may be markedly reduced.

This paper considers one country (New Zealand) in which all three aspects are important. It examines what potential exists for the exploitation of RE at significant scale in a highly transport-dependent economy, focusing particularly on road transport. The case of NZ is of interest because of NZ's already high utilisation of RE, and the fact that the problems which NZ faces are characteristic of those faced by others also, particularly smaller, physically isolated countries. Potential solutions to this issue may therefore be relevant to other countries also.

2. Context

New Zealand (NZ) is one of the smallest OECD economies (CIA, 2011a). Although similar in area to the United Kingdom, it has around one fifteenth of the UK's population. Its 4.4m people (CIA, 2011b) are spread over two main islands nearly 2000km long north to south. 70% of its population is concentrated in only 16 significant urban areas (Statistics NZ, 2008). In resource terms, NZ renewable resources play a greater role than do its non-renewable resources. The relative contributions to total primary energy supply are shown in Figure 1. NZ has significant reserves of coal (of which some 80% is lignite), but coal provided only 7% of total energy supply in 2012 (MBIE, 2014a). Based on 2011 consumption levels, oil reserves amount to a little over 18 years of consumption, and natural gas 6 - 7 years (EIA, 2013). Renewable resources however are extensive, with RE supporting some 78% of electricity generation in 2013, primarily through hydroelectricity, wind, and geothermal energy (MBIE, 2014a).

Agriculture is prominent, with productive pasture covering around 43% of total land area (MfE, 2007). Agriculture also plays a major role in trade - while only generating some 6.4 % of GDP in 2013, agricultural products comprised over 45% of NZ's total export in the same year (Treasury, 2013). NZ is home to the world's largest dairy products exporter, Fonterra (The Economist, 2009). Forestry is important also, with some 1.75 million hectares (around 7% of total area) covered by plantation forests. Indigenous forests cover a further 6.5 million hectares (MPI, 2012). In energy terms, energy used from biomass is some 45 PJ/a, and might be augmented to 105 PJ/a with the addition of residues from wood harvesting and processing (Scion, 2007). That compares to total consumer energy demand in 2013 of 553 PJ/a (MBIE, 2014a). Forestry products contributed around 9% to total exports (Treasury, 2013). Those exports are important, since NZ has run a current account deficit for nearly 40 years, in recent years around 2 - 8% of GDP (RBNZ, 2013a). Much of that is driven by the servicing of substantial overseas debt, over 120% of GDP in 2012 (RBNZ, 2013b). The persistent current account deficit has led in turn to concerns also about the level of foreign asset ownership in NZ - an inevitable outcome of continued overseas borrowing (BNZ, 2011). Improving the current account balance by either reducing imports or increasing exports (or both) is of major and long term importance to the economy.

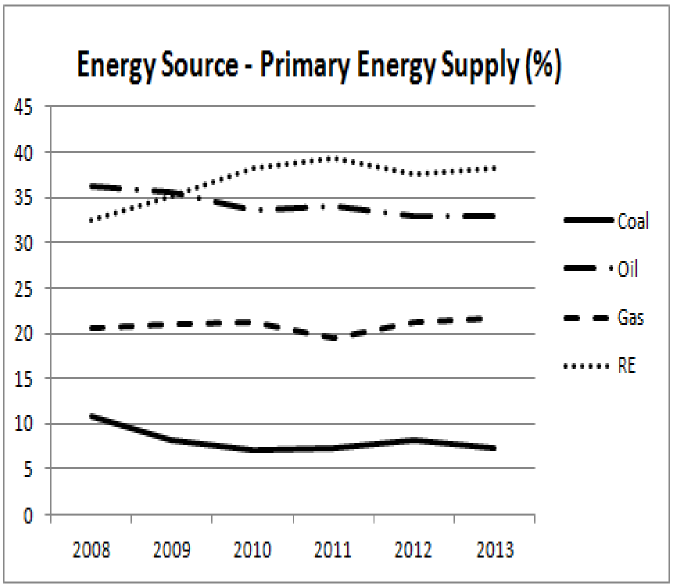

Fig 1: Primary energy supply percentages, NZ 2012 (MBIE, 2014a)

A further contextual factor in considering transport energy arises from NZ's environmental commitments relating to greenhouse gas emissions. Under the Kyoto Protocol, NZ undertook to contain nett emissions over the period 2008 – 2012 to the levels of 1990 (UNFCCC, 2009). It also later stated that it would contain emissions to 10-20% below 1990 by 2020, if other countries did likewise (PCE, 2010). The Kyoto commitment has been fulfilled, with NZ in fact being in credit over the measurement period by an amount of around 35 million tonnes of CO_2 equivalent emissions. That had been achieved through the contribution of some 86 million tonnes uptake by forests (MfE, 2013a), much of which had been planted in the early 1990s, and which offset actual emission increases of some 23%. With those forest approaching harvesting age, and consequent emissions, NZ will have to reduce actual emissions, undertake large scale plantings to offset emissions, or buy emission reductions ('carbon credits') elsewhere (PCE, 2010). Hence there is incentive to seek emission reduction, or offsets, to meet national commitments.

In summary, the context of transport energy in NZ points to all three elements of the policy triad. Transport demands are high while domestic hydrocarbon resources are limited - so transport is a driver of hydrocarbon imports with their cost and external dependency. Emission reduction is also an issue of some sensitivity. There is good reason therefore to pursue more sustainable energy sources. As the consumer of more than 80% of NZ's imported diesel and virtually all petrol (MBIE, 2014a), and the generator of over 40% of the country's energy greenhouse emissions (MfE, 2013b), transport clearly needs to be a central aspect of any such efforts.

3. Transport in NZ

The widespread distribution of population makes NZ much reliant on transport. Road transport is the dominant mode in both freight and personal transport. In freight, while government has made substantial expenditure on once-privatised rail systems (MoT, 2014), there has been a shift over years to road transport in a manner which will be difficult to reverse. Road systems carry some 70% of all freight tonne-kilometres (MoT, 2013a). The dominance of road transport in part is driven by geography and topography, both of which tend to favour lower cost and flexible road freight. Of importance also in NZ is the small size of the economy, and the consequent absence of economies of scale in constructing major infrastructure such as rail systems. Industries such as dairy production, one of the major growth industries over recent years, of their nature imply a need for flexible product collection and distribution systems. This is reflected in the fact that, unusually, road freight tonne-kilometres have over the years increased at a greater rate than real GDP, implying a higher freight intensity of real output (MfE, 2009). The principal energy source of road freight is diesel, around 70% of total diesel consumption going to this purpose, with off-road uses such as agriculture, fishing and hunting and other primary industry consuming a further 10 - 15% (MBIE, 2014a). Fig 2 shows consumption over recent years.

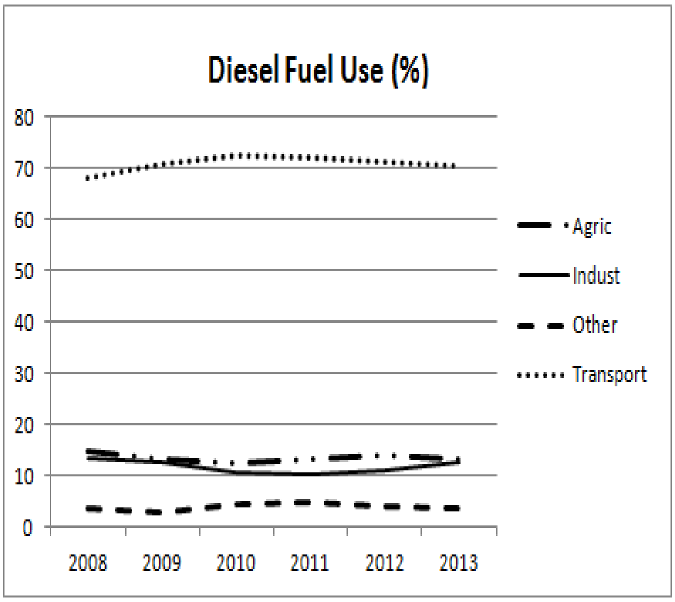

Fig 2: Diesel end use in 2011 (MBIE, 2014a)

Total diesel fuel energy used for road freight was 79.8 PJ/a in 2011 with a larger amount (107.1 PJ/a) going to petrol use for road transport. Of that, 95% was used in light passenger vehicles (MED, 2011b). The total consumption of some 188 PJ compared to 553 PJ total consumer energy (MBIE 2014a). As with road freight, the predominance of motor vehicles for personal transport is in part driven by the nature of the countryside and the trips to be undertaken. Earlier NZ urban development was undertaken in the context of car availability, and hence town planning of itself has influenced the later need for road transport. That task is essentially supported by cars. Travel surveys showed over 87% of journeys to work being done by motor car (MED, 2011b), with vehicle kilometres being further increased by the fact that in two thirds of all trip legs the driver was the sole occupant of the vehicle. Lifestyle preferences were also a factor, with around 25% of all trips being made for social or recreational purposes (MoT, 2013b). Motor vehicles facilitated a lifestyle which might include weekends at holiday locations, or living in ‘lifestyle’ homes – rural homes within commuting range of cities (Perreau, 2007). A tax structure on fuels which was among the lowest in the OECD (OECD, 2012) was no great deterrent to vehicle travel. The overall effect was that car ownership per capita was among the highest in the world (World Bank, 2013) and actual distance travelled per person, while declining in recent years (MoT, 2013c) had some years earlier been second highest in the OECD (MfE, 2013c).

While the distance travelled by diesel-fuelled freight vehicles was far lower than that by largely petrol-fuelled cars, the higher unit consumption of heavy vehicles meant that the overall energy consumption difference was by no means as great, road diesel use being around 80% that of petrol in energy terms (MED, 2011b). Hence any policy approach to fossil fuel reduction must necessarily engage with both avenues of consumption. What then are the avenues by which NZ might pursue more sustainable transport energy provision?

Three broad approaches for reducing the present almost total reliance on fossil fuel supplies are

1) to reduce overall transport energy demand - either by reducing the absolute transport demand, or by shifting to less energy-intensive modes of transport through modal shift
2) where that demand continues to be met by road vehicles, to increase the fuel efficiency of the two main vehicle fleets concerned and
3) move to fuel types supplied from renewable sources.

These approaches are by no means mutually exclusive but rather complementary, with each a contributor to a coherent transport energy policy, and involving a diverse range of possible initiatives. Approach 2 for example might include vehicle fuel efficiency standards (a move rejected in 2009 (MoT, 2014)), or other means by which the purchase of more efficient vehicles might be facilitated and encouraged. Here however the focus is on approach (3), and the means by which the policy triad of economy, environment and energy security in transport may be pursued through exploiting sustainable energy sources.

4. Alternative transport fuels to date

Measures to address NZ transport sustainability are not new. Arising from OPEC oil price shocks, the government promoted the introduction of compressed natural gas (CNG) as a vehicle fuel in the late 1970s. Through a combination of various subsidies, a very rapid introduction was achieved, with CNG vehicle numbers doubling every year between 1979 and 1985, and CNG usage reaching 10% of spark ignition vehicles in 1986. But in 1985 a recently-elected government removed support subsidies, with the virtual demise of the industry over the next few years (Kojima, 2001) - leaving a "collapsed market" (Yeh, 2007).

In another response to the oil price shocks, the government also encouraged the construction of the world's first (and only) commercial scale plant to convert natural gas to methanol, and then to petrol, using the Mobil MTG process (IPENZ, 2013). By the time the plant was completed in 1987 world oil prices were already dropping. The plant produced its last petrol in 1997 (Gregg & Walrond, 2013) but has continued to produce methanol, largely for export (Methanex, 2013). In terms of other liquid fuels, a modest supply of ethanol has been available since 2004 as the output from plants processing a waste dairy product (NZIC, 2013). Supply from such sources however could not feasibly supply more than 1% of petrol demand (PCE, 2010). Ethanol has been used as a blend in proportions of 5 and 10% in petrol, for spark ignition engines - primarily in cars.

Biodiesel is also available, primarily sourced from a by-product of meat processing, tallow. Other much smaller sources include used cooking oil (LBIG, 2013), and oilseed from purpose-grown canola crops. Production is small, with less than 1.8 million litres being produced in the year to June 2012 (EECA, 2013). Tallow as a biofuel source is limited both by availability, and its opportunity cost - it has alternative end-uses returning substantially higher prices than those arising from fuel substitution (Kelly, 2011). More critically, the total amount of tallow available in NZ, if diverted to biodiesel production, is only capable of replacing around 5% of current diesel consumption (MoT, 2013d). Figure 3 shows the most recent data on biofuel production which, notwithstanding earlier increases, is minimal in absolute terms. The recent total output of 0.13 PJ may be compared to the transport consumption of 79.8 PJ in diesel alone (MBIE 2014a, MBIE 2014b). No other significant renewable sources of transport energy are used at present.

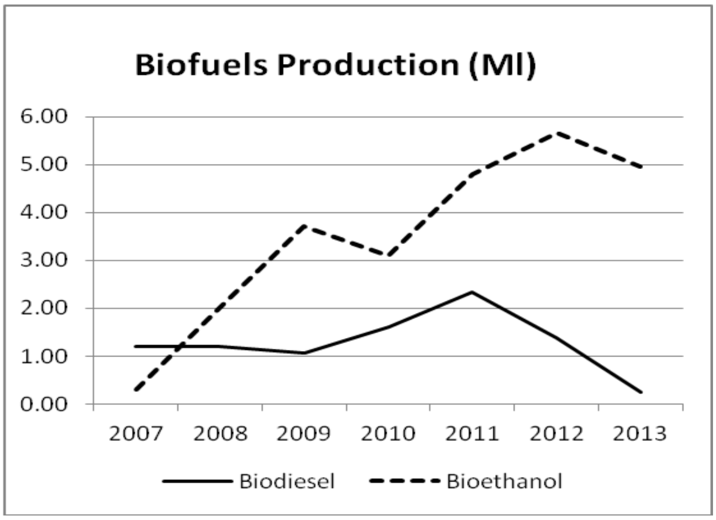

Figure 3: Biofuel production 2007 - 2011 (MBIE, 2014b).

It is apparent that current sources of alternative fuels are both modest and not scalable, other than CNG which has seen widespread adoption elsewhere since the end of the NZ program (NGV Global, 2013). Natural gas however only partly addresses the emissions issue, and in NZ is a fossil fuel of finite availability. The issue of scalability is however an important one, with implications for possible process adoption.

Current alternative fuel sources in NZ (ethanol and biodiesel) are sufficiently different to the fuels they seek to replace that they are limited in the percentage to which they can be used. Differing chemical characteristics may imply problems with fuel system materials, fuel handling systems, or engine performance. In the case of bioethanol, fuel replacement is generally limited to 10% ethanol in petrol, without requiring engine adaptation. Vehicles ('flex-fuel' vehicles) are available which allow operation on a range of ethanol percentages, but this is not possible on current vehicles, and hence significant reduction in petrol use through replacement by ethanol would require progressive replacement of the petrol-engined vehicle fleet.

More problematically, such a move would require a massive increase in the amount of ethanol fuel available - a major problem if supported by broad scale cropping in the manner employed elsewhere (Elbehri et al, 2013). In an already intensively farmed country, it would require the diversion of substantial cropping capacity to ethanol feedstock crops, with an agricultural production opportunity cost unlikely to be economically sustainable (PCE, 2010), and hence is not further discussed here.

In a manner similar to petrol, the replacement of fossil diesel by biodiesel is commonly limited to a percentage of 5% without engine modification, to protect engine performance and life (MoT, 2013d). These substitution limits lead to the so-called 'blend wall' - a cap on the fuel replacement achievable, arising from the differing chemical nature of the replacement fuels. If significant progress is to be made in the replacement of fossil transport fuels, the 'blend wall' must be bypassed - and this implies the use of fuels which are sufficiently similar to the fossil fuels concerned that they may be mixed and used in any proportion, with no negative consequences. Such 'drop-in' fuels require different processes to those now in use, with major implications for their production cost.

An approach premised on the larger scale application of current sources and technologies is not a viable avenue to sustainable transport energy. To date, three new approaches have attracted attention. Each has a different focus - the first two looking to provide substitutes for those fuels now in use, and the third looking to a different way to provide transport services.

5. Alternative pathways to renewable transport energy

Three broad avenues to large scale renewable transport energy deployment have been suggested, quite markedly different, but not mutually exclusive. The first looks to the utilisation of hydrogen as a clean energy carrier, with hydrogen from a variety of sources being used in vehicles powered either by fuel cells (FCVs) or internal combustion engines (ICEs) as part of a move to the 'hydrogen economy' (Barreto et al 2003). The second looks to retain existing transport vehicle infrastructure, but to provide its motive energy not from fossil fuel sources, but from biomass-derived "drop-in" fuels - fuels sufficiently similar to 'conventional' diesel and petrol that they may be used directly in current vehicles as a total fuel replacement. A major element of this approach is the utilisation of new large-scale forest plantings to produce the required biomass - notably on land classified as 'marginal' for other uses. ("Marginal" in this context is based on the NZ Land Use Classification and for the three principal cases relates to land in LUC classes 5, 6 and 7 (Scion 2009b).) This represents land classed as "unsuitable" for arable cropping, and of medium to low suitability for pastoral use (Lynn et al, 2009).) The third approach uses neither modified nor standard current vehicles, but replaces these with all- or partly-electric vehicles - battery powered electric vehicles (BEVs) or plug-in hybrid electric vehicles (PHEVs) combining electric and internal combustion engine drives. The transport energy source in this approach comes from expanded renewable electricity supplies, from those types already in use.

Each of the three alternatives has been suggested as being applicable at major scale. Each also has been the focus of a significant study. Other more recent alternatives have so far seen less detailed study. For example Kerckhoffs et al (2014) considered an alternative use of marginal lands for growing non-woody energy crops to furnish biomass for the generation of biomethane. Their analysis indicated that allocation of some 5% of the 'summer dry' marginal land classification in NZ to energy crop production, for processing to biomethane through anaerobic digestion, could effectively replace 160 % of the diesel used by the combined Agriculture, Fishing and Forestry Sectors in 2010 (13.3PJ). To date the economic evaluation has been of an overview nature for one case, but has been encouraging. A related assessment of potential grass-based biomethane use in Ireland was also positive (Thamsiriroj

& Murphy, 2011). Biomethane does however, like CNG, imply vehicle modifications to allow its use. Attention here is focused on the three major avenues outlined above.

The first of the options above is discussed briefly in Section 5.1 followed by more detailed discussion of the other two alternatives. Variations around the basic theme of each approach are noted where relevant.

5.1 *Hydrogen in transport*

The term 'hydrogen economy' was coined by John Bockris to describe an economy in which hydrogen would see widespread use for various purposes as an energy carrier, in a manner analogous to electricity. In a 1972 paper he noted in a prescient fashion that the term applied to the "energetic, ecological, and economic aspects of [the] concept" (Bockris, 1972) - a view close to the current concept of the energy policy triad. Like electricity, the impact of hydrogen use is determined not so much by its end-use consequences, but more by the manner of its generation.

That aspect was central to a 2007 research study carried out to evaluate issues associated with hydrogen as a transport fuel for NZ (MBIE, 2013a; CRL Energy, 2007a; CRL Energy, 2007b; CRL Energy, 2008). The study was part of an overall project ("Energyscape") aimed at understanding NZ's energy needs and potentials out to 2050, and the longer-term research needed to pursue that (NIWA, 2009). A total of 24 process chains for hydrogen production and use were assessed, including hydrogen generated from
- simple natural gas reformation
- coal gasification
- biomass gasification and
- electrolysis using renewable energy (wind), and current grid mix electricity.

A range of variants in terms of production location and product application were studied, including, in transport, both FCV and ICE vehicles. The outcome from the study was positive in its assessment of potential for the use of hydrogen from an energy perspective, although greenhouse gas emission outcomes varied widely between the chains studied. Coal-based processes required carbon capture and storage (CCS) to achieve any reduction in emissions from the base case (liquid fossil fuels) (CRL Energy, 2007b). Natural gas based fuels showed significant emission reductions, as did biomass gasification, with the latter route, in association with CCS, having the potential for negative emissions. The project developed a 'shadow roadmap' for implementation of the hydrogen strategy, setting out research needs, and a program for the provision of the infrastructure and vehicles required. The program envisaged the development of 100,000tpa refuelling capacity, and introduction of 200,000 FC vehicles and some 25,000 domestic FC installations for combined heat and power (CHP) by 2020 (CRL Energy, 2009).

Other assessments of hydrogen's potential were less positive. One analysis specific to NZ's situation compared the energy efficiency of eleven representatives of the hydrogen chains noted above with a basic all-electric transport system and concluded that the hydrogen options considered did not offer any efficiency advantage over an all-electric system. Some chains were identified as being markedly less efficient (Page & Krumdieck, 2009). The assessment noted also the dependence of a number of the energy chains proposed on natural gas, domestic supplies of which are limited. An earlier analysis focused on the losses associated with electrolysis, compression and fuel-cell use to demonstrate that hydrogen as an energy carrier was significantly less efficient than a simple all-electric transmission system (Hammerschlag & Mazza, 2005). It noted also that direct electric vehicles (BEVs and PHEVs) were much closer to commercial viability than were fuel cell vehicles. The latter point was acknowledged also in the most recent NZ government national energy strategy document. Noting that the coal-to-liquids (CTL) fuel route, and hydrogen fuel cells still had issues to overcome in environmental, technological and economic aspects, they were excluded from current reference scenario planning (MED, 2011a, MED, 2011b).

In the medium term the approaches of biofuel production with existing IC engine utilisation, and extension of current renewable electricity technologies to power electric vehicles are the more likely candidates for early uptake in New Zealand, and these are considered further below. The hydrogen route for transport fuels is not further discussed here.

5.2 Biofuels and electric vehicles

The other significant options for sustainable transport fuel in NZ both have certain components which are already well established. The proposed biomass to liquids (BtL) route relies for feedstock on much extended forestry production, from what has been a well-developed industry for many years. Its fuel end-use is in conventional internal combustion engines with, in the ideal, the ability to switch between fossil and renewable fuels without performance or maintenance problems. The latter factor readily facilitates a staged introduction of the replacement fuels concerned. The area of significant novelty is in the BtL process itself, as discussed further below.

The electric vehicle (EV) route relies for its energy source on the extension of already substantial renewable energy supplies, using technologies in use now. Figure 4 shows the present energy sources for electricity generation, with some three quarters of present supply coming from renewable sources, primarily hydro. Its end-use however implies a large-scale conversion of the light vehicle fleet to electric vehicles, and the development of a major national charging infrastructure to service those vehicles. It is also for the foreseeable future likely to be limited to light vehicles, leaving the important element of heavy freight and bus transport still reliant on liquid fuels.

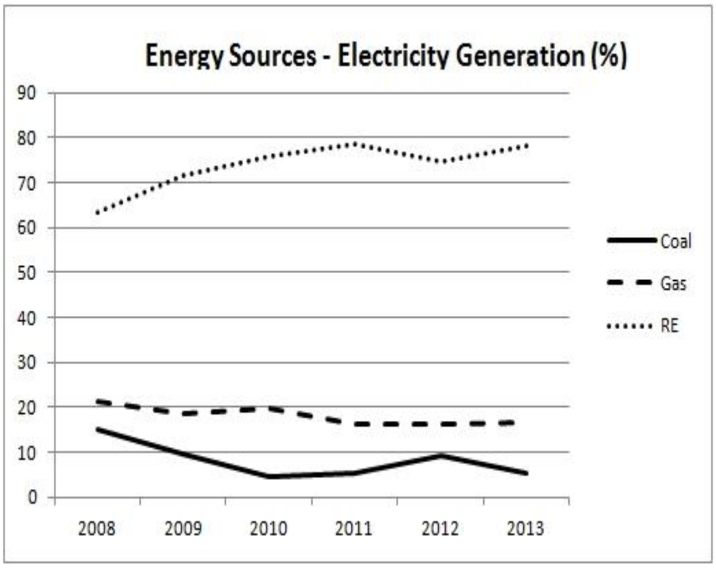

Figure 4: Energy sources for electricity generation (MBIE, 2014a).

5.2.1 Biomass to liquid - the production of alternative fuels

Over recent years there have been three biofuels policy initiatives in NZ
- a short-lived biofuels sales obligation in 2008
- a failed Bill to ensure the sustainability of biofuels in 2009 and
- a biofuels grants scheme which ran from 2009 to 2012 and saw only limited uptake (PCE, 2010).

A major concern had been to ensure that biofuels (both locally produced and imported) in NZ were truly sustainable. Notwithstanding the lapse of legislation, this concern has remained, and hence assessment of biofuel feedstocks in NZ has focused on sources which do not compete with food production, and which do not imply deforestation through land clearance for cropping. This mirrors the evolution in biofuels generally from the 'first generation' (1G) biofuels to 'second generation' (2G) biofuels. Introduced as early and readily available fossil fuel replacement sources, 1G feedstocks are characterised by easily extractable components amenable to relatively simple processing. They include sugars (from, for example, plant matter such as sugar cane) and starches which can readily be converted to alcohols through processes such as fermentation, and plant oils suitable to the production of biodiesel (IEA, 2013a).

While relatively easily produced, 1G fuels when subjected to life-cycle analysis in many cases may be questioned on overall sustainability grounds for various reasons:
- their production might compete with food production (e.g. corn-based ethanol), exacerbating food price pressures
- their intensive production with associated fertiliser and energy use could imply that emission reductions overall were only modest and
- with some crops (e.g. palm oil), the clearing of land for their production (particularly peat lands with high carbon content) might generate emissions which negate any emissions reduction in their end-use (PCE, 2010). Crops such as sugar cane and oil palm are not grown in NZ but their products are potential imports.

As the biofuel industry has evolved, focus has shifted to 2G feedstocks - materials which are more difficult to process, but which offer greater returns in emission reduction, and lesser impacts in their production. Generally these are lignocellulosic in nature - materials comprised of cellulose intimately bound up with lignin, and typified by the fibrous woody components of trees or crops. With these, the principal component converted to fuels is the actual cell-wall matter of the biomass concerned. The cell walls generally consist of sugar polymers, more difficult to convert through simple processes, but nonetheless amenable to being broken down for subsequent fermentation (Daka, nd). Such materials may also be thermally processed to produce both energy liquids and gases. Because far more of the biomass input can be converted, 2G processes have the potential for higher fuel yields than 1G processes (Haritos, 2013).

Some products may display elements of both first and second generation biofuels. The production of biogas from energy crops noted in Section 5 for example uses the long-established anaerobic digestion process, and hence may be included with 1G biofuels. At the same time, being grown on marginal lands, and able to utilise non-food crops, the approach is regarded as sustainable in the manner of 2G biofuels (EBTP, 2014).

In NZ's situation, consideration of overall sustainability in sourcing feedstock meant that only one avenue was available to support the input required for large-scale fuel supply - biomass from an expanded plantation forest industry (PCE, 2010). At present some 7% of NZ's total land area is taken up by plantation forests, with a further 26% occupied by slower-growing indigenous forest (MPI, 2012). Residues from the processes of felling and timber production from plantation forests are already used to an extent for thermal purposes, and any remaining and economically recoverable residues could be directed to biofuel feedstock - but much more would be required. That would need to come from expansion of forests on land which was considered economically marginal for other uses. Arguments were raised in fact that reafforestation of such lands might bring about an overall environmental improvement through erosion reduction, improved runoff water quality, and other factors (Stuthridge, 2010). Nitrogen leaching for example from marginal pastures converted to forestry was projected to reduce by amounts between 0.3% and 8.4% of total agricultural nitrogen leaching, for the three lowest conversion area scenarios assessed (Scion, 2009b). The consideration of major 2G biofuel production in NZ has been based on woody biomass from both residues and plantation forest feedstock, with new forests to be on land not suitable for agriculture (Hall, nd).

Three principal process routes are available for transforming lignocellulosic materials into energy liquids:
- saccharification, in which the sugar polymers comprising around two thirds of the woody and fibrous material are broken down to simpler sugars through the use of enzymes or sulphuric acid. These sugars may then be converted to alcohols, fatty acids and hydrocarbons through the use of fermentation or catalysed chemical reactions.
- gasification, where processing at temperatures over 700 C converts the plant material to a synthesis gas ('syngas') containing CO_2,, CO, and H_2. The syngas may then be further processed through chemical catalytic conversion to mixed alcohols; through fermentation to ethanol; or through the long-established Fischer-Tropsch reaction route to straight-chain hydrocarbons.
- pyrolysis, carried out at temperatures lower than that in gasification (500 C or lower) which converts the biomass to a complex liquid mixture of compounds ('biocrude' or 'green crude') which may then be further processed through to transport fuels (Haritos, 2013).

Substantial research and demonstration funding is being applied internationally to a variety of other technologies and process configurations for 2G fuels, including the integration of fuel production with combined heat and power (CHP) systems. These are at various stages of experimentation and development. The cost and risk of such development is shown by the decommissioning in 2011 of the Choren plant in Germany, claimed as the first commercial scale BtL plant in the world and a flagship plant for the BtL industry. After two years of operation and progressive development, the plant was shut down and put up for sale, with much of its equipment never used (Niagara, 2012; Landalv, 2013). That plant used a proprietary gasification/Fischer-Tropsch process route, the most proven of the available technologies.

The broadest assessment of biofuel development in NZ was, with the hydrogen study of Section 5, part of the 2007 'Energyscape' project (NIWA, 2009). In a series of reports between 2007 and 2009 a broad picture was developed of the potential for bioenergy in terms of feedstock, process routes available for its conversion, and the end-use contribution which it might make - of interest here, transport (Scion, 2007; Scion, 2008; Scion, 2009a; Scion 2009b; Scion, 2009c). Based on the premise that the only feasible biomass resource large enough to underwrite fossil fuel replacement was forest-based, scenarios were developed involving different afforestation areas, various market product allocations, alternative fuel production levels, and sensitivities on a range of other model variables. Areas proposed for afforestation were those which are currently economically or physically marginal in terms of agriculture. Fuel production was premised on the enzyme route for ethanol production, and a gasification/Fischer-Tropsch synthesis route for biodiesel production. Costing was largely based on literature costs for processes elsewhere.

The analysis of the NZ context, based on forest-sourced biomass (Scion, 2008; Scion, 2009b) showed that, subject to commercial proving of the proposed technologies, it would be technically feasible to effectively replace all fossil fuel in transport with biomass-based fuels. At the same time , significant greenhouse gas emission reductions might be achieved. Life cycle analysis suggested that reductions could be achieved ranging from 75% to 83% compared to fossil fuels for forestry residues, and 80% to 89% for purpose grown feedstock. In both cases bioethanol showed the lower result as compared to biodiesel (Scion, 2008). Economic assessments were however less favourable. Cost assessments indicated biofuel costs significantly higher than those then prevailing for fossil fuels - in the case of ethanol as a petrol replacement, by a factor of 3.1; in the case of biodiesel, by a factor of 1.9 to 2.3 times the fossil fuel price with both fossil and biofuel prices expressed in 2007 dollars (Scion, 2009b). The components of the biofuel cost may be seen from Table I, as an indication of the cost drivers for the two biofuels, and where and by how much costs must shift if biofuel production is to become price competitive. The significant difference in consumables arises from the enzyme cost associated with ethanol production. In both cases, feedstock costs are the largest single component, with plant capital cost of greater significance in the ethanol case.

Table I: Indicative cost breakup - biofuels production (Scion, 2009b)

Cost component	% of total unit cost - biodiesel	% of total unit cost - ethanol
Capital expenditure	19.8	31.3
Biomass feedstock	64.8	43.8
Consumables	8.1	15.6
Fixed costs (including` labour)	7.3	9.3
Total	100	100

The comparative results obtained were not dissimilar to those of Haarlemmer et al (2014) and Haarlemmer et al (2012). These two meta-reviews assessed the data and analyses from some fifteen other studies over the period 2000 - 2011, noting that as no full scale commercial BtL plants were in operation, economic assessment was essentially a prospective exercise. Their analysis identified among other issues the scale dependence of the BtL production cost, and the wide variation between the results of various studies, particularly in terms of assessed capital cost. The latter reflected the need for demonstration plants and pre-commercial units to derive real operating data (Haarlemmer et al, 2014).

The Scion economic assessment, using the estimated production costs, indicated that an oil price of $US200/barrel might economically support a land allocation of 1 - 2 million ha for feedstock forests. The base case used for subsequent discussion used an actual land area of 1.8 million ha (compared to the current plantation forest area of 1.7-1.8m ha) which, at a biomass yield of 640 to 900 m^3 per ha (Scion, 2009b), would be capable of supporting the replacement of 65% of NZ's liquid fuel demand in 2035 (Stuthridge, 2010).

Notably, the economic assessment excluded several factors relevant to sustainability. In environmental terms, gains would be made through the storage of large amounts of carbon dioxide. In addition, forest growth on marginal land (much of which is steep and hence may require the use of cable hauler systems) would both reduce erosion, and improve runoff water quality (Scion, 2007).) New forest areas offered a potential benefit in terms of biodiversity. From the energy security aspect, the existence of such forests would have a major insurance value as stored energy - in effect an implicit hedge against world energy price rises (Scion, 2009b). These externalities are difficult to objectively value - but nonetheless may comprise significant sources of national welfare. Other avenues existed also for improvement of the economics of the approach, including integration of energy biomass operations with higher value timber operations for export, and reduction in process capital and operating costs likely to arise through the implementation of the process technologies in other countries.

While recognising that theoretical potential existed for full replacement of fossil transport fuels, the target adopted by the bioenergy industry body for their long term bioenergy development strategy was 30% replacement - premised on projected international fuel prices, and geographic and other considerations (BANZ, 2010). Significant advanced biofuels targets have been incorporated in government energy planning also (MED, 2009). The extent to which these will be pursued will depend on what shifts may occur in production and feedstock costs, and also the value placed on other factors not currently included in assessments, most notably environmental and energy security considerations. This issue is discussed further in Section 7.

5.2.2 The electric alternative

The third renewable transport alternative is premised on the use of RE-based electricity to power electric vehicles (EVs). While superficially a more radical technical approach than those using conventional ICE vehicles, it is in fact less so, being based on two fully established technologies, the renewable production of energy, and electric vehicles. NZ already has over 70% of its total electricity supply from renewable sources, while electric vehicles are well established internationally, with 380,000 vehicles reported sold up until December 2013 (Hybridcars, 2014). One vehicle, the Nissan Leaf, has sold over 100,000 units since its introduction in December 2010 (Marketwatch, 2014).

The attraction of the all-electric concept is evident from a broad calculation. Making the reasonable approximation that all light passenger vehicles are private vehicles, if all the light passenger vehicle kilometres travelled (VKT) in NZ in 2011 had been travelled in a Nissan Leaf (at 0.18kWh/km) (DoE, 2013) rather than in ICE vehicles, oil-related imports would have reduced by more than one third in that year (MBIE, 2014a). Vehicle CO_2 emissions would have reduced by nearly two thirds (MoT, 2012). Though basic, the calculation serves to illustrate both the scale of the potential gains from the electric vehicle route (driven largely by the far higher efficiency of the overall electrical energy chain), and the fact that the transport energy demand and present renewable electricity supply are not orders of magnitude apart.

The additional electrical energy required (5,535 GWh) would have been slightly less than 17% of actual renewable electricity generation (33,097 GWh) in NZ in that year (MED, 2013). That may be compared to the nearly 55% by which RE electricity generation is predicted to increase over 2011 levels by 2030 (MED, 2011b). The most recent assessment of likely scenarios for future NZ electricity supply through to 2040 identified geothermal and wind energy as the likely lowest cost new supplies, with additional geothermal supplies currently available at some 9 cents (NZ)/kWh. In a sensitivity scenario embodying high EV uptake, predictions suggested that 40% of new vehicles would be EVs by 2040, with only some 3% of total electricity demand being required to serve the EV population (MBIE, 2013b). Hence there was little reason for concern that EV demand might ultimately drive a need for further fossil fuel based generation.

The major study of this route was carried out for two electricity supply companies, Meridian Energy and Contact Energy. The study included both battery electric vehicles (BEVs) and plug-in hybrid vehicles (PHEVs) - vehicles with small IC engines as well as battery power. It was framed as a national cost-benefit analysis, seeking to value the effect to the economy overall of the introduction of electric vehicles based on a range of assumptions, not least of which was a substantial decline over time in battery costs. The market penetration rate of EVs was modelled as the outcome of the evolution of EV prices over time, and operating costs, resulting in a prediction of an EV fraction of the light vehicle fleet of around one third after 20 years. Fixed values were assumed for electricity cost - no electricity supply interactions were assumed. The study did not include either the effects of improvements in NZ's trade balance as the result of import replacement, or any value for gains in energy security (Hyder, 2009).

The outcome of the study indicated that the modelled introduction of EVs would generate a positive nett present value around $NZ160 million per year over the 50 year model period - a small figure (less than 6% of the annual value of new car imports) in the context of the length of the study period, and the nature of the assumptions. A separate study (CAE, 2010) modelled the impacts of EV uptake on electric power systems, and concluded that, in part because of the ability to charge vehicles at off-peak times, impacts would not be major.

The Hyder study was a relatively 'broad-brush' study. A more detailed analysis undertaken for Austria (Schmidt, Gass & Schmid, 2011) demonstrated the superiority in energy efficiency terms of the EV route over biofuels, but is not directly comparable as it assumed that electricity supplies would be generated by biomass rather than the lower cost RE options available in NZ. It also assumed a land allocation for that biomass production with an opportunity cost higher than that projected for NZ.

The cost of EVs is largely dependent on the cost of batteries, with battery capacity contributing about half of total vehicle weight, and cost (CAE, 2010). The principal barrier to uptake of the electric route in NZ (as noted also in the Austrian study (Schmidt, Gass & Schmid, 2011)) is the cost of EVs and associated infrastructure generally. Other barriers include the impact of EV uptake on power system capacity, and consumer perceptions in terms of EV range and performance. The dominant technology is lithium ion based with variants in cell type, with that technology already offering expected life around ten years (Underhill, 2012). Reflecting intensive research and development programs, the output cost of batteries fell by more than half from 2008 to 2012 (from $US1000/kWh to $485/kWh) and is projected to reach $US300/kWh by 2020 (Hybridcars, 2014). There are indications that EVs are already more than competitive in terms of lifetime cost per km in both small and medium passenger vehicles and further innovations in both battery and vehicle design are expected to shortly extend that situation to large passenger vehicles also (AECOM, 2009). It has been suggested that EVs will become broadly price competitive with ICEVs by 2030

(AECOM, 2011) although other estimates place this much earlier, around 2020 for PHEVs and BEVs in China for example (Krieger, Radtke & Wang, 2012).

Infrastructure costs and market penetration by EVs are directly related. At low levels of takeup, infrastructure costs may be negligible with vehicle charging being limited to home charging at domestic power circuitry current levels. Charge times under this arrangement are long, of the order of two to three and a half hours (at a charge rate of 0.2 to 0.3 km/min) for a minimal vehicle trip rating of 40km (AECOM, 2009). That approach may facilitate early uptake, given that NZ car 'tours' (home to home round trips) are typically short, with some 53% less than 10km in length (O'Fallon & Sullivan, 2005). However it is unlikely to support large scale market transformation, the achievement of which will necessarily involve expenditure on a range of charging means both public and at-home. There is in addition the cost to address any impacts on the electricity supply system from both energy and demand increases.

The potential impact of large-scale EV uptake on power systems has received wide attention, with results illustrating the extent to which these impacts are heavily dependent on the manner in which charging is carried out. Several studies for example assumed that EV charging systems might be used for load control, with vehicle battery banks serving as an active system control element. That in turn implied that the advent of EV charging might in fact improve power system performance (Lund & Kempton, 2008), and increase the amount of intermittent renewable energy (e.g. wind) which could be utilised (Hindsberger, Boys & Ancell, 2012; Denholm & Short, 2006). Another study modelled on Christchurch, NZ suggested that the effect of EV charging with no demand side management would impact on distribution system capacity at even very low levels of EV uptake (Grenier & Page, 2012). The studies broadly indicate likely demand impacts to be very much a function of the individual circumstances assumed for the analysis - and circumstances which might be managed in a particular direction were the introduction of EVs to proceed. It is an interesting possibility that the use of EVs with the twin characteristics of energy consumption and onboard storage might in the long run serve to improve power system performance.

The final barrier to EV uptake lies in whatever negative perceptions of performance or cost may remain with the vehicle-buying public. Over recent years, in the broader field of energy efficiency and conservation, the potential for market transformation programs to deliver significant energy savings in different energy markets has been widely demonstrated . Application of such programs to the vehicle market is a logical development in EV introduction, and small scale demonstration programs have taken place already in several NZ cities with substantially positive consumer responses (Underhill, 2012; Yeaman, 2011). It would be expected that further appropriately designed market transformation programs should do much to address any negative consumer perceptions related to EV utilisation.

6. Options for sustainable transport energy in NZ

The preceding discussion has considered three alternative approaches through which NZ might pursue elements of the 'policy triad' - energy security, environmental improvement, and economic cost (Ringel, 2006) - in the provision of transport services. Of the three alternatives one (the 'hydrogen economy' approach) faces greater development challenges to overcome an efficiency disadvantage relative to the other two routes, while not necessarily offering greater benefits. With the latter two, conflict is evident between policy goals - both if successfully implemented are capable of delivering significant emission reduction, and a much lower exposure to world liquid fuel markets. Both are consistent with sustainability measures in substituting non-renewable fossil fuels with sustainable energy supply. At the same time, both face significant cost barriers. The biofuels route is at present materially more expensive than fossil fuel utilisation - with, as noted in Table 1, feedstock cost comprising up to two thirds of total cost. It also involves substantial and lumpy capital expenditure in production capabilities of a very specialised nature, with the risk of those becoming stranded assets in the event of incorrect technology choices.

The electric vehicle route also faces cost challenges, most notably through higher costs of EVs in the years before price parity is reached with ICE vehicles. That cost impost is however of a progressive nature, involving a large number of lesser cost increments, and is in that sense, a more controllable cost. Costs are likely also in electricity supply augmentation, although assessments suggest those costs may not be major, particularly if demand control measures are adopted. One important feature of difference, however, to the biofuel route is that the EV route is most unlikely to be able to satisfy all transport demands. While EV development has been rapid in the light vehicle sphere, it has been far less so in heavy vehicles, and mass replacement of fossil-fuelled trucks and buses with EVs is seen as many years away. As well, there is a recognition that while most passenger transport means are amenable to replacement with EVs, there are a number of fossil fuel applications which are not. These include off-road vehicles, road vehicles for towing of trailers and caravans, farm tractors, marine engines and many others. Both these factors point to ongoing demands for liquid ICE fuels, many of an economically important nature. All however are readily accommodated through the development of BTL fuels which are fully 'drop in' in nature.

A further point of difference lies in the facility offered by the EV route to provide a functional link between otherwise unrelated energy policy issues - in this case the broad pursuit of energy efficiency and the economic issue of dependence on liquid fuel imports. Energy efficiency has been noted by the IEA in their 2013 Clean Energy report (IEA, 2013b) as being one of the two most critical avenues to energy and greenhouse gas emission reduction. With an effective renewable electricity/EV transport system in place, measures which address efficiency in electricity use may be seen to also contribute directly to the reduction of fossil transport fuel imports.

These considerations in turn suggest that the two routes, rather than being full alternatives, may best be addressed as complements, in a strategy which would further enhance energy security through supply diversity. Giving priority to electric vehicles to suit light vehicle requirements, while focusing biofuel development to the provision of drop-in fuels both to light vehicles and most particularly for heavy vehicles would maintain a flexibility of approach as the two technologies evolve elsewhere. For either route, it is apparent that there are significant gains to be made if the challenges facing them can be overcome. That is unlikely to be the case however without a structured policy approach and support measures to catalyse commercial research, development, demonstration and investment in the two routes.

7. Policy support for sustainable transport fuels

Policy instruments affecting energy sustainability in NZ are largely limited to government support for public information provision through agencies such as the Energy Efficiency and Conservation Authority, which also administers several subsidy schemes supporting home insulation. In the transport area, an exemption from the Road User Charge (a road tax) has been provided for electric vehicles through to 2020 (PCO, 2012). Large scale private development of the industries and structures necessary to support renewable transport fuels in NZ is unlikely on a purely market basis because of the public-good nature of elements of the 'policy triad'.

The public-good characteristic implies that the gains from reduced dependence on price-volatile imported liquid fuels are not likely to be gathered by private investors - hence benefits from initiatives which involve those will be under-estimated, with under-investment as a result. That implies a role for government if potential societal gains are to be realised and social costs reduced. It is not the purpose of this discussion to assess the policy measures which might be deployed for that purpose, other than to note several types which might be used and have been used elsewhere. Two examples of approaches policy measures may take is to seek to address the presence of externalities, and to undertake support activities which for a range of reasons may only be able to be undertaken by government. (A broad list of measures may be found in the International Energy Agency/IRENA *Energy Policy Instruments* database (IEA, 2013c)).

Recognising externalities in renewable and non-renewable fuels may be achieved through the mandating of minimum renewable fuel percentages, such as the 2010 German Biofuels Quota Act, currently specifying a percentage based on energy content and later to specify a percentage based on greenhouse emission contributions. In an alternative approach, the Colombian tax exemption policy to promote the production and commercialization of biodiesel (Law 939) is an example of an economic instrument used to shift the relative prices of renewable and non-renewable diesel (IEA, 2013c). More generally, a recognition of externalities accruing to society as a whole may help justify other forms of support instruments, such as research and development incentives to support renewable uptake objectives. As noted in Section 4, NZ has had short-lived examples of the first two types of instrument in past moves to support biofuel uptake.

Other government support activities which function as policy instruments might include for example facilitating the aggregation of purchases where that might normally be precluded by competition requirements. It is recognised for example that the purchase price of EVs is a significant barrier to their uptake. In a small market such as NZ, aggregation of otherwise separate purchases from overseas suppliers may allow the negotiation of better terms than single firms might achieve. Other important coordination roles include the development of research funding plans directed to those areas identified as critical to the selected development path. The use of mandatory renewable energy targets may also be relevant to this approach.

Mandatory renewable targets, if implemented in the context of an ongoing and stable renewables policy, help create a degree of surety for potential investors and thereby help mobilise private investment. And it is that issue - a continuity and stability in policy - which is arguably the central factor in government support generally. Particularly in a situation where promising options may involve significant investment, it is essential that potential private investors hold a degree of confidence in future policy settings, as uncertainty is the major disincentive to investment. The development and maintenance of a long term, consistent renewables policy is an essential foundation where long-term investment decisions must be made about which technology avenues will be followed, and the manner in which that will be done.

8. Conclusion

Analyses have indicated that it is at least physically feasible for New Zealand to move to a transport system embodying fully sustainable energy supplies. That feasibility rests on the availability of significant renewable energy supplies through biomass utilisation, and energy from hydro, wind and geothermal sources. Moving towards such a system would have major benefits in greenhouse gas emission reduction, and in lessening the susceptibility of the economy to movements in international fossil energy markets, both in price and supply security terms.

The two most promising (and complementary) avenues are the production of 'drop-in' fuels from biomass arising from purpose-grown forests, using these at least initially in vehicles of the same design as those now in use; and the expansion of RE electricity generation to the level necessary to support light electric vehicle use. Both avenues offer significant emission and energy supply advantages: both also face significant barriers. Cost is the principal obstacle to both approaches - neither is economic at large scale in present terms, particularly given that much of the benefit to be gained is of a public good nature and hence difficult to value. Significant investment funding is required for both, although the funding is of a different nature. That for the BTL liquid fuel approach is likely to be large, lumpy capital subject to a degree of technology risk - a difficult proposition for private investment without some degree of surety being provided by government. Capital for the EV route consists in part of large numbers of smaller investments by individuals in new light vehicle types - investments again which are unlikely to occur without government inducement.

In terms of time, the option which offers most immediate promise is that of renewable electricity augmentation, associated with the promotion of light electric vehicles. The technologies for both elements are currently available, and are seeing further development as the result of renewable energy initiatives in other countries. The option also has the advantage of not requiring the scale of investment which would be required for a major biomass-to-liquid plant, and hence less risk. The implementation of such an approach is feasible now, and is at the discretion of government. The second approach, while it has the attraction of being able to address all vehicle classes, has the disadvantage of depending on technology demonstration elsewhere - and hence depending, in likely timing terms, on circumstances in other countries.

It is unlikely that private transformation of transport to a sustainable basis will occur in any meaningful way without government participation. To date, such participation in the RE field has been only modest in economic terms, and often short-term in nature. If in the long run NZ wishes to gather the potential of a sustainable transport system, much more substantial, and much more consistent, policy deployment will be required than that undertaken to date.

Abbreviations.

BEV	Battery electric vehicle
BtL	Biomass to liquid
CCS	Carbon capture and storage
CHP	Combined heat and power
CNG	Compressed natural gas
CTL	Coal to Liquid

EV	Electric vehicle
FC	Fuel cell
GDP	Gross Domestic Product
GWh	Gigawatt.hours
ha	Hectares
IC	Internal combustion
ICE	Internal combustion engine
LUC	Land Use Classification
MTG	Methanol to Gasoline
PHEV	Plug-in hybrid vehicle
PJ	Petajoules
PJ/a	Petajoules per annum
RE	Renewable energy

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