Powering Public Transport in New Zealand
Opportunities for alternative technologies

EECA

Prepared by:

MRCagney Pty Ltd

29 October 2012
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Executive Summary

Aside from heavy rail systems in Auckland and Wellington, and the latter’s trolleybus system, New Zealand’s cities and towns rely primarily on diesel buses for meeting their public transport (PT) needs.

This study considers whether there are opportunities for greater uptake of PT technologies in New Zealand that are more energy efficient and/or utilise renewable sources of energy. It considers a range of technologies, including but not limited to conventional diesel, natural gas, biogas, biodiesel, hybrid buses, electric buses, as well as trolley buses and trams. Technologies are assessed for their suitability to cities of Christchurch’s size, both on a system-wide level and within individual corridors.

Based on the results of this study we have identified three potential pathways for the use of alternative technologies within New Zealand’s PT fleet:

- The first pathway is the biogas substitution pathway. This is particularly suited to larger cities where large quantities of landfill/biogas may be available at low cost, and where large system size mitigates some of the fixed costs involved in establishing the system.
- The second pathway is the bio and synthetic diesel substitution pathway, which relies on a combination of more efficient diesel buses, such as hybrids, and more renewable diesel substitutes. This pathway is more readily integrated with existing fleets and therefore has lower risk and fixed costs, although may be more costly to operate should oil prices continue to rise.
- The third pathway is the all-electric pathway, which would seek to deploy battery electric buses. This option is suited to all cities and towns, although requires upfront capital investment in vehicle fleet and modifications to maintenance facilities.

Our analysis suggests that electric and hybrid electric-diesel buses are cost-effective options in a future characterised by higher fuel prices. However, on a corridor basis we found that the optimal fleet consisted of a mix of technologies, namely the use of diesel buses to meet peak demands with electric and hybrid buses used to meet all day demands.

To aid with the cost-effective procurement of more efficient and renewable PT technologies this study recommends the establishment of a “Public Transport Vehicle Procurement Forum” (PTVPF) to coordinate the procurement of public transport vehicles across operators. This recommendation notes that there are large economies of scale in vehicle procurement, especially for alternative technologies where global production is still ramping up. Greater coordination of PT vehicle procurement in New Zealand could seek to bundle vehicle orders across individual operators to achieve lower prices.

While this study demonstrates the relative performance of alternative technologies, we note that the circumstances in various New Zealand cities will differ, and as a result the right mix of technologies may differ also. As such, we envisage that this study serves only as a first step to widening people’s horizons, and a way of encouraging them to consider a wider range of options for public transport technologies. We also note that the study is based on a variety of assumptions, and it is important to recognise that the real-life performance of alternative technologies can only be properly and robustly assessed by way of field trials. For this reason we have recommended that central government, and regional and local councils work with operators to test the suitability of alternative technologies in a New Zealand context.

In terms of further research, there is a need to better understand the range of potential barriers to the uptake of alternative PT technologies. Such barriers may be best undertaken at the regional and local level, where relevant contextual parameters, such as system size and demand profiles, can be considered in more detail.
1. Introduction

The Energy Efficiency and Conservation Authority of New Zealand (EECA) commissioned MRCagney and Ian Wallis Associates (IWA) to study whether there is an opportunity for greater uptake of alternative public transport technologies in New Zealand that are more energy efficient and/or utilise renewable sources of energy. The following sections introduce the purpose of this study, define some performance indicators, and summarise the structure of the report.

1.1 The purpose of this study

Aside from heavy rail systems in Auckland and Wellington, and the latter’s trolley bus system, New Zealand’s cities and towns rely primarily on diesel buses for meeting their public transportation needs. This study considers whether there is an opportunity for greater uptake of alternative public transport technologies in New Zealand that are more energy efficient and/or utilise renewable sources of energy.

Energy efficiency and the use of renewable energy in the public transport sector are important because:

- When oil prices rise, the demand for public transport (PT) also rises. Improving the efficiency and renewability of PT becomes a “hedge” against the risks of higher oil prices; and
- Renewable energy technologies are typically low carbon sources of energy, thereby helping to reduce the contribution of New Zealand’s transport sector to national greenhouse gas emissions.

The need for a stand-alone study such as this reflects New Zealand’s distinctive context; our cities and towns are characterised by their small size, low densities, and extensive road networks. We also note that capital has historically been relatively scarce (as indicated by higher interest rates), which in turn tends to disadvantage investments that have high fixed costs, such as light rail. In addition, a number of government policies, such as minimum parking requirements, have actively promoted higher vehicle ownership and use. For all of these reasons New Zealand has historically not been able to justify the scale of investment in public transport that is found in many cities and towns internationally.

The New Zealand context provides another driver for this study: The recent Christchurch Earthquake creates a unique opportunity for “clean-slate” thinking about how public transport may be incorporated into a city. Several government organisations are currently discussing future public transport options for the Greater Christchurch area, which will in turn be integrated into the long-term recovery process. Because of the challenges and opportunities facing Christchurch, much of this report focuses on the potential application of public transport technologies in cities of Christchurch’s size. However, even though Christchurch is our benchmark, the findings are intended to be transferable to other urban areas.

The brief for this project noted that there is currently no independent information about the maturity of alternative public transport technologies that might be deployed in New Zealand. EECA believes that the absence of this information may act as a barrier to the uptake of new technologies. This study will thus attempt to plug this gap by bringing together information from a variety of sources. While the study attempts to compare alternative technologies, we caution that such comparisons are often fraught with difficulties because of the scarcity of independent, credible, and comprehensive sources of data.

In this study we attempt to answer the following specific questions:

- What alternative public transport technologies are available, how does their energy efficiency and renewability compare, and what is their suitability in New Zealand?
What is the cost-effectiveness of alternative technologies for public transport? This will consider various cost drivers, such as fixed capital costs (e.g. infrastructure), variable capital costs (e.g. vehicles); and variable operating costs (e.g. fuel).

How do alternative technologies for public transport compare when deployed in a city of Christchurch’s size?

In answering the last question we consider only first order benefits and costs, not wider impacts on the transport network and/or land use development. Finally, we note that any assessment of alternative public transport technologies is destined to date relatively rapidly from when it is published. In turn it may be necessary to update these findings on a regular basis. Those readers interested in more information are referred to endnotes (numbers) for sources of our information, whereas supporting explanations are provided in footnotes (roman numerals).

1.2 Defining our performance indicators

The following sections outline some of the indicators that can be used to measure the performance of alternative public transport technologies. We consider three performance indicators, namely: energy efficiency, energy renewability, and economic efficiency.

1.2.1 Energy efficiency

Energy efficiency measures the output of the transport system given a certain energy input. One of the most commonly used indicators is defined as:

\[ \text{Energy efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Passengerkm}}{\text{Megajoules}} \]

Diesel buses set the benchmark for this study. We have estimated the energy efficiency of Christchurch’s current bus network (prior to the Earthquake) as 0.76 passenger-km per MJ, which is about 50% more energy efficient than the average private light vehicle in New Zealand.

It is worth emphasising that improvements in energy efficiency can be achieved either by increasing transport output (holding the energy input constant) and/or reducing energy input (holding the transport output constant). This in turn highlights an important distinction between our chosen indicator of energy efficiency and what might be described as “pure” technological efficiency. While a technology can be very parsimonious in terms of the energy it consumes, if it does not carry many passengers then it will still perform poorly in terms of energy efficiency. Ultimately, a public transport technology needs to be both well-used and technologically efficient to justify the label “energy efficient.”

We note that unless otherwise specified we are focussed on energy efficiency on a “tank-to-wheel” rather than “well-to-wheel” basis. The former is more comprehensive, because it considers energy efficiency over the entire supply chain, but is considerably more data intensive. A more comprehensive life-cycle analysis of public transport energy efficiency would be a useful area for further research.

1.2.2 Energy renewability

We draw an important distinction between energy efficiency and energy renewability. Whereas the former measures the conversion of energy input into transport output, the latter measures the degree to which
energy consumption can be sustained given constraints on natural resources and/or environmental systems. The figure below shows how approximately 77% of New Zealand’s electricity is generated from what are considered to be “renewable” sources, such as hydro, geothermal, and wind.

Figure 1: Renewable/non-renewable electricity generation in New Zealand 1976-2010

From this figure we can see that the proportion of electricity generated from renewable sources decreased up until about 2006, since which time it has trended up as new geothermal and wind plants come online. The upwards trend in the proportion of electricity generated from renewable sources is as important as the overall share because it suggests that growth in demand for electricity in New Zealand will, at the margin, be met by renewable sources. We note that by 2025, New Zealand aims to generate 90% of its electricity from renewable sources, which is “challenging but realistic given New Zealand’s untapped renewable energy potential, our expertise in renewable development and our Emissions Trading Scheme”.

We note that rail public transport relies on electricity, whereas bus transport is almost universally diesel powered (with the exception of Wellington’s trolley buses), and diesel is almost universally sourced from fossil fuels. For this reason the renewability of bus transport would currently score very low, whereas electric rail would tend to score relatively highly.

1.2.3 Economic efficiency

While the focus of this study is on energy efficiency and renewability, we also need to consider how public transport technologies contribute, or otherwise, to economic efficiency.

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1 In Wellington the majority of passenger rail is electrified, in Auckland electrification is scheduled to be completed by 2015.
2 In 2011 approximately 0.25PJ of energy was generated from bio-fuels (consisting of bio-diesel and bio-ethanol). This accounts for only 0.1% of the total liquid fuels (petrol and diesel) consumed in New Zealand by the transport sector. Therefore, at the present time bio-fuels make a relatively marginal contribution to the renewability of liquid fuels consumed by the transport sector in New Zealand. Ultimately, public transport technologies that make use of electric motive power will tend to be more renewable.
The concept of economic efficiency is important because it highlights the relative “value-for-money” provided by different public transport technologies. We expect that adopting an alternative public transport technology will, in most cases, incur upfront capital costs (even if only in terms of the purchase of new vehicles) but deliver ongoing operational savings. In this context, the key economic question we must try to answer is whether the ongoing operational savings are large enough to warrant the additional upfront capital investment.

Differences in the timing of when costs are incurred are usually managed within a so-called “discounted cash flow model”, in which future costs are discounted to present day terms. In this study we assume a discount rate of 8%, as per the current NZTA Economic Evaluation Manual. In public transport it is often useful to divide the net present value of costs (NPC) by the total discounted number of passengers that are carried during the same period, i.e. to calculate the estimated NPC per passenger.

The economic efficiency of transport investments are typically analysed with so-called “benefit-cost analyses” (BCA), which compare the net present value of benefits and costs attributed to a particular project. In this report, however, we do not undertake full BCA of different public transport technologies.

1.3 The structure of this report

The following sections of this report are structured as follows:

- Section 2 considers alternative public transport fuel and power delivery technologies;
- Section 3 analyses the cost effectiveness of deploying selected technologies in Christchurch; and
- Section 4 presents our recommendations and conclusions.
2. Alternative public transport technologies

Here we introduce alternative PT technologies that are considered to have some potential in a New Zealand context. For the purposes of this study, we define alternative PT technologies as those related to PT fuel/energy sources and methods of power delivery that are not widely used in New Zealand, but which are available internationally. All technologies considered in this study can improve either the efficiency and/or the renewability of PT in New Zealand. Relevant technologies are summarised in the table below, and addressed in more detail in the following sections.

Table 1: Summarising Public Transport Technologies

<table>
<thead>
<tr>
<th>Technology type</th>
<th>Example</th>
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<tbody>
<tr>
<td><strong>Fuel or energy source</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Liquid Petroleum Gas (LPG)</strong></td>
<td>LPG is available as a transport fuel throughout New Zealand (where it is often used by taxis). LPG is a common transport fuel, used around the world. It is not currently used for public transport in New Zealand.</td>
</tr>
<tr>
<td><strong>Compressed Natural Gas (CNG)</strong></td>
<td>CNG is made by compressing natural gas. CNG is used in PT operations overseas and locally.</td>
</tr>
<tr>
<td><strong>Biogas</strong></td>
<td>Biogas is gas made from renewable resources and landfill gas. Its application in public transport is identical to CNG. Auckland operates a rubbish truck on biogas sourced from its Redvale landfill.</td>
</tr>
<tr>
<td><strong>Ethanol</strong></td>
<td>Ethanol is a pure alcohol made from various biomass sources, and can be used in heavy duty ethanol engines. Ethanol is not currently used in public transport in New Zealand.</td>
</tr>
<tr>
<td><strong>Biodiesel</strong></td>
<td>Biodiesel is produced from non-mineral oil sources, such as tallow and waste vegetable oil. Usually blended with mineral diesel to B5 – B20, although some vehicles are able to use B100. In New Zealand, biodiesel is produced in small amounts and used both in blends and as pure fuel.</td>
</tr>
<tr>
<td><strong>Renewable Synthetic Diesel (RSD)</strong></td>
<td>RSD is produced from various biomass sources, such as woody waste. RSD is chemically different from biodiesel and fully substitutable with fossil diesel, so it can be used in existing diesel engines without limitations. RSD is not currently produced in New Zealand.</td>
</tr>
<tr>
<td><strong>Electricity</strong></td>
<td>Electricity in New Zealand is produced largely from renewable sources (77%), with the corresponding benefits of low greenhouse gas emissions. For public transport, electricity can be used in very efficient electric motors.</td>
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<tr>
<td><strong>Power delivery</strong></td>
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<tr>
<td><strong>Hydrogen Fuel Cells (HFC)</strong></td>
<td>Hydrogen is an energy carrier that can be produced from water via electrolysis, which in turn can be powered by electricity produced from renewable sources. Vehicles can utilise hydrogen via fuel cells; some test vehicles are operating in Europe and the US but no widespread deployment.</td>
</tr>
<tr>
<td><strong>Hybrid Technologies</strong></td>
<td>Hybrid Technologies combine internal combustion engines (ICE) with electric motors to improve energy efficiency and recapture lost energy through regenerative breaking. Electric motors have a significant efficiency advantage over ICE; the latter may be powered by a variety of fuels.</td>
</tr>
<tr>
<td><strong>Electric Technologies</strong></td>
<td>Electric Technologies include overhead and battery technologies, and various combinations thereof – both bus and rail. Batteries may be charged overnight (plug-in) or via overhead wires and induction. Commonly deployed in Europe but limited local examples; Wellington’s trolley bus system the notable exception.</td>
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</table>

* Comprehensive comparisons are available overseas, such as VTT (2012), see endnote 47.
We note that other technologies, such as low rolling resistance tyres, increased vehicle capacity, and driver behaviour, are outside the scope of this report, even if they also influence energy efficiency.

In the sections that follow we will also comment on both harmful emissions and greenhouse gas emissions. Harmful emissions include NOx and particulate matter, which tend to have localised health effects. Greenhouse gas emissions include carbon dioxide, which have global effects on climate change (usually measured in CO2 equivalents). Greenhouse gas emissions obviously come under the auspices of renewability, whereas harmful emissions do not – even if they are important to health outcomes.

While few studies consider these two dimensions separately, those that have tend to find:

1. Non-diesel fossil fuels, such as petrol, LPG, and CNG, produce lower harmful emissions but have approximately the same impact on greenhouse gas emissions.
2. Biofuels tend to have similar harmful emissions profiles to the fossil fuel that they replace, but lower greenhouse gas emissions – assuming they are sourced from renewable feedstocks.
3. The greenhouse gas emissions profile of electricity depends on the proportion that is generated from renewable sources; the use of electricity does not cause harmful emissions at the tail-pipe.

Even if harmful emissions are not relevant to renewability, they are highly relevant to urban public transport, which often operates in central city areas that are sensitive to air quality issues.

### 2.1 Energy sources

#### 2.1.1 Liquefied petroleum gas (LPG)

LPG is a mix of hydrocarbons, principally propane and butane. As it is a gas at normal pressure and room temperatures it is normally stored in pressurised tanks. LPG has a lower energy density than diesel, so has higher volumetric fuel consumption. LPG is used relatively widely as an automotive fuel globally.

New Zealand has had significant experience with the use of LPG (and also CNG, see next section) in the 1980s, in the context of the Liquid Fuels Trust Board trying to reduce New Zealand’s reliance on foreign oil. However, in light of low oil prices in the 1990s and the significant reduction in government subsidies, the demand for LPG (and CNG) fell away. Nevertheless, LPG is still available widely in New Zealand due to a range of alternative uses (e.g. home appliances).

LPG buses tend to emit less harmful emissions than current diesel buses (Euro V standard). By most other operational measures LPG buses are out-performed by diesels, with LPG buses having higher operating costs due to the need for some specialised infrastructure such as LPG storage tanks. U.S. Transit agencies such as VIA Metro in San Antonio reported that LPG buses operate at life-cycle costs about 8% higher than diesel buses.

Several cities have a history of using LPG in their bus fleets, namely:

- Vienna, Austria, has operated LPG buses for 30 years; by 2009 it had 550 MAN LPG buses.
- DAF developed a dedicated LPG fuelled bus of which 150 are operating in Utrecht (Netherlands).
- Dallas, Texas, ran LPG bus trials in 2000; reports on these trials are available online.
- Tempe, Arizona expanded its fleet of LPG buses in 2002.
- Hong Kong makes extensive use of LPG mini-buses.

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1 For example, the number of (light) vehicles utilising LPG in the late 1980s was about 45,000.
2.1.2 Compressed natural gas (CNG)

CNG mainly consists of methane. It depends on the supply of gas via reticulation, from which CNG is made by compressing natural gas to less than 1% of its volume at standard atmospheric pressure and storing it in high pressure tanks. In New Zealand natural gas is currently available only in the North Island; there are presently no plans to extend natural gas reticulation to the South Island.

In terms of performance, CNG buses appear to have higher overall maintenance costs than diesel, although the former’s harmful emissions profiles are considerably lower. CNG buses also tend to have more limited ranges than diesel buses. CNG technology is widely used in public transport overseas, such as the following Australian cities:

- **Brisbane.** Has 216 Scania L94UB and 180 MAN 18.310 models, as well as 30 articulated CNG buses on a MAN or Scania chassis. Almost 50% of Brisbane’s bus fleet were at one point CNG.
- **Adelaide.** Adelaide Metro runs 213 CNG buses. Transport SA is currently evaluating MAN NL 202 CNG powered buses, which they suggest will deliver significant emission improvements.
- **Sydney.** CNG buses were introduced in 1993; STA now have 100 Scania L113CRB.
- **Perth.** As of 2010-11 approximately 50% of the Transperth fleet (1,100 buses) were CNG.
- **Canberra.** ACTION Buses have 42 Scania L94UB buses running on CNG.

Australian CNG buses are typically purpose-designed, single-fuel CNG buses, rather than converted diesel buses. In New Zealand, converted CNG buses were widely used in Auckland in the 1970s and 1980s but were phased out in the 1990s. Go Bus operates 24 CNG buses in its Hamilton fleet. Go Bus’ CNG buses resulted from collaboration with DesignLine in 2006. Reliability appears to be reasonably similar to diesel buses, with some additional costs for infrastructure and maintenance.
2.1.3 Biogas

Biogas (mainly methane) is a gas produced from renewable resources and/or landfill gas. Its application is identical to CNG, but results in lower net greenhouse gas emissions than CNG because it is derived from non-fossil fuel sources. Historically, biogas in New Zealand has been used for electricity co-generation. Where landfill gas is currently flared, it could be used as a cost-effective transport fuel.

One rubbish truck in Auckland is currently operating on biogas sourced from its Redvale landfill, which was considered to deliver the following benefits: “the conversion essentially preserves all advantageous features of a standard diesel engine, such as high fuel efficiency, engine longevity with matching power and torque plus the commercial benefits of lower fuel costs”.

Stockholm, Sweden, operates 129 biogas buses produced by Scania, MAN, Volvo, and Solaris. Scion (2007) provides estimates about the potential energy supply available from municipal waste in New Zealand. Auckland Council staff suggest biogas from Auckland’s landfills could meet 10-20% of regional diesel needs, which would easily be sufficient to power all of Auckland’s bus fleet.

2.1.4 Ethanol

Ethanol is pure alcohol and can be sourced from a renewable feedstock (sometimes distinguished as “bioethanol”). EECA research into the sustainability of Brazilian sugar cane ethanol concluded: Sugarcane based bioethanol remains one of the best performing commercially available biofuels. Even with transport of bioethanol from Brazil to New Zealand taken into consideration, the energy output of Brazilian ethanol is still better than fossil based petrol.

Ethanol is produced in New Zealand in limited quantities by Fonterra from whey, a by-product of the dairy industry. Increased local production of ethanol could change with the ongoing development of “cellulosic
ethanol” technology, which produces ethanol from a wider range of feed stocks. Ethanol is used in buses in dedicated diesel cycle ethanol engines and requires the addition of an ignition enhancer to the ethanol. In terms of performance, there are no operational drawbacks in the use of ethanol in buses as long as the scheduled maintenance requirements are followed. We note, however, that ethanol has a lower calorific content than diesel, which results in higher volumetric fuel consumption.

Stockholm, Sweden has operated ethanol buses since the 1980s through a partnership with Scania; the city now has a fleet of 459 ethanol buses. Scania is the world’s largest and most experienced manufacturers of dedicated ethanol-powered buses. The buses themselves are completely standard and use regular Scania components. Scania’s third-generation ethanol engines have the same thermal efficiency as a regular diesel engine and are certified for both Euro V and EEV standards.

The “BEST” initiative (Biofuels for Sustainable Transport) trialled ethanol powered buses in ten locations around the world. The BEST project was started in Stockholm but is now partly financed by the European Union (EU). Aside from Stockholm, participating locations include Sao Paulo, Rotterdam, Dublin, La Spezia (Italy), Madrid, the Basque provinces of Spain and Nanyang (China). Ventura bus lines in Melbourne have operated three Ethanol buses from 2007. Ventura uses all Heavy Duty Ultra Low Floor Scania buses, which have an engine equivalent to approximately Euro IV-V. Ventura noted that “the buses themselves have attracted considerable publicity and outstanding feedback.”

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<th>Ethanol summary</th>
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<tr>
<td><strong>Renewability</strong></td>
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<td><strong>NOx, particulates</strong></td>
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<td><strong>Status of technology</strong></td>
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<td><strong>Cost effectiveness</strong></td>
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<td><strong>Suitability for New Zealand</strong></td>
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2.1.5 Biodiesel

The term biodiesel refers to diesel that is sourced from animal or vegetable sources, i.e. non-petrochemical feed stocks. Biodiesel in New Zealand tends to be sourced from used cooking oil and rotationally grown rape seed. Used cooking oil, being a waste product, is widely considered to produce environmentally-friendly biodiesel. Bio-diesel can also be produced from tallow, although this has other potential uses and so is usually more expensive than used cooking oil, but cheaper than fresh plant oils.

In terms of emissions, biodiesel produces lower net greenhouse gas emissions. Harmful emissions tend to be slightly lower from biodiesel than from mineral diesel. However, in modern engines there will be little difference as they have to comply with the same emissions standards. Scania buses can now use any blend of biodiesel up to B100 (100%), provided the operator’s bus engine is fitted with a modern fuel injection system and the fuel meets relevant fuel standards. Volvo vehicles can also operate on 100% biodiesel (B100) provided the recommended maintenance and service schedules are followed.

Christchurch ran a biodiesel trial from 2007 until 2010. Results suggest a noticeable decrease in carbon monoxide and opacity (smoke and particulates) from the use of 5% and 20% bio-diesel blends. No detectable negative impacts were noted during the trial even during winter. Based on these positive results, Leopard’s buses have elected to run their fleet of 45 buses on biodiesel blends.

---

*Some technical data is available from VTT (2012), see page 65-66 in endnote 47.*
2.1.6 Renewable synthetic diesel (RSD)

Synthetic diesel can be produced from the transformation of natural gas (GTL), coal (CTL), or biomass, such as renewable wood sources (BTL) to a synthetic gas and then to a diesel-fuel like liquid. Beer et al. (2001)\textsuperscript{32} found that the greenhouse gas emissions from GTL diesel on a life-cycle basis exceed that of regular diesel. For this reason we focus on synthetic diesel sourced from non-fossil fuel sources.

Synthetic diesel is diesel-like, but with virtually no sulphur levels. Scania undertook laboratory tests of a synthetic diesel manufactured by Neste, Finland. The tests involved monitoring of exhaust emissions and engine condition under different mixes of the fuel in standard diesel vehicles in the Stockholm region, as well as city buses in Helsinki. Results suggested buses fuelled by Neste’s synthetic diesel had lower harmful emissions and 10-20% less greenhouse gas emissions compared to comparable buses using mineral diesel.\textsuperscript{33} Neste’s use of palm oil as a feed stock has, however, been criticised as unsustainable.\textsuperscript{34}

In New Zealand research has been undertaken by Scion\textsuperscript{35} and BANZ\textsuperscript{36} into the potential to produce synthetic diesel from wood, which would be considered to be renewable, with significant potential for net reductions in greenhouse gas emissions on a well-to-wheel basis. The Parliamentary Commissioner for the Environment (PCE) has estimated the production costs of synthetic diesel in New Zealand at $1.85 per litre,\textsuperscript{37} which would be likely to translate into a retail pump price of approximately $2.40 to $2.50 per litre\textsuperscript{vii}. In comparison, the current diesel retail pump price is $1.50-$1.60 per litre.\textsuperscript{viii}

\begin{table}[h]
\centering
\begin{tabular}{|c|p{0.7\textwidth}|}
\hline
\textbf{Renewability} & Lower net greenhouse gas emissions \\
\hline
\textbf{NOx, particulates} & Better than diesel, but with new vehicle emission control technologies (Euro V+) there is little difference between biodiesel and conventional diesel \\
\hline
\textbf{Status of technology} & Technology has been widely tested \\
\hline
\textbf{Cost effectiveness} & Slightly more expensive than mineral diesel per litre; other costs are the same \\
\hline
\textbf{Suitability for New Zealand} & B5-20 blends suitable for most heavy duty diesel engines. Blends higher than B20 may be suitable in some engines specifically designed for higher blends. Local production facilities exist although on small scale. \\
\hline
\end{tabular}
\caption{Biodiesel summary}
\end{table}

\begin{table}[h]
\centering
\begin{tabular}{|c|p{0.7\textwidth}|}
\hline
\textbf{Renewability} & Lower net greenhouse gas emissions \\
\hline
\textbf{NOx, particulates} & Better than diesel \\
\hline
\textbf{Status of technology} & Field trials completed successfully; progressing to market roll-out in some countries \\
\hline
\textbf{Cost effectiveness} & Currently much more expensive to produce than diesel, but economics may change in the future; no change in infrastructure or vehicle engines needed \\
\hline
\textbf{Suitability for New Zealand} & Not viable in short-term; considerable long-term potential \\
\hline
\end{tabular}
\caption{Renewable Synthetic Diesel summary}
\end{table}

\textsuperscript{vii} The pump price is calculated as the production price plus taxes and levies = $0.0038 per litre, as well as a retailers’ margin (15%) and GST (15%), i.e. ($1.85 + $0.0038) x 115% x 115% = $2.45 per litre.

\textsuperscript{viii} We note that domestic prices for logs are approximately the same now as they were when PCE costs were estimated.
2.1.7 Electricity

While electricity is not technically a fuel, it is included in this section as it can be used in a variety of applications, including powering public transport. As mentioned previously, New Zealand's electricity production is currently 77% renewable with a target of being 90% by 2025.

Electric motors are highly energy efficient, due to fewer moving parts, with no harmful tail-pipe emissions and lower non-exhaust related emissions due to their ability to use regenerative breaking. We note that the use of electricity depends on alternative power delivery technologies, which are described in more detail in Section 2.2.

New Zealand's electricity system sets prices based on short-run marginal costs. When combined with high peaks in daily demands this creates large price variation, i.e. prices are much higher during the day than they are at night. This in turn will tend to benefit PT technologies that can re-charge over-night, when prices are lower, rather than draw down electricity during the day. In terms of the costs per unit of energy, commercial electricity prices are comparable with the current cost of diesel.

Importantly, New Zealand's electricity system seems able to cater for the increased demand from the electrification of transport. In 2010, a CAENZ study found that if 390,000 light electric vehicles were on the road by 2025, then the total additional required generation capacity would not exceed 180MW, or 2% of current installed capacity (assuming the majority of charging was off-peak or in the peak shoulders). This suggests the electrification of PT in New Zealand is not constrained by the supply of electricity.\(^{39}\)

<table>
<thead>
<tr>
<th>Electricity summary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Renewability</strong></td>
</tr>
<tr>
<td><strong>NOx, particulates</strong></td>
</tr>
<tr>
<td><strong>Status of technology</strong></td>
</tr>
<tr>
<td><strong>Cost effectiveness</strong></td>
</tr>
<tr>
<td><strong>Suitability for New Zealand</strong></td>
</tr>
</tbody>
</table>

2.2 Power delivery

In this section we consider power delivery technologies for public transport. These are not fuels or energy sources per se, but are simply technologies that provide motive power.

2.2.1 Hydrogen fuel cells

Fuel cells use a chemical reaction to convert chemical energy into electricity. Hydrogen is the most common energy source, although other hydrocarbons, such as natural gas, can also be used. Fuel cells utilising hydrogen have a number of advantages such as lower harmful emissions and greater energy...
efficiency compared to a diesel engine, but they are also currently significantly more expensive than conventional technologies. Hydrogen fuel cells are not as efficient as pure electric technologies\textsuperscript{\textsc{i}}.

An analysis by Owen et al (2006)\textsuperscript{\textsc{iii}} compared hydrogen fuel cell (HFC) buses with conventional buses, which took into account private costs, such as initial purchase cost, fuel and maintenance cost, and social costs, such as greenhouse gas emissions, health costs of pollution etc. They concluded that technological improvements, mass production of hydrogen technologies, and identification of renewable feedstocks were all necessary before HFC buses would be cost effective.

Three HFC “EcoBuses” were trialled in Perth, Western Australia as part of a wider trial involving 47 HFC buses in 10 cities on three continents. A life-cycle assessment found that the net greenhouse gas emissions from the use of the hydrogen fuel cells were slightly worse than when using diesel as Australia’s electricity supply (used to produce the hydrogen) is primarily generated from brown coal. Results also suggested that production of hydrogen from renewable sources would have lowered the emissions for the fuel cell buses compared to diesel vehicles. The EcoBus trial was conducted in conjunction with the CUTE and ECTOS\textsuperscript{\textsc{iv}} programs for the initial two years of the project. The HyFLEET: CUTE\textsuperscript{\textsc{v}} program formally concluded in 2009 and also found that the energy efficiency and net greenhouse gas emissions from fuel cell buses depended heavily on the fuel source.\textsuperscript{\textsc{vi}}

For a more comprehensive overview and assessment of fuel cell technology for buses, readers are referred to VTT (2012)\textsuperscript{\textsc{vii}}. Because HFC are a relatively nascent and expensive technology we do not consider them further in this study, but simply highlight it as a technology that may have future potential.

### 2.2.2 Hybrid electric engines

Hybrid electric engines typically combine an electric engine (and energy storage unit, such as a battery or a capacitor) with an internal combustion engine.\textsuperscript{\textsc{viii}}

To a fleet operator, hybrid vehicle technology is attractive because it does not require the development of new refueling infrastructure or major modifications to existing maintenance areas. Hybrids improve energy efficiency, although have limited impacts on renewability unless coupled with low carbon fuels.

Hybrid technology allows the internal combustion engine to operate near its optimum level, thereby maximizing energy efficiency and reducing emissions. Typically, hybrids incorporate regenerative braking, which transform kinetic energy into electrical energy under braking, further improving energy efficiency.\textsuperscript{\textsc{ix}, \textsc{x}} Hybrid buses excel in urban environments characterised by frequent stopping and starting, which is better suited to the low speed torque from the electric drive system. The converse is also true: If hybrid buses are used primarily on long-distance routes then there may be little fuel savings.\textsuperscript{\textsc{xi}} While diesel engines are typically the power plant of choice for hybrid buses because of the extra torque that they offer, hybrid buses can be coupled with any variety of fuels.

Auckland deployed diesel gas turbine-electric hybrid buses on its “City Circuit” for several years beginning in 2000. However, in 2010 after technical problems with their gas turbine, especially under heavy loads on steep uphill sections (e.g. Bowen Street up to the University of Auckland), the buses were withdrawn.
from service. It appears this technology was not sufficiently mature, especially compared to more recent technology that is used successfully elsewhere. London, for example, operates over 300 hybrid electric buses in regular service. The Alexander Dennis Enviro H400, which was originally developed for Transport for London (TfL), is illustrated below. The ADL H400 costs GBP 300,000, or approximately $600,000 NZD, and has capacity for 110 passengers.

Figure 3: Alexander Dennis Enviro H400 hybrid diesel electric bus

Other bus manufacturers also have hybrid offerings:

- Scania has developed a hybrid-drive concept based on supercapacitor technology for energy storage. Scania contend that supercapacitors are more robust and have a longer life than batteries, as well as being more cost-effective in the long run. Scania suggests that its hybrid bus cuts greenhouse gas emissions by up to 90 percent (if fuelled by ethanol) and achieves at least 25 percent overall fuel savings. We understand that Scania have trialed their hybrid bus in Stockholm and are due to report back with results sometime in the near future.

- Daimler has a diesel-electric hybrid Citaro. This bus utilises series hybrid technology with lithium-ion batteries. The system was installed into a Citaro G articulated bus and field trials have commenced with public-transport operators. In Japan, Fuso (which is a subsidiary of DaimlerChrysler) has delivered a number of standard series hybrid buses.

- MAN has a diesel-electric hybrid drive system that incorporates high-performance electric storage units referred to as super or ultracapacitors. When combined with a regenerative braking system this leads to fuel savings of up to 30%. MAN has a test fleet of their hybrid system buses in service with VAG, the transport authority in Nürnberg, Germany.

The fuel economy of hybrid buses varies considerably, but most offer considerable improvements over conventional diesel buses. Fuel savings of 37% were reported in New York\textsuperscript{46}, VTT (2012)\textsuperscript{47}, based on data from various on-road tests, reports fuel efficiency improvements of 20-30%, with up to 40% in certain drive cycles. In Connecticut in-use testing\textsuperscript{48} found that hybrid buses were 10% more fuel efficient than comparable diesel buses. Lothian Buses in Edinburgh informally report approximately 30% fuel savings from their new ADL double-decker diesel-electric hybrid buses.\textsuperscript{49}
2.2.3 Electric technologies

The following sections discuss three distinct electric public transport technologies: Trams and light rail; trolley buses; and battery buses.

2.2.3.1 Trams

While trams and light rail transit (LRT) are established technologies, they are not deployed in New Zealand at present. The distinction between trams and LRT is, in our experience, a reasonably blurry one, with the primary distinction usually that the latter operates in a segregated right of way. Both operate on rails and are powered by electricity delivered via overhead wires or a third rail.

We focus on trams in mixed traffic, because they are more comparable with buses in the context of this report. To be comparable with bus-based options we should only include those costs that are associated with delivering the tram technology itself, rather than the costs of purchasing land to develop the corridor.

The number and diversity of tram systems and technologies makes it difficult to obtain comparable cost data. Earlier studies in Christchurch suggested that the first stage of the first line from Christchurch Central to the University (which is shown in orange in the following figure) would cost $400 million to construct (5km double-tracked), including corridor widening works.

Figure 4: Potential light rail network in Christchurch

Because trams are implemented on a corridor level, rather than a system-wide basis, it is quite different from the alternative fuel and engine technologies considered in previous sections, which could potentially be implemented across an entire fleet. As such, the energy efficiency and renewability benefits of trams will be concentrated on the corridors where they operate. This is an important but often unstated question about alternative public transport technologies: Is it better to invest in improvements to a single corridor, such as with trams, or is it better to invest in wider upgrades of the entire bus fleet? This trade-off will be discussed and investigated in more detail in subsequent sections.

In terms of energy efficiency, Calgary’s LRT system is reported to consume approximately 1,260MJ per 100 vehicle-km. While this is about the same energy used by a standard diesel bus, an LRT vehicle has around 4 times the seated capacity, which suggests trams and LRT may deliver energy efficiency improvements in busy corridors that can make effective use of the additional capacity that they provide.
2.2.3.2 Trolley buses

Trolleybuses are similar to conventional buses but are instead powered by electricity delivered by way of overhead cables. A trolleybus usually has a single electric motor connected directly to the axle. As trolleybuses do not have a gearbox, they can accelerate and decelerate more smoothly than diesel buses, improving ride quality for passengers.

Figure 5: Electric Trolley Bus operated by NZ Bus in Wellington

Wellington’s trolley buses are New Zealand’s only electric powered bus-based technology. Data suggests vehicle operating costs for Wellington’s trolley buses are similar to diesel buses (excluding any costs associated with the overhead system).

A recent refurbishment of Wellington’s fleet cost approximately $550,000 per vehicle (2008 purchase price inflated to 2012 values). We assume that entirely new vehicles are more expensive. We also note that annual maintenance of trolley bus infrastructure in Wellington costs approximately $4.5 million per year, or approximately $90,000 per route kilometre of overhead wire.

Trolley buses are also operated in several other cities internationally, such as Seattle, Arnhem, and Solingen. In terms of energy consumption, a new trolley bus system developed in Landskrona, Sweden reported energy consumption of approximately 650MJ/100 vehicle-km, whereas an earlier analysis from Canada assumed 720MJ/100km.

Trolley buses have environmental benefits compared to diesel vehicles due to no harmful emissions, much lower net greenhouse gas emissions, and lower noise levels. However, trolley bus overhead wires tend to have a visual impact on the street scape.

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Energy data for Wellington’s trolley system was not available.
2.2.3.3 Battery Buses

Battery buses store electricity on the vehicle itself. The primary advantage of battery buses is their lower fuel costs, which reflects the high efficiency of the electric motor. Maintenance costs can also be lower, primarily because they avoid many of the mechanical components, such as gearboxes, required in diesel buses.

One of the interesting advantages of battery buses compared to overhead reticulated technologies, such as trams and trolley buses, is that battery buses can re-charge overnight when electricity demand (and hence prices) are lower. Thus, even though the losses associated with batteries are higher than those associated with reticulated technologies, the former costs less per unit of electricity consumed.

Battery buses have higher capital costs and a somewhat limited range (200-300km), due to the lower energy density of batteries compared to diesel technology. Nevertheless, a range of technological improvements and innovations have emerged in response to these issues, such as improved battery technology (including fast-charging), as well as inductive and overhead re-charging while in-service.

We identified the following recent deployments of modern electric battery buses:

- Seoul, Korea has operated plug-in battery buses (manufactured by Hyundai) since 2010, currently there are 9 battery buses in operation and further plans for expansion. The Hyundai buses are 11m long and have a maximum range of 100km and a top speed of 100km/hr respectively. The buses take about half an hour to re-charge via a fast-charging facility.
- Shenzhen, China has operated 200 standard size electric buses (manufactured by BYD) and recently purchased 1,000 additional electric battery buses. The BYD buses are 12m long and have a maximum range of 225km and a top speed of 100km/hr. (BYD also appears to have sold electric buses to Uruguay and Israel and they are being road tested in the Netherlands.)

Figure 6: BYD Electric Bus – Operating in Shenzhen

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Induction describes the transfer of electrical energy by way of magnetic fields, rather than a physical connection. Electric induction buses are therefore (by definition) also electric battery buses, with the only difference being that induction buses can be charged while in operation (such as when stopping at stations) as well as by being plugged in.
While performance data on these recent deployments of standard size electric buses is relatively limited, some data is available from cities that have operated smaller electric buses for some time (although these buses tend to be smaller and with less range than their more modern counterparts). The city of Chattanooga, for example, has operated battery buses since 1992, and the service was recently expanded with the addition of 3 new battery buses. The performance of electric buses in Chattanooga is summarised in the table below.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Units</th>
<th>Electric</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cost</td>
<td>Per km</td>
<td>$0.03</td>
<td>$0.10</td>
</tr>
<tr>
<td>Maintenance</td>
<td>Per km</td>
<td>$0.04</td>
<td>$0.11</td>
</tr>
<tr>
<td>Fuel economy</td>
<td>Kwh/100km</td>
<td>241</td>
<td>500</td>
</tr>
<tr>
<td>Range</td>
<td>Km</td>
<td>84</td>
<td>300</td>
</tr>
<tr>
<td>Top speed</td>
<td>Km per hr</td>
<td>64</td>
<td>100</td>
</tr>
</tbody>
</table>

While the purchase costs equate to approximately $255,000 NZD in 1995, or approximately $420,000 in today’s dollars, we note that Chattanooga’s buses have a top speed of only 64km/h, a maximum range of 80km, and low capacity. In response to the range limitations of early electric battery buses, some electric battery buses use in-service charging. This can be achieved by (i) induction, or (ii) overhead wires, both of which are explained in the following sub-sections.

### Induction charging

Turin, Italy operates a fleet of 23 battery buses in central city areas that are most sensitive to noise and emissions. Turin’s electric buses have space for 37 passengers, split between 15 seated and 22 standing. The buses reach a maximum speed of 70km/h and consume 95 kWh/100 vehicle-km, which equates to 342 MJ/100 vehicle-km.

A key feature of Turin’s battery buses is their inductive power transfer (IPT) technology, which allows for in-service re-charging. The IPT technology is illustrated below. The figure to the left shows an induction mat at a standard stop, whereas the figure to the right shows the (more powerful) induction mat used for buses that are “laying-over”, i.e. they are waiting for the next trip to begin.

While the IPT technology used in these buses is apparently sourced from a New Zealand company Halo IPT.
The IPT technology extends the buses’ range to the point that they can operate for an entire day without having to be plugged-in. The impact of in-service inductive charging on the “state of charge” is illustrated below. This shows how the decline in battery charge of a pure plug-in electric battery bus (blue line) is partly offset by IPT at approximately 45 minute intervals (purple line).

Figure 8: Impact of in-service re-charging on state of charge

![Figure 8: Impact of in-service re-charging on state of charge](image)

The manufacturer claims that Turin’s battery buses have operating costs of $9,000 per year versus $50,000 for a diesel bus (based on U.S. prices), which results in a pay-back period of less than 4 years. This in turn implies that the buses cost approximately NZD $210,000 more than a standard diesel bus, although it is not clear whether this additional cost covers just the vehicles themselves, or also the additional infrastructure (NB: The manufacturer was unable to clarify this point for us or supply detailed pricing information).

**Overhead re-charging**

Hybricon has developed a fully electric full-sized bus called the “Arctic Whisper”, which is a battery bus with an all-electric range of up to two hours.

At the end of a normal trip, however, the batteries are re-charged up (in approximately 5-10 minutes) by way of overhead wires, as illustrated below. Umeå, a small city in Sweden, successfully runs the Arctic Whisper on some urban routes. Bedell (2011) provides details on the original trials in 2011. The Arctic Whisper consumes approximately 540 MJ/100 vehicle-km, or approximately half of that used by a similar diesel bus.

We note that Bombardier and Siemens are also developing electric induction technologies for LRT and Bus Rapid Transit respectively. Information on energy efficiency and costs of these technologies is not yet available, but the established nature and financial resources of these companies suggest their product offerings are worth monitoring closely in the future, as they may develop relatively rapidly.

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For a quick overview of the system, go to [http://www.youtube.com/watch?v=1wieMbgERto](http://www.youtube.com/watch?v=1wieMbgERto).
2.3 Summary of technologies

Previous sections have introduced a range of alternative public transport technologies that could improve the efficiency and renewability of New Zealand’s public transport systems. The following sub-sections summarise and provide a quick comparison of these technologies.

2.3.1 Fuels

Table 3 summarises the range of alternative fuels in terms of two key features:

- Renewable, i.e. the fuel’s sustainability and impact on net greenhouse gas emissions; and
- Suitability, i.e. how easy it would be for a typical operator to utilise the respective fuel option in terms of available fuel supply and required investments in infrastructure or vehicle technology.

We have excluded considerations of energy efficiency as this is generally not impacted greatly by the choice of fuel (except for electricity) and because this aspect is addressed in more detail for the different power delivery technologies.

We make the following observations:

- CNG has moderate potential because it requires the purchase of purpose-built vehicles or at least a modification of vehicle technology currently in use in New Zealand. Having said that, the fuel is readily available in the North Island and used for buses in Hamilton, so technical knowledge already exists. Biogas is chemically identical to CNG and has significant benefits in terms of renewability; viable local supplies already exist in some places (e.g. landfill gas).

- LPG and ethanol are assessed to have moderate suitability. While the fuels themselves are widely used, both require different vehicle technology. While ethanol does deliver significant benefits in terms of renewability, most fuel would have to be imported. Moreover, as LPG technology is not currently used for public transport in New Zealand the barriers to uptake may be relatively high.
Biodiesel and RSD can substitute fossil fuels and their renewability compared to diesel is high (assuming that they are sourced from renewable feed stocks). In terms of their suitability in New Zealand context, both fuels are traded internationally and there are local biodiesel supplies, even if they are more expensive than diesel. They can also be blended for use in diesel powered buses. While local production of RSD is not currently viable, it has relatively high potential in the longer term because of the availability of biomass. Both these fuels benefit from being able to leverage off existing distribution infrastructure.

Electricity is assessed to have high short and long term suitability. As a fuel it is relatively cost-effective, and various technological innovations, such as induction charging and fast re-charge technologies, are gradually overcoming issues with electricity storage.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Renewability compared to diesel</th>
<th>Suitability in New Zealand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Short term</td>
</tr>
<tr>
<td>LPG</td>
<td>Similar</td>
<td>Moderate</td>
</tr>
<tr>
<td>CNG</td>
<td>Similar</td>
<td>Moderate</td>
</tr>
<tr>
<td>Biogas</td>
<td>High (can be mixed with CNG)</td>
<td>Moderate</td>
</tr>
<tr>
<td>Ethanol</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Biodiesel</td>
<td>High (can be blended with diesel)</td>
<td>High</td>
</tr>
<tr>
<td>Synthetic Diesel</td>
<td>High (can be blended / fully interchangeable with diesel)</td>
<td>Low</td>
</tr>
<tr>
<td>Electricity</td>
<td>High</td>
<td>High</td>
</tr>
</tbody>
</table>

Based on this evaluation we suggest there are three potential pathways for the increased use of low carbon (renewable) fuels in New Zealand’s public transport system.

The first pathway is based around the use of biogas buses, where biogas sourced from landfills and other sources is used. This could be supplemented with CNG where needed.

The second pathway is based around the progressive substitution of mineral diesel, initially with bio-diesel and ultimately with renewable synthetic diesel.

The third pathway is based on the use of electricity for public transport.

All pathways have their merits. The “biogas substitution pathway” may be more suitable in the North Island, and Auckland in particular, due to the availability of reticulated natural gas and large scale landfills for generating biogas. The scale of public transport operations in Auckland may also help to mitigate the fixed costs associated with operating CNG buses. However, in small to medium sized cities, especially in the South Island, the “bio and synthetic diesel substitution pathway” may be more appropriate. This pathway has lower fixed costs and integrates more readily with existing diesel bus operations. The electricity pathway could be utilised anywhere in New Zealand.

Speaking more generally, the viability of low carbon fuels depends on their price relative to conventional fuels. Increasing oil prices and carbon charges (associated with the ETS) may place upwards pressure on fossil fuel prices. At the same time prices for low carbon fuels should drop due to ongoing technological
improvements and economies of scale in production. For these reasons we are reasonably confident that the price gap between low carbon and fossil fuels will decline over time.

2.3.2 Power Delivery

We now summarise power delivery technologies. While the comparison of alternative fuels in the previous section focused heavily on their ‘renewability’, this focus is not justified in the comparison of power delivery technologies. For example, electric buses are only a ‘low carbon’ technology insofar as New Zealand’s electricity generation is primarily generated from renewable sources.

Instead the more important consideration for power delivery technologies is the energy efficiency of the technologies themselves. This is summarised in the following table in terms of two key indicators of energy efficiency, namely MJ per 100 vehicle-kilometres and MJ per 100 seat-kilometres. Vehicle-km defines the energy required to move the public transport vehicle itself for 100 kilometres, whereas seat-km defines the energy required to provide one seat for 100 kilometres. The difference between these indicators is subtle but important; seat kilometres are relevant in environments where demand is high and may warrant investment in higher capacity technologies, otherwise vehicle kilometres are more relevant.

Table 4: Summarising the efficiency impacts of alternative power delivery technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Seated Capacity (seat)</th>
<th>Efficiency (MJ/100km)</th>
<th>Level/location of deployment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vehicle Seat</td>
<td></td>
</tr>
<tr>
<td>Diesel Bus</td>
<td>50</td>
<td>1,200</td>
<td>24.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Universally deployed</td>
<td></td>
</tr>
<tr>
<td>Hybrid electric buses</td>
<td>50</td>
<td>840</td>
<td>16.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deployed overseas; trialled locally</td>
<td></td>
</tr>
<tr>
<td>Electric LRT</td>
<td>200</td>
<td>1,260</td>
<td>6.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Widely deployed overseas</td>
<td></td>
</tr>
<tr>
<td>Electric trolley buses</td>
<td>50</td>
<td>650</td>
<td>13.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deployed overseas and locally</td>
<td></td>
</tr>
<tr>
<td>Battery buses</td>
<td>50</td>
<td>540</td>
<td>10.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Deployed overseas</td>
<td></td>
</tr>
</tbody>
</table>

LRT is the most energy efficient per seat-kilometre by virtue of its higher capacity. Battery electric buses are the second most energy efficient option after LRT, placing ahead of trolley buses. Aside from diesel buses, hybrid electric buses are the least energy efficient of the alternative forms of power delivery.

Unlike our summary of alternative fuels, Table 4 does not provide an assessment of the short or long term suitability of power delivery technologies in the New Zealand context; indeed this is the subject of the next section of this report. What we can summarise, however, is the relative costs of the alternative power delivery technologies in terms of the following dimensions, namely:

- **Infrastructure related costs** – in the form of upfront capital costs for track and power delivery technologies, and ongoing maintenance costs; and

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xvi The comparison does not include HFC technology. In comparison to the other power delivery technologies, HFC buses are relatively nascent and expensive – as such they are not considered to be a viable alternative public transport technology at this stage.

xvii For reasons of simplicity we have assumed that all buses have a seated capacity of 50. We note that there are several types of higher capacity buses, such as articulated and double-decker buses.

xviii This is an interesting result because it suggests that the energy lost from transmitting electricity via overhead wires is greater than the losses involved with battery storage. Further research should seek to confirm this result, which may reflect the specific technologies that we have selected.
Vehicle related costs – in the form of upfront capital costs and ongoing operational costs, which can be split in costs per vehicle hour and kilometre, as well as a fuel cost per kilometre.

Our estimated values for these cost dimensions are summarised in the following table. These figures are based on information presented in previous sections, as well as a number of additional sources, such as NZTA research reports and the Australian National Transport Guidelines on Urban Transport, which are discussed in more detail in the notes that follow the table.

### Table 5: Comparing prices of engine and vehicle technologies

<table>
<thead>
<tr>
<th>Power delivery</th>
<th>Infrastructure related costs</th>
<th>Vehicle related costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power/Track [per km]</td>
<td>Maintenance [per km p.a.]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hybrid electric</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Electric battery</td>
<td>$5 million</td>
<td>$90,000</td>
</tr>
<tr>
<td>Trolley bus</td>
<td>$40 million</td>
<td>$130,000</td>
</tr>
<tr>
<td>Trams</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The basis for our cost estimates are as follows:

- **Diesel** – were drawn mainly from NZTA research report 472 (page 90, Table D4).
- **Hybrid electric** – vehicle capital costs are drawn from published data on ADL hybrid purchases, whereas fuel costs assume 30% better fuel efficiency compared to diesel bus; otherwise costs are identical to standard diesel bus.
- **Electric battery** – vehicle capital charges were assumed based on the BYD buses used in Shenzhen (China), which have an estimated capital cost of USD $650,000 or NZD $900,000. The manufacturer BYD notes an efficiency of 120kwh/100km, and we assume electricity costs of $0.15/kwh.
- **Trolley bus** – overhead infrastructure costs estimated from Swedish experience in Landskrona, which constructed a 3km trolley bus line for NZD $3.7 million in 2004; infrastructure maintenance and vehicle capital costs are estimated from Wellington (vehicle costs adjusted for inflation and need for new vehicles); for efficiency we assume 180kwh/100km (based on the Landskrona system), and $0.15/kwh for electricity costs. We assume vehicle operating costs per kilometre are the same as for standard diesel buses.
- **Trams** – fixed infrastructure costs and vehicle capital costs drawn from previous studies in Christchurch; infrastructure maintenance costs, vehicle costs per kilometre and hour from Australian Guidelines; for efficiency we assume 350kwh/100km, and $0.15/kwh for electricity costs.

The cost estimates are subject to a number of caveats, namely:

- Vehicle capital costs will be influenced by a number of external factors, such as exchange rates, the size of the order, and any modifications required for New Zealand conditions. In our case, we have used exchange rates at the time of writing, and assumed reasonably large order sizes.

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xx We note that all infrastructure costs are specified per route-km and assume bi-directional operation.
xx We note that Road User Charges, which are payable by buses, are included in vehicle operating costs, although infrastructure costs paid from local rates are not included – these will be highly context dependent.
xx New Zealand’s regulations restrict the weight, height and width of buses, and they are more restrictive than those which apply in the European countries of design and manufacture. Therefore, public transport vehicles are often not delivering the maximum
We have marked infrastructure maintenance costs, such as bus stop renewals, for bus-based power delivery technologies as “context dependent” because these costs will depend greatly on the size of the bus system being analysed, rather than the length of the network.

Road user charges payable by buses are included in vehicle operating costs. While this accounts for some of the costs to build and maintain infrastructure, it is not a comprehensive reflection of all costs. This is because the New Zealand Transport Agency only contributes part of the costs for building and maintaining local roads, with the remaining share paid for from local rates. Therefore, the true infrastructure costs for buses will be somewhat higher than shown here.

We note also that there are a number of other physical and operational constraints on these technologies that are not summarised here. For example, the area where trolley buses and LRT can operate is limited to the extent of supporting overhead infrastructure, which does not affect the other technologies. Electric battery buses, for example, currently have an all-electric range of approximately 200-300km, although this can be extended in various ways. Such constraints are difficult to consider in the context of a report such as this, although can be considered in more detail at the level of individual cities and/or operators.

The following section will compare the performance of these alternative power delivery technologies within the context of Christchurch’s public transport system.
3. Application of alternative technologies

In this section we apply alternative power delivery technologies in a context similar to Christchurch. First we present some future oil price and patronage scenarios, before then considering system-wide and corridor-level applications of alternative power delivery technologies to Christchurch.

3.1 Future energy prices

While energy efficient and renewable public transport technologies can mitigate the effects of higher energy prices, quantifying this benefit requires forming a view on future energy prices. Our views on future energy prices were informed by the IMF (2012) and MED (2011).

Historical weekly data collected by the MED was used to link these two international oil price forecasts to the diesel pump price. The resulting pump prices for diesel are illustrated in the following figure.

Figure 10: Diesel price scenarios 2012-2042

The “IMF expected” forecast (solid orange) was selected as our base oil price because it was the most recent; whereas the “IMF High” (dashed orange) and “MED low” (dotted green) provide upper/lower scenarios respectively. We note that the IMF expected and MED high scenarios are very similar.

For the purposes of this study we have also assumed that commercial electricity prices start at $0.15/kwh in 2012 and increase at 3% p.a. in real terms (i.e. constant 2012 dollars) thereafter. We assume that all electric public transport technologies, namely trolley buses, battery buses, and trams, face the same electricity costs. This is likely to over-estimate electricity costs for battery buses, which are

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As the IMF only forecasts to 2020, we assumed that prices beyond this point increase at half of the rate they did from 2012-2020.
re-charged overnight when electricity prices are lower. Trolley buses and trams, in contrast, draw down electricity during the day, when electricity prices are generally higher.

3.2 Public transport system parameters

Christchurch currently operates a bus-based public transport network with 32 routes. Historical boarding trends on Christchurch’s public transport network are illustrated in the figure below, which shows both the 12-month rolling total and also boardings by month since June 1993.

Figure 11: Patronage trends on Christchurch’s public transport system

The impacts of the new downtown bus station in 2001, as well as the recent Christchurch Earthquakes in 2011, are the most evident shocks in an otherwise fairly steady upwards trend over the last 20 years. Boardings dropped significantly after the earthquakes, and while they have recently begun to recover they are still not yet back up at pre-earthquake levels. We note that in the wake of the Earthquake public transport routes serving travel to/from the City Centre are likely to have been more adversely affected than those serving all-day markets.

The patronage data shown can be used to calculate annual average growth rates. We estimated three annual growth scenarios, which were defined as follows (and illustrated in the following figure):

- The period from 1994-2012, when average annual growth = 2.9% (red);
- The period from 1994-2010 (pre-Earthquakes) when annual average growth = 5.4% (green); and
- The period 1994-2010 but excluding the June 2001-September 2003 period when Christchurch’s new downtown station caused growth to spike to unprecedented levels = 3.5% (purple).

We suggest that the purple line (i.e. annual average growth of 3.5%) is the most reasonable estimate of the underlying historical growth in Christchurch’s public transport patronage, because it excludes the two major exogenous shocks to the system, i.e. the bus station and the Earthquake.
In our forecasts we assumed that patronage rebounds to previous levels circa 2015 (assuming the City Centre re-build goes as planned); thereafter patronage is expected to grow at 3.5% per annum (linear). The figure below illustrates historical and forecast public transport patronage.

Figure 13: Annual public transport patronage in Christchurch 1993-2042
As a check on our forecasts, we used Statistics New Zealand’s population forecasts to calculate public transport trips per capita. Christchurch’s population is expected to grow to approximately 424,000 by June 2031, by which time we have forecasted 25.8 million trips per year. This suggests public transport trips per capita per annum will rise from 43.7 in January 2011 to 60.9 in June 2031. This equates to 1.6% growth in per capita trips per annum, which seems reasonable given Christchurch’s recent experience.

This patronage analysis, however, does not tell us how the supply of service changes. To understand how patronage affects service levels, we analysed the relationship between boardings and the supply of services, as measured by vehicle-km. This analysis suggests that, on average, 1.13 vehicle-km are required for each boarding; a relationship that is surprisingly static over time. Using this ratio, we converted our forecast patronage into vehicle-km. But of course not all vehicle technologies have the same capacity, so we subsequently multiplied the number of vehicle-km by the approximate seated capacity of a standard diesel bus (50) to yield seat-km, as illustrated in the figure below.

Figure 14: Forecast seat-km in Christchurch 2012-2042

The takeaway message is that “seat-km” is the supply-side variable that we will hold constant in the next section where we are comparing public transport technologies with differing capacities.

3.3 System-wide application of new technologies

In this section we use the information presented in previous sections to compare public transport technologies at a system-wide scale, based on a medium diesel price scenario. We also carry out a sensitivity analysis of our results by considering the effects of high and low diesel prices on the relative costs, energy efficiency, and renewability of different public transport technologies.

xxi While higher diesel prices may in turn be expected to flow through into higher public transport patronage, we argue that this “impact” is already accounted for in our projections, because these are based on historical patronage growth that occurred during a time of rising fuel prices.
### 3.3.1 Comparing the costs

In estimating the costs of rolling out various public transport technologies in Christchurch we have considered a number of potential infrastructure and operating cost drivers. These cost drivers were incorporated into a discounted cashflow model (with an 8% discount rate and a 30 year lifetime). A timeframe of at least 30 years is important in order to achieve a fair comparison between high capital cost technologies, such as light rail, and those with potentially higher operating costs, such as diesel buses.

While we use a 30 year time frame we have not assumed that vehicles will be in service for this long without replacements. Instead, vehicle costs are annualised assuming linear annual depreciation over its lifetime, which we assumed to be 10 years (NB: While buses are operated for up to 15 years, we have chosen a slightly shorter lifetime to allow for some additional refurbishment costs).

The annual costs of a standard diesel bus is thus calculated as \( \frac{\$400,000}{10} = \$40,000 \). We estimated annual vehicle costs for trams using the same formula, but assumed a 20 year lifetime. Key cost assumptions for our different scenarios are summarised in the table below.

**Table 6: Summarising key assumptions for application of power delivery technologies to Christchurch**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Key assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Diesel bus</td>
<td>Diesel buses have an annual vehicle cost of $40,000 per vehicle per annum.</td>
</tr>
<tr>
<td>2. Hybrid electric bus</td>
<td>Diesel buses are progressively replaced by diesel-electric hybrids over a period of 10 years. The hybrids are 30% more fuel efficient than standard diesel buses; hybrid vehicles cost $60,000 per vehicle per annum.</td>
</tr>
<tr>
<td>3. Electric battery bus</td>
<td>Diesel buses are progressively replaced by electric battery buses over a period of 10 years. Battery buses consume 120kwh/100km and cost $90,000 per vehicle per annum (including re-charging facilities).</td>
</tr>
<tr>
<td>4. Electric trolley bus</td>
<td>By 2016, a fleet of 70 electric trolley buses are delivering approximately 20% of total seat-kilometres. 10km of trolley wire is constructed in the three year period 2013-2015, incurring additional construction and maintenance costs of $50 million and $900,000 per year respectively. The trolley buses themselves cost $70,000 per vehicle per annum and consume 180kwh/100km.</td>
</tr>
<tr>
<td>5. Tram</td>
<td>Assumes 5km of tracks and supporting overhead wire are constructed in the three year period 2013-2015, incurring additional construction and maintenance costs of $200 million and $325,000/year respectively. By 2016, a fleet of 14 trams are delivering approximately 16% of total seat-kms. Trams consume 350kwh/100km and are assumed to depreciate at half the rate of buses, yielding annual vehicle costs of $250,000.</td>
</tr>
</tbody>
</table>

We note that the hybrid and electric battery bus options (options 2 and 3 respectively) replace all diesel buses, whereas the trolley bus and tram options (options 4 and 5 respectively) replace only a proportion of the diesel bus fleet. All other unit costs are the same as those present previously in Table 5. Thus the key trade-off for the hybrid and electric bus scenarios is whether the higher capital cost of the vehicles is offset by their lower operating costs as diesel prices rise. For the trolley bus and tram scenarios the key trade-off involves substantially higher capital costs (for both infrastructure and vehicles) versus operational cost savings across a proportion of the wider network. Scenarios 2-5 are essentially trying to claw back the additional capital costs that they incur compared to the diesel bus scenario.
Using these assumptions and with the trade-offs mentioned above in mind, we calculated the annual and cumulative costs for each public transport technology, as illustrated in the following two figures.

Figure 15: Annual costs for each public transport scenario

![Figure 15: Annual costs for each public transport scenario](image)

Figure 16: Cumulative annual costs for each public transport scenario

![Figure 16: Cumulative annual costs for each public transport scenario](image)
The following table summarises the cost effectiveness, energy consumption, and relative renewability of the various scenarios presented above. These results suggest that over a 30 year timeframe electric battery and hybrid buses incur similar costs compared to diesel buses, while consuming considerably less energy overall. The electric battery bus scenario uses the least energy overall (by a considerable margin) and the largest proportion of renewable energy.

### Table 7: Summarising cost and energy impacts of alternative public transport technologies

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Costs</th>
<th>Energy [TJ per year]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gross</td>
<td>NPC</td>
</tr>
<tr>
<td>Diesel</td>
<td>$2.23 billion</td>
<td>$742 million</td>
</tr>
<tr>
<td>Hybrid</td>
<td>$2.19 billion</td>
<td>$739 million</td>
</tr>
<tr>
<td>Battery</td>
<td>$2.19 billion</td>
<td>$751 million</td>
</tr>
<tr>
<td>Trolley</td>
<td>$2.28 billion</td>
<td>$791 million</td>
</tr>
<tr>
<td>Tram</td>
<td>$2.43 billion</td>
<td>$920 million</td>
</tr>
</tbody>
</table>

Because battery buses replace the entire fleet, we can also conclude that their emissions are lower than other scenarios. Note also that scenarios 1 and 2 could be complemented with low-carbon fuels, such as renewable synthetic diesel; this could increase the ‘renewability’ of those scenarios, albeit at higher cost.

The cost effectiveness per passenger is illustrated in the figure below. We note that in this figure the costs presented for the trolley and tram options represent the weighted sum of the costs of running a trolley and tram system within a wider diesel bus system, as such that we can conclude that the impacts of these technologies on costs at the margin is actually higher than it appears in this figure.

**Figure 17: Cost effectiveness of technologies in Christchurch [$ NPC / passenger]**
The figure suggests both hybrid buses and electric battery buses are similarly cost-effective to diesel buses. Trolley buses and trams are found to be considerably less cost-effective, primarily because their higher capital costs are not able to be offset by sufficiently lower operating costs.\textsuperscript{xxiv}

### 3.3.2 Sensitivity to diesel prices

In this section we investigate the sensitivity of our analyses to changes in diesel prices, namely a higher (IMF) and a lower (MED) scenario; all other assumptions are left unchanged. The impact of these changes in fuel price on the relative cost-effectiveness of different technologies is illustrated below.

**Figure 18: Cost effectiveness of technologies in different diesel price scenarios [\$ NPC / passenger]**

This analysis suggests that diesels become the most cost-effective option under a low diesel price scenario, as we would expect.\textsuperscript{xxv} Battery buses are unaffected by changes in oil prices and as a result, under a high diesel price scenario, electric battery buses gain a relatively cost advantage over the other transport technologies that we have considered.

### 3.4 Corridor level application of new technologies

In this section we focus on the application of public transport technologies to a hypothetical transport corridor. While the analysis is described as “hypothetical” in the sense that it is constructed rather than based on an actual live corridor experience, we intend that the parameters of the corridor are broadly representative of those typically found in Christchurch and cities of a similar size.

The point of this exercise is three-fold:

\textsuperscript{xxiv} We note that this report considers only first order costs and benefits; there may be other reasons why trams are a viable option. \textsuperscript{xxv} The ‘trolley’ and ‘tram’ scenarios are still subject to some of the effects of lower/higher diesel prices since they only replace part of the public transport fleet. The rest of the fleet would continue to be made up of diesel buses.
First, it helps us to understand the relative performance of various public transport technologies at a more refined level, where changes in demand across the day may be relatively important; Second, it also allows us to understand how vehicle fleets might be configured in response to more realistic public transport demands; and Third, it provides a partly independent quantitative check on the network-wide analysis presented in the previous section.

The key difference between this section and the previous one is that here we investigate how the demand profile across the day impacts on the relative cost-effectiveness of different technologies. The daily demand profile is important for two reasons. First, it is the peak demand that defines the number of vehicles required to serve a particular corridor. Second, the total number of daily users defines the population over which fixed infrastructure costs are able to be spread.

We set the corridor length to be 10km and daily demands to a level that was likely to be similar to public transport corridors in Christchurch (pre-Earthquakes), as illustrated below. (NB: Surveys suggest that peak hourly public transport demands on main corridors in Christchurch are currently approximately 1,000–1,500 passengers per hour).

Figure 19: Demand profile for hypothetical public transport corridor in Christchurch

Key features of this demand profile include:

- A peak demand of 2,250 passengers per hour in the AM peak, which defines the number of peak vehicles that are required to meet demands on this corridor; and
- A total daily demand of 17,650 passengers, which defines the number of passengers over whom the costs of fixed infrastructure can be spread.

We have assumed that relatively high-level bus priority measures are required to meet this demand. The costs of high quality bus priority measures were estimated based on the Central Connector bus corridor in Auckland, which came to $32.5 million in 2007 dollars (NB: We have excluded $7.5 million associated
with strengthening Grafton Bridge to cater for light rail). We inflated this cost to 2012 dollar values, which equates to $12.5 million per kilometre, or a total of $125 million for our 10km corridor. We then assumed general maintenance costs of $50,000 per kilometre, yielding total maintenance costs of $500,000 per annum along the entire corridor.

Operating costs were calculated as follows:

- To determine peak vehicle requirements the demand in every 30 minute period was divided by the maximum capacity of the vehicle (NB: Maximum capacity is higher than seated capacity); and
- The hours and kilometres travelled by these vehicles was then calculated based on the length of the route (10km) and an assumed average speed (for all scenarios) of 25 km/h.

The maximum capacity of buses was estimated at 60 passengers per vehicle, whereas trams were estimated to have a maximum capacity of 300 passengers per vehicle. All other unit costs remain the same as those presented previously in Table 5. Costs per passenger for each technology are summarised below.

Based on these results we find that diesel buses deliver the lowest cost option. This reflects their ability to meet the peak demands in a relatively low cost manner; the other bus-based technologies incur relatively high costs in the peak because the vehicles are more expensive. The cost effectiveness of trolley buses and especially trams is adversely impacted by fixed costs associated with infrastructure and peak vehicles, which are spread over relatively few passengers.

This highlights two important cost drivers that are relevant to the deployment of public transport technologies in this corridor, namely the need to meet a relatively “peaked” demand profile (i.e. at low cost) while avoiding high fixed costs that cannot be spread over many users.

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**Footnotes:**

\* We assume that all public transport technologies have similar levels of priority and thus can maintain similar speeds.

\*\* Peak vehicle capacity, which is used here, is higher than their seated capacity, which was used in the previous section.
This result is quite different from that presented in the previous section, and for good reason. In the previous analysis we considered demands at the level of the wider system rather than for an individual corridor. When we drill down to the level of the latter, we find that the daily travel demand profile that is generally found in small to medium sized New Zealand cities is likely to disadvantage public transport technologies that are capital intensive – because they incurs costs for vehicles and/or infrastructure that is used for only a few hours per day, and therefore is spread over relatively few people.

It is important to place two caveats on this finding: The first caveat is that we have thus far considered technologies individually. It may be, for example, that electric battery buses are more cost effective at meeting base travel demands, where they are able to operate all day and thereby offset higher capital cost savings with operational cost savings. In such a situation diesel buses would then be used more to meet the peak demands, where their lower capital costs can offset their slightly higher operating costs.

We investigated the potential benefits of “mixing” bus technologies in such a corridor by setting up our cost model in a way that allowed us to find the optimal mix of bus technologies. Using Excel Solver we did indeed find that the optimal scenario involved the use of electric buses to meet the all-day demands (2 vehicles) and hybrid buses (2-5 vehicles), with diesel buses operating in peak and shoulder periods (7-14 vehicles). The optimal fleet mix for each half hour period is illustrated below.

Figure 21: Optimised fleet split between diesel and battery buses

The overall cost savings of a mixed fleet were modest but not insignificant; with approximately $193.4 million in costs incurred over a 30 year period, compared to $198.1 million in the diesel bus only scenario. The mixed fleet therefore offers a saving of approximately 2.4% over an all-diesel option. We note that the benefits of a mixed fleet would need to be weighed up against the additional costs of operating more than one type of vehicle technologies, costs which are difficult to quantify but nonetheless real.

The second caveat to place on our findings is that we have fixed the daily demand profile. It may be prudent, in light of projected growth in patronage in Christchurch, to consider how these results might...
change were the demand profile to grow – which would in turn provide more scope to offset higher capital costs, such as those associated with trolley buses and trams.

To this end, we again used Excel solver to find the level of demand along the corridor at which trolleys and trams would be similarly cost effective to the diesel option. Results are summarised in the following table; they suggest that demands would have to increase by a factor of 3 to 5 before the more capital intensive trolley and tram technologies would become similarly cost effective to diesel buses.

Table 8: Demand at which capital intensive public transport technologies become cost-effective

<table>
<thead>
<tr>
<th>Technology</th>
<th>Peak volumes [pass per hour]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base</td>
</tr>
<tr>
<td>4. Trolley</td>
<td>2,500</td>
</tr>
<tr>
<td>5. Trams</td>
<td>2,500</td>
</tr>
</tbody>
</table>

When we pull all these analytical results together we find, unsurprisingly, that different technologies have different optimal operating conditions, which can best be summarised as follows:

- Diesel buses are generally most competitive in situations with low and/or peaky passenger demands, where their lower capital costs mean they are a relatively cost effective way of meeting demand. In these situations, it seems most prudent to focus efforts on improving energy efficiency through the procurement of more efficient diesel buses and developing supply chains for alternative fuels where and when they are found to be cost competitive;
- Where passenger demands are higher and are spread more across the day, alternative public transport technologies, such as hybrid and electric buses become more competitive – as their higher upfront costs are able to be spread across more passengers. In these situations, alternative bus-based public transport technologies may become viable in specific busy corridors; and
- Where passenger demands are very high, more capital intensive technologies, such as trolley buses and trams/LRT, may become more cost effective – as their higher infrastructure costs are again able to be spread across more passengers. However, the level of demands at which these technologies become viable are likely to only exist in in the larger cities (or in very high demand corridors). We also note that we have not explored higher capacity bus options, such as double-deckers, which may further increase the range over which bus technologies are cost-effective.

Based on this analysis, we suggest the optimal mix of public transport technologies in the types of corridors that are found in cities of Christchurch’s size is likely to involve a combination of electric buses and hybrid diesel-electric buses (which operate all day as much as possible), and efficient diesel buses (which operate in peak periods when needed to meet demand).
4. Conclusions and recommendations

4.1 Conclusions

Based on the material presented in this study we have drawn the following conclusions:

• Low carbon fuels, such as biodiesel and synthetic diesel, could make a significant contribution to the ‘renewability’ of New Zealand’s public transport systems, especially if the price differential to conventional fuels declines over time. Initiatives to reduce production and distribution costs (through, for example, improving technology and economies of scale) are the most likely way to achieve this outcome. Higher fuel prices and/or carbon charges will also tend to reduce the price differential. Should alternative fuels become cost-effective then we would expect them to be adopted by the market. We note that public transport operations are an ideal ground for testing the performance of alternative fuels, primarily because they provide a concentrated point of demand.

• Our analysis identifies three possible development pathways for the use of alternative fuels within New Zealand’s public transport fleet:
  o The first pathway is the biogas substitution pathway, which may be suitable where biogas is available at low cost, such as large landfills. Biogas could be complemented with CNG, at least in the North Island where natural gas is available through reticulation.
  o The second pathway is the bio and synthetic diesel substitution pathway, which can be more readily integrated with existing bus fleets and therefore has lower risk and fixed costs. This may mean it is more suited to smaller cities and operators.
  o The third path is the electric pathway, which would seek to deploy battery electric buses in place of the existing diesel powered fleet.

• Our analysis of alternative power delivery technologies suggests that battery and hybrid buses seem to provide a cost-effective whole-of-life option for public transport systems in small to medium sized cities. Battery buses deliver operating cost savings that are sufficiently large to offset their higher capital costs, at least in a future characterised by sustained high fuel prices. We note that electric technologies are considerably quieter and cleaner than their diesel counterparts, which may also flow through into higher patronage and ultimately more liveable cities.

• The cost-effectiveness of fixed-route public transport technologies is adversely affected by their higher infrastructure costs, even if they also contribute to improved energy efficiency and renewability outcomes. Our analysis suggests that investing in whole-of-fleet technologies, rather than individual corridors, is likely to be a more effective way of improving the efficiency and renewability of New Zealand’s public transport systems.

• We expect emerging public transport technologies, such as hybrid diesel-electric buses and battery electric buses, to evolve more rapidly over time than the more established technologies, such as diesel buses, trolley buses and trams.

4.2 Recommendations

We recommend that EECA work with public transport operators and central and local government partners to:

• Continue to closely monitor developments in emerging public transport technologies globally. We note the rapid development of electric battery bus technology in particular.

• Systematically analyse potential barriers to the uptake of alternative technologies. Such barriers may be best investigated at the regional and local level, where relevant contextual considerations, such as system parameters, can be considered. Other barriers are the domain of central government, for example, New Zealand’s current mass and dimension requirements constrain use...
of some public transport technologies. It will be important to identify and understand these different barriers, and devise potential ways that they can be overcome.

- Engage with the existing Public Transport Leadership Forum (PLTF) as a means for distributing information on alternative public transport technologies in New Zealand. This engagement should emphasise the spectrum of fuel and vehicle solutions and seek feedback from PLTF members as to their relative attractiveness. For example, electric battery buses seem more suited to central city environments, where the additional demands justifies their higher capital costs. Such feedback could facilitate greater awareness and knowledge sharing around technological issues.

- Where alternative public transport technologies appear to be cost-effective but are not already deployed in a New Zealand context, consider implementing a possible trial so as to gain insight into the actual performance of the respective technology in New Zealand conditions. For example, a trial involving a small number of hybrid or battery electric vehicles may assist in building confidence with public transport funders and operators. A trial could possibly be achieved through a partnership of relevant organisations, including operators, public transport funders, and also EECA.

- Lastly, seek to establish a ‘public transport vehicle procurement forum’ (PTVPF) to coordinate the procurement of alternative public transport vehicles across private operators (possibly as an extension of the PTLF). The relatively small size of New Zealand’s public transport operators and the large economies of scale present in the procurement of public transport vehicles may present barriers to the uptake of alternative public transport vehicles of any kind. The PTVPF could help local bus operators achieve economies of scale in their vehicle orders, by essentially operating in a similar manner to PHARMAC, i.e. bundle vehicle orders from individual operators together so as to increase collective purchasing power and ultimately reduce overall costs. Operator involvement in the PTVPF would of course be optional and we expect that administration costs would be covered by charging a commission on successful procurements, i.e. the PTVPF would be self-funding.
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28. NZCAE, Electric Vehicles Impacts on New Zealand’s Electricity System, 2010
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49. C.f. endnote 47

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