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# Cost-effective energy options for transitioning New Zealand to a low-carbon economy

Prepared for the Parliamentary Commissioner for the Environment

September 2017



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# Part A – Background to New Zealand’s emissions reduction challenge

## 1 Introduction

*This is a **working paper** – it is a companion paper to the summary report “Summary insights on energy-related carbon-abatement opportunities” September 2017*

The Parliamentary Commissioner for the Environment has commissioned Concept Consulting to analyse the greenhouse gas abatement opportunities in the New Zealand energy sector.

This analysis has assessed the likely nature, scale, and cost-effectiveness of greenhouse abatement opportunities in each component of the energy sector (e.g. electricity, transport, etc), and what barriers or market failures may significantly impede achievement of these potentials.

This has required a significant amount of modelling and analysis, the outcomes of which are summarised in the ‘Summary Insights’ report mentioned above. This document is a ‘working paper’ that provides more detail on the modelling and analysis undertaken in support of the ‘Summary Insights’ paper.

It is a compilation of various technical notes provided to the Parliamentary Commissioner for the Environment to facilitate discussions on various aspects of New Zealand’s de-carbonisation challenge.

Given the limited audience for this more detailed material, we have not sought to provide comprehensive documentation (this would run to many hundreds of pages), or turn it into a completed report format. Therefore, if you have any queries, or want to understand the analysis in more detail than presented here, please contact Concept Consulting.

***This analysis identifies the most economic greenhouse gas abatement potentials that will help New Zealand to transition to a low-carbon economy***

Developments in technology mean that New Zealand households and industry have a growing number of choices for meeting their energy needs. They can choose amongst both fuel and technology options for energy uses such as heating, lighting, and transportation.

The recent significant reductions in the cost of solar photovoltaic (PV) and batteries, consumers now also have choices about whether to generate some of their own power rather than buying it all from the grid.

These different choices that households and businesses make will have different implications in terms of:

- The greenhouse emissions created
- The cost of providing the energy service

This report assesses the emissions and cost consequences of different fuel and technology options for providing various energy services (e.g. heating, lighting, transport, etc), and thus which options are likely to be ‘best’.

### *This analysis highlights where externalities may frustrate uptake of the 'best' technologies*

This evaluation of the best option is undertaken from two perspectives:

- The 'public' benefit based on the underlying costs of the different options.
- The 'private' benefit to individual consumers, based on the prices they see.

There can be divergences between the public and private benefits where prices to consumers do not reflect the underlying costs of provision – something economists call 'externalities'. Examples of these externalities include:

- The costs of greenhouse emissions not being reflected in consumer fuel prices; and
- Electricity tariffs not varying according to the time of day/year, and thus not distinguishing the large difference in cost between supply at times of peak demand versus times of low demand.

Where prices do not equal cost, there is the potential for consumers to make the 'wrong' choices. In particular, choosing an option which may be least-cost for the consumer based on the prices they face, but which is a higher cost option for New Zealand as a whole.

A key objective of this report is to highlight situations where these externalities may materially hinder New Zealand's transition to a low-carbon economy.

### *This analysis focusses on the key energy choices that really matter*

There are a vast number of different services which use energy, ranging from the obvious (such as heating) through to the almost inconsequential (e.g. electric toothbrushes). This report doesn't attempt to address every instance where energy is used. Instead it focusses on those energy services where:

- Consumers have a real choice for meeting their energy service; and
- The different options have material consequences for New Zealand's greenhouse emissions.

It is estimated that the energy uses assessed in this study (and which are listed below), are responsible for over 95% of New Zealand's energy-related greenhouse emissions:

- Transport (road, rail, aviation, but not marine)
- Industrial Process heat
- Space and water heating
- Lighting and refrigeration

In terms of electricity, we also look at the supply-side of the industry, identifying the opportunities (and costs) to lower the carbon intensity of the fuel itself.

### *Structure of this paper*

This paper has three main parts. Part A is largely an introduction – it outlines the scope of the paper, and summarises New Zealand's greenhouse emission profile. Part A also assesses which energy-related activities may have the greatest potential for transitioning to a low-carbon economy.

Part B addresses each of the main energy-related activities, and identifies:

- Which options for providing these energy-using services are most likely to enable New Zealand to cost-effectively transition to a low-carbon economy.
- Whether there are significant pricing externalities, or other policy barriers, which may frustrate uptake of the best options for New Zealand.

Part C contains various technical appendices.

- Appendix A details the power-station-related emissions from electricity generation. Crucially, it presents analysis which shows that the emissions from consuming electricity vary hugely depending on *when* the demand occurs. E.g. summer versus winter, or day versus night.
- Appendix B provides additional information about land transport
- Appendix C covers further information about solar PV
- Appendix D provides more details about biofuels, and
- Appendix E covers briefly covers hydrogen.

## 2 Breakdown of New Zealand's greenhouse emissions

New Zealand, has committed to significantly reduce its greenhouse emissions (e.g. the target set in 2011 for a 50% reduction in emissions from 1990 levels by 2050) in order to try and prevent dangerous anthropogenic global warming. However, as Figure 1 below shows, New Zealand's emissions have not started to materially reduce. Indeed, they have risen since the start of this decade.

**Figure 1: New Zealand's historical greenhouse emissions (ktCO<sub>2</sub>-e)<sup>1</sup>**

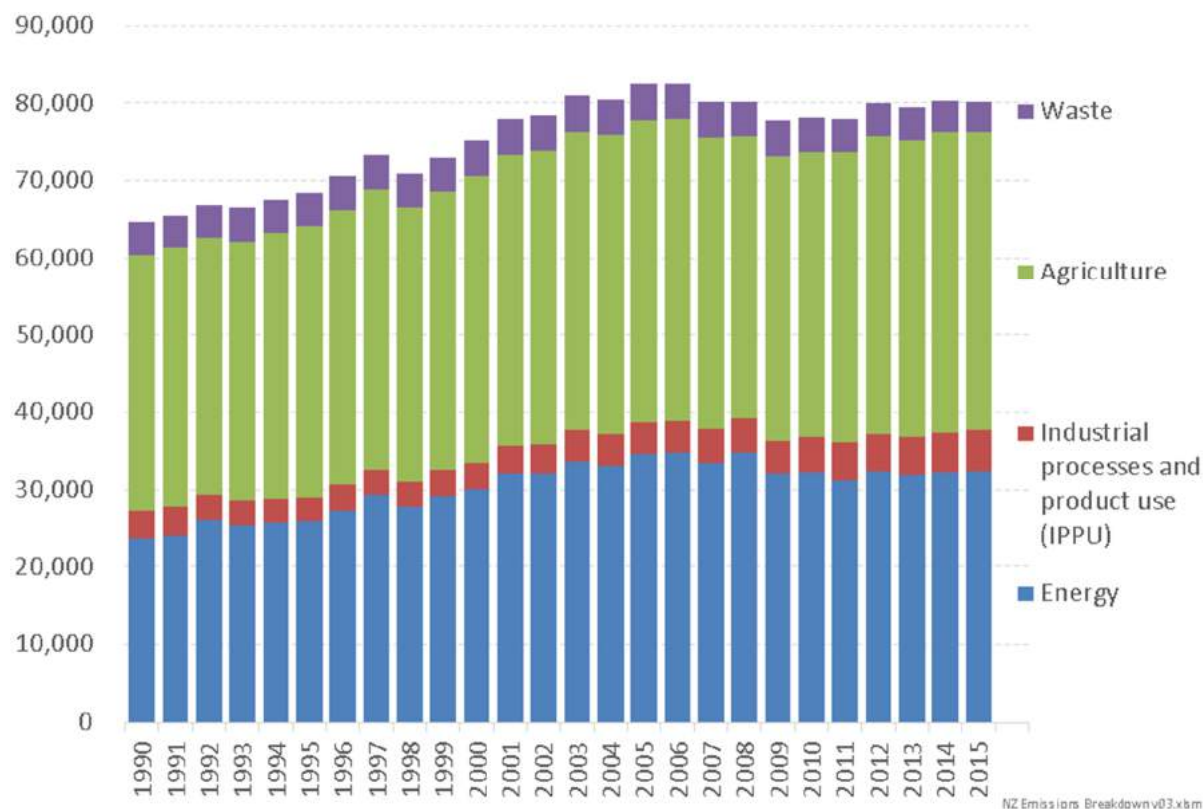


Figure 1 above, and Figure 2 below, show that New Zealand's emissions are dominated by agricultural emissions (primarily methane emissions from cattle and sheep), but with emissions from energy-related activities coming a close second. It is these energy-related activities which are the focus of this report.

<sup>1</sup> ktCO<sub>2</sub>-e stands for kilo tonnes of CO<sub>2</sub> equivalent greenhouse gases. This standard unit recognises that it is not just CO<sub>2</sub> that causes global warming, but other gases such as methane, nitrous oxide, etc. We have used 'CO<sub>2</sub>' as a shorthand for CO<sub>2</sub>-e in the body of this report.



Figure 2: Breakdown of New Zealand's emissions in 2015

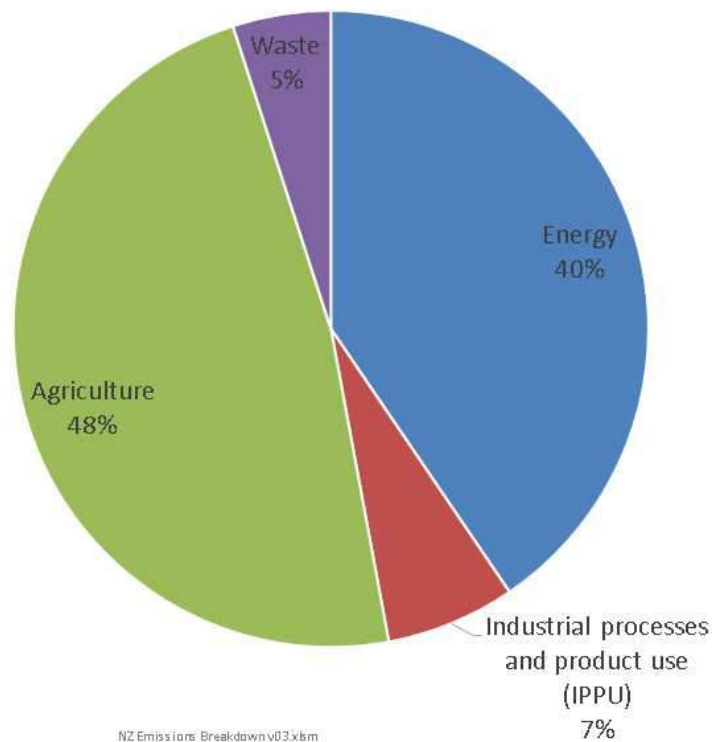
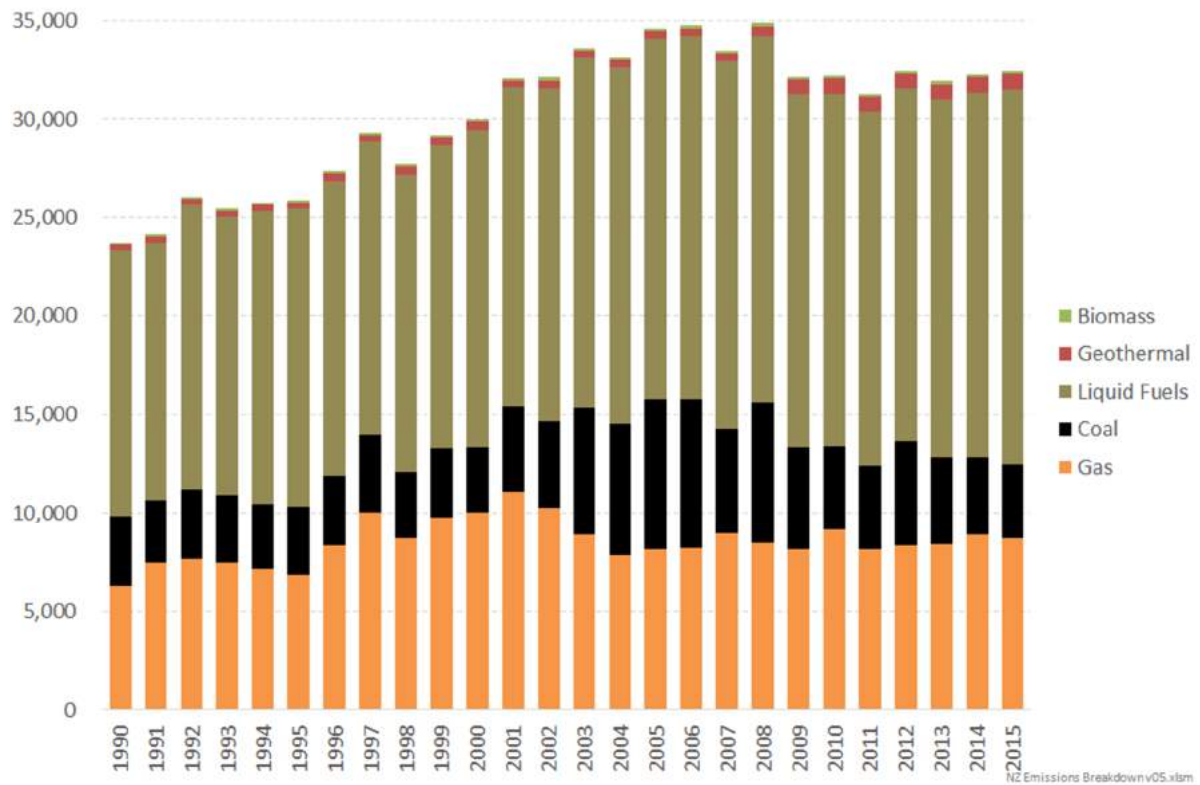


Figure 3 to Figure 5 below show the historical breakdown and movement of New Zealand's energy-related greenhouse emissions, split by fuel.

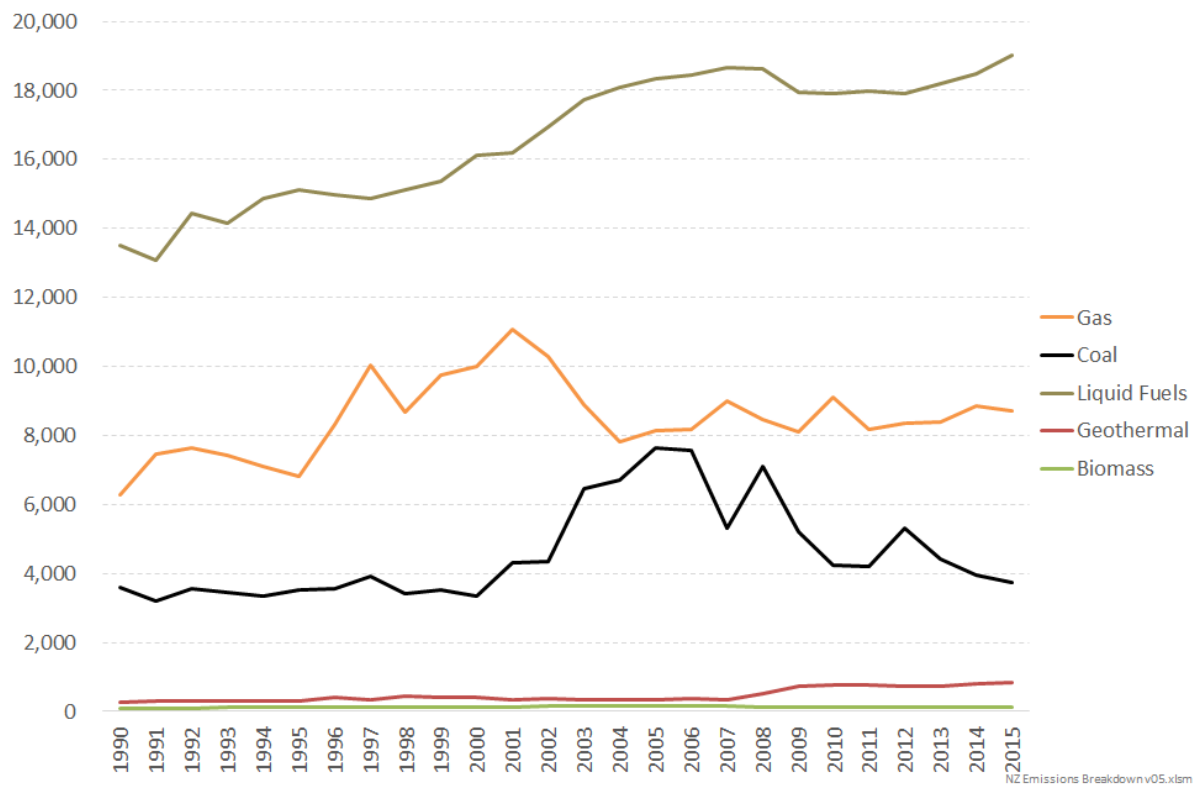
They show that:

- 'Liquid fuels' (i.e. derivatives of oil, such as petrol, diesel, heating fuel, and LPG) are responsible for almost 60% of New Zealand's energy-related greenhouse emissions, and have experienced an average annual rate of growth of 1.4% over the last 25 years.
- Natural gas is responsible for a quarter of New Zealand's energy-related greenhouse emissions. They have also risen over the 25 years' period (an average annual rate of growth of 1.3% over the past 25 years), but have largely plateaued over recent years, with an average annual rate of growth of 0.4% over the last 10 years.
- Coal-related emissions are responsible for 10% of New Zealand's energy-related greenhouse emissions. After more than doubling during the 2000s, they have fallen significantly during the past 10 years, and are back down to the levels seen at the start of the 1990s.
- Geothermal energy is now responsible for 2.5% of New Zealand's energy-related greenhouse emissions. While a relatively small percentage of the total, it has experienced significant recent growth, with an annual average rate of 10% over the last 10 years.

**Figure 3: Historical bar-chart breakdown of New Zealand's energy-related greenhouse emissions by fuel (ktCO<sub>2</sub>-e)**



**Figure 4: Historical line-chart breakdown of New Zealand's energy-related greenhouse emissions by fuel (ktCO<sub>2</sub>-e)**



**Figure 5: Breakdown of New Zealand's 2015 energy-related greenhouse emissions by fuel**

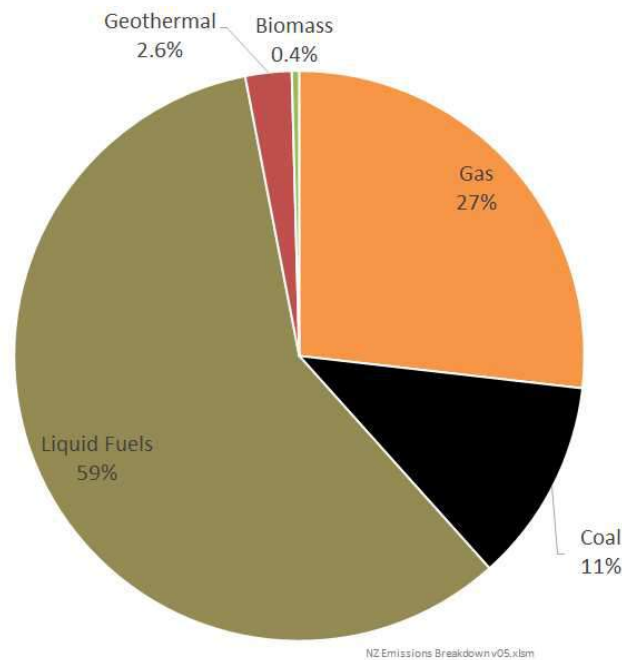
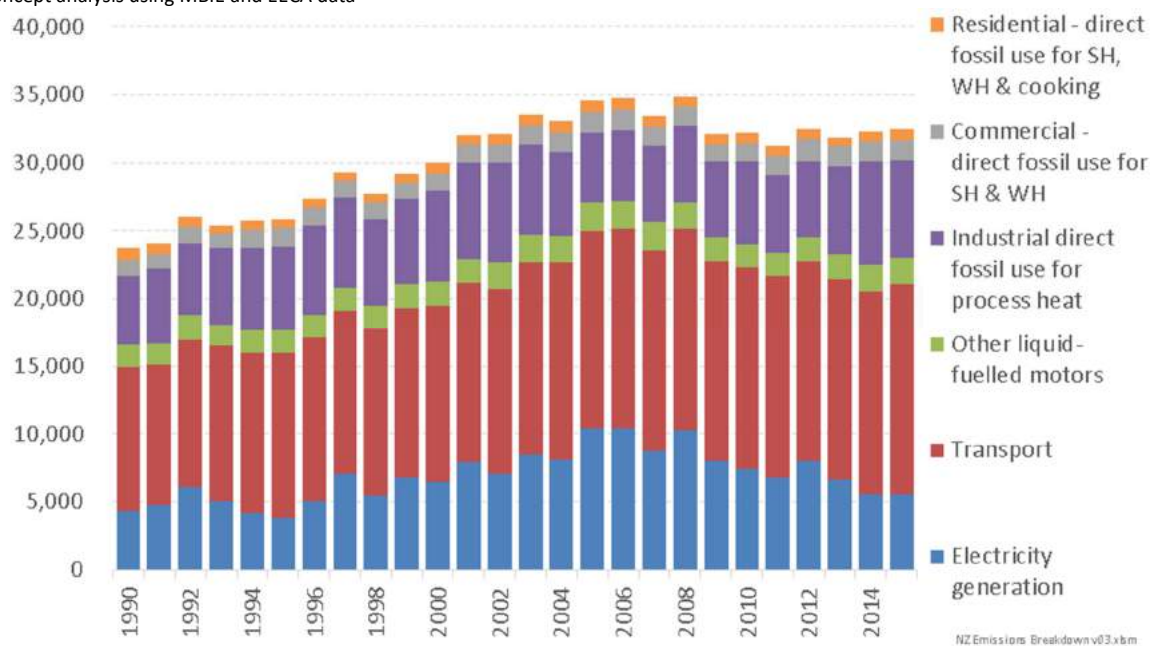


Figure 6 to Figure 8 below show how New Zealand's energy-related greenhouse emissions are broken down among key energy-using activities.<sup>2</sup>

**Figure 6: New Zealand's historical energy-related greenhouse emissions by end use (ktCO<sub>2</sub>-e)<sup>3</sup>**

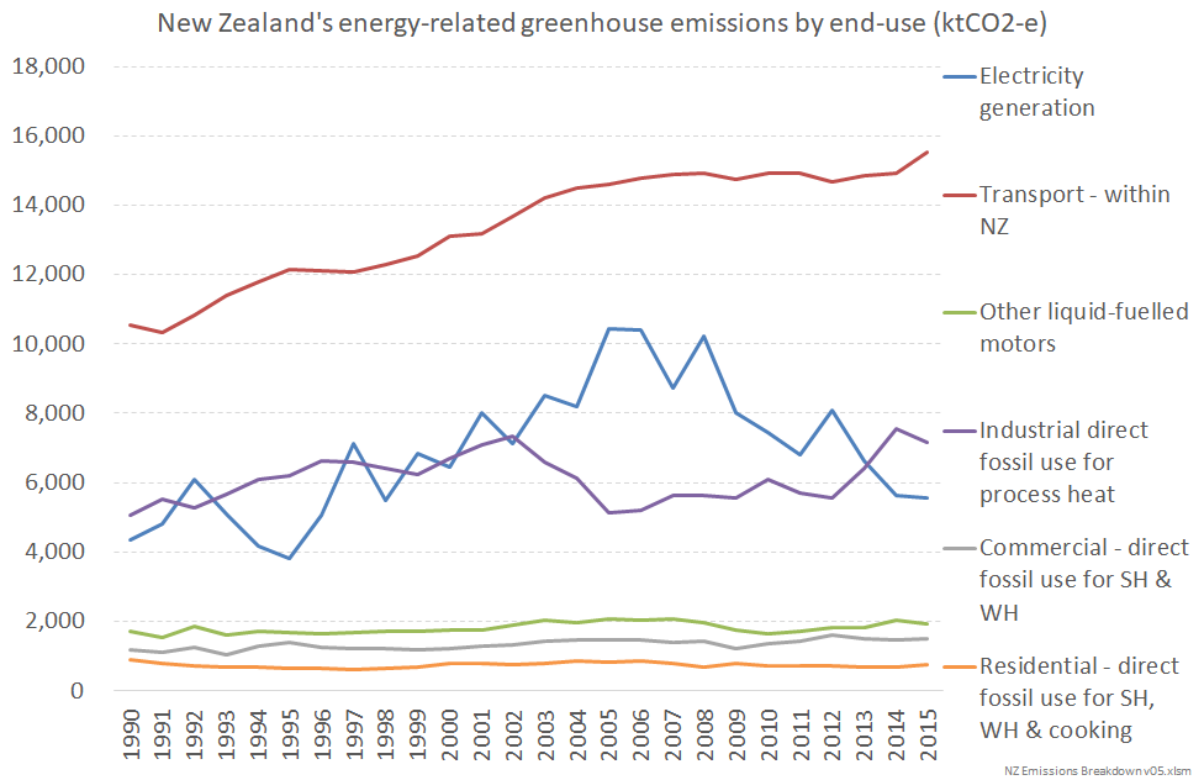
Source: Concept analysis using MBIE and EECA data



<sup>2</sup> In producing these breakdowns, we have assigned those emissions associated with the production and transportation of fuels (e.g. oil and gas processing and refining; fugitive emissions from the extraction of coal, gas, oil, and geothermal) to those end-use activities which use those fuels in proportion to their fuel use. We have also sought to estimate the proportion of liquid fuels used by industrial and commercial users for motors that aren't used for road transport. This includes agricultural machinery (e.g. tractors), as well as other motors used for industrial and commercial equipment. This estimate was developed using data from EECA's Energy End-Use Database.

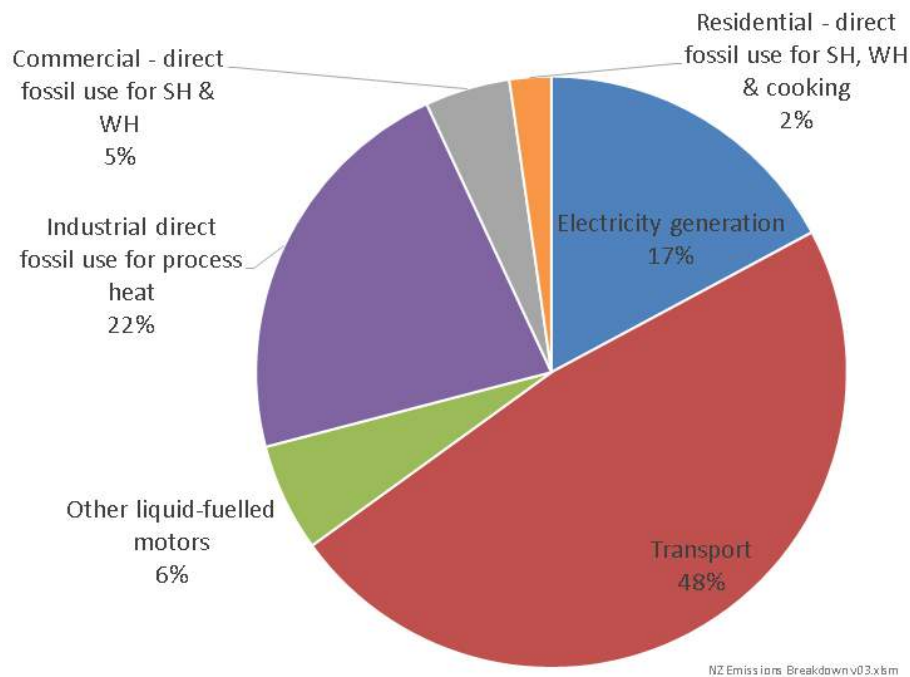
<sup>3</sup> 'Direct use' for space and water heating for residential and commercial consumers relates to the direct use of fossil fuels (e.g. natural gas, LPG, diesel, coal) for space- and water-heating.

**Figure 7: Historical change in New Zealand's energy-related greenhouse emissions by end use (ktCO<sub>2</sub>-e)**



Source: Concept analysis using MBIE and EECA data

**Figure 8: Breakdown of New Zealand's 2015 energy-related greenhouse emissions**



Source: Concept analysis using MBIE and EECA data

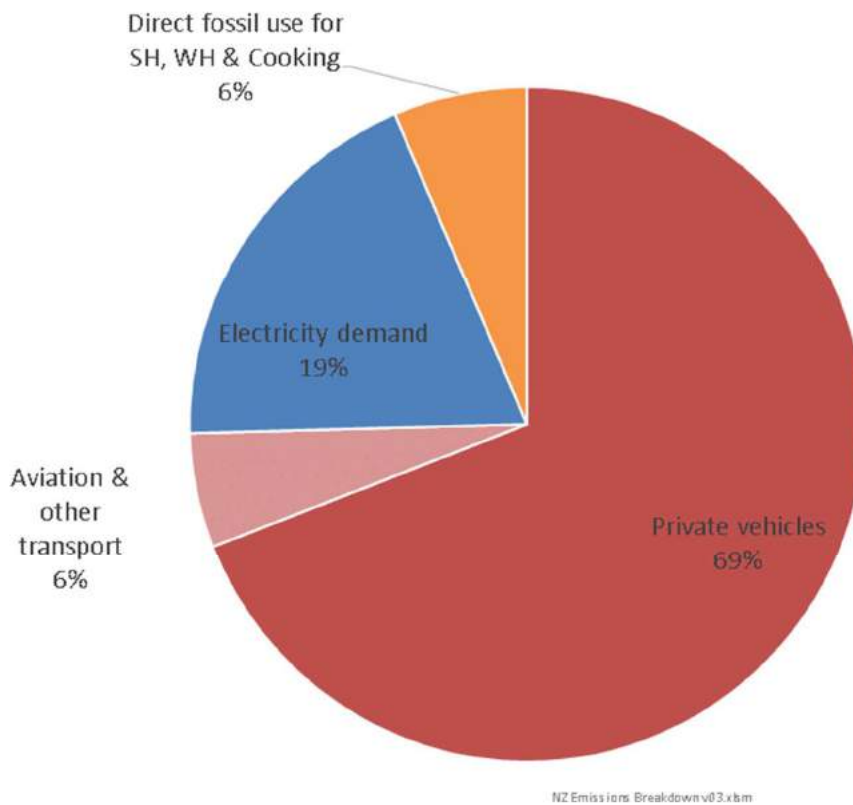
The key take-aways from the above analysis are:

- Transport and other liquid-fuelled motors (e.g. diesel motors for farm machinery or running industrial machines) dominate New Zealand’s emissions – with transport emissions also having experienced the most significant growth over the past 25 years.
- Industrial process heat is the next most significant source of emissions, followed by electricity generation.

The following two charts show another way of considering the breakdown of New Zealand’s emissions, this time by type of consumer: Households, and Businesses (the latter being the sum of Industrial, Commercial, and Agricultural and Forestry emissions).

Figure 9 below shows the breakdown of emissions which are directly attributable to households. As can be seen, the vast majority of emissions are transport-related – primarily people driving their cars. Electricity emissions are the next most significant, followed by the emissions related to people using gas-fired or oil-fired heaters for space heating, water heating and cooking.

**Figure 9: Average breakdown of New Zealand household emissions for 2015<sup>4</sup>**

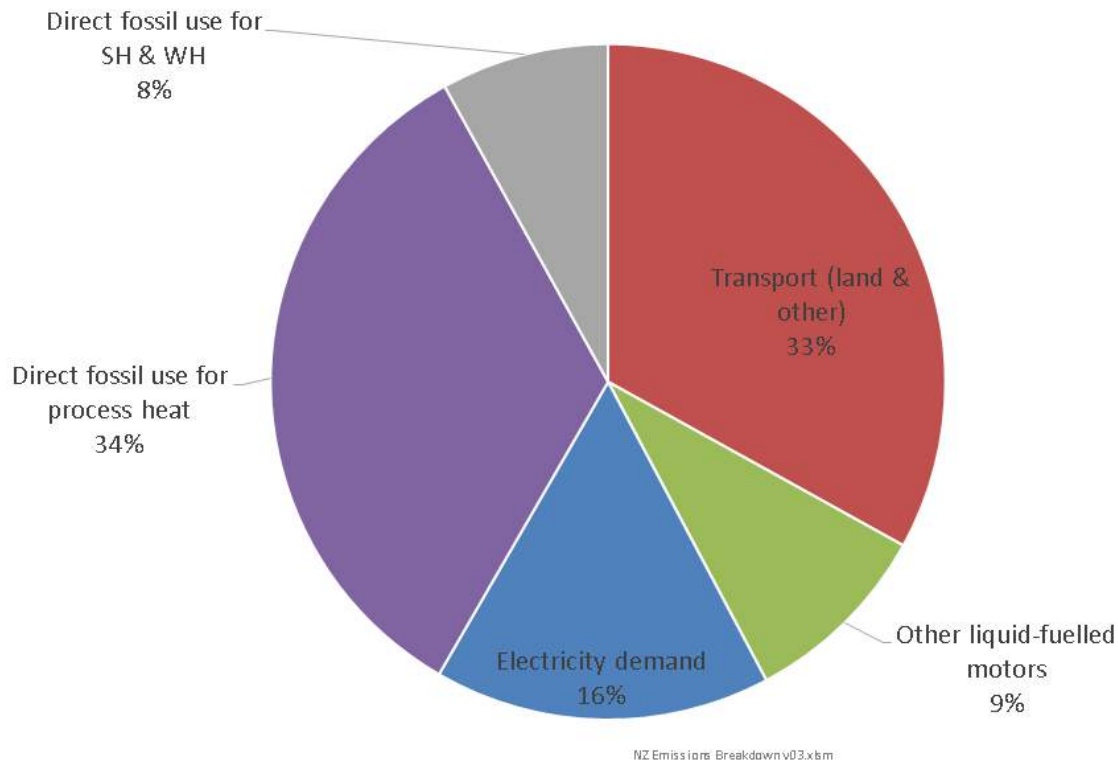


Source: Concept analysis of MBIE & MOT data

<sup>4</sup> The apportionment of land-transport emissions to households is based on Concept analysis of Ministry of Transport (MoT) and MBIE data relating to fuel use splits for private versus commercial vehicles. The apportionment of electricity emissions to households is based on Concept estimation of the relative contribution of residential demand versus business demand to the requirement for peaking generation – particularly on a seasonal basis. This is based on the analysis set out in Appendix A.

Figure 10 below shows a breakdown of the emissions attributable to business consumers (i.e. relating to industry, commerce, and agriculture and forestry). As can be seen, process heat emissions are the most significant, followed by transport, and then electricity demand.

**Figure 10: Breakdown of New Zealand Industrial, Commercial, and Agricultural and Forestry energy-related emissions for 2015**



Source: Concept analysis of MBIE, MOT and EECA data

Based on all the above charts, it is clear that key areas of focus for opportunities to de-carbonise our economy are:

- Transport (plus other liquid-fuelled motors for stationary energy)
- Electricity generation
- Industrial process heat
- Space and water heating

However, in order to consider electricity generation, it is not sufficient to solely consider the supply-side of the equation (i.e. replacing gas or coal-fired power stations with low-carbon power stations such as wind farms or solar PV). As the analysis in section 4 sets out, the profile of demand has a strong bearing on what type of power station (fossil or low-carbon) is most economic to meet that demand.

It is therefore necessary to consider the time of use of electricity, because electricity used in summer has a much lower CO<sub>2</sub> intensity compared to electricity used on winter evenings. The majority of this analysis is in the appendices, though the key results can be seen in Figure 11 below.

Figure 11: Estimated breakdown of non-transport energy (i.e. stationary energy)

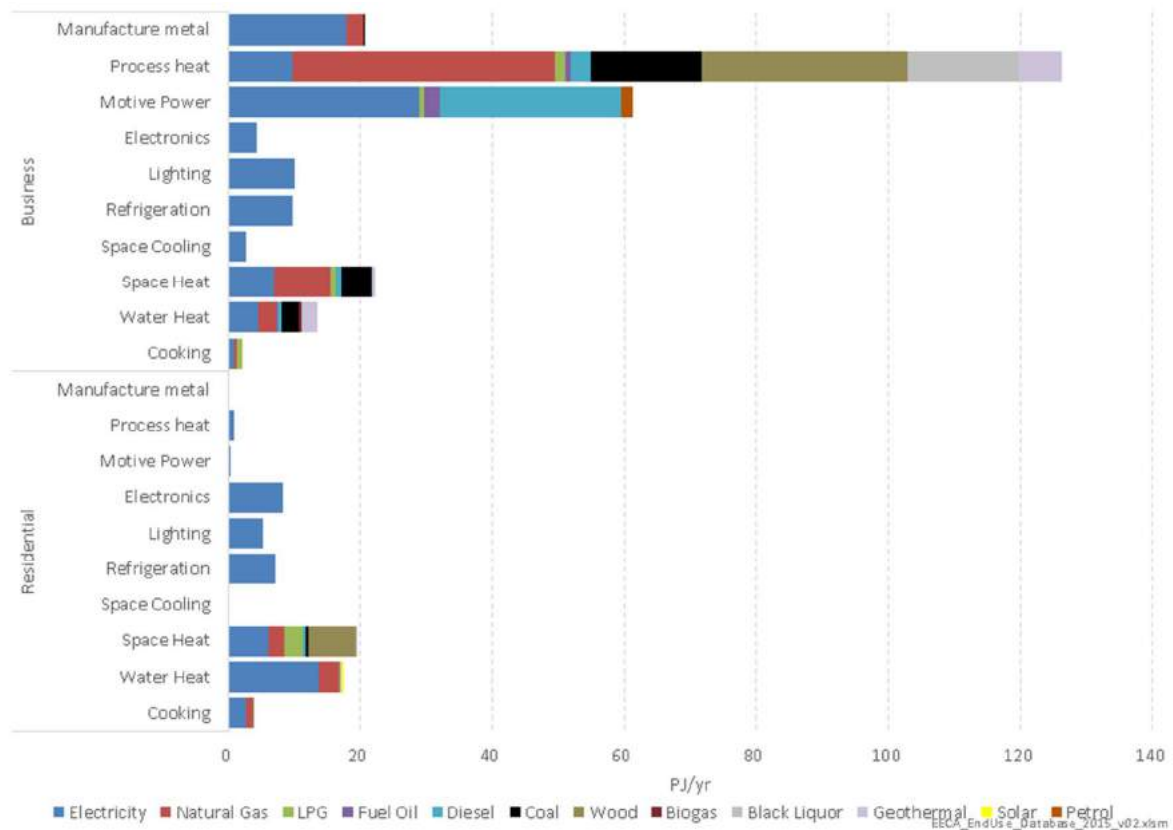


Figure 11 above is very useful in helping us identify the areas of New Zealand’s economy where have significant source of non-transport emissions, and real prospects of moving to low-carbon alternatives.

Based on all the above analysis, the following table sets out which energy technologies and end-uses have been selected for analysis in this report, and why.

End-use / technology	Reason
<b>Electricity generation</b>	Major source of fossil emissions.  Options available for fuel switching from fossil generation to low-carbon generation  Increasing number of options for generation and storage (such as wind, solar PV and batteries), but each type of renewable generation has a different impact in terms of displacing fossil fuel generation (and as is the case for geothermal, may emit or increase CO <sub>2</sub> itself).
<b>Transport</b>	Largest source of fossil emissions. Growing opportunities for fuel switching between petroleum driven vehicles and alternatives such as electric vehicles or biofuel blends.
<b>Other non-transport motors</b>	Major source of fossil emissions. Fuel switching opportunity from petroleum to electric.

<b>Industrial process heat</b>	Major source of fossil emissions.
<b>Other consumer energy end-uses</b>	
<b>Space heating</b>	Major source of direct fossil emissions and electricity demand. Peaky demand profile. Fuel switching options between gas, electricity and biomass (and technology choice for electricity).
<b>Water heating</b>	Major source of direct fossil emissions and electricity demand. Fuel switching options between gas, electricity, and solar heating.
<b>Lighting</b>	Major source of electricity demand. Peaky demand profile. New technology opportunities (e.g. LEDs).
<b>Refrigeration</b>	Significant source of electricity demand, but with a seasonally and daily flat demand profile (contrasts lighting and space heating)

Taken together, these end-uses and technologies are responsible for over 98% of New Zealand’s energy-related emissions.



## Part B – Assessment of energy options

### 3 Overview of approach

For each of the energy services, this study identifies the key options for consumers for provision of the energy service. For example, in the case of home heating the options include different types of heater as well as home insulation. In the case of transport, the options include different types of car (e.g. petrol versus electric) as well as different modes of transport (private car, shared car, bus etc.)

The study identifies the key factors which will determine the cost-effectiveness of the different options, and thus which is likely to be best. Importantly, it identifies the extent to which different consumer situations may result in different options being best. For example, the annual distance driven (per vehicle) will influence whether an electric vehicle may be cost-effective. Likewise, it may not be worth incurring the high capital cost of a high-efficiency space heater for a room which is used relatively infrequently.

This study focusses on a few different household situations which are most typical, and assesses which option is likely to be best for each situation.

The framework for assessing the different options assesses the total lifetime cost of useful service provided (heating, lighting, transport, etc.).

The 'lifetime cost' takes account of the fact that many appliances which provide a service (e.g. heater, light bulb, car) have a significant up-front capital cost. Such a cost needs to be spread over the amount of service provided (heating, lighting, transport) over its lifetime. As do, any fixed costs of maintaining the appliance.

The 'useful service' takes account of the fact that the efficiency of the option is critical in assessing the cost of the service provided (e.g. in heating a home, or lighting a room).

Lastly, the study also identifies the extent to which the apparent best option for a consumer may differ from the best option for New Zealand as a whole due to pricing 'externalities'. For example:

- It assesses whether the pricing of electricity is materially distorting consumer energy choices. In particular, the fact that the standard 'flat' tariffs for provision of electricity do not reflect how the cost of provision varies hugely between supply at times of peak demand, versus periods of low demand.
- It also assesses whether the best option is likely to vary depending on the price of CO<sub>2</sub> which consumers face. This will help assess the extent to which having a CO<sub>2</sub> price which is too low (or even too high) will result in New Zealand residential and business consumers making the 'wrong' technology choice – which, given the high capital cost of many of these options, may take decades to correct.
- Some options have human health consequences which are not faced by the parties who have chosen to use the service. For example, vehicle exhaust emissions causing respiratory diseases.

#### Technologies versus energy services

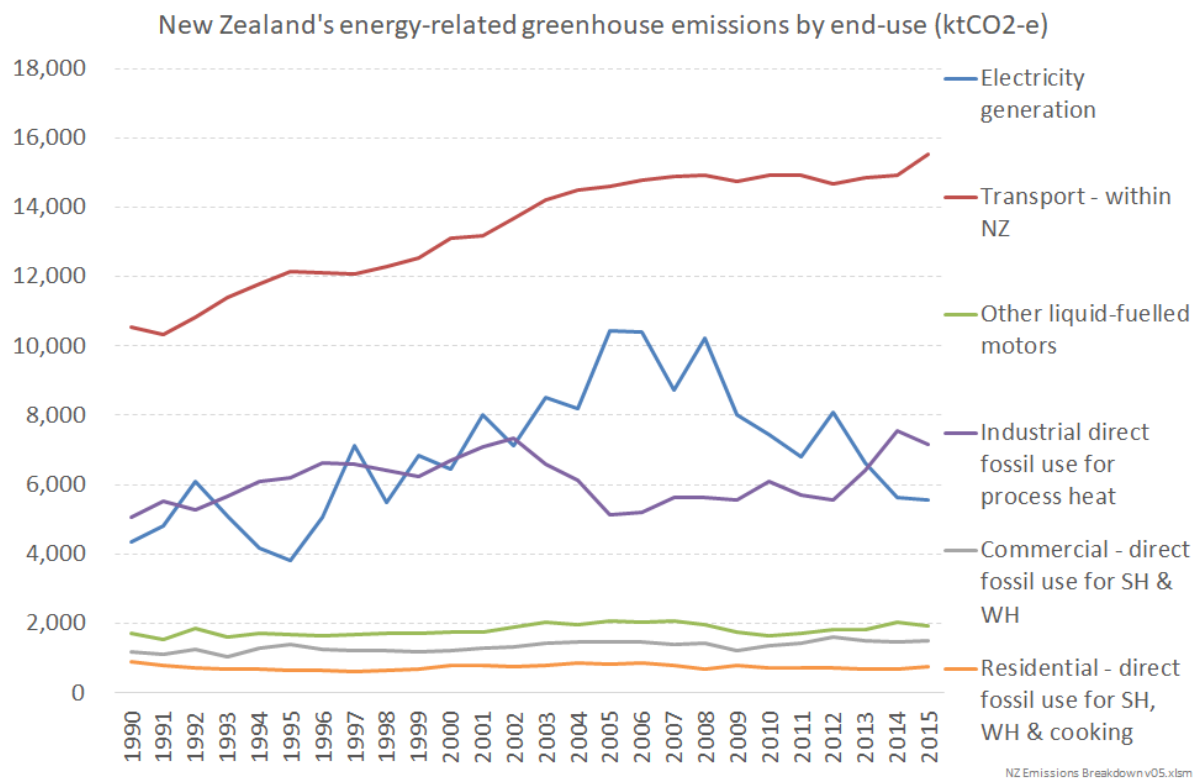
In this report, we try and focus on energy services, rather than technologies. For example, if the energy service is lighting, then this could be achieved through a variety of technologies such as incandescent, CFL or LED lamps. However, the service can be made more efficient through 'daylight harvesting' (automatically reducing electric lighting where ambient light from windows is available, or sensors to turn lights of automatically when not in use. All of this is part of the lighting service.

## 4 Electricity generation

### 4.1 Introduction

Figure 12 below (a repeat of Figure 7) shows that emissions from electricity generation are a very significant source of New Zealand's energy-related greenhouse emissions.

**Figure 12: Historical change in New Zealand's energy-related greenhouse emissions by end use (ktCO<sub>2</sub>-e)**



Source: Concept analysis using MBIE and EECA data

However, this graph also shows that emissions from electricity generation have seen very significant reductions over the past ten years. Thus, in 2006 electricity generation emissions were the second largest source of emissions (after transport), and twice as large as emissions from industrial process heat.

However, since that time, electricity generation emissions have halved as New Zealand's fossil-fuelled power stations (subsequently referred to as 'fossil generators') have generated progressively less electricity. At the same time, industrial process heat emissions have increased, so that electricity generation emissions have now dropped to the third most significant source of emissions after industrial process heat.

This section of the report considers the possible futures for power generation emissions as follows:

- Section 4.2 analyses why fossil generators have reduced their output so much over the past decade;
- Section 4.3 examines the economics of additional low carbon sources of generation (both grid-scale such as wind or geothermal, as well as micro-scale such as rooftop photovoltaics, or 'PV'), to consider whether this trend of fossil generation reduction is likely to continue;

- Section 4.4 examines the extent to which future changes in demand will result in changes in output from fossil generators – particularly whether differences in the ‘shape’ of demand change (e.g. flat across the year versus more in winter than summer) will affect the extent to which there will be changes in fossil generation. This last section on the fossil generation consequences of demand changes is then used as a key input into consideration of the other consumer energy technologies (e.g. electric vehicles for transport, electric heating, lighting, etc.)

## 4.2 Analysis of historical changes in New Zealand’s power generation greenhouse emissions

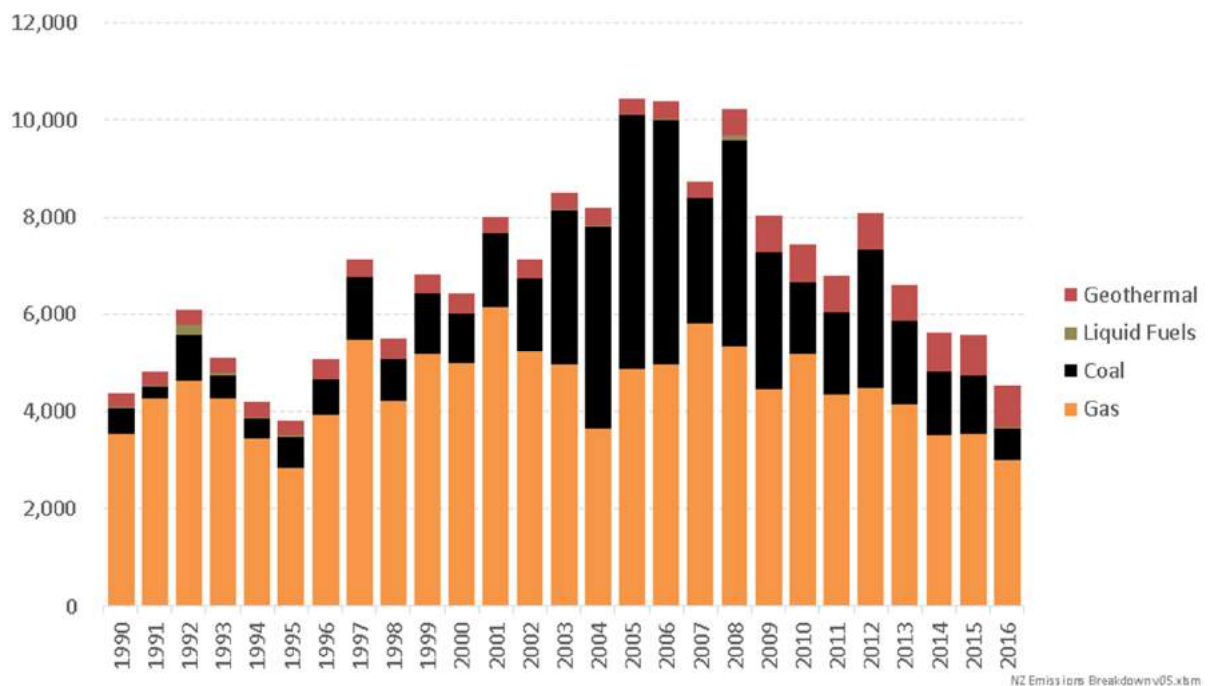
Figure 13 and Figure 14 show the historical movement of power generation emissions by fuel.<sup>5</sup>

They show that the biggest source of emissions reductions since the mid-2000s has been a rapid decline in coal-fired generation – almost all of which is from the Huntly Rankine station.

Indeed, the scale of coal-fired decline is so great that in 2016, greenhouse emissions from geothermal power stations were greater than from coal-fired generation – albeit noting that these geothermal power stations produced 7.5 times as much electricity as the coal-fired generation.

The graphs also show that gas-fired generation has also fallen, but not by as much as coal.

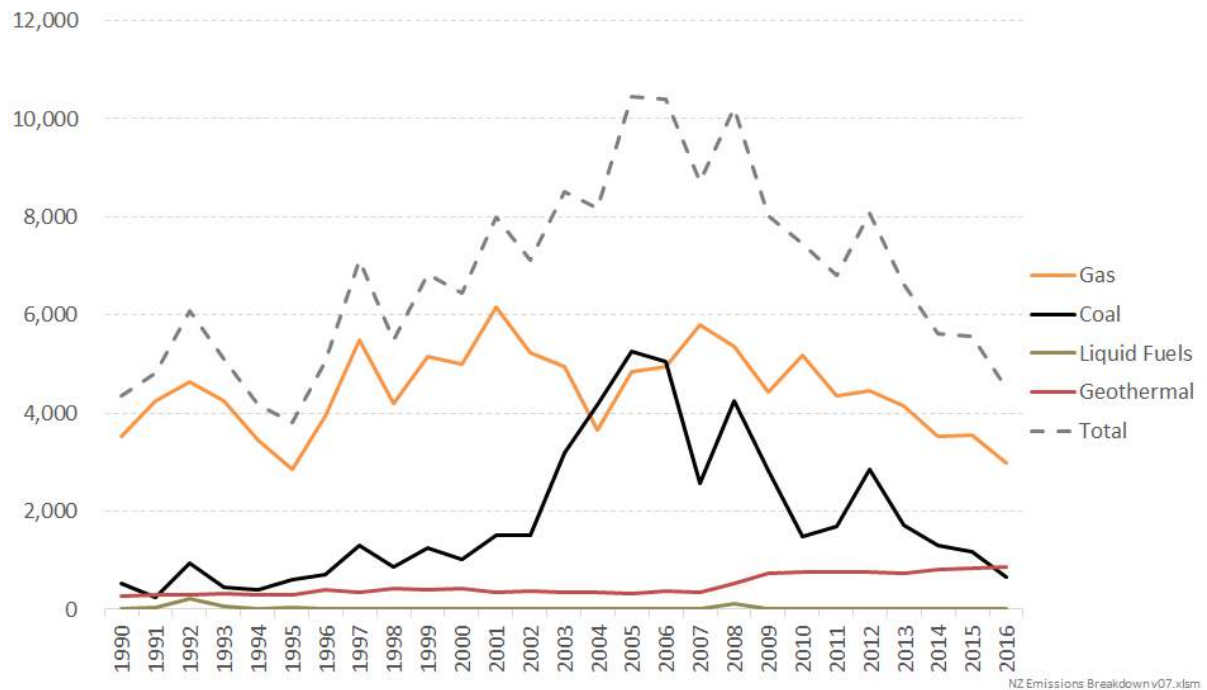
**Figure 13: Bar-chart of historical power sector emissions by power station fuel (ktCO<sub>2</sub>-e)**



Source: Concept analysis of MBIE data

<sup>5</sup> Emissions data for 2016 has not been published, but the values for 2016 in Figure 13 Figure 14 are Concept estimates based on MBIE reported GWh generation volumes for the different power stations.

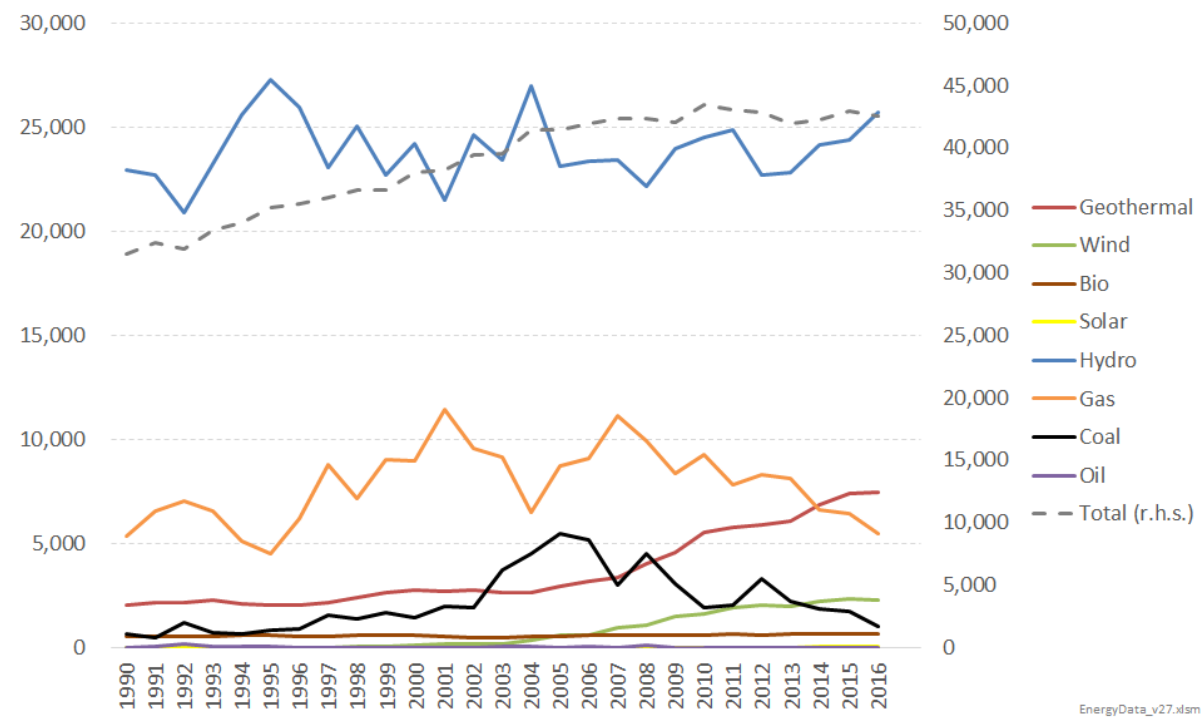
**Figure 14: Line-chart of historical power sector emissions by power station fuel (ktCO<sub>2</sub>-e)**



Source: Concept analysis of MBIE data

Figure 15 gives further insight into these observed emissions outcomes, by detailing the annual generation (GWh/year) from the different plant types.

**Figure 15: Historical generation by plant type**



Source: Concept analysis of MBIE data

Appendix A presents some detailed analysis of the drivers behind these observed outcomes. The key findings of this analysis are that:

- The reduction in the quantity of fossil generation over the past ten years is due to:
  - Development of new renewables – particularly geothermal and wind; combined with
  - A reduction in growth of overall electricity demand
- Some fossil generation has been retired (most notably the Otahuhu B and Southdown combined-cycle gas turbines (CCGTs), and two of the dual-fuelled Huntly Rankine units<sup>6</sup>)
- Variations in coal and gas prices over the past 25 years (coupled with some variation in CO<sub>2</sub> prices) are responsible for some of the variation in coal and gas burn over the years – including the proportion of coal (versus gas) burnt at the Huntly Rankine station
- The displacement of fossil generation has largely been from providing baseload duties, with only one CCGT (the e3p station) now operating in a close-to-baseload mode of operation. All the other fossil plant (the Taranaki CCGT, the remaining two Huntly Rankine units, and the open-cycle gas turbines or OCGTs) are operating in mid-merit-to-peaking modes for a range of low-capacity factor duties (e.g. seasonal peaking, within-day/week peaking, and hydro firming).
- Hydro plant are the only other type of generation to provide low-capacity factor duties (most notably seasonal and within-day/week peaking), but physical and RMA constraints mean they are limited in their ability to provide significantly more seasonal and within-day/week peaking.

Some of these outcomes are illustrated in the following figures taken from Appendix A.

Figure 16 below illustrates the average within-year and within-year generation profile of fossil generation. It illustrates the seasonal and within-day/week peaking performed by the fossil generators (i.e. more in winter than summer, more on weekdays than weekends, and more during the day than during the night).

**Figure 16: Average fossil generation profiles (MW)**

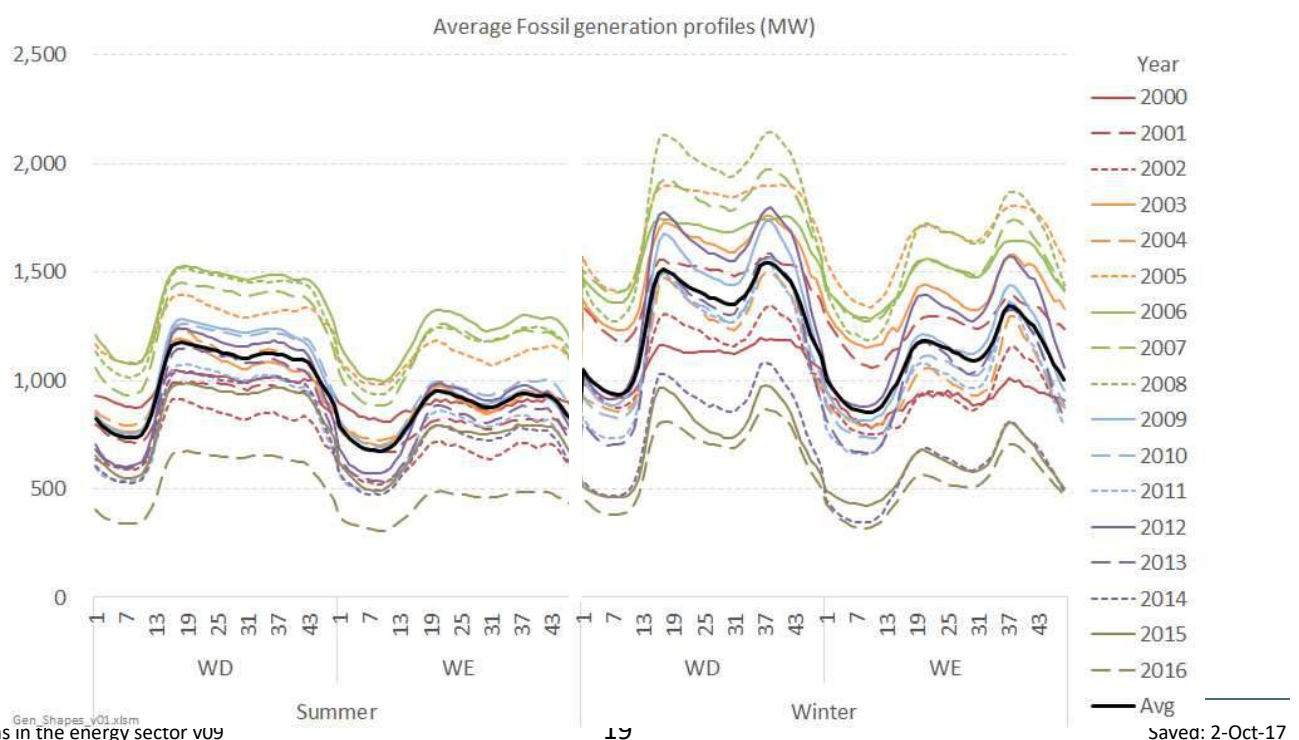
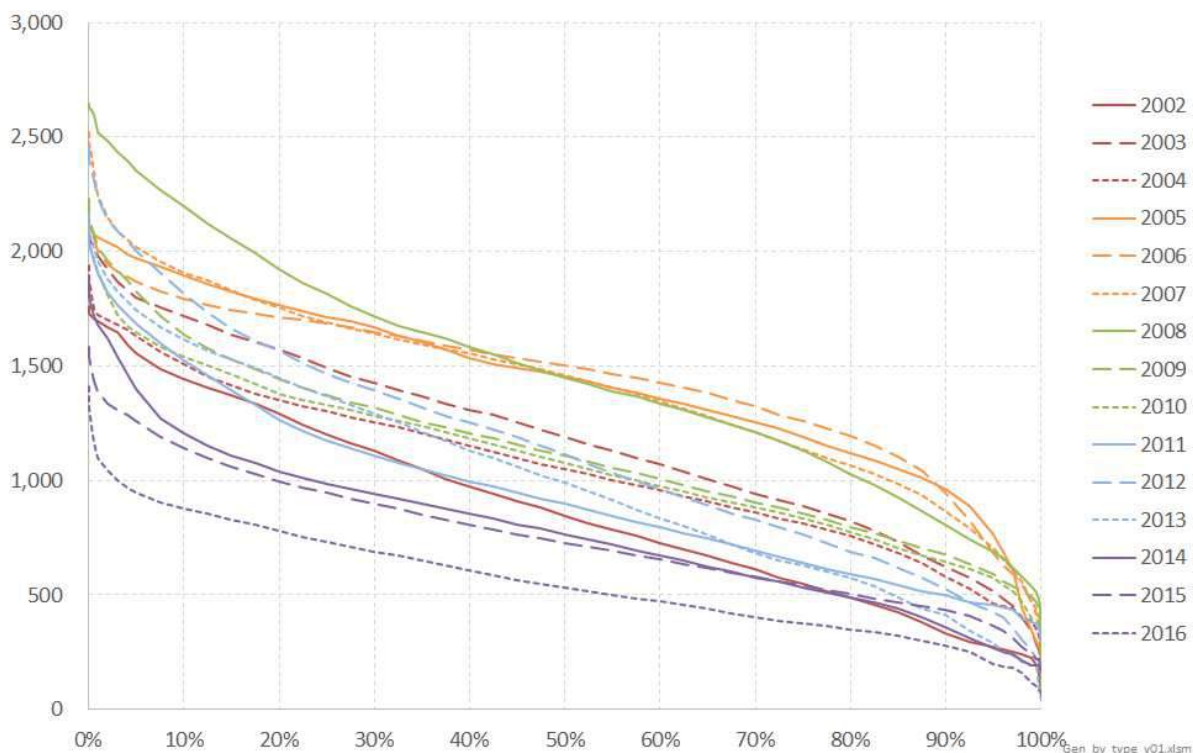


Figure 17 below shows the within-year duration curves of fossil generation.<sup>7</sup> It shows that in 2016 there was a baseload fossil requirement of only  $\approx 250$  MW, but a peaking requirement (i.e. the quantity of generation below the 10% capacity factor level) of approximately 500 MW, and a further 700 MW of fossil generation operating at capacity factors between this level.

**Figure 17: Within-year duration curves of fossil generation (MW)**



<sup>7</sup> A duration-curve better reveals the greater variation in generation requirements that occurs due to day-to-day demand variation or day-to-day (and hour-to-hour) variation in output from hydro and wind plant – noting that average generation profiles, such as that shown in

Figure 16 above, tend to under-state the extent of generation variability required.

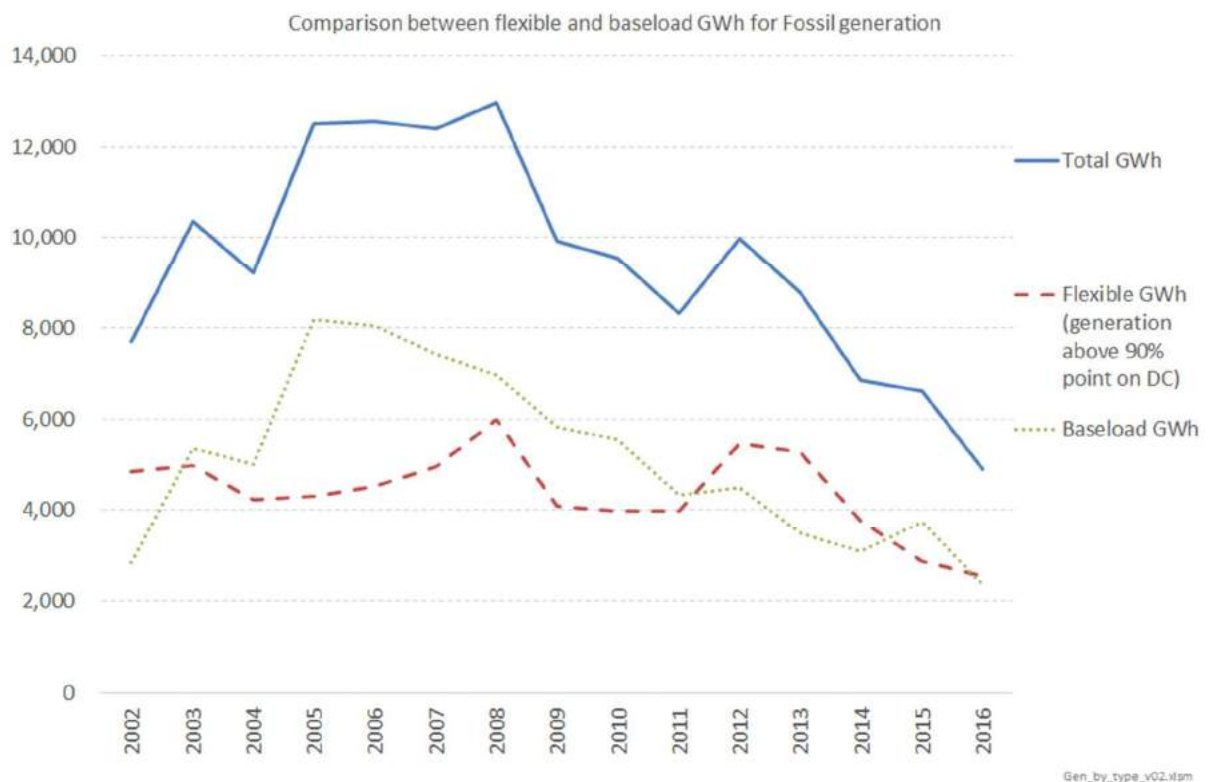
For those who are not familiar with them, Figure 69 on page 102 of Appendix A gives a stylistic explanation of what a duration curve represents.



This figure, and Figure 18 below, also show that the overall amount of fossil generation required has varied significantly – in particular, there has been a steady reduction from 2006 onwards.

This decline has largely been in the requirement for baseload generation, whereas the requirement for flexible fossil generation (being the mid-merit and peaking fossil generation which doesn't operate all the time), has not changed by as much

**Figure 18: Comparison between baseload and flexible GWh for all fossil generation**



### 4.3 Consideration of the economics of building additional low-carbon generation options to further displace existing fossil stations

If New Zealand is to further reduce greenhouse emissions from the power sector it will be necessary to build more low-carbon power stations to displace existing fossil generation.

As set out in the previous section, the displacement of fossil generation by renewables that has occurred to date has reached the point where only one CCGT (the e3p station, also known as 'Huntly unit 5') is now operating in a close-to-baseload mode of operation. All the other fossil plant (the Taranaki CCGT, 'TCC', the remaining two Huntly Rankine units, and the OCGTs) are operating in mid-merit-to-peaking modes for a range of low-capacity factor duties (seasonal peaking, within-day/week peaking, and hydro firming).

### *With reference to*

Figure 17 above, and given the limitations on hydro plant to undertake significant further seasonal and within-day/week sculpting, absent any demand growth:

- The first 500 to 800 MW of renewable generation (pending the mix of renewable generation types<sup>8</sup>) will be displacing the remaining e3p CCGT from baseload operation.
- Subsequent new renewable power stations will be progressively displacing fossil plant from progressively lower capacity factor operations. i.e.
  - the next few hundred MW of new renewable plant will only be effectively operating<sup>9</sup> for approximately **85%** of the time
  - the next few hundred MW of new renewable plant will only be effectively operating for approximately **75%** of the time
  - and so on.

The question is, will this progressive displacement of existing fossil stations be cost-effective? The high-level answer is that there will come a point where the combination of low-capacity-factor operation, and inherent higher capital costs of renewables (compared to fossil generation), means that it will be uneconomic to use renewables to displace fossil plant.

To help understand this, Figure 19 below shows the levelised-cost of energy (LCOE) – which is broadly equivalent to the long-run marginal cost – from different types of power station. The LCOE is expressed in \$/MWh and is comprised of a number of components:

- **Capital costs.** Being the annualised capital cost of building the station, divided by the annual MWh production from the station. Capital costs are not shown for existing fossil power stations, as these costs are sunk, and are thus not avoidable from the perspective of considering which generation options are likely to be least-cost for New Zealand.
- **Fixed operating and maintenance (FOM) costs.** These are the annual fixed costs of the station (e.g. labour, rates, some network charges), divided by the annual MWh production of the station.
- **Variable operating and maintenance (VOM) costs.** These are the non-fuel variable costs of operation (typically maintenance for wear-and-tear).
- **Fuel costs,** being the delivered \$/GJ cost of the fuel, factored by the fuel efficiency of the power station. Most renewable power stations (other than bio-fuelled stations) do not have any fuel costs.
- **CO<sub>2</sub> costs,** being the CO<sub>2</sub>-intensity of the fuel, factored by the fuel efficiency of the power station, and multiplied by the \$/tCO<sub>2</sub> cost of CO<sub>2</sub>. Three different CO<sub>2</sub> prices are shown to help illustrate how different CO<sub>2</sub> prices will affect the relative economics of the stations: \$8/tCO<sub>2</sub>

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<sup>8</sup> Some renewable power stations only generates when the wind is blowing or sun is shining. Thus, over a year, a 10 MW wind farm may only produce as much electricity as a 4.5 MW ‘firm’ generator operating full time, and a 10 MW solar farm may only produce as much electricity as a 1.5 MW ‘firm’ generator operating full time. In contrast, geothermal generation operates almost continuously.

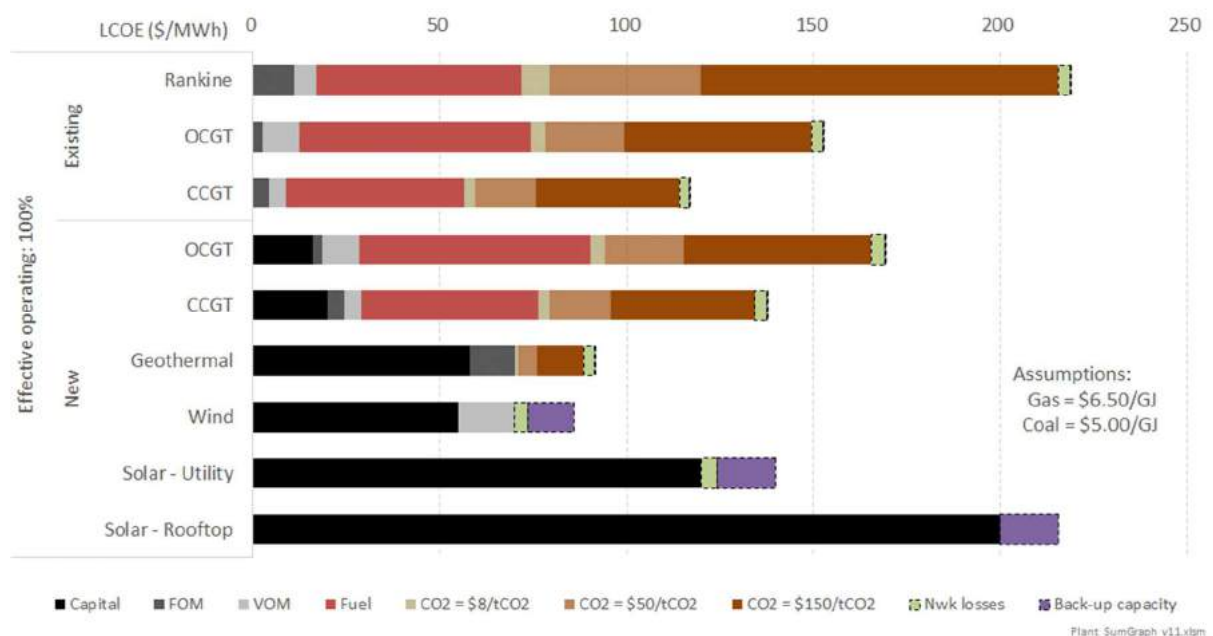
<sup>9</sup> The phrase ‘effectively operating’ means that for other times, the energy the plant will be producing will be surplus to requirements and will be ‘spilt’ (or will cause some other renewable station to spill its energy). This assumes that the existing hydro fleet is unable to materially alter the pattern of storage and release decisions to sculpt even more water away from low demand periods, and into high demand periods. This is based on analysis presented in Box 1 on page 35.



(being the current level of CO<sub>2</sub> prices faced by fossil generators under the NZ ETS<sup>10</sup>), \$50/tCO<sub>2</sub>, and \$150/tCO<sub>2</sub>.

- **Network losses.** This is an estimate of the costs of transporting power over the transmission and distribution networks to the end consumers. The purpose of this factor is to enable like-for-like comparisons of utility-scale generation with rooftop-solar PV which doesn't incur such network losses.
- **Back-up capacity.** To be a true like-for-like comparison it is necessary to take account of the extent to which the different types of station contribute MW at times of capacity scarcity – being the times when a significant amount of cost is incurred through having to carry infrequently-used power stations to provide capacity at such times. To estimate this, the graph adds on the cost of such back-up capacity to the extent that power stations are not firm at times of peak. Geothermal and fossil stations are assumed to contribute 98% of their installed capacity at times of peak, whereas the values for wind and solar are 20% and 0%, respectively.

**Figure 19: Estimated levelised cost of energy from different power stations for baseload operation**



As can be seen, by far the largest cost component for a new renewable plant is the capital cost, whereas for a fossil-fuelled station the largest costs relate to the fuel and (depending on the CO<sub>2</sub> price) CO<sub>2</sub> costs.

There are some important key take-aways from this graph.

- **New wind and geothermal power stations are much lower cost low-greenhouse options than new solar PV power stations** – whether they be micro-scale rooftop installations, or multi-MW utility-scale power stations. Accordingly, investing in solar (particularly rooftop solar) will be much more expensive for New Zealand than investing in wind or geothermal as a means of displacing fossil power stations.

This holds true even when considering the costs of transmitting the power from utility-scale power stations over the transmission and distribution networks to end-consumers, compared with rooftop solar where no network transport is required. Although rooftop solar generation

<sup>10</sup> NZU prices under the NZ ETS have been around NZ\$16/tCO<sub>2</sub> for the past year which, when factored by the one-for-two requirement, results in an effective price of NZ\$8/tCO<sub>2</sub>.

*may not* need the lines networks to deliver the power to the consumer (see below for why it generally does), it doesn't avoid the need for the consumer to be connected to the lines networks. This is because the consumer will still need power for those periods when the sun isn't shining. Nor do they reduce the extent of this consumer requirement for lines capacity, as this requirement is set at times of peak demand – typically 6-7pm on an extremely cold winter evening – a time when the sun is not shining. The only costs which rooftop solar avoids are the losses associated with transporting electricity from utility-scale generation over the lines. However, these are only of the order of 4-5%, so this benefit is nowhere near large enough to overcome the much higher capital cost of rooftop solar.

The italicisation of the words 'may not' in the previous paragraph is because approximately 60% of power generated by rooftop solar is exported from a house during those periods when it is generating more than the household is consuming. In order that this surplus power is not wasted the consumer needs to be connected to the grid so that it can be sold to other consumers. Thus, arguably, solar PV needs the grid just as much as other generation technologies. Further, if there were to be high levels of solar PV uptake by consumers, it would be likely that this would give rise to *extra* network investment being required to cope with reverse power flows on the network. i.e. rather than avoid the need for grid investment, large-scale solar PV uptake may actually increase it.

This assessment of the economics of rooftop solar PV is considered to hold true, even when batteries become economic. This is because, as set out in Appendix C batteries would be most cost-effectively used to manage surplus *grid-scale* low-carbon generation (e.g. wind, hydro, geothermal or even utility-scale solar), rather than rooftop solar. In addition, as further set out in Appendix C, it is likely to be most cost-effective for New Zealand to invest in utility-scale batteries rather than domestic scale batteries, to meet the storage demands that won't already be met from utilising batteries within EVs.

- ***New wind and geothermal power stations may be more cost-effective than the Huntly Rankines (using coal) for baseload operation.*** This is particularly the case if there is a material cost of CO<sub>2</sub>. The caveat indicated in the word 'may' is for a number of reasons:
  - Firstly, it assumes that new wind and geothermal stations can be built for the price indicated in Figure 19 (≈ \$70/MWh). In this it is worth noting that the LCOE of different wind and geothermal schemes are very site specific, with huge variation in the scale of wind and geothermal resource (i.e. average wind speed, and extent of geothermal fluid), and huge variation in the cost of building the power station (e.g. due to the extent of remoteness and ruggedness of the terrain of the wind site, or the extent of wells needing to be drilled for geothermal). Nonetheless, it appears that there are some options with LCOE of the order of \$70/MWh (maybe even less for some wind schemes).
  - Secondly, when the lack of firmness of wind is taken into account, it is potentially the case that an existing Rankine on coal may be cheaper than building a new wind farm – provided the cost of CO<sub>2</sub> is low. Nonetheless, the graph suggests that the displacement of the Rankine units from baseload operation that has occurred from building new geothermal is likely to have been cost-effective for New Zealand.
- ***New wind and geothermal power stations may not be more cost-effective than the existing CCGTs for baseload operation.*** Figure 19 indicates that the LCOE of an existing CCGT is cheaper than that of building a new geothermal or wind station for baseload operation, even if the cost of CO<sub>2</sub> is \$50/tCO<sub>2</sub>. Only if the cost of CO<sub>2</sub> were significantly higher would it be cost-effective to build new wind and geothermal plants to displace existing CCGTs from baseload operation. This has a couple of important ramifications:

- Firstly, some of the displacement of existing CCGTs (both TCC, and the now-retired Otahuhu B and Southdown CCGTs) that has occurred because of the wind and geothermal that has been built over the past five years may not have been least-cost for New Zealand – at least not with the CO<sub>2</sub> prices that New Zealand has faced over that period.
- Secondly, if there was a growth in baseload demand, it may be most cost-effective for this to be met by increasing output from the existing CCGTs – particularly the heavily under-utilised Taranaki CCGT – rather than building more baseload renewables. Again, this is only if the CO<sub>2</sub> prices faced by New Zealand are less than about \$55/tCO<sub>2</sub>.

In summary, it appears to have been cost-effective to have displaced the Huntly Rankines from baseload operation. In future, displacement of existing CCGTs from baseload operation by building new wind and geothermal is also likely to be cost effective for New Zealand if we face a cost of CO<sub>2</sub> – of the order of NZ\$55/tCO<sub>2</sub>.

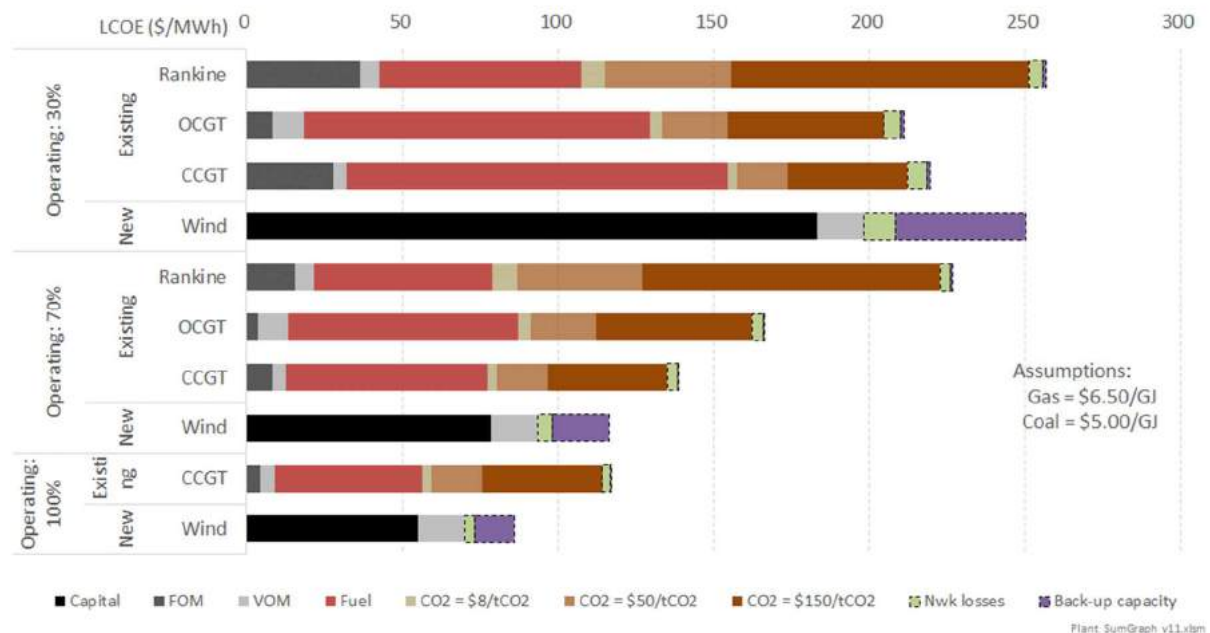
Looking forward, it is potentially the case that we will face CO<sub>2</sub> prices of this order. A large number of respected international organisations are estimating that the social cost of greenhouse emissions could be of the order of US\$150/tCO<sub>2</sub> (i.e. over NZ\$200/tCO<sub>2</sub>). For example, the International Energy Agencies scenario for limiting global temperature rise to 2°C has carbon prices rising to NZ\$225/tCO<sub>2</sub> by 2050.

In addition, it is likely that renewable technologies will continue to come down in price – particularly wind and solar – through ongoing technology improvements and manufacturing scale economies. Accordingly, in a world of ever-higher CO<sub>2</sub> prices and reducing costs of renewables, it would appear to be cost-effective to build new renewable power stations (particularly wind farms) to displace existing CCGTs from baseload operation.

Might this also be the case for building new renewables for displacing existing fossil stations from lower capacity factor duties – e.g. winter peaking, within-day / week peaking, and hydro firming?

To consider this Figure 20 below shows the estimated levelised cost of energy (LCOE) from different power stations for different effective operating factors. Thus, for building a new wind plant to meet an effective operating requirement of 70% is equivalent to 30% of the output of the plant being spilt due to oversupply at times of low demand and/or high national renewable flows (hydro plus wind) to an extent that can't be managed by storage. The economics of building a wind farm whose output is only needed for 70% of the time is the equivalent of recovering the capital costs over 70% of the annual output – as reflected by the capital component of the LCOE being higher by a factor of 1/70% (i.e. a factor of '1.43').

**Figure 20: Estimated levelised cost of energy from different power stations for different effective operating factors**



The key take-aways from Figure 20 are:

- The capital intensity of renewables means that it becomes increasingly expensive to build new renewables plant such as wind to displace fossil plant operating at lower capacity factors (i.e. it is expensive to build a wind farm just to operate in winter).

Put another way, because much of the cost of fossil fuelled generation is in the fuel use (and not in the upfront capital), fossil generation (and biomass plant) is more ‘pay as you go’, so if you don’t use the generation you pay less because you don’t burn the fuel. With wind and geothermal generation, almost all costs are borne upfront, you bear the same costs even if you use less generation. So, for low capacity factor operation (i.e. when a large amount of generation capacity, e.g. 100 MW, is required over a relatively short period such as winter), fossil fuelled plant<sup>11</sup> has a distinct cost-advantage over renewable generation such as wind, geothermal and solar PV.

- The relative economics of the fossil generation plant (coal, CCGT etc) change for different capacity factors of operation. In particular, absent the effect of CO<sub>2</sub> prices, coal-fired Rankine units can be cheaper for operating at very low capacity factors compared to gas-fired power stations. This is because the costs of providing low capacity factor fuel are a lot less for coal than for gas – particularly for providing low-capacity factor fuel on a year-to-year timeframe to cope with dry/wet hydro years.<sup>12</sup> Also, CCGTs are not designed for low-capacity factor operation as, compared with OCGTs, they have high start-up costs and high minimum operating levels. This

<sup>11</sup> Biomass plant has some advantages as well for low capacity factor operation. However, the costs of the fuel supply chain would also be much higher as woody biomass is not a readily traded fuel source at the volume required for grid-scale generation, thus the intermittent demand would cause high supply-chain costs (on a \$/GJ basis).

<sup>12</sup> Ironically, the need for significant amounts of variable energy to provide hydro firming is the main reason the coal-fired Huntly Rankines are being kept going, as this type of duty is very expensive to meet with gas.

means that at lower capacity-factor modes of operation, OCGTs will be lower cost than CCGTs, despite CCGTs having higher fuel efficiencies.

- The relative economics of new wind versus fossil, and the different types of fossil, is sensitive to the cost of CO<sub>2</sub>e. Thus, as the cost of CO<sub>2</sub>e increases, the threshold capacity factor where it becomes economic to build new wind to displace existing fossil plant slowly falls. Further, the type of fossil plant which is least cost will also change – particularly for the lowest capacity factor operations as Huntly Rankines on coal will eventually become more expensive than gas-fired OCGTs.

#### 4.4 Estimation of the abatement cost curve for electricity generation greenhouse emissions

The above analytical framework has been used to estimate the marginal abatement cost of CO<sub>2</sub> from investing in the cheapest form of renewable generation to progressively displace existing fossil generation.

In other words, what cost of CO<sub>2</sub> is required in order for it to be cost-effective to invest in new renewables to displace existing fossil generation, noting that once the remaining baseload fossil generation is displaced, additional new renewable generation will be operating at progressively lower effective capacity factors – both for within-day/week and seasonal peaking purposes, and to provide dry/wet year hydro balancing.

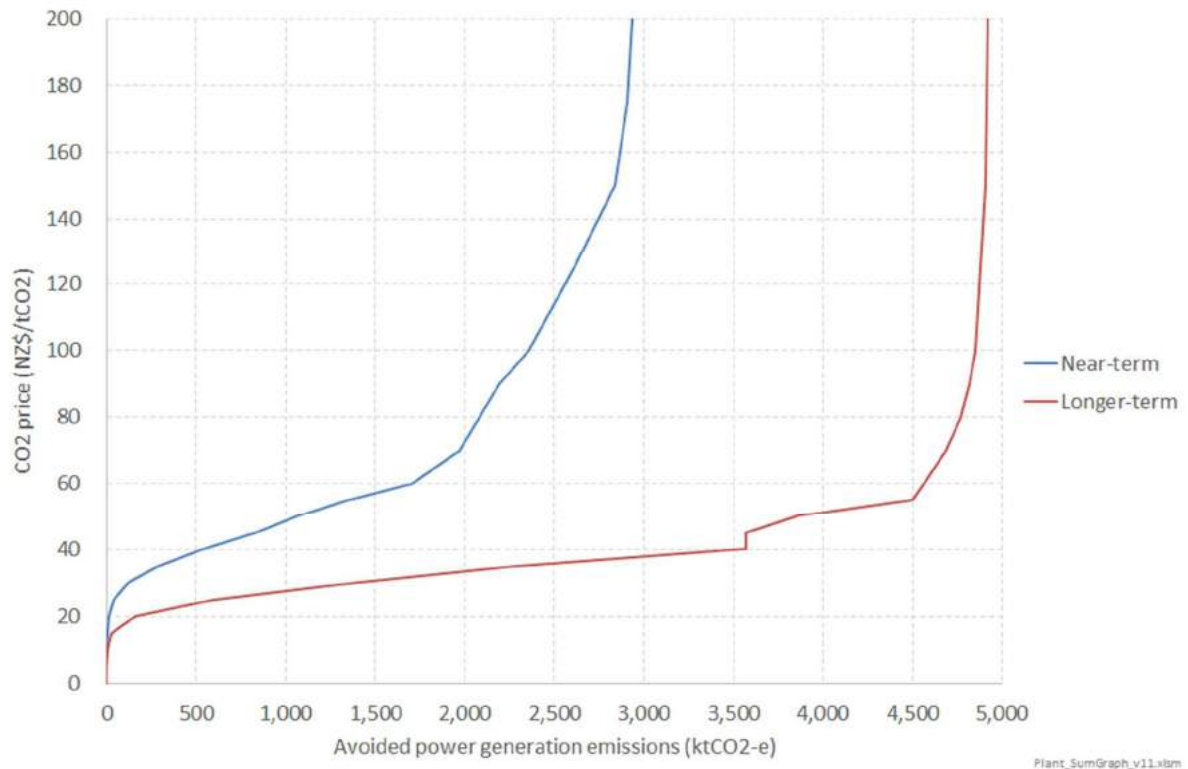
The analysis has been done for the near-term (i.e. investment within the next couple of years to displace existing stations), and the medium to long-term (approximately 10-15 years' hence).

This longer-term consideration takes account of demand growth (including the extent to which EV-driven demand growth will predominantly be overnight, and batteries and other control technologies will reduce peak demand), and the fact that renewable generation technologies will continue to reduce in cost as technology improves.

It has also only been done for a central view of coal and gas prices (and the flexibility costs of providing lower capacity-factor gas and coal), and assumes that there are no other major system discontinuities (e.g. retirement of Tiwai).

The results of the analysis are shown in Figure 21 below. For reference, without any new renewable stations being built, the mean hydrology power-generation emissions are projected to be 4,750 ktCO<sub>2</sub>-e in the near term, 6,700 ktCO<sub>2</sub>-e in the longer-term (due to demand growth being taken up by increased operation of under-utilised existing fossil stations, and development of new OCGTs).

**Figure 21: Central estimate of marginal abatement cost (MAC) curve for new renewable power generation**



The MAC curves have the same basic shape, with key characteristics as follows:

- A very steep initial part of the curve, where no savings are made until a price is reached ( $\approx$  NZ\$35/tCO<sub>2</sub> in the case of the near-term curve,  $\approx$  NZ\$20/tCO<sub>2</sub> for the longer-term curve) when it starts to become cost-effective to build the cheapest renewable options to start to displace the fossil stations from baseload operation.
- A flatter part of the curve as this remaining baseload fossil operation is progressively displaced
- A steeper curve as the baseload fossil is completely displaced, and additional renewables need to operate at progressively lower capacity factors to displace the remaining fossil that is operating to provide such a duty.
- The steepness grows asymptotic to the right of the curves, but at a level which is less than the projected total power generation emissions in a zero CO<sub>2</sub> price scenario (which, as mentioned above, are projected to be 4,750 ktCO<sub>2</sub> in the near term, 6,700 ktCO<sub>2</sub> in the longer-term).
- The potential emissions savings in the longer-term are greater because, absent a CO<sub>2</sub> price, demand growth would be taken up by increased operation of under-utilised existing fossil stations, and development of new OCGTs.
- The price to achieve emissions savings is also projected to be lower in the longer-term because of the projected continued reduction in the cost of new renewables such as wind power.

To further understand what's behind these numbers, Figure 22 below displays the results for the near-term projection in a different format. It shows the emissions from the different types of plant at different CO<sub>2</sub> prices.



**Figure 22: Projected variation in power generation CO<sub>2</sub> emissions, and renewables proportion, due to varying CO<sub>2</sub> prices in the near term**

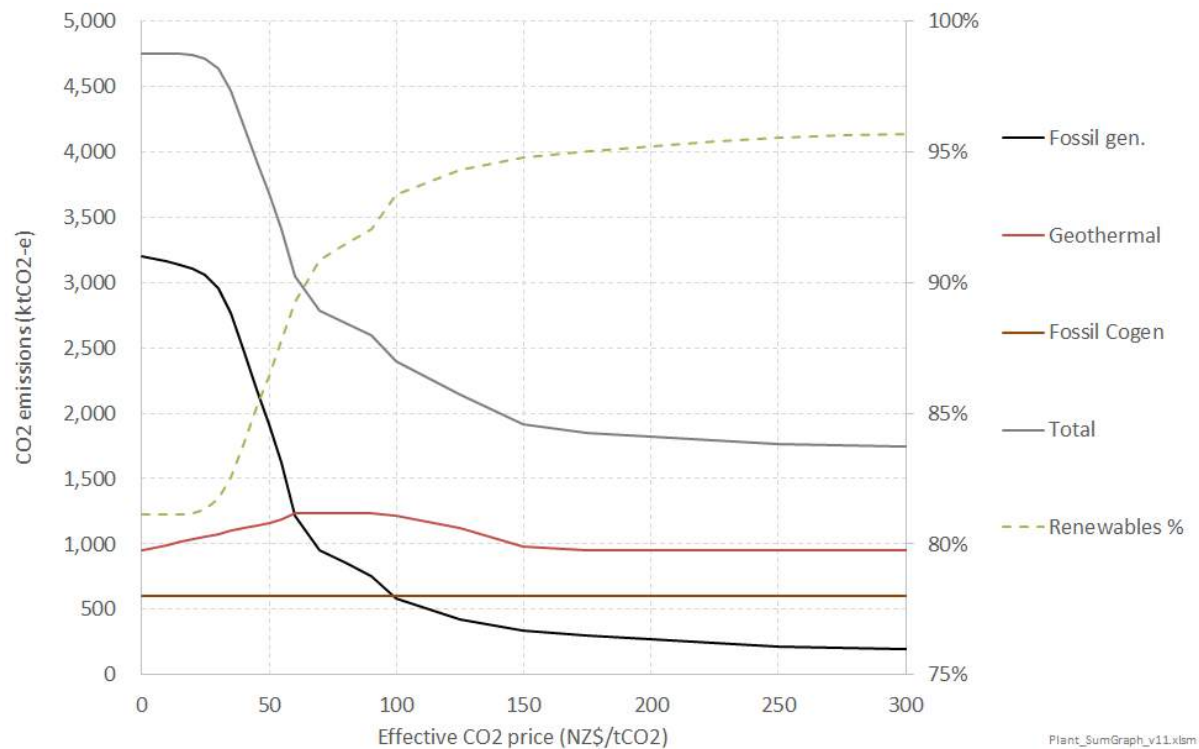


Figure 22 shows that once CO<sub>2</sub> prices rise above a certain level, new renewables start to be built to displace fossil generation from baseload modes and emissions from fossil generation start to drop steeply as more and more renewables are built to displace baseload generation. Then, after all baseload fossil generation is displaced, the rate of decline of fossil generation emissions with ever higher CO<sub>2</sub> prices reduces.

However, importantly, it also shows that what have been classed as ‘fossil generators’ (i.e. CCGTs, OCGTs, and the Huntly Rankine station) are not the only material source of greenhouse emissions:

- Geothermal plants are a significant source of emissions, and once CO<sub>2</sub> prices rise above NZ\$50/tCO<sub>2</sub> causing fossil generators to be displaced from baseload operation, it is likely that they will be the largest source of emissions. What is more, once they are built, they are very unresponsive to CO<sub>2</sub> prices.<sup>13</sup>
- Emissions from fossil-fuelled cogeneration plants are also material. They have been projected to not vary with CO<sub>2</sub> prices from their current levels because of the presumption that such plants will continue to receive credits under the NZ ETS Industrial Allocation scheme – designed to protect energy-intensive New Zealand industry which faces competition from overseas manufacturers who don’t face a cost of carbon.<sup>14</sup> This fossil cogeneration is a significant reason why the proportion of power from renewable generation doesn’t rise significantly above 95%.

<sup>13</sup> The ‘hump’ in projected Geothermal emissions with increased prices shows that, particularly in the near term, new geothermal plants will be built to displace fossil generation with an increase in CO<sub>2</sub> prices up to a certain level. However, beyond that level it would be cheaper to build new wind plants. Thus, if CO<sub>2</sub> prices were to be at very high levels, no new geothermal stations would be likely to be built, with only the existing geothermal stations continuing to emit greenhouse gases.

<sup>14</sup> Were this Industrial Allocation to stop, a significant proportion of the industrial processes using the cogeneration plants could close, rather than switch to lower-greenhouse alternatives. Given that the lost

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production would most likely be taken up by more fossil-intensive overseas producers who don't face a cost of carbon, the assumption that emissions wouldn't change with an increased NZ CO2 price seems appropriate – at least in a global sense.

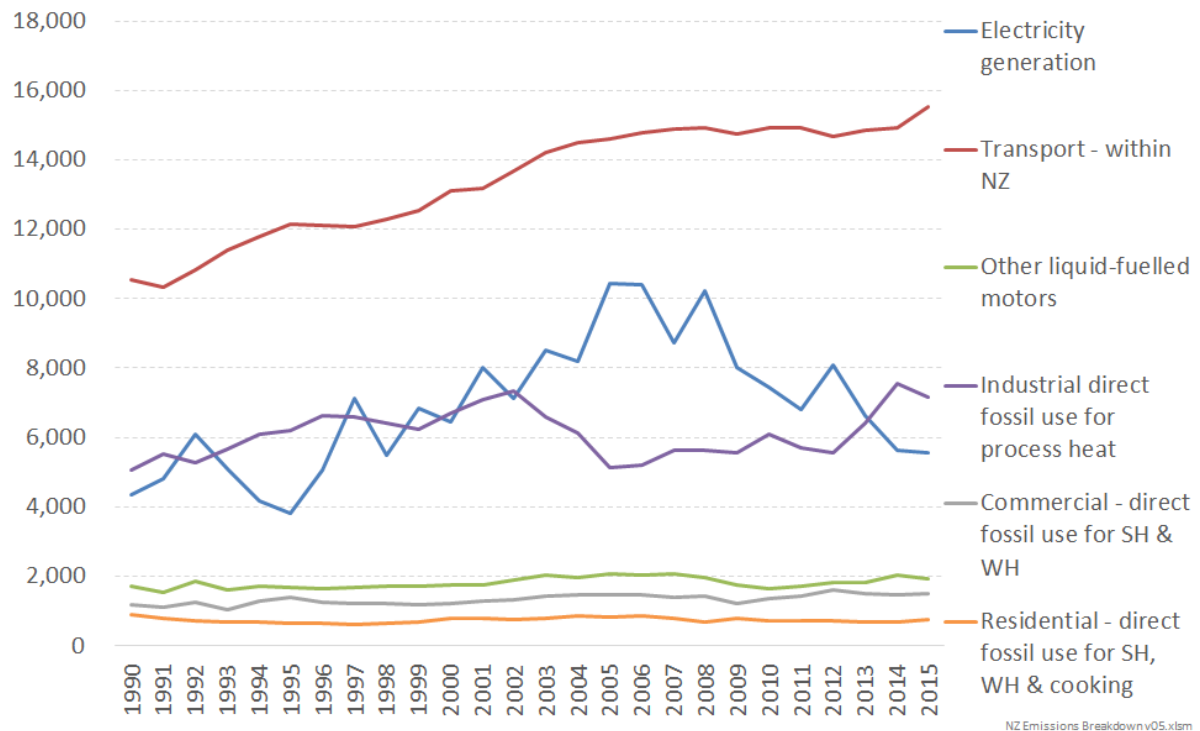


## 5 Transport

### 5.1 Breakdown of New Zealand's transport emissions

As Figure 23 below shows (reproduced from Figure 7 previously) transport emissions are by far the biggest source of New Zealand's energy-related greenhouse emissions. They are responsible for almost half of total within-New Zealand greenhouse emissions (more than half if international transport emissions are included), and have grown significantly over the past 25 years.

**Figure 23: Historical change in New Zealand's energy-related greenhouse emissions by end use (ktCO<sub>2</sub>-e)**



Source: Concept analysis using MBIE and EECA data

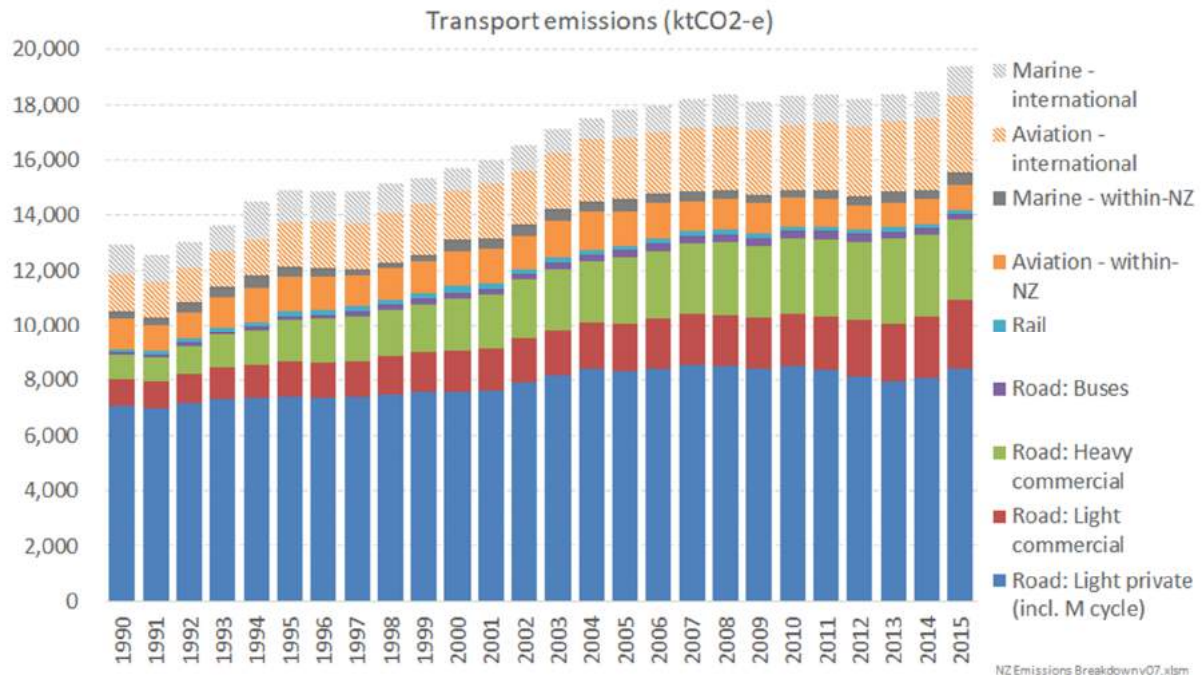
To start to understand what is behind this growth, Figure 24 to Figure 26 below show the historical breakdown of New Zealand's transport-related emissions, by the main modes and types of transport.

For aviation and marine emissions there is a further split between within-NZ journeys versus international journeys (from New Zealand to another country).

Road-transport emissions are further split between the four main types and use of vehicle.

- **Light passenger.** Mainly private vehicles used for passenger transport. This is predominantly cars, but also includes motorcycles (although these are estimated to account for less than 1% of light private emissions).
- **Light commercial.** These are predominantly vans used for business-related transport (e.g. transporting people and materials to jobs, or for deliveries of goods).
- **Heavy commercial.** Also known as heavy-goods vehicles. These are trucks used for transporting heavy goods and materials.
- **Buses.** i.e. buses used for public transport.

**Figure 24: Historical bar-chart breakdown of New Zealand's transport-related greenhouse emissions (ktCO<sub>2</sub>-e)**



**Figure 25: Historical line-chart breakdown of New Zealand's transport-related greenhouse emissions (ktCO<sub>2</sub>-e)**

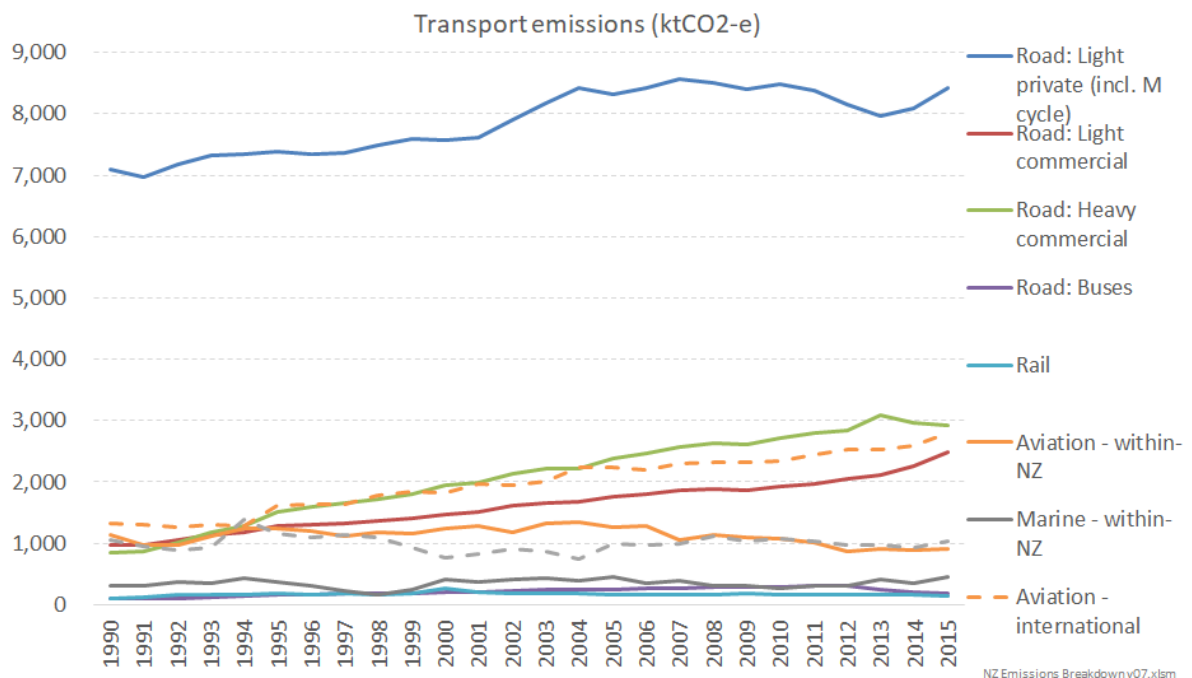
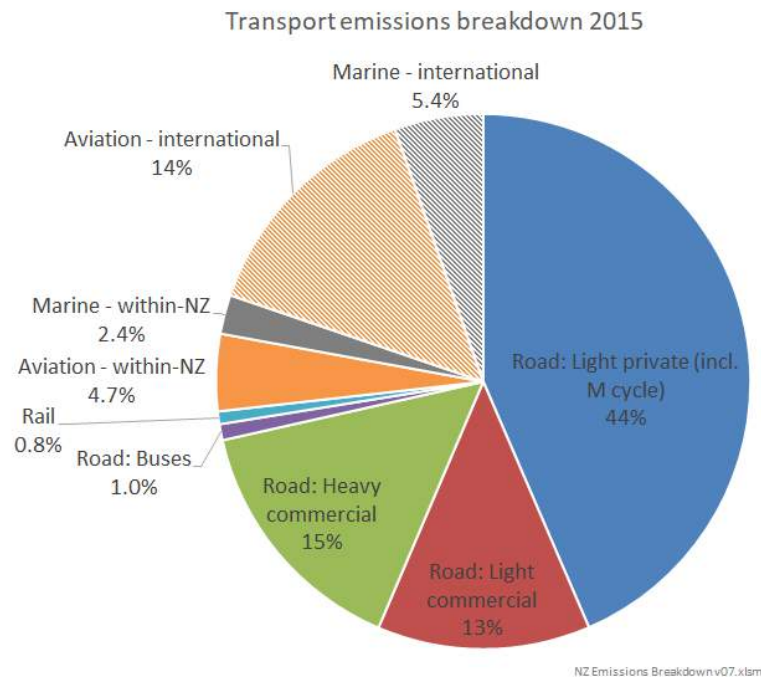


Figure 26: Breakdown of New Zealand transport-related greenhouse emissions for 2015



The key take-aways from the above graphs are that:

- Private vehicles (principally cars) account for  $\approx$  45% of New Zealand's transport-related emissions ( $\approx$  55% if international transport emissions are excluded), and is a sector which has accounted for significant growth: An average annual growth rate of 0.7% over the past 25 years.
- Commercial vehicles – heavy (i.e. trucks) and light (i.e. vans) – are the next largest contributor of emissions, and are also the segments which have experienced the greatest growth over the past 25 years: An average annual growth rate of 5.1% for heavy trucks, and 3.8% for light commercial.
- Aviation emissions account for almost 20% of New Zealand's transport emissions. Within-New Zealand aviation emissions have been largely static (indeed, declining slightly), whereas international aviation emissions have grown significantly over the past 25 years – an average annual growth of 3.0%.

## 5.2 Options for reducing transport-related greenhouse emissions

There are a variety of potential options for delivering lower-carbon transport services:

- **Mode-shifting** from one mode of transport to another. For example,
  - Individuals shifting from driving a private vehicle to using public transport, or cycling or walking. Car-sharing, rather than driving your own vehicle, is also considered mode-shifting for private travel.
  - Freight shifting from road to rail or marine.
- **Fuel-shifting.** This can either involve shifting to a vehicle with an alternative propulsion mechanism (e.g. an electric vehicle, or a hydrogen-fuelled vehicle), or altering the fuel for existing vehicles (e.g. using a bio-fuel blend for existing combustion engines).
- **Improving the efficiency of use of existing vehicles.** For example:
  - Changing driver behaviour: more efficient driving, tyre inflation, engine maintenance, etc

- Improving the throughput of vehicles through measures such as: speed limits, ‘green wave’ traffic light management, congestion minimisation through ‘smart highways’ etc

In the rest of this section we consider the potential scale and cost for the above options to reduce greenhouse emissions for most of the transport types detailed in the breakdowns in Figure 24 to Figure 26 above.

The analysis is service-based, in that it considers the options for delivering transport services for the three main types of transport requirements

- Passenger travel: Enabling people to travel for various purposes (e.g. to go to work or school, undertake ‘chores’ (e.g. shopping, visiting doctor, etc.), make a social visit, or go to a leisure activity)
- Light commercial. Moving people and light equipment / goods, to enable the delivery of goods and services around New Zealand.
- Heavy Freight. Moving heavy goods around New Zealand – i.e. goods of a weight / quantity which would result in a truck weighing more than 3.5 tonnes.

For each of the above services, only the option of mode-shifting between road, rail, and (only in the case of passenger) public transport is considered. The option of shifting to aviation and marine – i.e. coastal shipping – has not been considered in any detail.

- For marine, this is because it is only a realistic option for bulk freight
- For aviation, this is because its characteristics (particularly the speed and distance travelled per trip) are sufficiently different from the other modes of transport that they are generally not substitutable to the same extent.

This section of the study separately looks at the potential scale and cost of greenhouse emissions reductions for the three main modes of transport:

- Land transport (itself split between private, light commercial, and heavy freight)
- Aviation

## 5.3 Land transport

### 5.3.1 Drivers of land transport outcomes

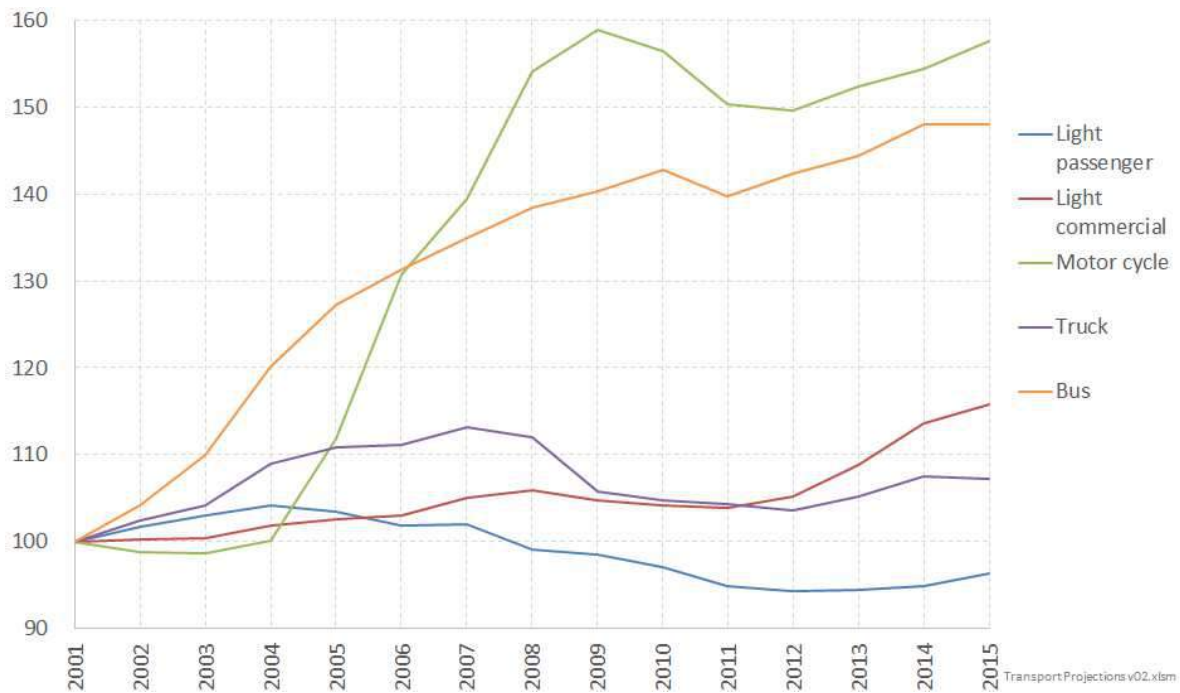
The largest driver (pardon the pun) of the increase in transport emissions is the significant growth in population that has occurred over the past 25 years. Since 1991, the population has grown by 1.2 million, to reach 4.75 million by the end of 2016 – an average annual growth rate of 1.2%.

This has led to a significant increase in the number of people wanting to travel, and a similar increase in light and heavy commercial travel driven by a growth in population-driven economic activity.

Rates of vehicle ownership have also increased significantly – at twice the rate of increase population – with the number of private vehicles owned per head of population rising significantly from 2000 to 2015.

However, as indicated in Figure 27, it appears that for light passenger travel, the distance travelled by light passenger vehicles per head of population has declined slightly – potentially indicating that the per-person demand for transport services has not changed significantly.

**Figure 27: Relative change in vehicular distance travelled per head of population**

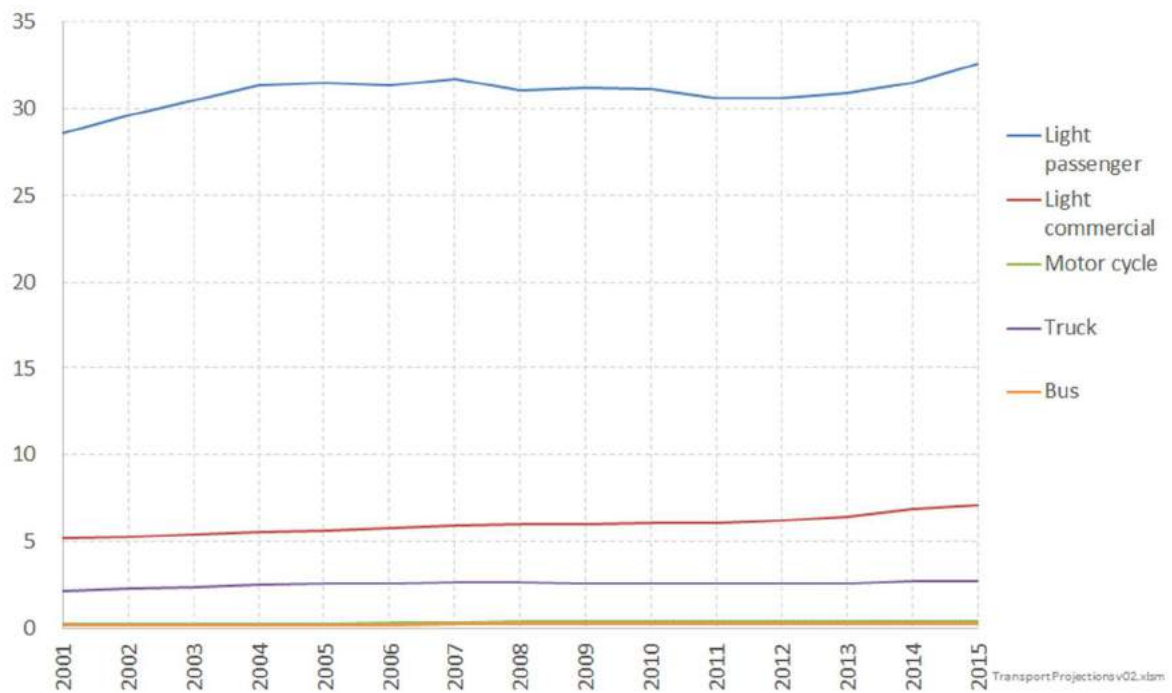


In contrast, growth in distance travelled by light and heavy commercial vehicles per head of population has grown over the past 15 years. This may reflect the fact that GDP has grown at a faster rate than population, over this past 15 years – with light commercial vehicle kilometres travelled ('VKT') growing at roughly the same rate as GDP, and heavy truck VKT growing at half the rate of GDP.<sup>15</sup>

The growth in motorcycle and bus vehicle kilometres travelled per head of population has been very large. However, as indicated by Figure 28 below, these modes of transport still only account for a small fraction (approximately 1.5%) of vehicular distance travelled.

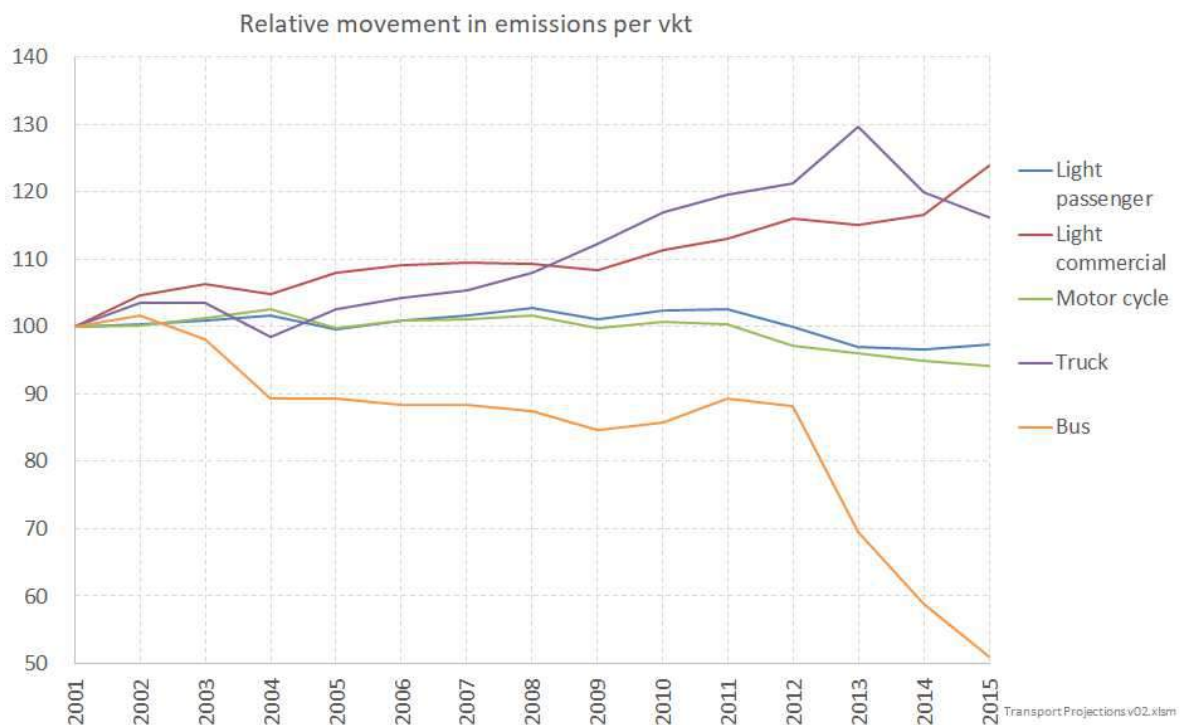
<sup>15</sup> This latter statistic may reflect the fact that there has been a steady shift to larger vehicles that can carry more freight per vehicle.

**Figure 28: Total distance travelled by vehicle class (billions of km)**



Lastly, as indicated in Figure 29 below, it is worth noting that over this period, the quantity of greenhouse emissions per kilometre travelled has not changed significantly for light passenger vehicles.

**Figure 29: Relative change in greenhouse emissions per kilometre travelled by class of vehicle**





This lack of change in the average per kilometre fuel-efficiency (and hence emissions-efficiency) of light passenger vehicle travel is understood to be the combination of two countervailing factors:

- The average fuel efficiency per size of engine has been improving over this period
- The average size of engines has been increasing over this period.

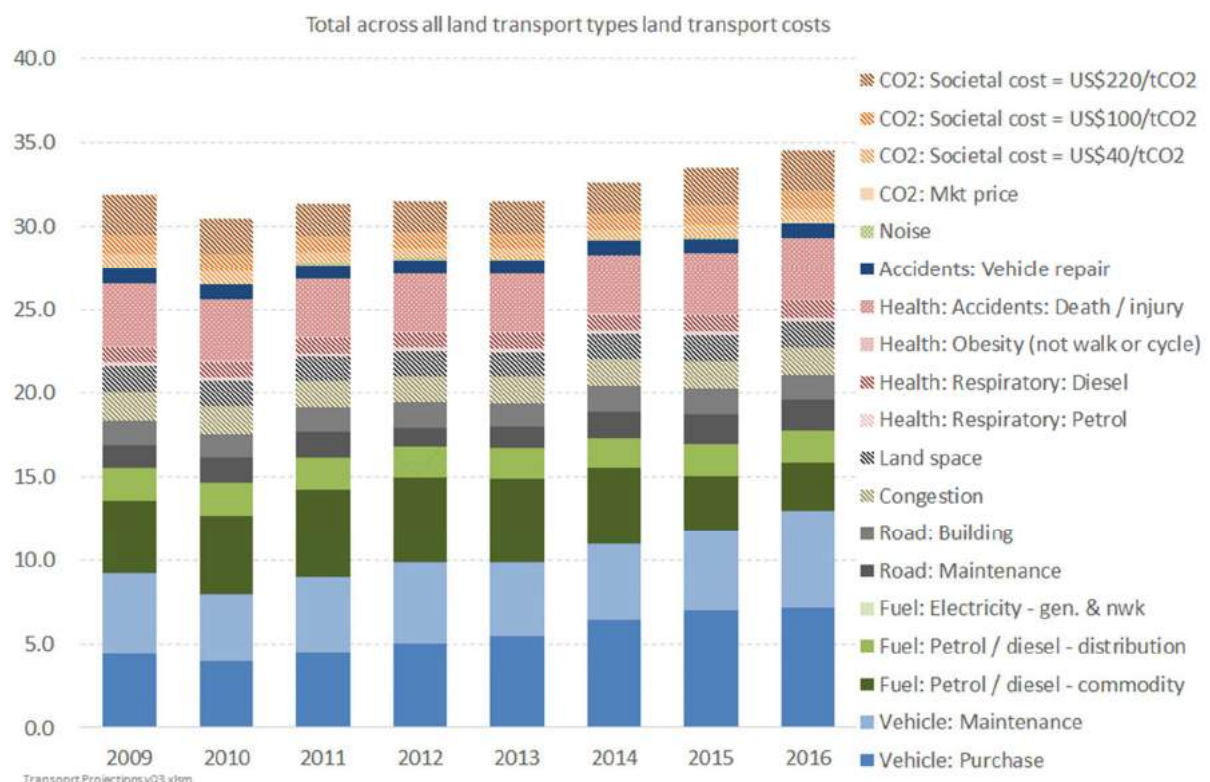
While light passenger per kilometre emissions-efficiency has changed relatively little over this period, it has increased significantly for light and heavy commercial vehicles. For heavy freight vehicles in particular, this is understood to be due to a move to larger vehicles that can carry more freight. Thus, on an ‘emissions per freight tonne-kilometre’ basis, there may have been an improvement in fuel and emissions efficiency. However, data was not available to establish whether this was the case. Light commercial vehicles may also have increased in size over this period, but it is not known the extent to which this may be the case.

### 5.3.2 Land transport costs

Before considering the potential scale and cost of options for reducing transport-related greenhouse emissions, it is important to understand the current costs incurred in providing land transport – particularly road transport, as that is the cause of the vast majority of New Zealand’s transport emissions.

Figure 30 below shows the estimated costs arising from New Zealand’s land transport sector (excluding the costs of providing public transport and cycling).

**Figure 30: Estimated costs of land transport (excluding public transport and cycling), 2016 \$bn**



As can be seen, the costs of land transport don’t just include the ‘direct’ costs such travel: purchasing and maintaining the vehicles, the costs of the fuel to run them, and the costs of building and maintaining the roads to drive them on. One of the most important take-aways from Figure 30 is that a significant proportion of the costs associated with vehicular transport are what economists

term ‘externalities’ – i.e. these are costs which arise because of the use of a good or service, but which do not fall directly on the parties using the good or service.

All costs which have some form of patterned shading in the above chart (most cost categories from Congestion upwards) are costs where the party giving rise to the cost does not face the full cost of their actions. In total, these costs which are not fully priced for the party giving rise to the costs account for approximately [40%] of the overall costs of land transport.

This matters because if users of a good or service pay less than it actually costs, they will demand more of it than would be efficient. In the case of transport, this largely results in:

- People driving cars rather than using alternatives (e.g. public transport, walking, cycling, car sharing) which would deliver a superior overall cost/benefit for New Zealand.
- People or businesses driving vehicles which produce more emissions than alternative modes of transport or alternatively fuelled, or more efficient, vehicles.

Appendix B sets out the detailed derivation of all the above costs, but a brief summary is set out below:

#### ***Costs which are largely borne by road transport users***

- Vehicle costs
  - Initial purchase costs. Total costs derived from Stats NZ historical data on annual vehicle import costs.
  - Ongoing maintenance costs and replacement of parts (e.g. tyres). Estimate based on various reports.
- Fuel costs
  - The commodity costs of petrol and diesel. Estimate based on MBIE stats on petrol and diesel consumption for land transport, factored by world oil prices and NZ\$ exchange rate.
  - The costs of the fuel distribution infrastructure (i.e. petrol stations, and associated infrastructure). Estimate based on reported petrol retailer margin.
  - Electricity generation and network costs arising from charging electric vehicles. (Extremely small to date, but with the potential to grow significantly). Estimates based on Concept analysis.
- Road building and maintenance
  - Reported historical central and local government spend.
  - Note, while all vehicle users pay for such road infrastructure *on average* (through the Petrol Excise Duty and, for diesel-vehicle drivers, Road User Charges), this is an area where there are significant cross-subsidies / externalities. This is because drivers in parts of the country where there is little road-building requirement (e.g. many of the provinces), will be paying for road-building in other parts of the country suffering significant demand-driven congestion (e.g. Auckland). Similarly, drivers who drive predominantly outside of peak times will be paying for road-building to meet peak-time-congestion.
- Vehicle repair costs from accidents.
  - Estimate based on Ministry of Transport study on accident costs. Overall, these costs are borne by drivers through insurance premiums. However, there is inevitably some cross-subsidy between drivers who are relatively dangerous / drive a lot, and those who are safer / drive relatively little.



### **Costs which feature significant externalities**

- Congestion costs – i.e. the lost productivity and value of time for individuals and commercial vehicles stuck in traffic
  - 2005 Ministry of Transport estimate, updated to present day to take account of increased population.
- Land space
  - Estimate of the value of land taken up for providing vehicle parking space
- Human health / welfare costs
  - Respiratory illness from tailpipe emissions. Cost estimate based on two studies for Ministry of Transport (MoT). Split between diesel and petrol emissions based on proportions of PM10 emissions per litre of fuel consumption.
  - Obesity costs from individuals systematically taking motorised transport for trips which could have been undertaken by cycling or walking. Estimate based on New Zealand study on health cost of obesity, and UK study on extent to which such costs would be avoided if people walked or cycled.
  - Death or injury from road accidents. Estimate based on Ministry of Transport study on such costs. Drivers do face some proportion of these costs through the Motor Vehicle Levy collected on behalf of ACC to fund motor-vehicle-accident-related claims. However, the \$450m collected from this levy for 2016/17 is only 12.5% of the estimate of the injury costs in the MoT study.
- Noise.
  - Cost estimate from Ministry of Transport considering reduced quality of life, and costs of mitigation, arising from traffic noise.
- CO<sub>2</sub>
  - Cost estimate based on the reported tonnes of CO<sub>2</sub> emissions from land transport, multiplied by the \$/tCO<sub>2</sub> ‘price’ of carbon.
  - A number of different prices are shown.
    - The market price faced by New Zealand motorists to date under the NZ ETS. These costs are currently borne by consumers – but are relatively small.
    - Three different scenarios for the possible ‘true’ societal cost of greenhouse emissions.

Different low-carbon transport alternatives incur the above costs to different proportions. For electric vehicles incur higher capital costs, but enjoy lower fuel and emissions costs, but make no difference to congestion or accident costs. In contrast, public transport can significantly reduce congestion costs, but may not fuel and CO<sub>2</sub> costs to the same extent.

The remainder of this section considers all the costs and benefits of the different low-carbon transport alternatives to determine their likely CO<sub>2</sub> abatement costs.

### **5.3.3 Low-carbon options for passenger travel**

As set out in Figure 26 on page 33 previously, approximately 45% of New Zealand’s transport emissions (55% if excluding international travel emissions) are from people driving private vehicles – principally cars, but with a small contribution (≈ 1%) from motorbikes.

Further, over the past 25 years, emissions from private vehicles have grown at an average rate of 0.7% per year.

This section of the report progressively explores the following potential options for improving the emissions from passenger travel:

- **Mode-shifting** passengers out of their cars to more greenhouse-friendly alternatives (e.g. public transport, cycling or walking, or car sharing)
- **Fuel-shifting** for the cars that people continue to drive towards more greenhouse-friendly alternatives:
  - alternative-fuelled vehicles (e.g. electric vehicles, hydrogen-fuelled vehicles, biofuels)
  - higher efficiency petroleum-fuelled vehicles
- **Improving the efficiency of use** of private vehicles
  - Changing driver behaviour: more efficient driving, tyre inflation, engine maintenance, etc
  - Improving the throughput of vehicles through measures such as: speed limits, ‘green wave’ traffic light management, congestion minimisation through ‘smart highways’ etc

### **Mode-shifting**

The main options for mode-shifting people out of their cars are

- Public transport (bus or rail)
- Cycling or walking
- Car sharing

We have sought to establish the potential for mode-shifting people from their cars to these alternatives, the emissions benefits of doing so, and the costs and benefits involved in achieving such mode shifting.

### *Scale of mode-shifting potential*

The Household travel survey, undertaken by the Ministry of Transport, provides useful data as to why and how people are travelling – and thus some consideration as to the extent to which non-car alternatives may be feasible.

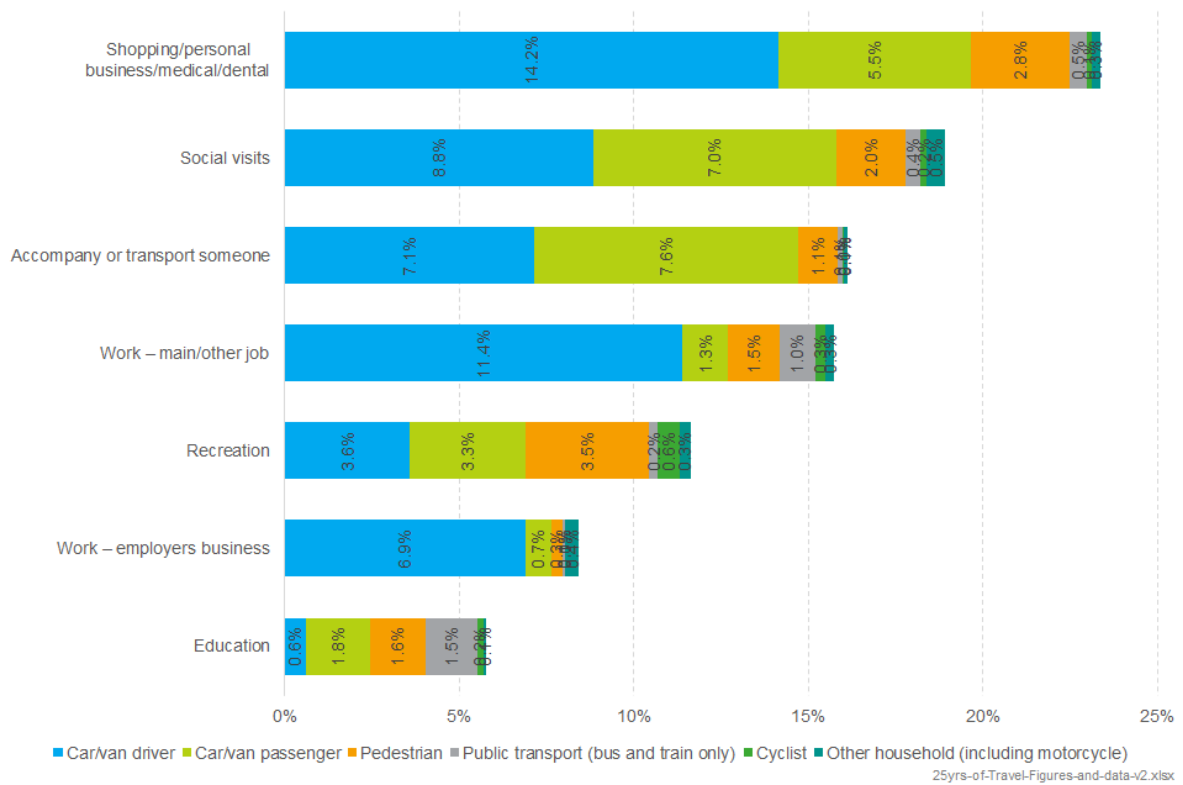
Figure 31 and Figure 32 below reveal that 80% of the time Kiwis spend travelling is in a car – 2/3 of this amount being as the driver, with the other 1/3 being as a passenger.

They also reveal that the proportion of trips made by different modes of transport also vary significantly by trip purpose. Thus, individuals travelling to/from work<sup>16</sup> is the trip purpose which has the highest proportion of journeys made by driving a car. Interestingly, other than students travelling to school / university for education, it is also the trip purpose which also has the highest proportion of journeys made by public transport.

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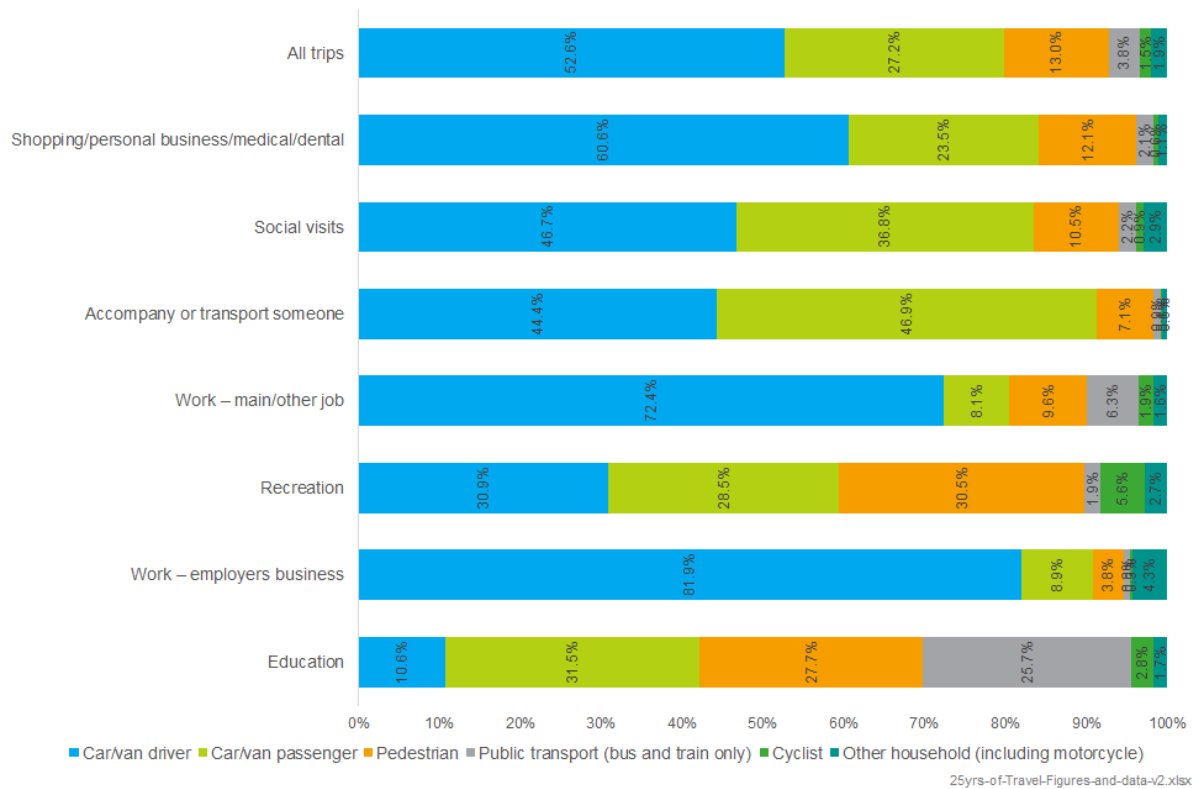
<sup>16</sup> There are two types of work-related trip destination in the survey: “Work – main/other job” refers to individuals usual place of work. “Work – employer’s business” refers to travelling to destinations on work business – typically where individuals work at different sites to perform their work function.

Figure 31: Breakdown of time spent travelling by purpose and mode



Source: "25 years of New Zealand travel: New Zealand household travel 1989–2014", Ministry of Transport, 2015

Figure 32: Proportion of trip purposes by mode of travel



Source: "25 years of New Zealand travel: New Zealand household travel 1989–2014", Ministry of Transport, 2015

There are a number of data points which suggest that there is considerable potential to increase the proportion of trips made by alternative modes of transport.

For example, in terms of public transport, Figure 33 below shows there is considerable regional variation within New Zealand as to the proportion of people using public transport. It is not clear that there is something fundamentally different about Wellington’s geography as to make it much more suitable for public transport than other New Zealand cities. Further, even Wellington’s levels of public transport use are less than many other cities around the world.

**Figure 33: Proportion of individuals using public transport different numbers of days in a typical month in the main urban areas**

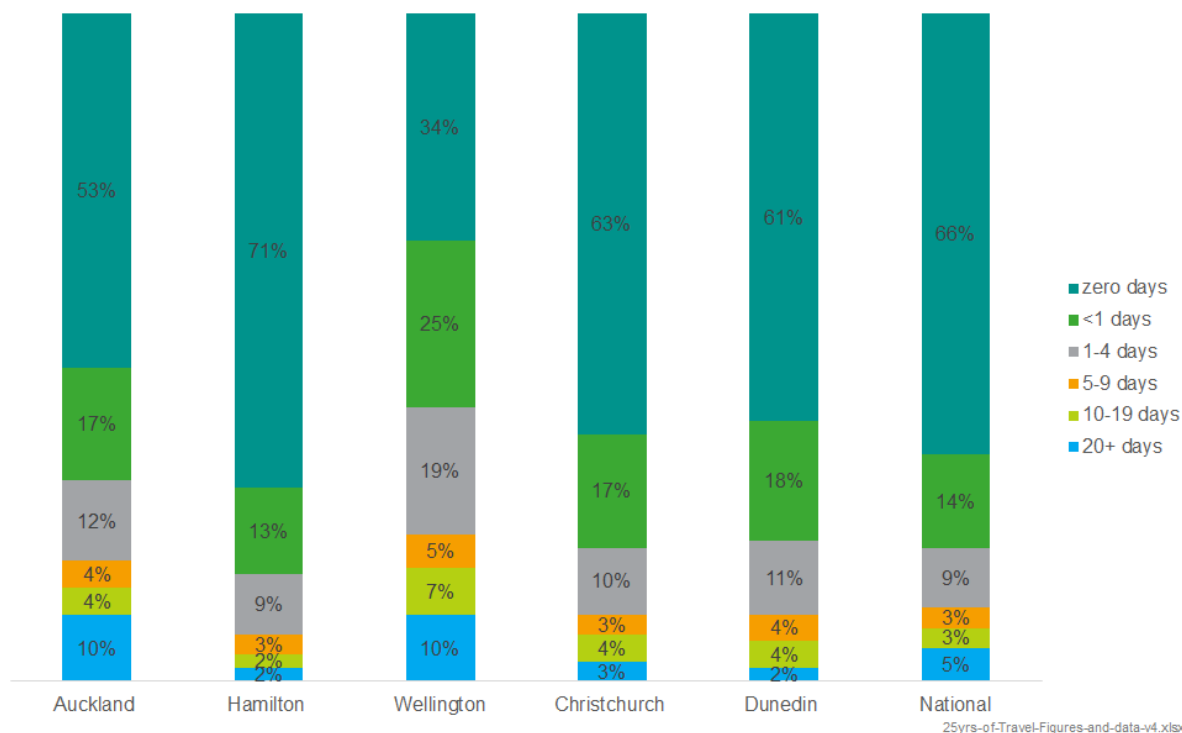
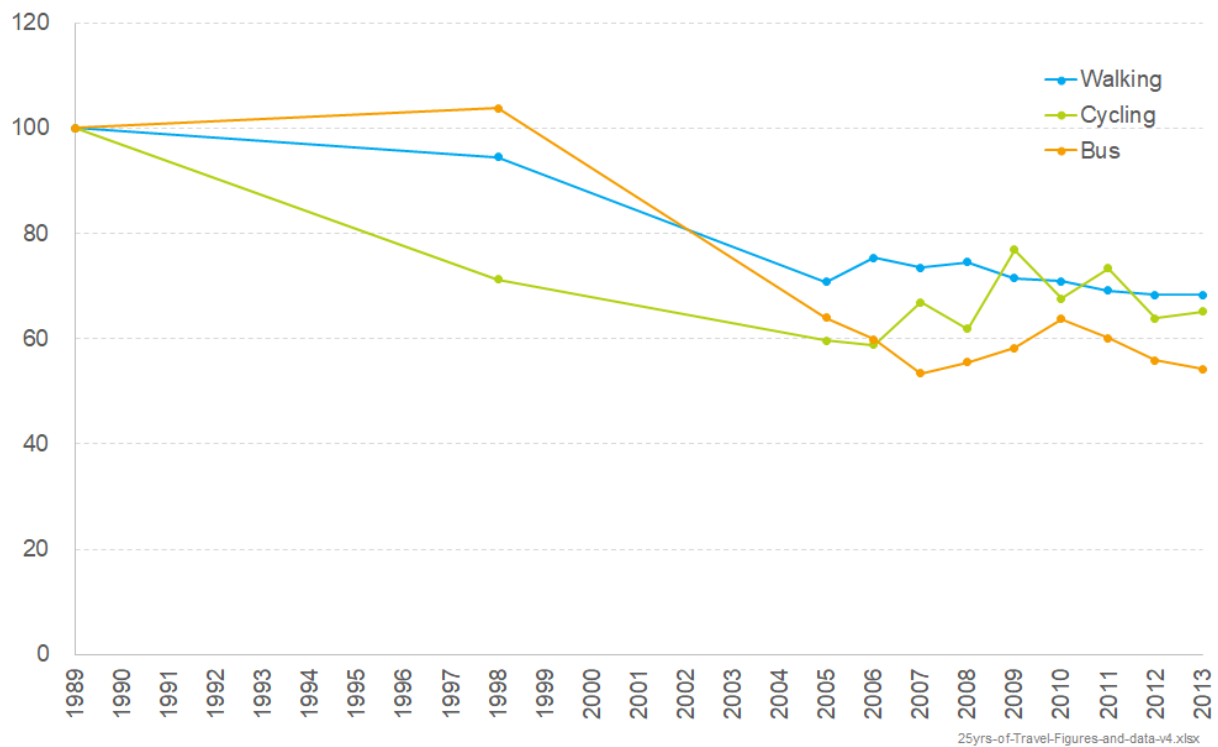


Figure 34 below also shows there has been a significant drop in the proportion of individuals walking, cycling, or taking the bus. Simply getting back to the levels in the late ‘90s would be a considerable increase in usage of these modes of transport relative to current levels.

Figure 34: Change in average daily per person distance travelled by walking, cycling, or bus



Source: Concept analysis of data presented in “Comparing Travel Modes - New Zealand Household Travel Survey 2011-2014”, Ministry of Transport, March 2015

### Costs and benefits of alternative modes of transport

Information on the costs of public transport is not easy to find in a format which enables reasonable cost-benefit analyses.

NZTA data<sup>17</sup> reveals that central and local government<sup>17</sup> funding of public transport for the period 2007 to 2016 averaged about \$500m per year. No split is given between bus and rail transport, although examination of the regional splits, noting that only Wellington and Auckland have rail, would suggest that a significant proportion of this is for funding the rail network.

The Ministry of Transport indicates that “Government aims for half the operating costs of public transport services to be funded through fares, with the remaining costs split between central and local government.”<sup>18</sup>. It is not clear to what extent capital expenditure is included within these ‘operating costs’, although it does go on to say that capital investment in Wellington and Auckland metro rail is funded by separate Crown appropriations. As such, it would appear that capital costs for the bus network are included within this broad category of ‘operating costs’.

The capital investment in the Auckland and Wellington metro rail networks appears to have been of the order of \$2.3 billion over the past eight years<sup>19</sup> - approximately half of the funding that has occurred for public transport.

This remaining public funding was notionally apportioned between bus and rail broadly in proportion to passenger-kilometres travelled (as published by MoT from its household travel

<sup>17</sup> <http://www.nzta.govt.nz/assets/userfiles/transport-data/FundAllActivities.html>

<sup>18</sup> <http://www.transport.govt.nz/land/land-transport-funding/public-transport-funding/>

<sup>19</sup> <http://www.transport.govt.nz/rail/metro-rail/>

survey). Coupled with the assumption that half the cost of the bus network is funded from fares, this gives an estimated annual cost of running New Zealand's public transport bus network of \$300m.

When divided by the reported average annual quantity of passenger kilometre undertaken by bus (1.15 billion km), this gives an average cost per passenger-kilometre of \$0.28/PKT (i.e. passenger-kilometre travelled).

This contrasts with an estimated average *direct* cost (i.e. excluding externalities) per passenger kilometre travelled (PKT) of \$0.27/PKT for light private vehicles. If the cost of purchasing and maintaining the vehicle is not taken into consideration (noting that someone taking public transport may still own and operate a car for other journeys) the cost per passenger kilometre for light private vehicles is \$0.135/PKT.

On this basis, it would appear that bus travel is more expensive than light private travel. However, this ignores the externalities associated with each mode of transport.

Externality costs are estimated to add an additional \$0.16/PKT to light passenger travel, particularly due to congestion, accidents, and CO<sub>2</sub> emissions (which are estimated to cost \$0.02/PKT for a social cost of carbon of US\$100/tCO<sub>2</sub>).

In contrast, externality costs for bus travel are estimated to be \$0.11/PKT – the vast majority of which is due to human health from diesel fumes and CO<sub>2</sub> emissions.

To the extent that battery-powered EV buses could be introduced without substantially increasing the long-term operating costs, these externality costs would be removed.

That said, the cost-benefit for bus transport in terms of avoiding CO<sub>2</sub> emissions would still be challenging:

Assuming EV buses could be introduced that would only increase long-term operating costs by 10 % (to give a PKT cost of \$0.3/PKT), this would be fractionally more than light passenger vehicle costs per PKT (including externalities (with CO<sub>2</sub> valued at US\$100/tCO<sub>2</sub>), but excluding vehicle purchase and maintenance costs) per PKT of \$0.295/PKT.

On the face of it, increased bus travel does not appear to be a significant low-cost opportunity to reduce CO<sub>2</sub> emissions.

In large part, this is because of the relatively low utilisation of buses over the entire course of the day and year. Dividing report bus VKT by reported bus PKT gives an estimated average bus occupancy of 6.5 passengers per VKT. This compares with an average private vehicle occupancy of 1.45 passengers per VKT. Allowing for the differing carrying capacity of buses and cars, the cars have more than double the occupancy (in percentage terms) compared to buses.

That is not to say bus transport is not valuable – particularly in certain conditions. The congestion costs per passenger kilometre for light private vehicles have been spread over all passenger kilometre, whereas the congestion costs are incurred over relatively short spaces of time (and associated PKT). Assuming that 20% of PKT is responsible for congestion costs, this almost doubles the externality costs of light passenger travel during peak periods, and makes this externality cost for peak travel more than six times greater than that of CO<sub>2</sub> emissions (valued at US\$100/tCO<sub>2</sub>).

That said, the corollary of this dynamic is that the relative costs of light passenger vehicles compared to bus transport during non-peak times are even more in favour of light passenger vehicles than bus transport.

Bus transport is also considered valuable from a social mobility and community cohesion perspective – particularly to enable the proportion of the population (predominantly the poorest) without access

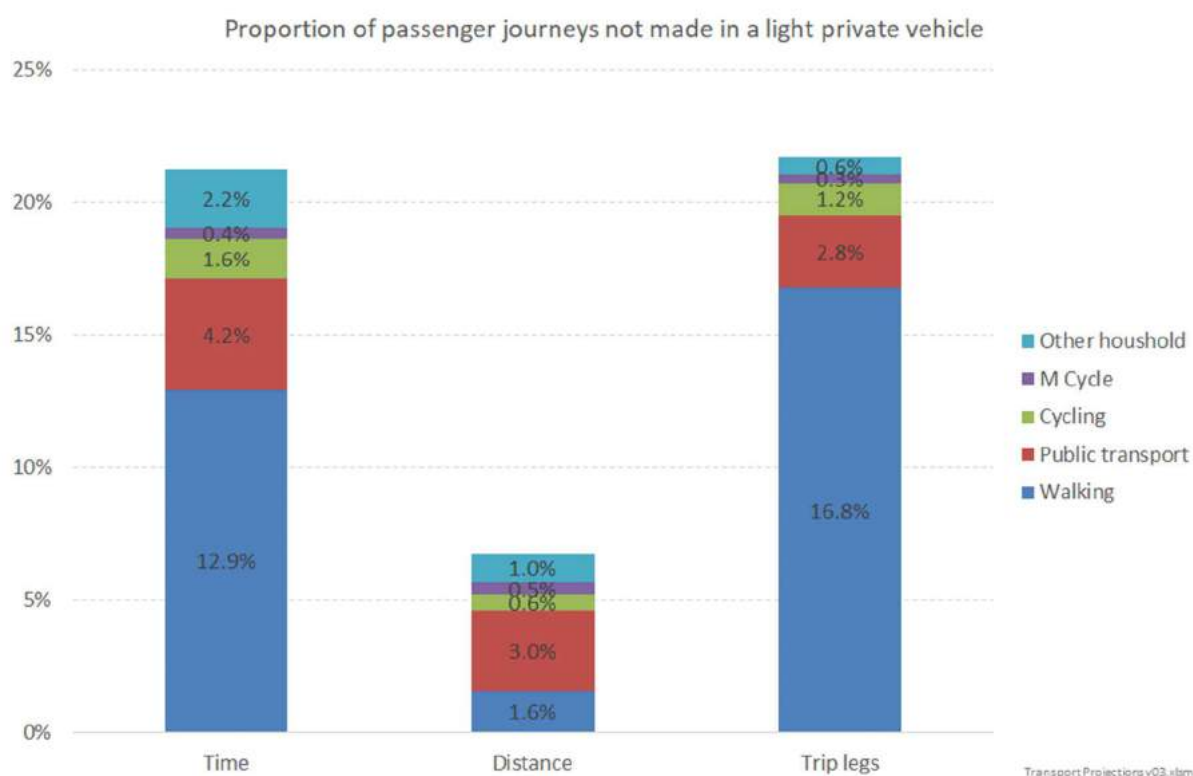
to a private vehicle. These benefits are qualitatively considered to be large, but very hard to try and place a monetary value upon.

The last aspect to consider is that the potential for bus transport to replace a significant proportion of the VKT from light private vehicles is likely to be limited. Based on reported statistics on trips, including distances and durations, it is estimated that if the proportion of journeys made by bus were to increase by 100%, with no change in the proportion of cycling and walking, light passenger VKT would only fall by 2.1%. This surprising statistic is due to two reasons:

- The low starting point of the proportion of passenger journeys made by public transport
- Per hour of passenger travel, light passenger vehicles undertake 60% longer journeys. i.e. Public transport would largely displace shorter light passenger vehicle journeys rather than the longer journeys (which account for a significant proportion of light passenger VKT).

Further, it is not clear whether increasing the proportion of public transport trips to this extent would result in a further deterioration in the average passenger occupancy of buses below the current level of 6.5 passengers per VKT.

The above factors (low current levels, and shorter average trips) will also feature to just as much of an extent for increased cycling and walking, and the impact they have on light passenger VKT. This is illustrated in the following figure:



All in all, it does not appear that mode shifting from road to bus, cycling or walking is going to lead to massive reductions in light passenger VKT – and associated emissions reductions.

That said, much of this mode shifting is likely to be relatively low cost, particularly where there are avoided congestion benefits, improved health benefits, and improved quality of life. In these cases, there are likely to be negative costs per tonne of CO<sub>2</sub> avoided.

Mode shifting to increased car sharing is also likely to be relatively low cost, with the potential per PKT for such modes of transport to be cheaper than public transport. The internet and smartphone revolution is starting to enable increasingly sophisticated ride-sharing options which would also likely have negative costs per tonne of CO<sub>2</sub> avoided.

It is not clear the extent to which people would be prepared to move from private vehicles to sharing vehicles with other people (often strangers), and thus the potential scale of reduced VKT and associated emissions that could be achieved.

In the future, autonomous vehicles and car-transport-as-a-service developments (i.e. where people call up a vehicle as needed) may not, in and of themselves, result in significant reductions in vehicle emissions unless they are also accompanied by increased ride-sharing. That said, they could deliver significant cost savings through reduced car ownership costs, and other costs such as reduced land taken up by private vehicles, and reduced accidents.

### *Fuel shifting*

The next transport emission option to be considered is fuel-switching, or fuel-shifting. The main fuel-shifting options for light passenger vehicles are:

- Electric vehicles
- Biofuels
- Hydrogen-fuelled vehicles

### *Electric vehicles*

The rapid improvement in the cost and performance of batteries is heralding one of the most significant revolutions in automotive transport: the development of electric vehicles (EVs) where the main propulsion mechanism is an electric motor driven by a battery, rather than an internal combustion engine (ICE) fuelled by petrol or diesel.

Electric vehicles offer a number of significant advantages:

- The fuel costs of EVs are significantly lower than ICEs for two key reasons:
  - Firstly, the energy conversion efficiency of an electric motor (converting a kWh of chemical energy stored in the battery into kinetic energy) is inherently much more efficient than a combustion engine (which uses chemical energy stored in the petrol/diesel). Thus, electric motors require approximately three to three-and-a-half times less input energy than a combustion engine to produce an equivalent amount of motive power.
  - Secondly, the cost of producing and delivering petrol / diesel is higher than electricity on an input \$/kWh basis. At a world oil price of US\$50/bbl, and including an estimate of the distribution costs of petrol (i.e. the costs of the service station network) the delivered \$/kWh price of petrol / diesel is estimated to be 35% greater than the delivered \$/kWh cost of electricity to charge an EV (including both the generation and electricity network costs). At a world oil price of US\$70/bbl, the delivered cost of petrol /diesel is estimated to be 60% greater than that of electricity.
- Electric vehicles are lower cost to maintain as an electric motor is far simpler than a combustion engine, and not subject to the same intense temperatures and pressures in its operation. It is estimated that the lifetime maintenance costs of an EV are approximately two-thirds of an ICE.



- EVs cause far less greenhouse emissions than ICEs. Concept's modelling<sup>20</sup> indicates that significant EV uptake in New Zealand<sup>21</sup> will (over the long-term) be predominantly met by new low-carbon electricity generation. On average, this results in EVs resulting in less than 5% of the greenhouse emissions per kilometre driven than ICEs.
- EVs don't produce tailpipe emissions which are harmful to human health. The human health cost can be significant for diesel vehicles in large urban centres, although less so for petrol vehicles.

Offsetting these benefits are some drawbacks of electric vehicles:

- The most significant drawback is the higher up-front capital cost. At the moment, the up-front cost premium for a mid-sized light vehicle appears to be approximately \$10,000-\$12,000 (excluding GST) – the vast majority of which is due to the cost of the battery.
- The second main drawback is that EVs have more limited range than ICEs – of the order of 120 km on a full battery compared to approximately 4-500 km on a full tank. Further, it takes a lot longer to re-charge a battery (6 hours on slow charge, 20 minutes on fast charge for a 'part-fill') than it does to fill up a tank of petrol (2 minutes). While the vast majority of trips made by most drivers in a day are under 100 kilometres, most vehicles do have a small to moderate percentage of long journeys which couldn't be handled by a single EV battery charge. This means that an EV is not a direct substitute for all current vehicles. Even if there was a comprehensive network of fast charging stations, the need to relatively frequently recharge makes travel times slower than they would be in an ICE vehicle.

These drawbacks are currently significant deterrents to most consumers. However, both such drawbacks are steadily reducing in impact:

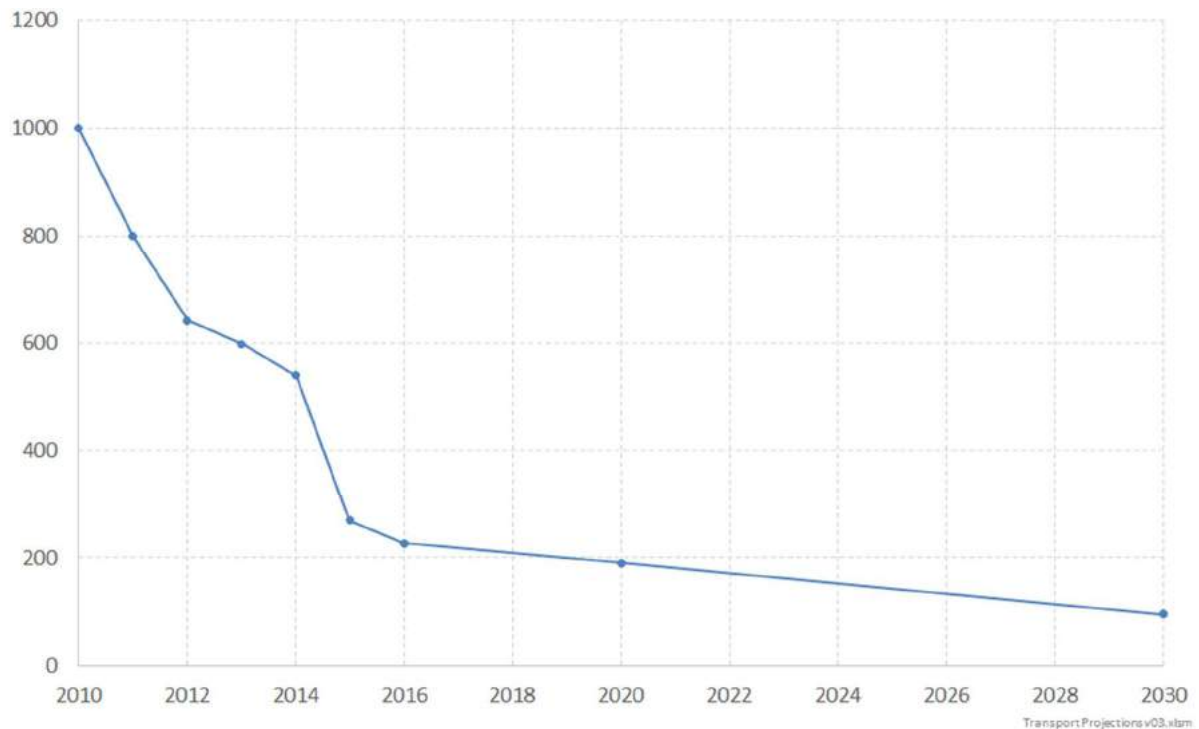
- Battery technology is improving rapidly in cost and performance. As the following graph illustrates, the cost per kWh of storage has fallen rapidly over the past seven years, and is projected to continue to fall significantly.

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<sup>20</sup> A detailed description of such modelling is set out in a recent Concept Consulting report "Electric cars, solar panels and batteries – how will they affect New Zealand's greenhouse gas emissions?", see [http://www.concept.co.nz/uploads/2/5/5/4/25542442/new\\_technologies\\_emissions\\_report\\_final.pdf](http://www.concept.co.nz/uploads/2/5/5/4/25542442/new_technologies_emissions_report_final.pdf)

<sup>21</sup> Other countries which don't have such a significant low-cost wind generation potential will have a much higher proportion of EV-driven electricity demand growth met by gas- and coal-fired generation.

**Figure 35: Average EV battery pack price projection (US\$/kWh)**



Concept reproduction of data presented in: *“Electrifying insights: How automakers can drive electrified vehicle sales and profitability”*, McKinsey & Company, January 2017

- EV charging stations are starting to be progressively rolled out around the country. While there is nowhere near the same coverage yet as petrol stations, there is the potential for a similar extent of coverage to be reached in future. In addition, the range of EVs is steadily increasing. Thus between 2013 and 2017, the range of new Nissan Leafs and Tesla Model S’s grew by between 20-40% - largely due to increasing the size of the battery.

Further, two car households (which are the majority in New Zealand) are highly suited to having an EV to do the majority of their ‘every day’ driving, and an ICE (if not a plug-in hybrid electric) vehicle which they use for the less common longer trips.

Putting the range issue to one side, the economic trade-off for EVs is higher up-front capital cost in return for lower ongoing operating costs. With this kind of dynamic, the cost-effectiveness of EVs depends critically on how much the EV is going to be driven.

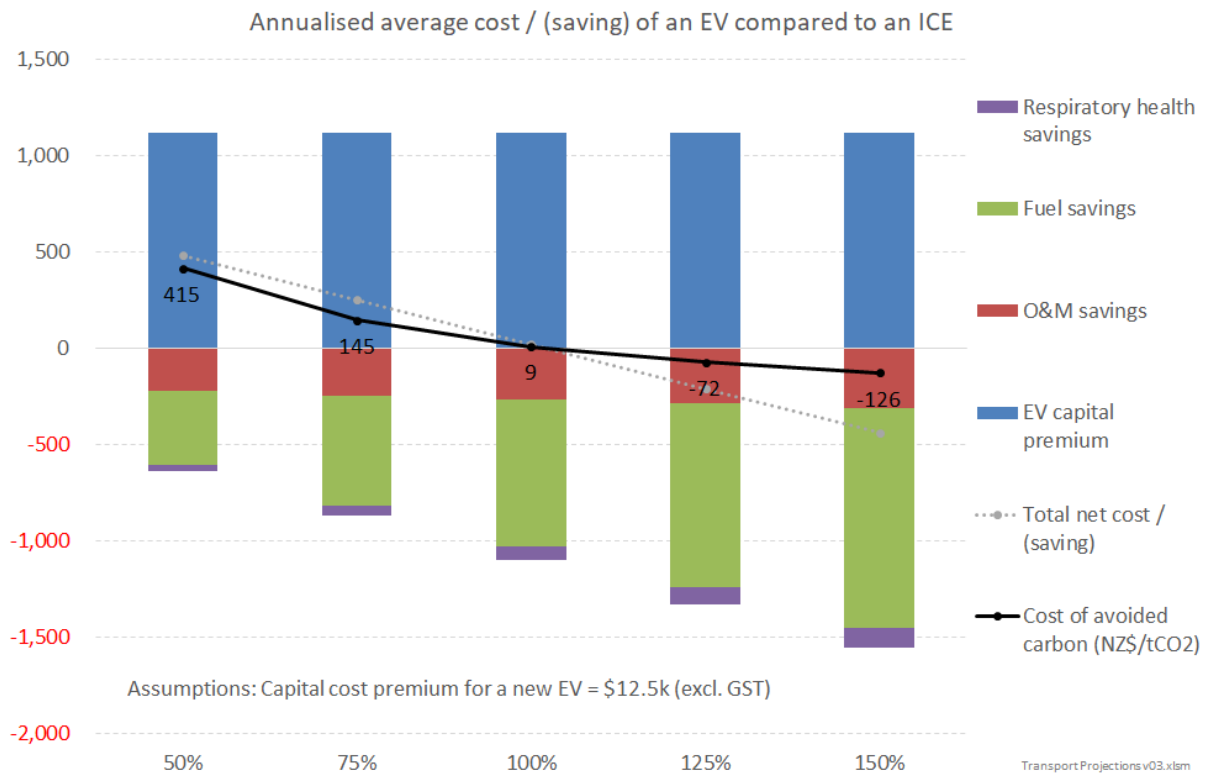
MoT data indicates that the average light vehicle spends about 19 years on New Zealand roads before it is scrapped, travelling 210,000 km (if it is petrol) and 250,000 km (if it is diesel).

However, MoT data also indicates that there is considerable variation between vehicles, particularly over the distance travelled over a vehicle’s life.

The following graph shows an estimate of the difference in annualised costs (from the perspective of NZ Inc) between an EV and an ICE for different lifetime distances travelled (expressed on the x-axis as a % of the average lifetime distance travelled by an NZ vehicle).

The dotted grey line shows the average net annual cost from choosing an EV over an ICE, with the black line translating this into an effective cost per tonne of CO<sub>2</sub> saved by choosing an EV over an ICE (negative numbers indicate savings).<sup>22</sup>

**Figure 36: Annualised average cost (negative numbers indicate savings) of an EV compared to an ICE from an NZ Inc perspective**

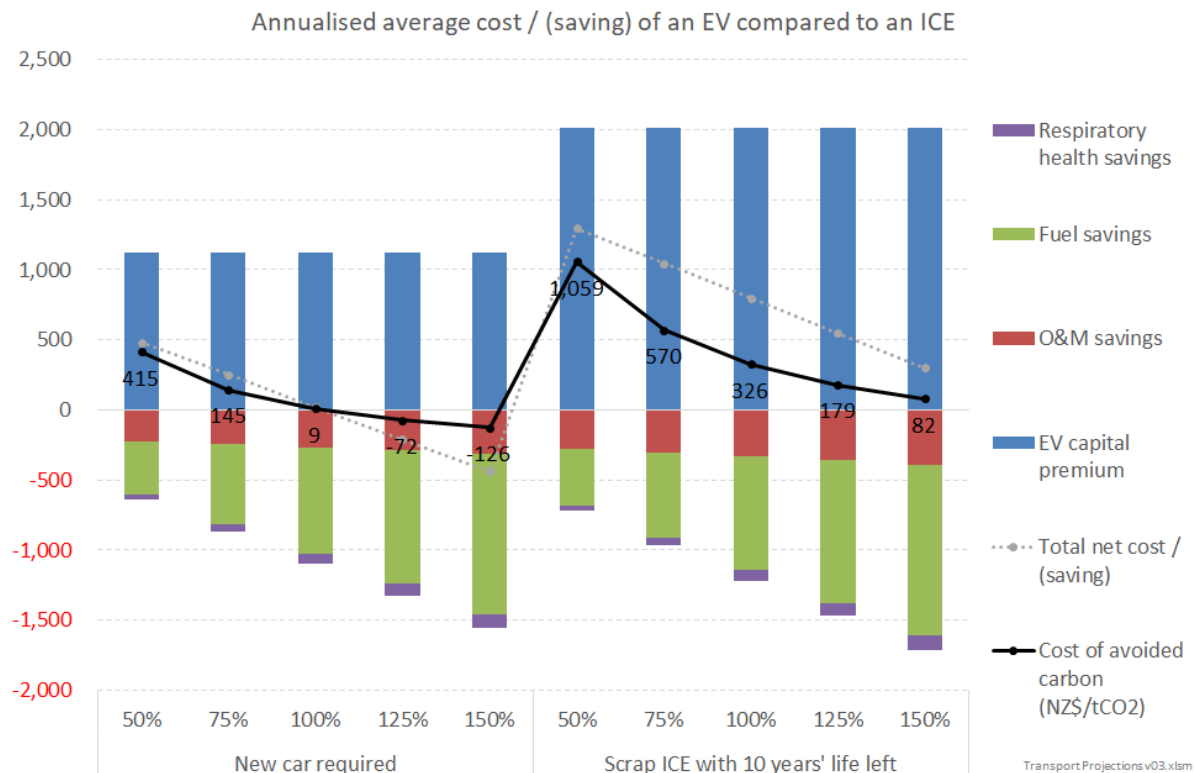


As can be seen, from an NZ Inc (i.e. economic) perspective, it is already cost-effective to purchase EVs for vehicles which are going to be driven a lot, rather than purchase an ICE. Thus, the effective cost per tonne of CO<sub>2</sub> saved by purchasing an EV rather than an ICE for a vehicle which is going to be driven 25% more than average is *minus* 72 \$/tCO<sub>2</sub>.

However, as the following graph illustrates, unless the social cost of CO<sub>2</sub> is relatively high, the savings aren't large enough for these high-use vehicles to justify scrapping an ICE with 10 years remaining useful life left in it – noting that the effective capital premium of an EV is significantly greater in such a scenario.

<sup>22</sup> For example, for a vehicle which is driven 100% of the average VKT over its life (210,000 km), the annualised net cost premium of an EV would be approximately \$21/year, but would save approximately 2.4 tonnes of CO<sub>2</sub> per year. This translates to an average cost per tonne of CO<sub>2</sub> saved of approximately \$9/tCO<sub>2</sub>.

**Figure 37: Annualised average cost of an EV compared to an ICE from an NZ Inc perspective – for two purchase situations (negative numbers indicate savings)**



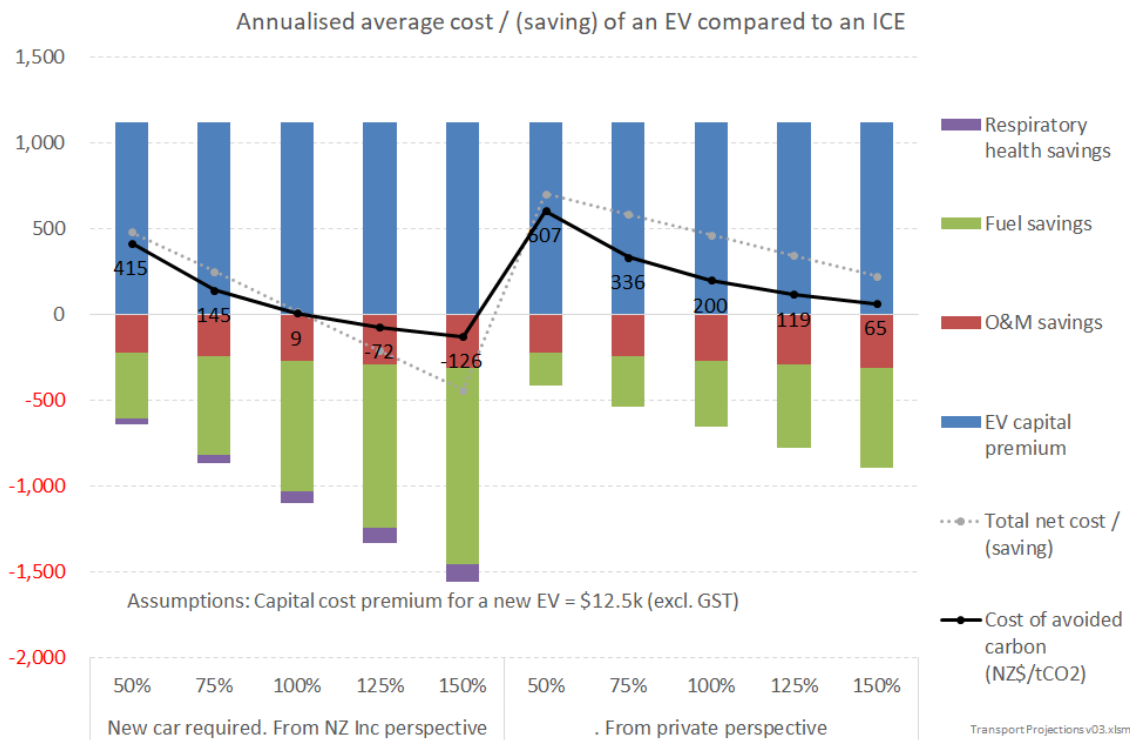
The above analysis is from the perspective of NZ Inc. However, there are a number of pricing externalities facing EVs:

- The price of EVs paid by residential consumers for charging their EVs is typically a lot higher than the 'true' cost of supplying electricity. This is due to the typically 'flat' tariff structure, and the fact that the low-fixed charge regulations require a lot of the fixed costs of network and retail to be recovered from consumers via variable charges.
- EV-owners are not rewarded for the avoided respiratory health costs associated with tailpipe emissions from ICEs.

The following graph shows the above cost/benefit analysis from the perspective of a typical residential consumer, taking account of these pricing externalities.<sup>23</sup>

<sup>23</sup> This analysis takes account of the fact that EV owners currently avoid paying for RUCs, but assumes that this discount will only last for two years.

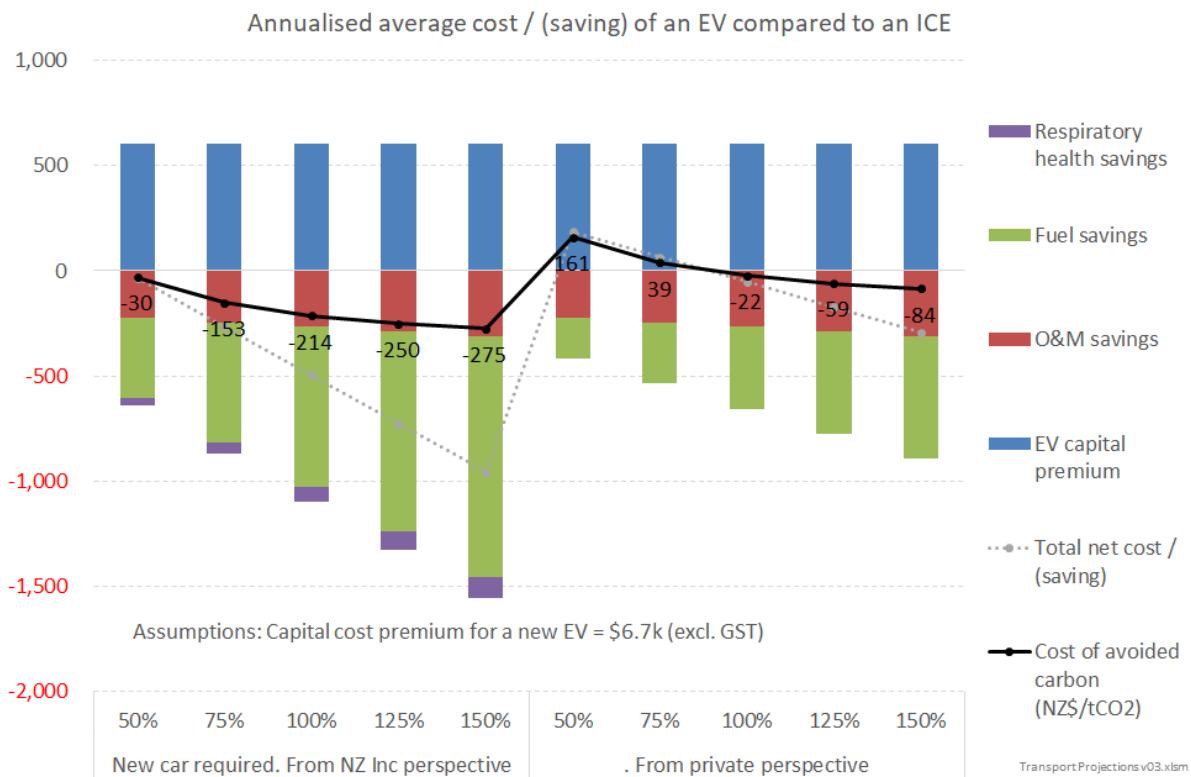
**Figure 38: Annualised average cost / (savings) of an EV compared to an ICE from an NZ Inc and a private consumer's perspective**



Thus, for the situation of a household needing to purchase a new vehicle whose lifetime VKT will be 100% of the NZ average, the annualised cost premium of an EV will be approximately \$465/yr. This would require a CO<sub>2</sub> price of \$200/tCO<sub>2</sub> to be included in petrol prices to overcome – rather than the ‘true’ NZ Inc cost of CO<sub>2</sub> savings for choosing an EV in this situation of \$9/tCO<sub>2</sub>.

Looking forward, significant reductions in battery costs are expected. The following graph shows the effect on the economics of choosing an EV in 10 years’ time if the EV capital cost premium has reduced by 6% per annum in the interim.

**Figure 39 - Annualised average cost / (savings) of an EV compared to an ICE from an NZ Inc and a private consumer's perspective (lower capital cost scenario)**



### Biofuels

Another possible low-carbon transport solution is to produce the liquid fuel used to power ICEs from renewable sources. i.e. to convert biomass produced from forestry or agricultural crops into 'biofuel' diesel or petrol substitutes<sup>24</sup>. This is carbon-neutral in that the CO<sub>2</sub> released from burning the biofuel would be sequestered back out of the atmosphere by re-growing the trees/crops<sup>25</sup>.

A significant potential advantage of advanced biofuels is that they do not require changing existing vehicles as they are 'drop-in' replacements for existing fuels and require no modification. Not only does this save capital cost, but it creates the potential for wholesale transformation of transport emissions if enough biofuels can be produced to displace existing petroleum fuels.

However, there are two significant drawbacks from biofuels which, to date, have limited their effectiveness as cost-effective petroleum substitutes:

- The cost of producing the biofuels is significant
- The scale of current biofuel resource limits the potential extent of petroleum which could be displaced.

<sup>24</sup> These are typically called 'advanced' or 'second generation' biofuels (to distinguish them from existing biofuels made from high oil-content residues). Advanced biofuels are chemically identical to their mineral counterparts (i.e. diesel and petrol).

<sup>25</sup> We are assuming only plantation forestry is used (with 100% replanting), and thus there is a net emissions benefit from this fuel source.

Turning first to cost, Appendix D details some analysis which estimates the cost of producing biofuels from waste woody residues from forestry processes.

The central estimate of this is that bio-diesel could be produced at a cost of about \$35/GJ (this is approximately \$1.15 per litre). However, there is significant uncertainty in this estimate, particularly as the capital costs of the plant are not reliably known<sup>26</sup>. This overall estimate of advanced biofuels costs is consistent with information from IRENA in terms of cost estimates for advanced biofuels.<sup>27</sup>

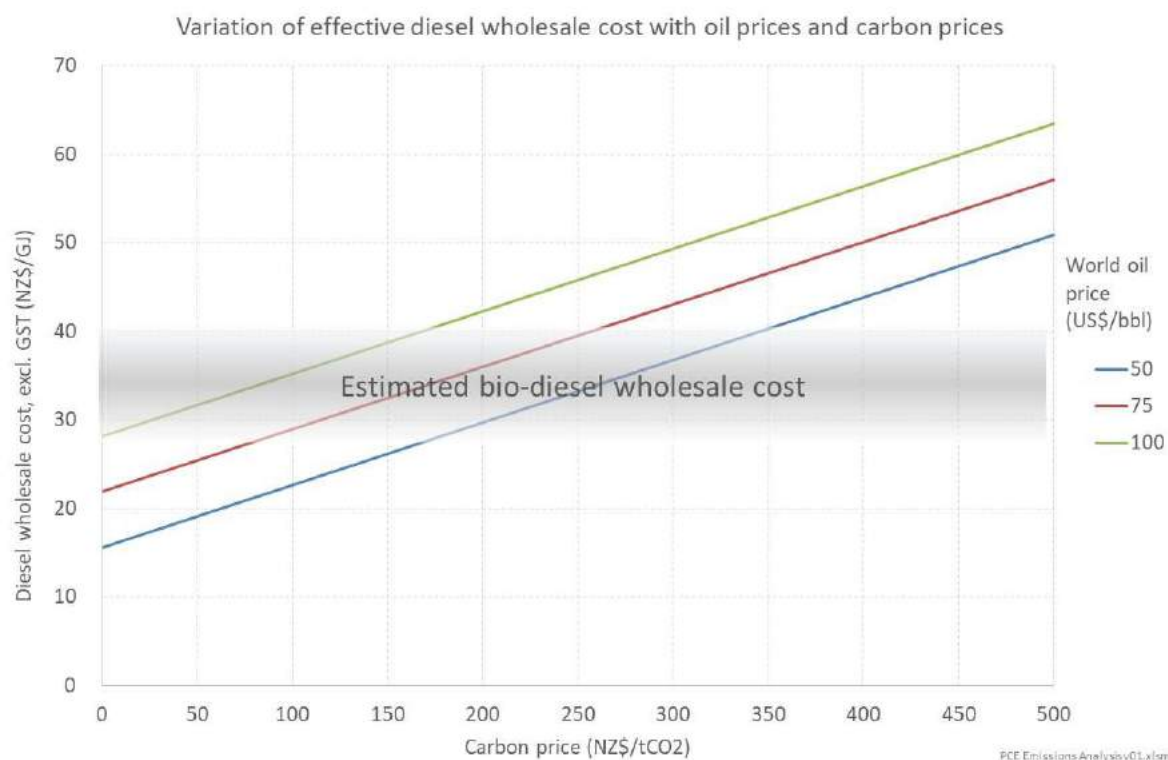
At first sight, this might appear competitive with diesel at higher oil prices (i.e. over US\$100/bbl). However, almost half of the current \$1.15 diesel price includes GST and the costs of distributing and retailing the diesel in the service station network – costs which haven't been included in the \$1.15 per litre estimate of advanced biodiesel.

A true comparison of the relative cost of bio-diesel with petroleum-diesel is to compare the wholesale costs of each product. In the case of petroleum-diesel this would be

- The cost of importing refined diesel to a port (which sets the price of diesel produced from the Marsden refinery). This diesel cost is primarily a function of world oil prices, plus refining and international shipping costs, factored by the NZ\$ exchange rate.
- Any CO<sub>2</sub> cost from a price of CO<sub>2</sub> being levied on fossil fuels in proportion to their carbon content.

Figure 40 below details how the wholesale cost of petroleum diesel varies with world oil prices and CO<sub>2</sub> prices.

**Figure 40: Variation in effective diesel wholesale cost with world oil prices and CO<sub>2</sub> prices**



<sup>26</sup> See Appendix D for further details of this estimation.

<sup>27</sup> [http://www.irena.org/EventDocs/Transforming the Transport Sector/IRENA%20Innovation%20Technology%20Outlook%20for%20Advanced%20Liquid%20Biofuels.pdf](http://www.irena.org/EventDocs/Transforming%20the%20Transport%20Sector/IRENA%20Innovation%20Technology%20Outlook%20for%20Advanced%20Liquid%20Biofuels.pdf)



As can be seen, with current world oil prices of US\$50/bbl, CO<sub>2</sub> prices would need to rise to about NZ\$250/tCO<sub>2</sub> in order for production of bio-diesel to be cost-effective.

If world oil prices were to rise to US\$100/bbl (as they were 4-5 years ago), the break-even CO<sub>2</sub> cost falls to about NZ\$100/tCO<sub>2</sub>.

Even were oil prices to go back to these high levels, it is not clear that producing liquid biofuels would be the best use of this biomass resource.

Section 6 estimates that the break-even CO<sub>2</sub> price for converting large coal-fired boilers used for industrial process heat to biomass boilers is approximately NZ\$70/tCO<sub>2</sub> – i.e. materially less than the break-even CO<sub>2</sub> price for producing bio-diesel (~\$100/tCO<sub>2</sub>) to displace petroleum-diesel in a future of high (>US\$/bbl) world oil prices.

Given that the scale of wood-waste resource is limited (the other main limitation mentioned above), such that biomass could either be used for industrial process heat or liquid bio-fuels, it would appear that the highest value use would be displacing coal from industrial process heat.

In theory, more land could be devoted to the production of advanced biofuels, to satisfy the demand for industrial process heat and transport. Indeed, Scion have identified that New Zealand has sufficient marginal land (where the opportunity cost is very low) to achieve this volume of biomass production<sup>28</sup>. However, this can get expensive as higher transport costs (and the opportunity cost of land use) add up.

Such widespread changes in land use would warrant a study in itself. Consideration would need to be given to factors such as opportunity costs (as mentioned above), potentially positive effects such as reduced erosion, and social issues (fewer people on the land as forestry is less intensive use than sheep farming).

## Hydrogen

The production of hydrogen for use as a transport fuel is expected to be a similar magnitude of cost (in \$/GJ terms) as for advanced biofuels discussed above. While currently uneconomic (requiring carbon prices of about \$100-\$250/tCO<sub>2</sub>), there is technical potential to use hydrogen for 'return to base' type transportation. This type of transport minimises the refuelling infrastructure that would need to be deployed for hydrogen.

New Zealand has the potential to produce significant quantities of renewable hydrogen using electrolysis of water, and our extensive renewable generation resources that are as-yet untapped.

Hydrogen uptake in future will be very dependent on the economics of hydrogen production relative to competing fuels (primarily advanced biofuels and existing fossil fuels with a carbon price).

Existing biofuel blends (derived from tallow and waste oil) are not a direct competitor to hydrogen in the medium term because bio-diesel is a very limited resource and can only meet a small proportion of the current transport energy demand.

Hydrogen has a considerable advantage over battery-electric vehicle technology in some transport market segments because battery-electric vehicles have limited travel range and recharging times can be significant. Hydrogen fuelled vehicles can achieve a much higher asset utilisation than electric vehicles. The downtime of charging battery electric vehicles can represent a material cost for high utilisation vehicles such as taxis (or forklifts) that are used on multiple shifts (i.e. the taxi on the road nearly 24 hours a day, but with different drivers).<sup>29</sup>

<sup>28</sup> <https://www.bioenergy.org.nz/documents/resource/IEA39-Opportunities-for-biofuels-NZ.pdf>

<sup>29</sup> Even with fast charging technologies, battery electric vehicles are unsuitable in many roles.

Further, hydrogen has an advantage over battery-electric vehicles where payload capacity is important (e.g. the majority of the heavy vehicle fleet). The weight of the batteries further reduces the payload capacity of these vehicles, thus adversely affecting the economics of battery electric heavy vehicles.<sup>30</sup>

### 5.3.4 Low carbon options for light commercial transport

#### *Mode shifting*

There are opportunities to cost-effectively shift the mode of travel from private cars to walking, cycling, and car sharing.

However, such modes of transport face significant pricing distortions and barriers which favour private vehicles generally (whether they be internal-combustion or electric vehicles), relative to these other more cost-effective low-carbon transport options. These challenges include:

- Lack of congestion pricing
- Behavioural and social issues (if parents didn't cycle, children are unlikely to cycle)
- Under-pricing of the land-space devoted to motorised vehicles (e.g. land available for parking)
- Urban speed limits which may be too high relative to the cost of accidents and impact on crowding out more cost-effective forms of transport – particularly cycling.
- Human health externalities relating to: the costs of accidents; and, obesity costs from individuals taking motor transport for journeys which are suitable for walking or cycling.

While potentially very cost-effective, mode-shifting is likely to only ever result in a very small volume of abatement. The small amount of abatement is due to the generally shorter distances of journeys suitable for such modes of transport, and because of the EVs entering the fleet thereby reducing the overall emissions anyway. For example, our low-carbon scenario has the number of journeys taken by public transport, walking and cycling growing by 30%, 30% and 100%, respectively over 20 years. However, on their own, these effects only reduce light private emissions by approximately 1%. In contrast, our low-carbon EV uptake scenario reduces light private emissions by 45%.

While mode-shifting to public transport is possible, this may not be cost-effective (see page 47 above, section 5.3.3).

#### *EVs for light commercial vehicles*

The economics of using EVs to displace light commercial ICEs vehicle is very similar to those of the light passenger fleet (see 5.3.3 above). However, the range issue is materially greater for commercial vehicles where there is greater vehicle utilisation, without necessarily having same dynamics of a 'spare' car in two car households (i.e. less redundancy for commercial vehicles).

That said, there are likely to be some segments of the light commercial vehicle fleet where the daily travel is high enough to make EVs attractive, but not so high as to cause range issues (around 150 kilometres per day). Some vehicles would also be able to be recharged during the day (e.g. during a lunch break or similar). However, charge times would need to be staggered for vehicles to avoid the need for excessive costs for charging infrastructure for a particular vehicle fleet.

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<sup>30</sup> Heavy electric vehicles do have a role for short-range transport and for volume-based goods (i.e. where weight is less of an issue). However, our initial analysis indicates that about 75% of heavy vehicle travel may be unsuitable for battery electric vehicles.

A significant opportunity arises within fleets (e.g. courier vehicles) where companies have some control over the daily driving distances. In the short term, companies can use EVs on those central business district (CBD) routes where driving range is less (due to the high delivery density). In the longer term, to the extent that it is economic, fleet-owners can re-draw the delivery boundaries such that slightly more vehicles are required in the fleet overall, but the daily driving distance per vehicle is suitable for EVs.

Further, as battery technology and cost improves, and as charging stations rolled-out around country, likely to be a situation of ‘when’ not ‘if’ EVs become cost-effective for many light commercial purposes.

### 5.3.5 Low-carbon options for heavy freight transport

#### *EVs for trucks (i.e. heavy freight)*

The heavy vehicle fleet has very different characteristics to the light passenger fleet. Therefore, EVs are not economic for much of the heavy fleet (based on the current state of battery technology). Key issues for electrification of the heavy fleet are:

- Limited battery range
- A need for a greater proportion of battery capacity per vehicle (compared to passenger vehicles), thus a greater capital cost premium compared to passenger vehicles
- Long battery-recharging times can be material issue on economics of EV trucks, for high utilisation-factor applications (i.e. where trucks are operated continuously on shifts, having significant down-time to re-fuel can affect the economics)
- The extra weight of batteries can be a material factor: Many trucks are operating at the limit of allowable weight on the road. Increasing the weight of the vehicle (due to batteries) will reduce the amount of freight that can be carried – thereby increasing the effective cost of the vehicle per quantity of freight carried.

As such, presently the break-even CO<sub>2</sub> price for EVs for heavy fleet vehicles is very high.

These economic realities presumably explain why a relatively small number of electric trucks are currently being manufactured (and then only in Europe).

The breakeven point of EV trucks (compared to an ICE equivalent) is stated as being at about 42,000 km/year by one manufacturer<sup>31</sup>. While this is a manufacturer’s claim, it indicates that even in a relatively favourable policy environment, it is challenging to make EV trucks viable. This because the daily driving range needs to perfectly match to the battery capacity (being neither too low or high).

Initial analysis suggests that of the order of 70% of the New Zealand heavy fleet may currently be unsuitable for electrification. There are niches in the heavy fleet where electrification is ideal – rubbish collection trucks are good example. Their low speed ‘stop-start’ type operation in urban areas makes them ideally suited to electrification. However, these uses make up a very small portion of the overall heavy fleet fuel use.

That said, as battery prices reduce and performance improves, and if CO<sub>2</sub> prices faced by truck owners rise significantly, it is likely that more EV trucks may emerge in the next decade or so.

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<sup>31</sup> See ‘[http://eforce.ch/wp/wp-content/uploads/2013/06/E\\_FORCE\\_Fact\\_Sheet\\_E\\_2015.pdf](http://eforce.ch/wp/wp-content/uploads/2013/06/E_FORCE_Fact_Sheet_E_2015.pdf)’, the cost analysis includes the waiving of some taxes and fees that are unlikely to be waived in New Zealand (so our ‘km/yr’ threshold for EV/ICE breakeven point will be even higher).

## 5.4 Aviation

As set out in Figure 26 on page 33 previously, aviation-related emissions account for approximately 20% of New Zealand's transport-related emissions, with international aviation emissions (flights departing NZ for overseas) account for approximately 75% of this total.

There are few economic options for materially reducing the emissions from air travel. In this section, we discuss the following potential options below:

- Mode-shifting of passengers to alternatives
- Improving the efficiency of the airline fleet
- Improving the efficiency of the operation of the fleet
- Fuel-shifting to alternative fuelled aircraft.

### 5.4.1 Mode-shifting

There are not many alternatives to flying which will achieve the same outcomes in terms of time taken to travel the distances involved.

The main realistic alternative is not flying, and instead:

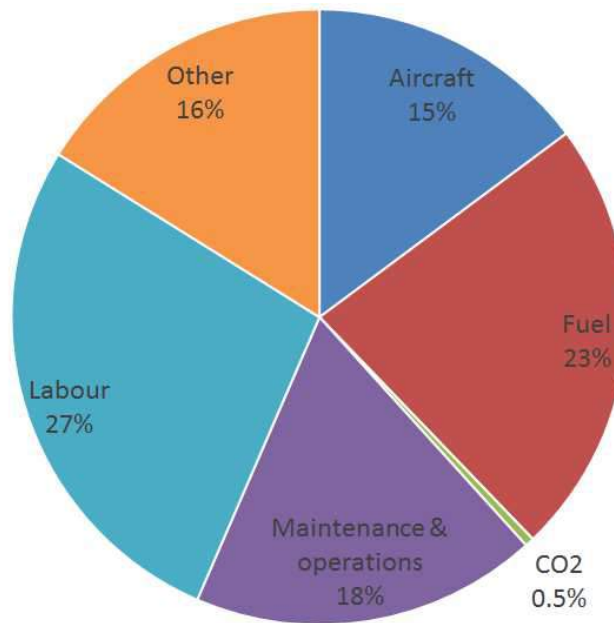
- Using video-conferencing to achieve the face-to-face interaction that would have been achieved from flying to the destination. This is increasingly becoming a realistic option for business travel, and is also an option for social interaction with friends and family.
- Holidaying at a domestic destination, rather than overseas.

To achieve these outcomes would likely require the cost of greenhouse emissions being better reflected in the price of a flight.

To estimate the potential impact of different CO<sub>2</sub> prices on aviation-related emissions outcomes, we did some analysis which broke-down the average cost of flying into its component parts, and simulating the effect of higher CO<sub>2</sub> prices on travel using assumptions regarding the price elasticity of air travel.

Figure 41 presents our high-level estimate of the cost-breakdown of air travel. This was achieved through analysis of Air New Zealand's accounts, coupled with subsidiary analysis about the emissions intensity of aviation fuel and the CO<sub>2</sub> price faced by Air New Zealand over the period 2014 to 2016 – which was estimated to be approximately NZ\$5/tCO<sub>2</sub> during this period.

**Figure 41: Estimated breakdown of air travel costs**



Air Travel Analysis v01.xlsm

Figure 42 below shows our estimate of the average increase in the price of air travel for different CO<sub>2</sub> prices faced by airlines.

**Figure 42: Estimated increase in the price of air travel for different CO<sub>2</sub> prices**



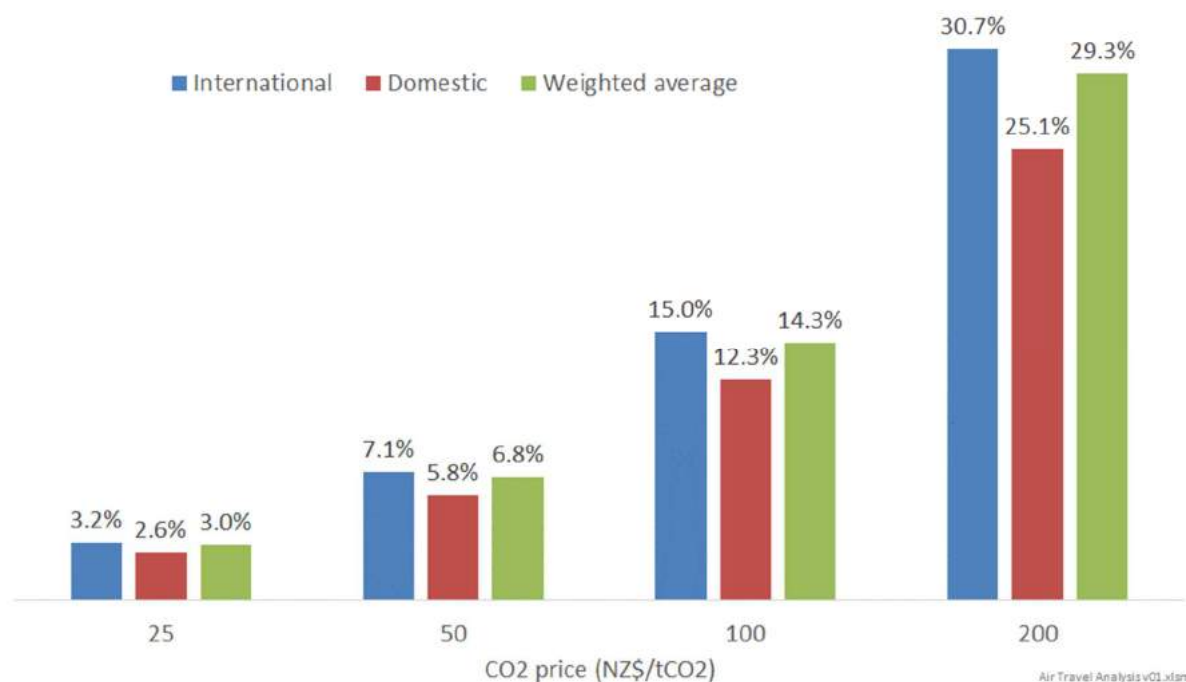
Air Travel Analysis v01.xlsm

At a price of \$200/tCO<sub>2</sub>, the CO<sub>2</sub> cost is likely to be roughly the same as the cost of the fuel (assuming long-term world oil prices of approximately US\$70/bbl).

Lastly, Figure 43 presents our estimate of the long-term reduction in aviation travel (and associated emissions) arising from different CO<sub>2</sub> prices. In developing this estimate we used the price elasticities that were reported to be used by Air New Zealand for internal modelling purposes, as

reported by Network Economics Consulting Group.<sup>32</sup> These were -0.7 for business travellers and -1.65 for non-business travellers. We also estimated the proportion of business travellers to be 10% for international travel, and 40% for within-NZ travel, based on information provided by Statistics NZ and MBIE, respectively.

**Figure 43: Estimated reduction in aviation travel (and associated emissions) arising from different CO2 prices**



### 5.4.2 Fuel-shifting to alternative fuelled aircraft

Biofuels are being explored internationally as one option for lowering the emissions costs of air travel, and a number of test flights worldwide have demonstrated that specific blends of biofuels and conventional jet fuel can safely power aircraft.

However, this is considered to be an unlikely avenue for the cost-effective reduction in aviation-related greenhouse emissions. As set out in Appendix D, and the discussion on biofuels for land transport on page 52, this is principally because of the very high cost of biofuels.

Electric-powered aircraft are similarly considered to currently be very expensive options (and at an early stage of development) for reasons similar to that for electric vehicles for heavy freight trucks. However, in the long term (i.e. decades away) it is plausible that battery-powered propeller-driven aircraft may become commercially viable – particularly for domestic regional routes.

### 5.4.3 Improving the efficiency of the aviation fleet

#### *Improving the efficiency of the airline fleet*

The International Air Transport Association has set targets of

- an annual fuel efficiency improvement of 1.5% between 2010 and 2020

<sup>32</sup> “NECG analysis of competitive detriments and public benefits of the proposed Alliance between Qantas and Air New Zealand”

- carbon-neutral growth from 2020.
- A reduction of 50% in net emissions by 2050 compared to 2005 levels.

A significant part of this improvement will be through replacement of aging aircraft with modern aircraft with improved fuel efficiency.

No analysis has been done for this report as to the extent to which this 1.5% average annual improvement is reasonable, or whether there is significantly greater unrealised potential.

This is an area where New Zealand is unlikely to make significant difference in emissions from acting alone. The size of our aviation market is tiny compared to the totality of international air travel.

Thus, only if there was a concerted international effort to reflect the cost of CO<sub>2</sub> on air travel would it be likely that aircraft manufacturers would respond by producing materially more efficient aircraft. Estimation of the potential for such an initiative is outside the scope of this study.

#### *Improving the efficiency of the operation of the fleet*

In its September 2016 report, *“Managing New Zealand’s International and Domestic Aviation Emissions”*, the New Zealand Government identified that measures such as improved airspace management systems, and on-ground measures (e.g. single-engine taxiing) could make some fuel savings.

While useful, these are unlikely to result in significant changes in the amount of fuel consumption (i.e. changes are likely to be of the order of 1% or less). Accordingly, this is not an area which has been studied for this report.

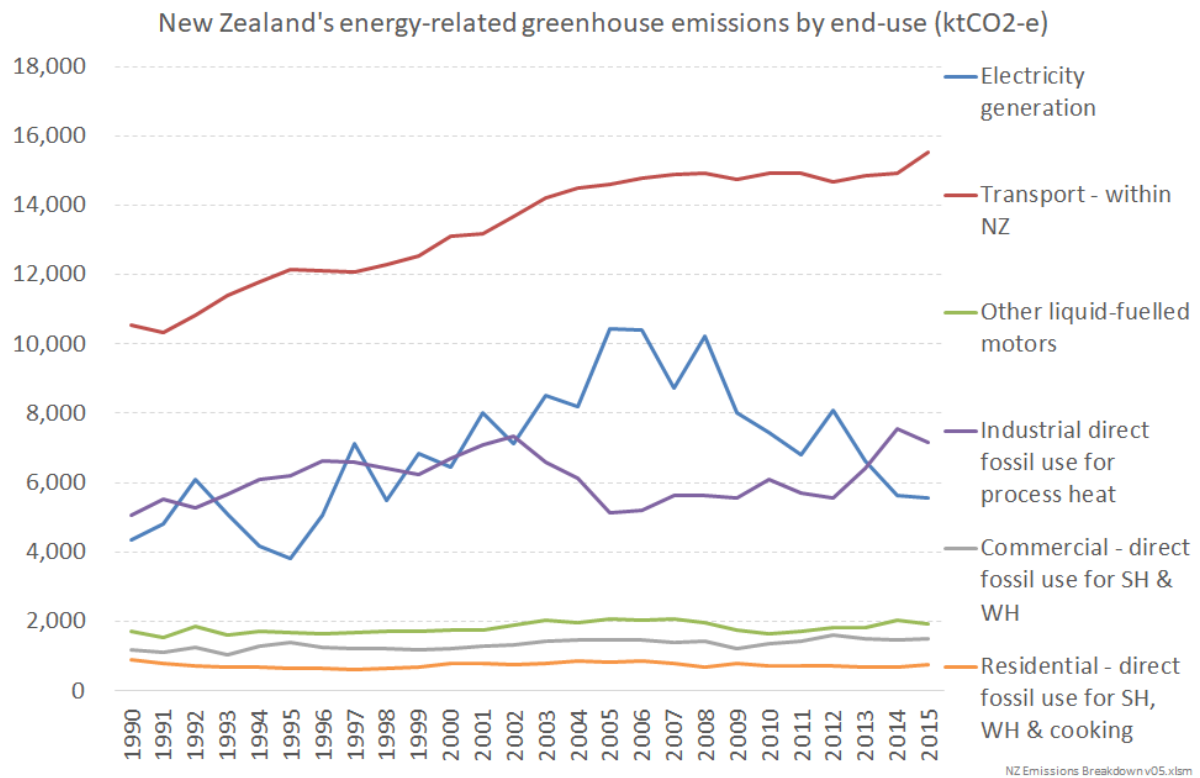


## 6 Industrial process heat

### 6.1 Industrial process heat background

Figure 44 below (previously shown as Figure 7) shows that emissions from industrial process heat are the second largest source of New Zealand's energy-related greenhouse emissions, having recently overtaken electricity generation.

**Figure 44: Historical change in New Zealand's energy-related greenhouse emissions by end use (ktCO<sub>2</sub>-e)**

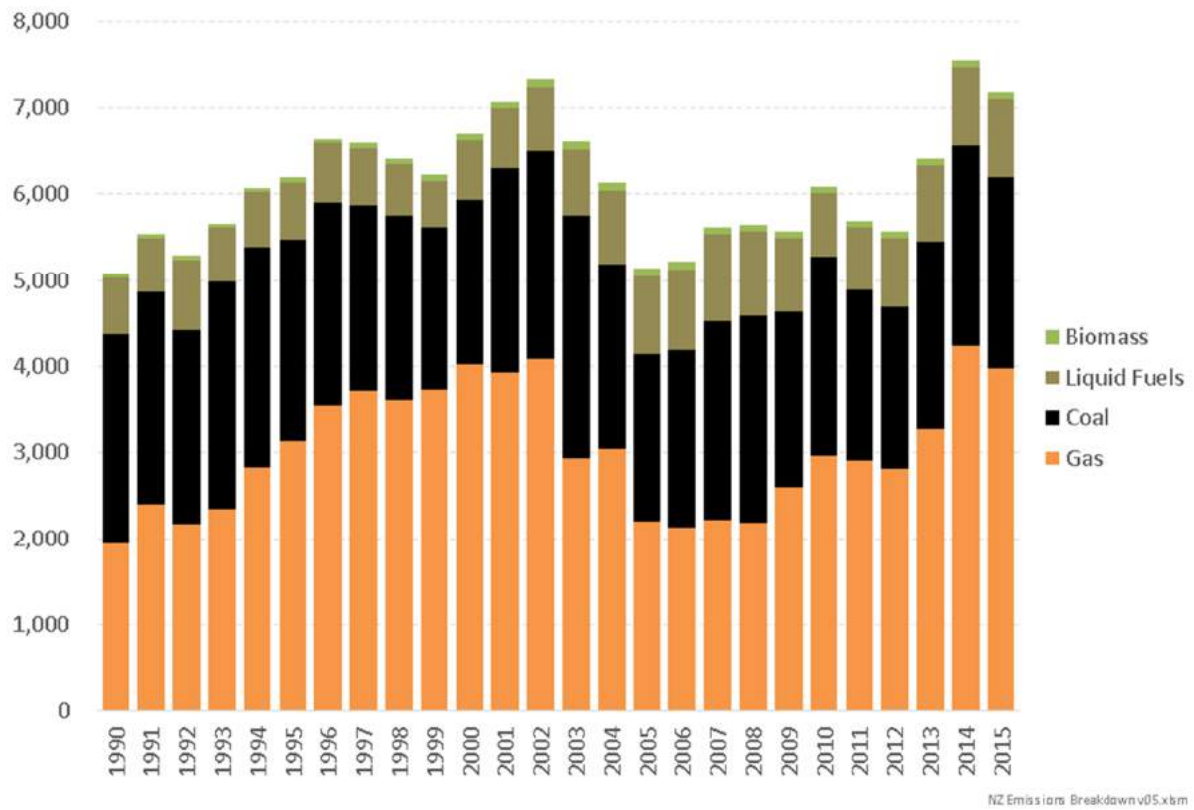


Source: Concept analysis using MBIE and EECA data

Figure 45 and Figure 46 below show that

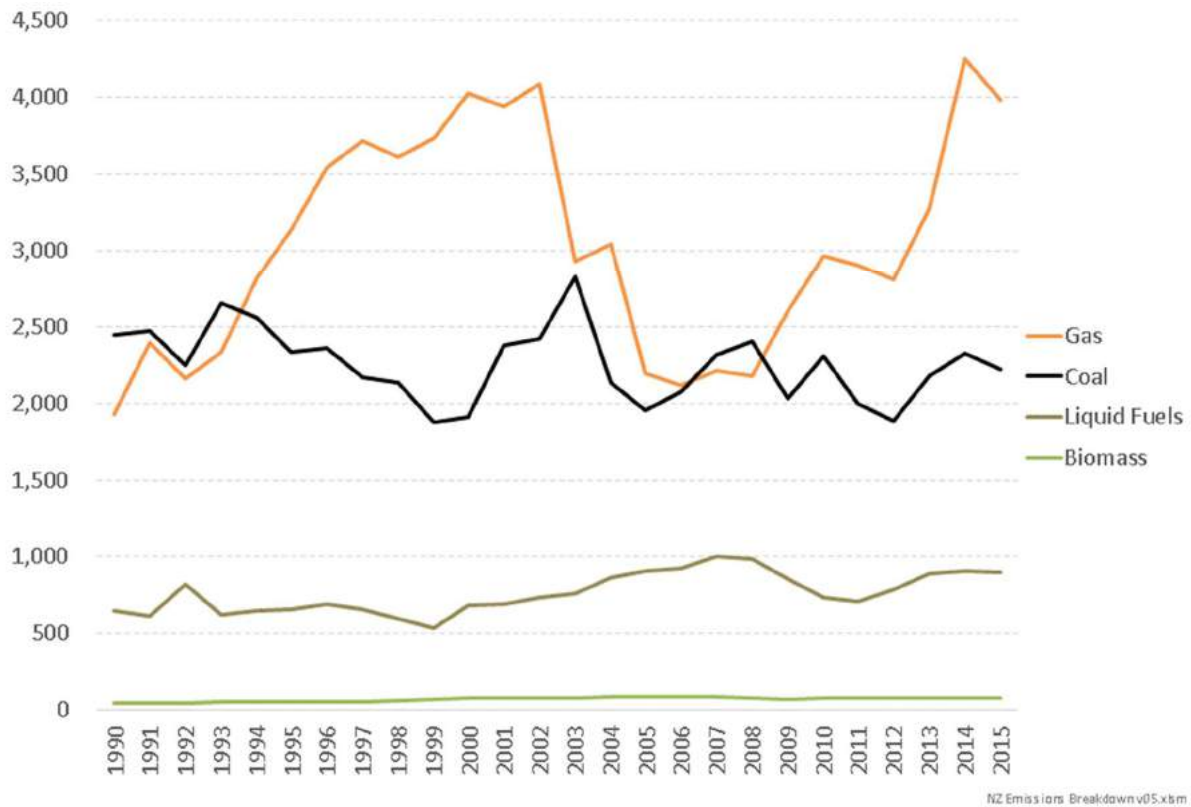
- Emissions from gas-fired industrial process heat account for over half of New Zealand's industrial process heat emissions
- Gas-fired process heat emissions have been very volatile over the past 25 years, with emissions doubling in the past decade
- Emissions from coal-fired and oil-fired (liquid fuels) process heat have been relatively stable over the past 25 years.

Figure 45: Bar-chart of historical industrial process heat greenhouse emissions (ktCO<sub>2</sub>-e)



Source: Concept analysis using MBIE and EECA data

Figure 46: Line-chart of historical industrial process heat greenhouse emissions (ktCO<sub>2</sub>-e)

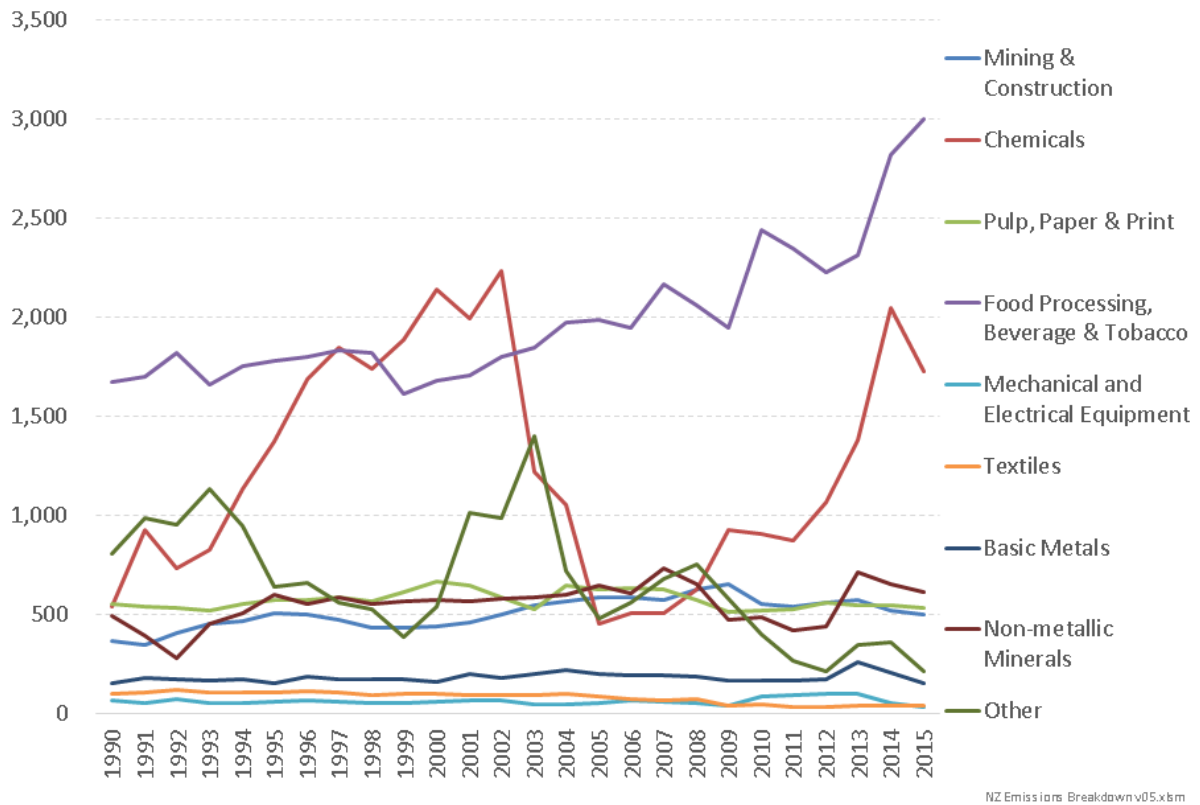


Source: Concept analysis using MBIE and EECA data

Figure 47 and Figure 48 below give insights into which industrial sectors are causing the industrial process heat greenhouse emissions. They reveal that:

- The two largest sectors by far are food processing and chemicals production, responsible for 44% and 25% of total process heat emissions, respectively.
- Both sectors have grown significantly over the past 25 years: the food processing sector steadily, but the chemicals sector exhibiting significant variation over this period
- The chemicals sector emissions are entirely gas-related, but the food processing sector emissions are dominated by coal-related emissions
- Process-heat greenhouse emissions from other sectors have remained relative steady over the past 25 years.

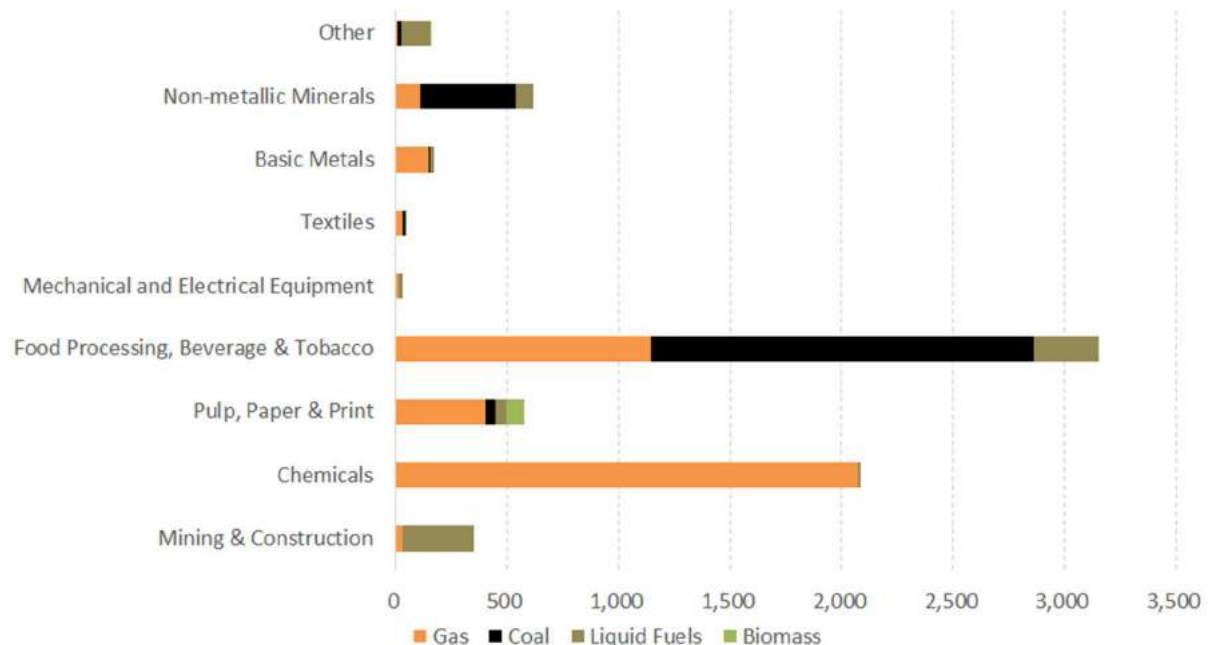
**Figure 47: Industrial process heat greenhouse emissions by sector (ktCO<sub>2</sub>-e)**



NZ Emissions Breakdown v05.xlsm

Source: Concept analysis using MBIE and EECA data

**Figure 48: 2015 direct emissions by industrial sector (ktCO<sub>2</sub>-e)**

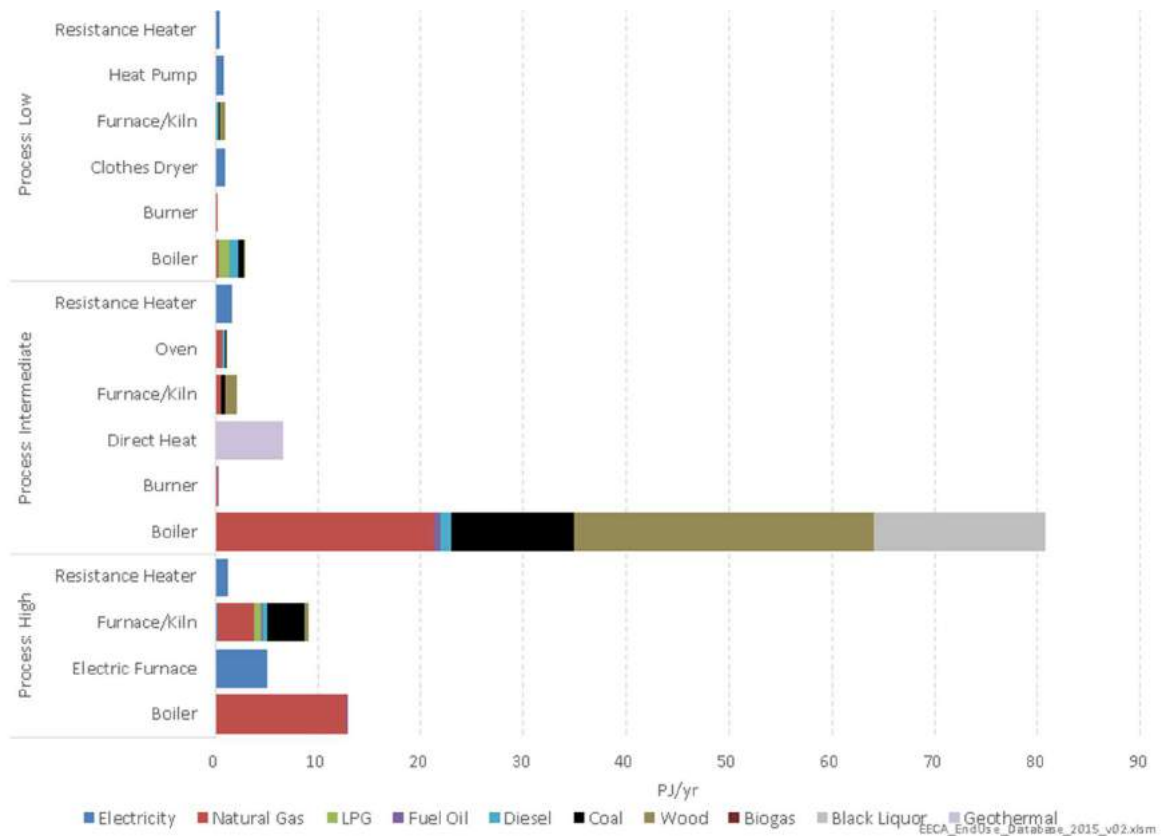


NZ Emissions Breakdown v07.xlsm

Source: Concept analysis using MBIE and EECA data

Figure 49 gives further insights as to the type of industrial processes giving rise to these process heat emissions. It reveals that by far the biggest source of process heat emissions is raising intermediate temperature heat (100° to 300°C) in boilers. The next largest is raising high temperature heat (>300°C) in boilers or furnaces.

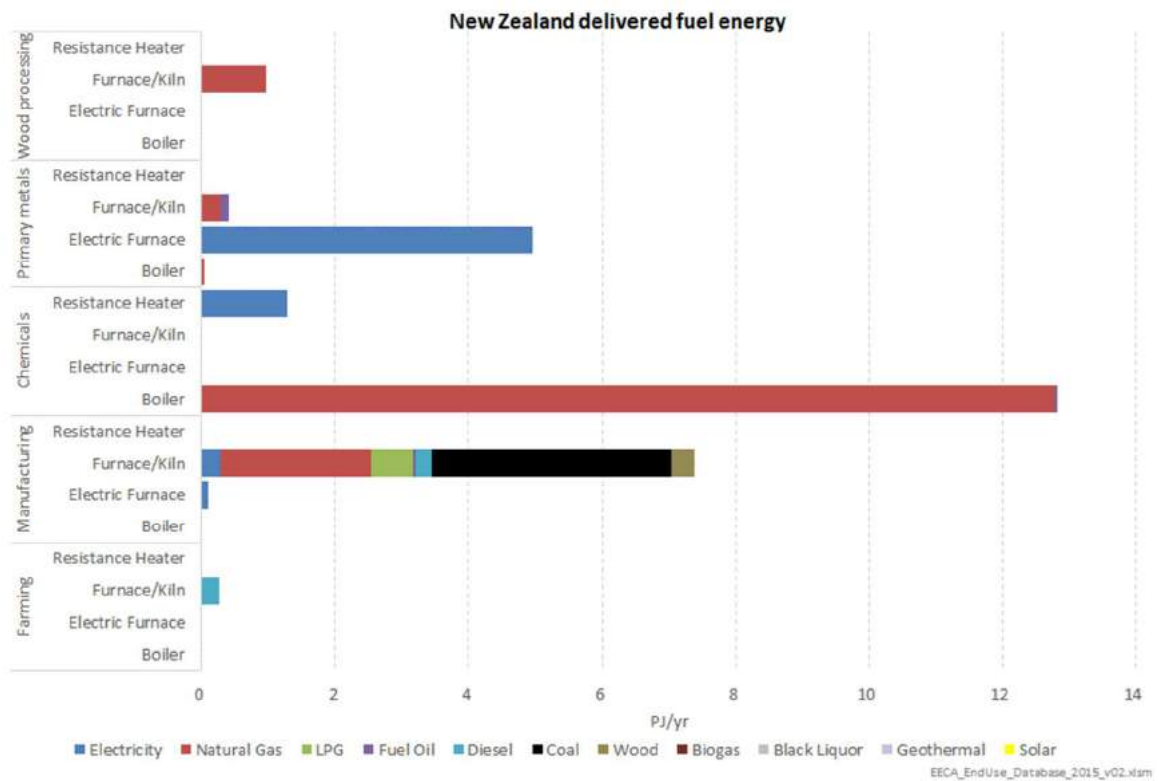
**Figure 49: Estimated breakdown of delivered fuel consumption for process heat**



Source: Concept analysis of EECA Energy End-use database data

Turning first to high-temperature process heat, Figure 50 below indicates that high-temperature process heat fossil fuel consumption is dominated by gas-fired boilers for the chemicals sector, and coal and gas-fired furnaces in the manufacturing sector.

**Figure 50: Estimated breakdown of high-temperature process heat delivered fuel consumption by sector and technology**



Source: Concept analysis of EECA Energy End-use database data

The vast majority of the chemicals sector emissions are from the use of gas to raise process heat in the manufacture of methanol – which also uses significant quantities of gas as a feedstock for the creation of methanol. Methanol manufacture is a specialised process, and converting to an alternative fuel source such as biomass would require considerable capital expenditure and increased operating costs – plus would incur significantly higher fuel input costs. As such, it is not considered a feasible option for cost-effective transition to lower greenhouse alternatives.

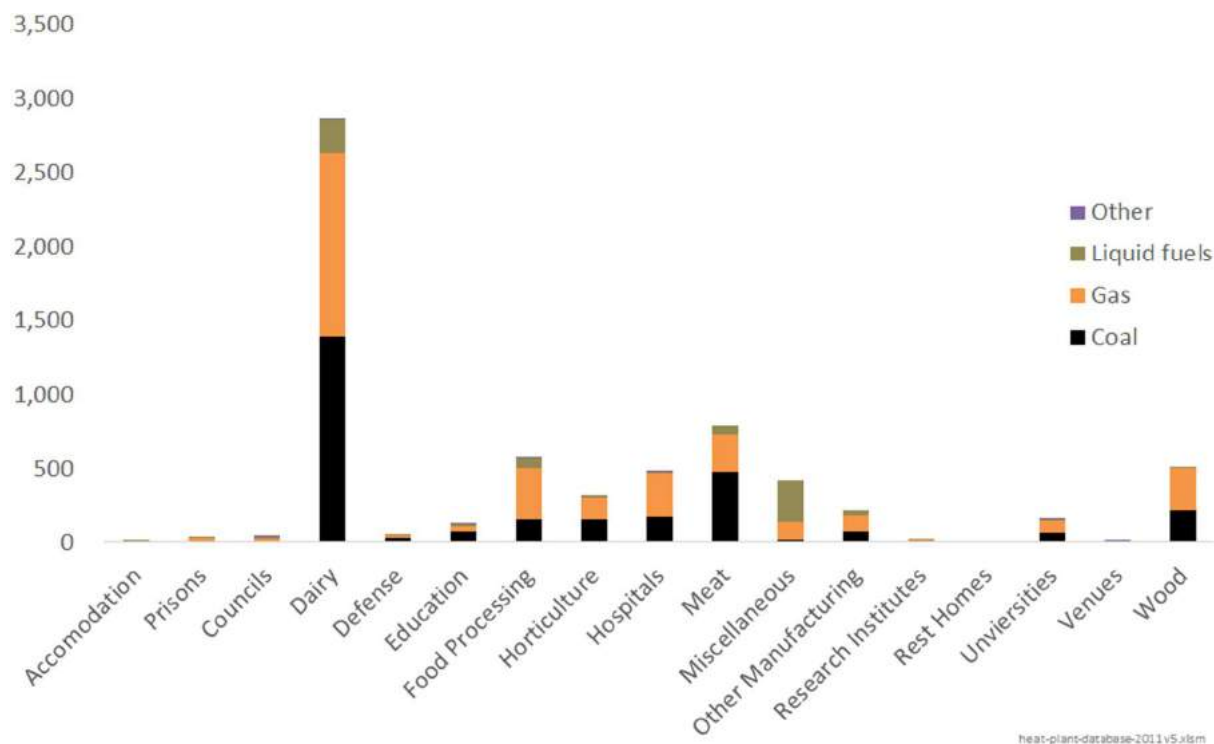
Likewise, high-temperature furnaces have many process-specific requirements that dictate to a significant extent the fuel choice, and which would incur significant costs from switching to a lower greenhouse alternative such as biomass.

Further, both the chemicals sector, and much of the manufacturing sector using high-temperature heat, are exposed to competition from overseas manufacturers who don't currently face a cost of CO<sub>2</sub>. As such, were these New Zealand producers to face a higher cost of CO<sub>2</sub>, there is a real likelihood that New Zealand production would shut down, in favour of overseas producers – many of whom are more fossil intensive than the New Zealand producers. (For example, methanol production from coal. As such, until such time as there is a consistent international CO<sub>2</sub> price faced by all energy-intensive industries around the world, it is likely that imposing a cost of CO<sub>2</sub> on these New Zealand industries will lead to an increase in global CO<sub>2</sub> emissions.

With regards to intermediate process heat from boilers, EECA’s heat plant database<sup>33</sup> gives further insights into which sectors and types of boiler are responsible for emissions. Figure 51 below shows that the largest emissions-emitting sector by far is dairy processing (responsible for 43% of emissions), followed by meat and other food processing (responsible for a further 20%, combined).

In both cases, coal-fired process heat is a larger source of emissions than gas-fired process heat.

**Figure 51: Estimated boiler emissions by fuel and sector (ktCO<sub>2</sub>-e)**



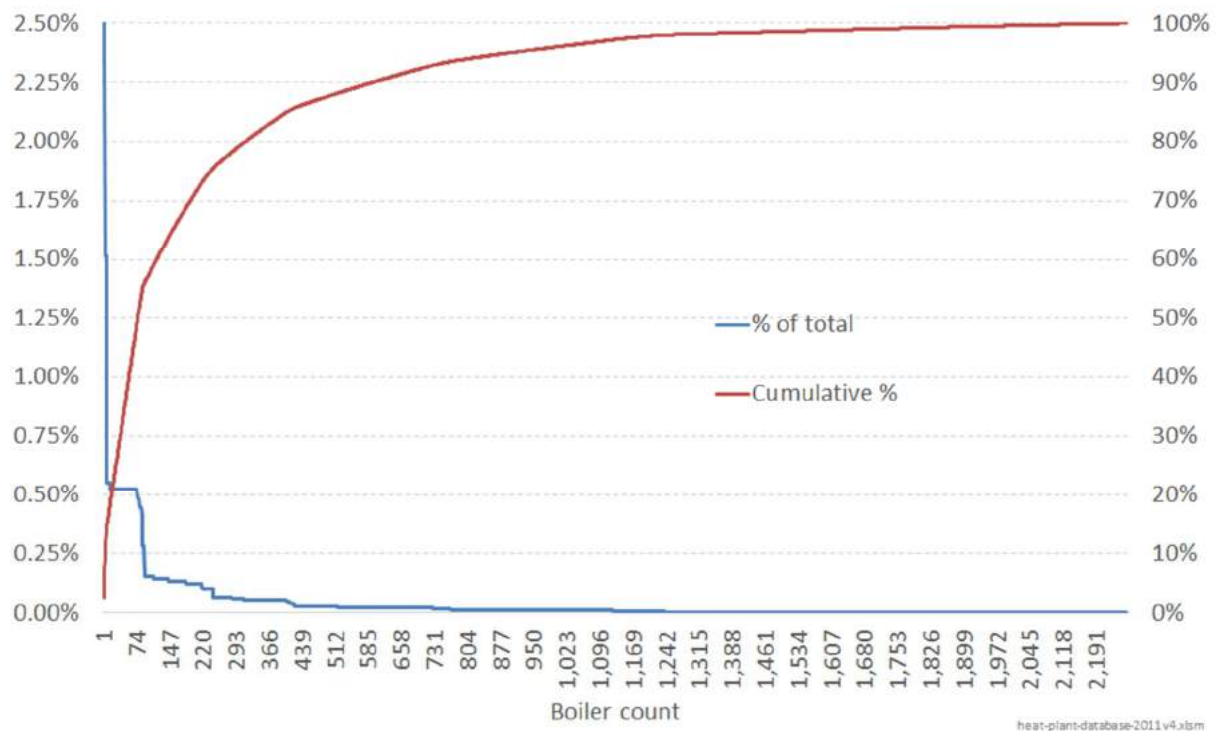
Source: Concept analysis of EECA heat-plant database data

Lastly, Figure 52 below shows that industrial process heat emissions are concentrated in a handful of super-large fossil-fuelled boilers – particularly coal-fired boilers. For example, 50% of process heat emissions are from approximately 75 boilers.

<sup>33</sup> This database was published on the EECA website in 2013 and contains 2011 data on industrial and commercial boilers. It is no longer published, and thus more recent data is not available. However, it is not considered that there have been material changes to New Zealand’s industrial boiler fleet which would significantly alter the pattern of fuel use and emissions from this 2011 position.



**Figure 52: Estimated distribution of individual process heat boiler's share of total process heat emissions**



In summary, all the above analysis indicates that industrial process heat emissions are dominated by a relatively small number of super-large boilers fuelled by coal and gas, raising intermediate process heat for the Dairy, Meat and other food processing sectors. It is these sectors which have also seen the greatest growth in emissions, driven most significantly by the growth in New Zealand’s dairy production.

If New Zealand is to materially reduce its industrial process heat emissions, it must find lower greenhouse alternatives for these currently fossil-fuelled super-large industrial boilers.

## 6.2 Economics of lower-greenhouse alternatives for industrial process heat emissions

Unlike space and water heating, it is not considered that ‘conventional’ electricity heating is currently a cost-effective alternative for raising intermediate temperature process heat. This is because

- Heat pumps are not well suited to producing the large quantities of ‘high quality’ process heat required by such applications.
  - Heat pumps are well suited for space heating because they only need to raise the air temperature by a relatively small amount (i.e. increasing the temperature of the air by approximately 10 to 20 °C). Their coefficients of performance are materially poorer for water heating because they need to raise the water temperature by a greater amount (i.e. by approximately 50 to 60°C). However, heat pump water heating is still practicable.
  - In contrast, using heat pumps to raise large volumes of water to temperatures of between 100 to 300°C for intermediate-temperature water heat is currently not practicable due to the materially poorer coefficients of performance that this would entail.

- The relatively high \$/kWh variable costs of electricity make it an expensive option for raising steam via standard resistance heating boilers relative to combustion boilers.
  - For example, a delivered variable coal price of \$5/GJ, passing through an 85% efficient boiler gives rise to a variable useful energy cost of \$5.8/GJ, or 2.1 c/kWh. This compares with a delivered variable electricity price of approximately 10 to 15 c/kWh for industrial and commercial consumers (noting that resistance electric heating is 100% efficient, and thus doesn't need to be factored by boiler efficiency to give an end-use cost of useful heat).

Thus, despite baseload electricity demand largely being fossil free (as set out in 0), the very low delivered fuel cost of gas and coal outweighs the carbon cost of such fossil-fuelled options relative to these conventional electricity technologies.

Therefore, it is considered that the main options for lower-greenhouse alternative to gas or coal for industrial process heat combustion boilers are:

- Biomass or geothermal fuelled options using conventional boiler technologies
- New 'unconventional' electricity technologies to produce industrial process heat.

### 6.2.1 Economics of conventional intermediate heat boiler technologies

#### *Switching to biomass fuel*

The framework for considering the relative economics of the different options seeks to establish the lifetime cost per useful kWh of heat provided, taking into account the capital and non-fuel operating costs of the boilers, as well as the fuel and CO<sub>2</sub> costs of the different fuels.

The size of the heat load can have a significant impact on the relative economics of the different options. This is not just because of the different capital costs of the options, but also because the \$/kWh costs of the fuel can vary significantly with different levels of consumption. This is particularly the case for gas, where the \$/kWh network charges for a very large transmission-connected boiler can be orders of magnitude less than for a small distribution-connected boiler.

Accordingly, the analysis considers the relative economics of the different fuel options for the following three types of industrial user (whose estimated share of total New Zealand process heat load is indicated in the square brackets)<sup>34</sup>:

- very-large ( $\approx$  40MWth) [45%];
- large ( $\approx$  7MWth) [38%];
- medium ( $\approx$  2MWth) [12%]; and

Figure 53 to Figure 55 below presents the results of the analysis:

For each industrial user situation, two sets of graphs are presented:

- 1) based on current effective CO<sub>2</sub> prices ( $\approx$  NZ\$8/tCO<sub>2</sub>); and
- 2) based on a NZ\$75/tCO<sub>2</sub> CO<sub>2</sub> price.

For each graph, the costs are shown for an industrial user with an "Existing" workable boiler of a particular type, and also the costs that would be incurred if a user were to install a "New" boiler of a particular type.

As can be seen, in situations where a user has an existing boiler there is no recovery of boiler capital costs ('capex') because this is a sunk cost, whereas such costs would be incurred from installing a

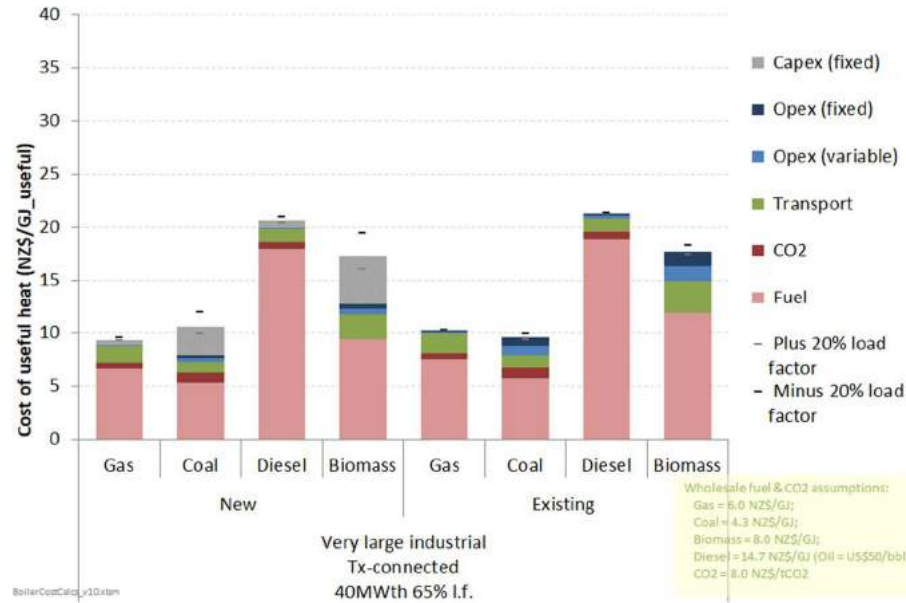
<sup>34</sup> Source: Concept analysis using EECA's 'Heat plant database'

new boiler. Conversely, an existing boiler is assumed to have higher non-fuel operating costs ('opex') and worse fuel efficiencies (leading to higher fuel and CO<sub>2</sub> costs).

The only liquid-fuelled option shown is diesel. This is because the cost of the other two liquid options (LPG and fuel oil) are broadly similar – at least in the context of comparison with the other main fuel options – with the prices of all three liquid fuels fundamentally driven over the long term by the international price of oil.

Figure 53: Intermediate process heat boiler economics for very large gas transmission-connected industrial users

Current CO<sub>2</sub> prices



NZ\$75/tCO<sub>2</sub> CO<sub>2</sub> prices

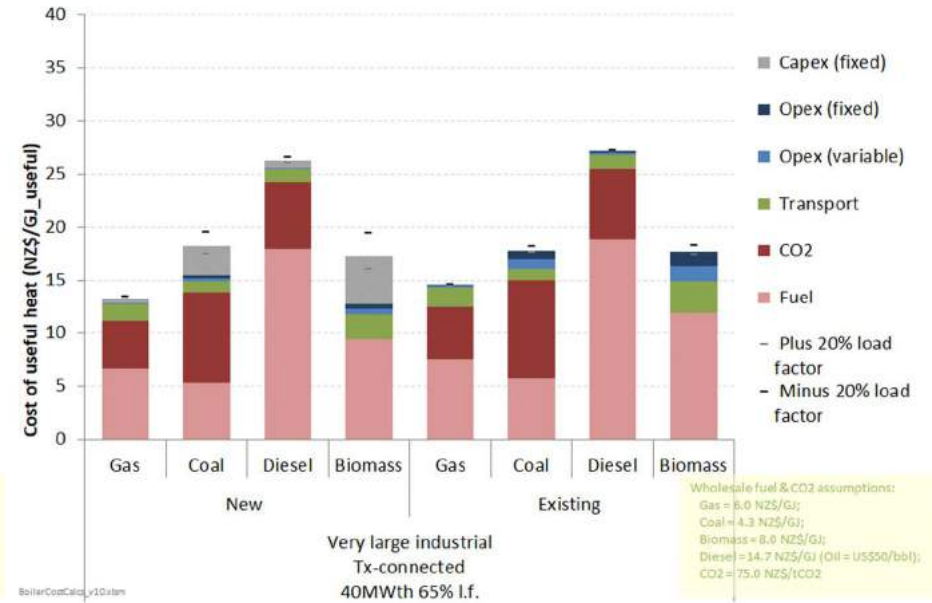
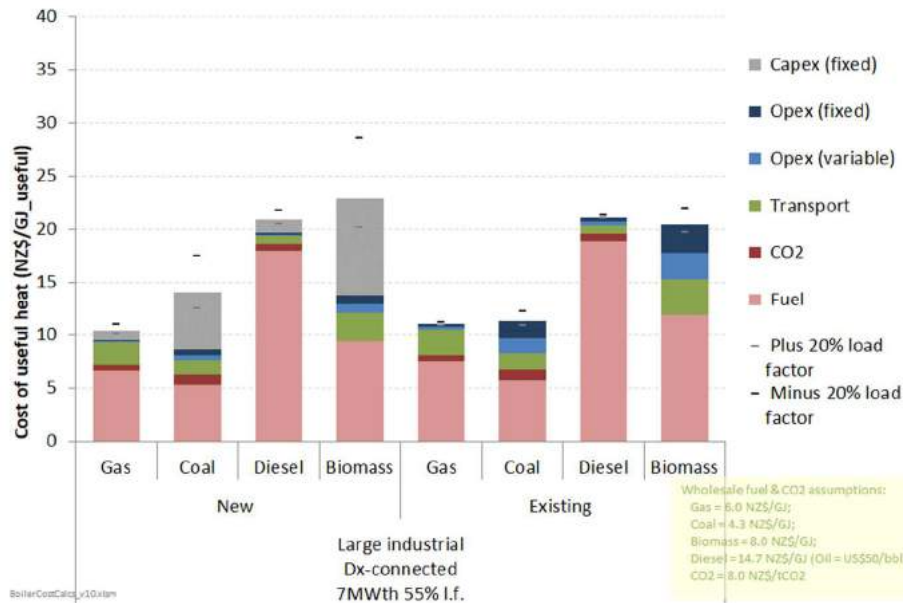


Figure 54: Intermediate process heat boiler economics for large gas distribution-connected industrial users

Current CO<sub>2</sub> prices



NZ\$75/tCO<sub>2</sub> CO<sub>2</sub> prices

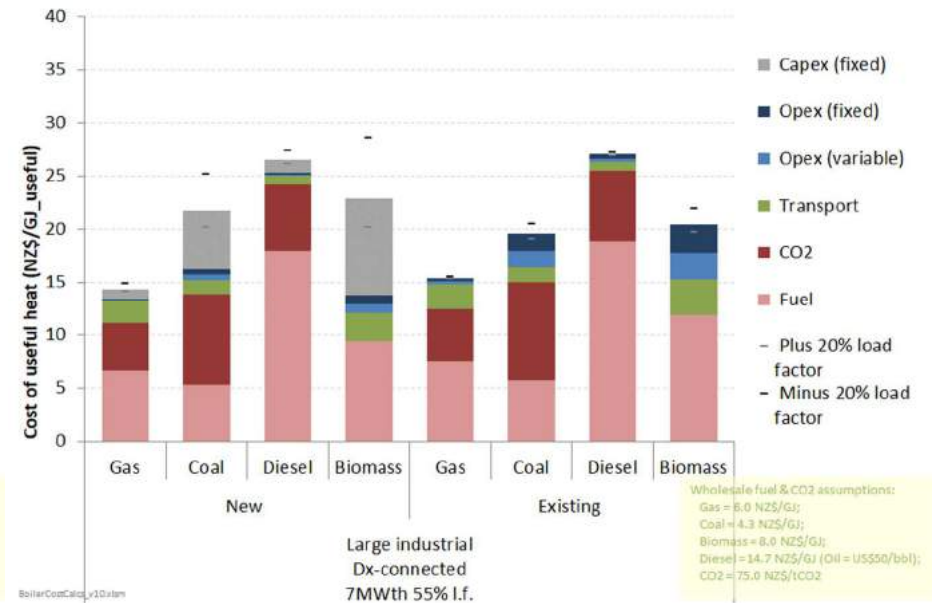
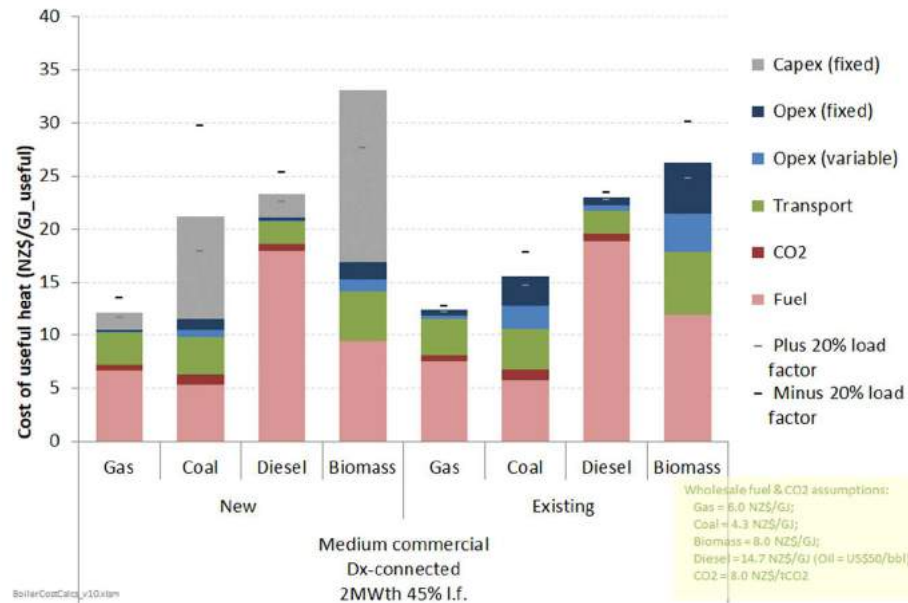
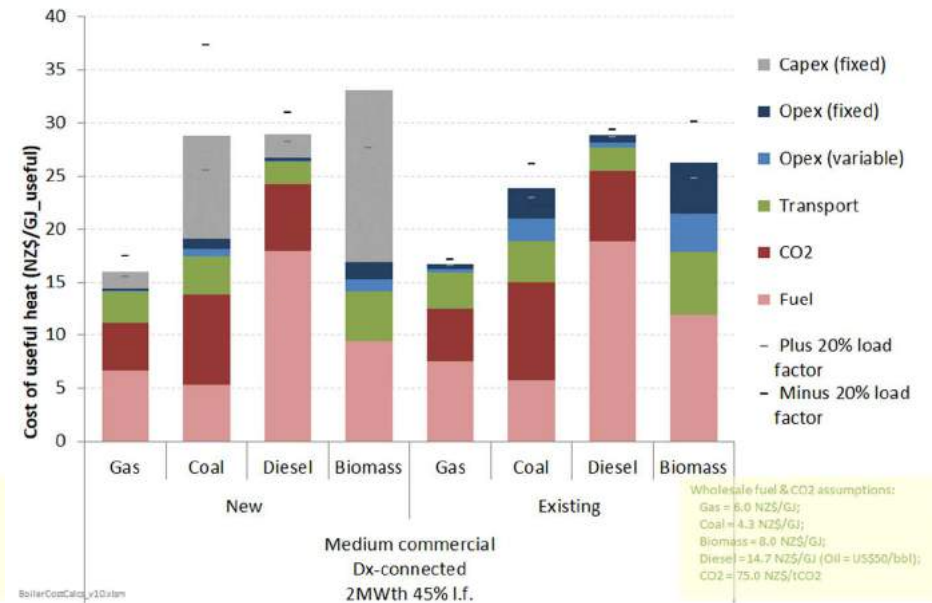


Figure 55: Intermediate process heat boiler economics for medium gas distribution-connected industrial users

Current CO<sub>2</sub> prices



NZ\$75/tCO<sub>2</sub> CO<sub>2</sub> prices



The above charts reveal that for the solid-fuelled options (coal and biomass), the capital and non-fuel operating boiler costs are a very significant proportion of the overall lifetime costs of useful heat. This has a significant bearing on the economics of switching away from an existing coal or gas-fired boiler (where the capital costs are sunk) to a new biomass boiler.

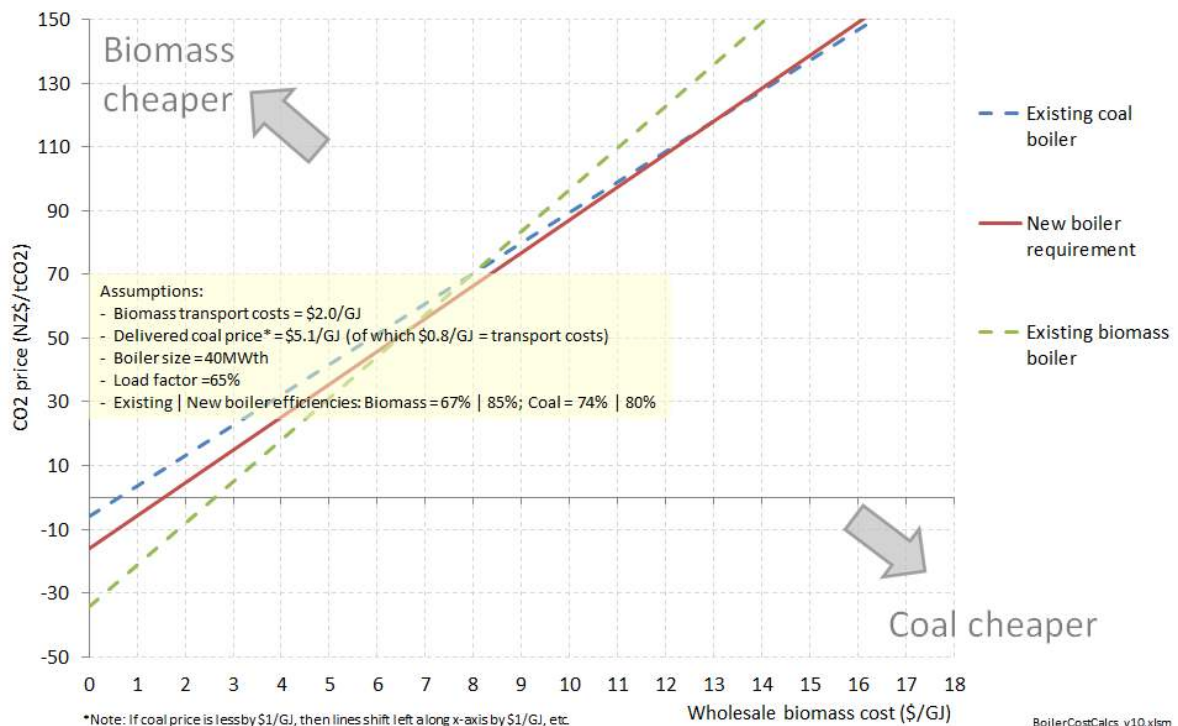
At \$75/tCO<sub>2</sub>, switching to biomass only makes sense for switching from coal – and even then only for the very largest boilers. The economies of scale for boilers mean that the capital component of useful heat costs for biomass boilers gets proportionately larger for smaller-sized boilers, such that even at \$75/tCO<sub>2</sub> it is not cost-effective to switch.

Further, the above analysis assumes a wholesale biomass cost of \$8/GJ, plus a \$2/GJ transport cost. However, it should be noted that there is significant variation around New Zealand in the wholesale and transport costs of biomass for delivery to the various industrial sites with large coal- and gas-fired boilers. Sites which are relatively close to major forestry operations should be able to acquire biomass at this price. However, sites which are more distant from forestry operations could pay considerably more – particularly due to considerably greater transport costs.

Figure 56 and Figure 57 below give further insights as to how the break-even price for switching to/from biomass will change for different biomass (and coal/gas) prices for very large boilers

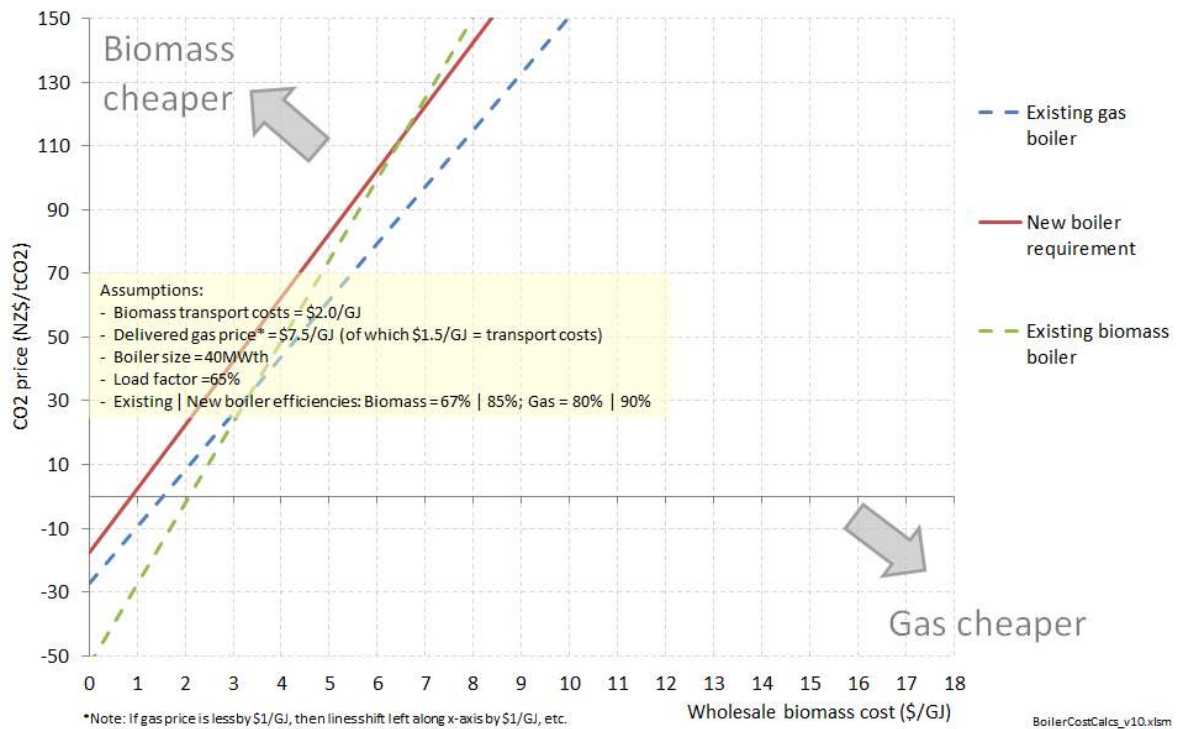
- Figure 56 shows that for every \$1/GJ increase in delivered biomass costs, the break-even price for switching away from an existing coal-fired boiler will rise by NZ\$10/tCO<sub>2</sub>.
- Figure 57 shows that for every \$1/GJ increase in delivered biomass costs, the break-even price for switching away from an existing gas-fired boiler will rise by NZ\$18/tCO<sub>2</sub>.

**Figure 56: Break-even CO<sub>2</sub> prices for switching to/from biomass and coal for very large industrial process heat boilers**





**Figure 57: Break-even CO<sub>2</sub> prices for switching to/from biomass and gas for very large industrial process heat boilers**



In summary, if large industrial coal-fired boilers are to switch to biomass as a fuel source, it appears that they will need to face CO<sub>2</sub> prices of at least NZ\$70/tCO<sub>2</sub>. However, this assumes that the delivered cost of biomass is \$10/GJ (incorporating a \$2/GJ transport cost), and the delivered cost of coal is \$5.1/GJ.

However, there are cases where industrial users may face either higher delivered biomass prices and/or cheaper delivered coal prices. For each \$1/GJ increase in biomass prices, and each \$1/GJ reduction in coal prices, the breakeven CO<sub>2</sub> price will rise by NZ\$10/tCO<sub>2</sub>.

And the economics of switching from gas to biomass are even more challenging, with the breakeven price being at least NZ\$115/tCO<sub>2</sub>, rising by almost NZ\$20/tCO<sub>2</sub> for each \$/GJ increase in delivered biomass prices or reduction in delivered gas prices.

### Switching to geothermal fuel

As Figure 49 previously indicates, a reasonable amount of intermediate process heat is provided by using geothermal fluid as the heat source.

However, the potential for geothermal as a heat source to displace gas and coal-fired process heat relies on existing facilities being located very close to a source of geothermal heat. It is understood this is the case for some existing industrial process facilities, particularly in the Central North Island. Further, there is clearly the potential to locate new industrial process facilities on top of geothermal resources – although this also relies on such locations also being close to the raw material which would require processing (e.g. dairy, timber, etc.)

Given the very site-specific nature of this resource, detailed consideration of this option is beyond the scope of this study. However, a recent report<sup>35</sup> indicates that there is a reasonable potential for several PJ worth of additional geothermal-fuelled process heat facilities – particularly in the Central

<sup>35</sup> “Geoheat strategy for Aotearoa NZ 2017-203”, New Zealand Geothermal Association, 2017

North Island and Northland – both for intermediate temperature process heat, as well as for horticulture for heating glasshouses.

### **6.2.2 Possible new electricity technologies to raise intermediate process heat**

Electricity is New Zealand's cleanest fuel, and it is available across New Zealand. While the average \$/GJ fuel cost of electricity is about five times that of coal (absent a price of CO<sub>2</sub>), electricity prices vary strongly by season due to seasonal variations in demand, hydro inflows and wind generation.

This means that it is worthwhile investigating the potential for electrification of some heat loads. In particular, there may be opportunities for heat-loads which are anti-correlated with electricity prices (e.g. dairy processing, and specifically milk drying which is very emission intensive).

Initial analysis indicates that electric solutions for some plant could give rise to a sub \$100/tCO<sub>2</sub> abatement cost.

This is likely to be very plant specific, but we note that South Island electricity prices are lower on average (particularly in spring when most milk production occurs), and it is predominantly in the South that coal is used in dairy processing.

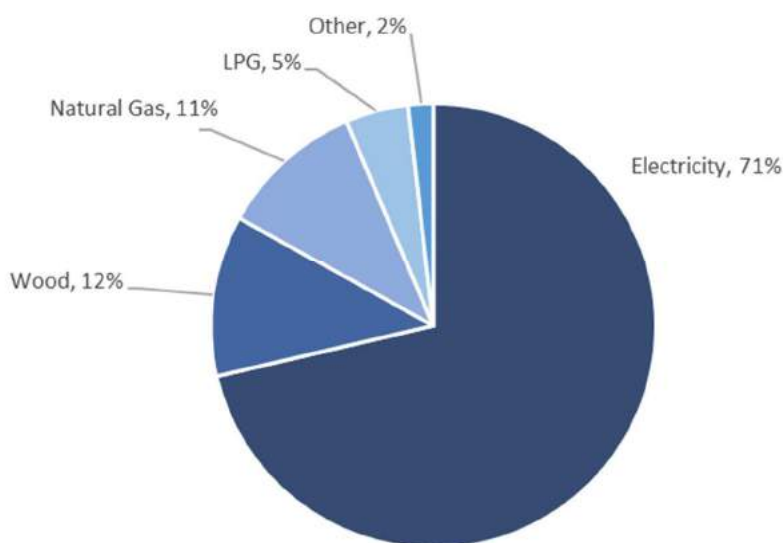
## 7 Residential space and water heating

### 7.1 Introduction

We can see from Figure 58 below that electricity is the dominant fuel used in New Zealand households.

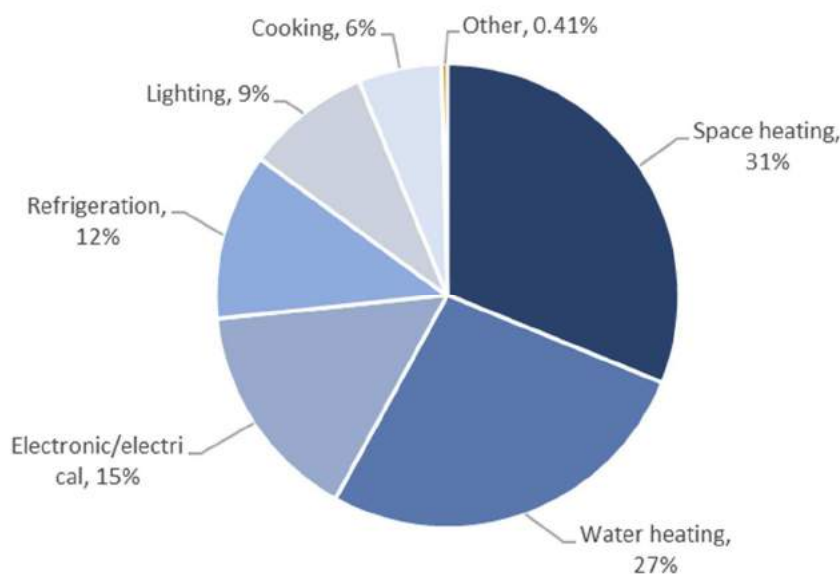
Earlier in this report (see Section 4) we saw that, on average, fossil fuel generation (and thus CO<sub>2</sub> emissions) are biased towards winter, and are highest at peak electricity demand times. In this section, we consider which residential end-uses of electricity are highly correlated to (and causative of) the winter peak electricity demand, and which are not. In this way, we will see which end uses of electricity have the greatest potential to provide cost savings (i.e. the network and energy savings that arise from peak demand reductions) and CO<sub>2</sub> emission savings.

**Figure 58 - Proportions of energy from the various fuels in the residential sector**



Source: Concept analysis of EECA data

**Figure 59 – Proportions of household energy end use**



Source: Concept analysis of EECA data

At a high level, we see from Figure 59 above that space heating and lighting are the services that are responsible for the majority of the winter demand peak, and thus represent the biggest opportunity for CO<sub>2</sub> savings, and also the largest cost reductions.

We will show that, of these, lighting is far more cost effective as the efficient technologies are much lower cost. In contrast, efficient space heating is a relatively large capital investment. This means that the net-benefit from investing in more efficient space heating is very situation specific (and sometimes negative).

We explore lighting and space heating in more detail below, looking at the public and private benefits of efficiency investments for these energy end-uses. We also consider other services such as refrigeration, which use a similar amount of electricity, but all year round as opposed to mainly in winter, thus providing a contrast to the lighting and space heating services.

## 7.2 Space heating

Space heating (along with water heating) is one of the largest areas of energy use in the home, responsible for about 31% of household energy use (space heating and water heating combined is about 58%).

As with most residential electricity use, the need for space heating services (on average) across the residential sector is mainly driven by the time of day (when people are home) and time of year (i.e. negatively correlated to outdoor temperature).

There are a variety of space heating technologies each capable of providing a similar service, the main ones considered here are electric resistive, and heat pumps.

Analysis of space heating in particular is incredibly complex, with the private benefit being influenced by such factors as:

- Whether there is an existing serviceable appliance
- living patterns (when people are home, and whether they heat the whole house or only the occupied room)
- whether reticulated gas is used for other purposes (thus the fixed daily network costs being faced already)
- the real-world efficiency of heat pumps (i.e. they are typically used in the coldest weather, which can affect their COP)
- the price of wood (some households, particularly in rural areas have access to very low-cost wood)
- geographic location (this affects the size of the heat load, and also electricity tariffs)
- whether the household is a 'low' or 'standard' electricity user

Concept Consulting has undertaken detailed analysis of residential space and water heating options in the report 'Consumer Energy Options' for the Gas Industry Company.<sup>36</sup>

Rather than duplicating the analysis in this report, we draw on this existing analysis, and discuss the findings particularly in relation to CO<sub>2</sub> impacts.

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<sup>36</sup> See <http://gasindustry.co.nz/about-us/news-and-events/events/release-of-consumer-energy-options-in-new-zealand-2016-update-by-simon-coates/>

A key finding is that the optimal solution is very household-specific, there is no single ‘best’ option. Given the complexity, and number of variables, it is also very challenging for householders to identify their best option for their unique situation<sup>37</sup>.

There is also strong connection between household indoor air temperatures and health of the occupants. Many homes are under-heated, so if a more cost-effective heating solution is offered, and heating becomes more affordable, then more heating may be used rather than less. While this may not result in an energy and thus CO<sub>2</sub> saving, research has shown that it will result in health benefits (i.e. a net economic benefit to New Zealand).<sup>38</sup>

The Consumer Energy Options report analyses variety of situations (e.g. small, medium, and large heating demand), and looks at the private and public benefits, as well as the GHG implications.

### 7.2.1 Cost

Each heating technology has a different profile of power consumption, cost, and lifetime. For example, a heat pump has a much higher upfront cost, but a lower operating cost (as it’s more efficient) compared to a resistive heater. Typical information used in the space heating analysis is shown below.

	Energy consumption	Nominal efficiency	Cost	Life
Electric resistive	4 kW	100%	\$400	10 years
Heat pump	1.5 kW	275%	\$2,500	10 years
Ceiling insulation	(assumes resistive heating is used)		\$2,000	20 years

### 7.2.2 Benefits

#### Public

Space heating is highly correlated to peak electricity demand, so greater use of more efficient (or gas/wood) heating results in lower electricity network costs, and lower peaking generation costs, in the long run.

In the case of gas heating, gas networks are typically lower cost than electricity, and have inherent storage (line pack), thus gas networks can meet energy peaks at a lower cost than electricity networks (on average). Gas networks are also less capacity constrained in long run.

#### Private

The use of efficient electric (or wood/gas) heating reduces electricity consumption, and thus has a private benefit when the ongoing savings outweigh the additional capital cost - this depends on how much space heating is required.

<sup>37</sup> Not only are consumers typically unable to assess the least-cost heating option for their situation, there is almost no independent advice they can receive that is specific to their situation. Organisations such as EECA and Consumer provide some generic advice, but it is not specific to a particular household’s characteristics.

<sup>38</sup> See [http://www.healthyhousing.org.nz/wp-content/uploads/2012/05/NZIF\\_CBA\\_report-Final-Revised-0612.pdf](http://www.healthyhousing.org.nz/wp-content/uploads/2012/05/NZIF_CBA_report-Final-Revised-0612.pdf)

The current 'flat' electricity pricing structure under-rewards more efficient electric (or wood/gas) heating. This is because the current consumer pricing doesn't reflect the true cost of using electricity at peak demand times. Efficient electric (or wood/gas) heating would be expected to be more cost-effective for consumers under more cost-reflective electricity pricing (i.e. consumer electricity tariffs would be higher at peak times, so the energy savings are worth more).

### 7.2.3 Emissions consequences

Space heating occurs at times of peak electricity demand, so greater use of efficient heating typically results in lower CO<sub>2</sub> emissions (as outlined in Section 4).

### 7.2.4 Space heating overall outcome

In some cases, under the current electricity pricing, the least-cost choice for a consumer doesn't reflect the least-cost choice to New Zealand. In particular, differences in the way that electricity and gas fixed costs are recovered can result in consumers being encouraged to choose options which don't represent the least-cost outcome for New Zealand.

On average, under a move to more cost-reflective electricity pricing, it appears that electric space heating will face an increase in consumer costs. Therefore, cost-reflective pricing will, over time, help to encourage consumers to move to lower emission space heating technologies.

Conversely, gas-fired space heating consumers are expected to face a decrease in prices from a move to more cost-reflective tariffs. This will improve the economics of gas-fired options for consumers, making them cheaper than electricity options in many cases – although for small heat loads, resistance electric heaters are still likely to be least-cost.

## 7.3 Water heating

### 7.3.1 Introduction

The residential demand for water heating services is relatively constant across the year. However, there is a strong intra-day pattern such that the hot water demand contributes to the morning and evening electricity demand peaks

There are a variety of water heating technologies each capable of providing a similar service, the options considered here are electric storage either controlled (off peak) or uncontrolled (on at peak times). The controlled storage will have a similar 'grid cost impact' as gas water heating (i.e. not adding to peak demand).

### 7.3.2 Cost

Each water heating option has a slightly different cost because slightly different hot water cylinder (or gas heating) capacities are required to provide the same hot water service (and a ripple control receiver for controlled electric heating).

In general, a slightly larger electric hot water cylinder (i.e. volume) is required for controlled heating compared to uncontrolled heating – this is to ensure sufficient hot water is available through the controlled period.

### 7.3.3 Benefits

#### *Public*

Uncontrolled electric water heating is used at peak times, so switching to controlled water heating results in lower electricity network costs, and lower peaking generation costs, in the long run. However, even when controlled, electric water heating could be on during many winter evening peak demand periods because the control may only be exercised for the very highest peak periods (i.e. not continuously throughout winter).

Controlled water heating also offers the benefit of a large controllable load (i.e. when aggregated at network level) that can provide grid balancing services (interruptible load, IL).

#### *Private*

Even on a 'flat' electricity tariff structure, consumers do see a lower rate if their hot water cylinder is controlled (compared to uncontrolled). While this varies across the country, it is generally a net benefit to consumers to have their hot water controlled.

The benefit would be much more marked under more cost-reflective pricing.

### 7.3.4 Emissions consequences

Electric water heating is a daily electricity demand, and even controlled electric water heating has a significant portion of demand at peak times (i.e. all but the coldest winter evenings). Therefore, water heating has some CO<sub>2</sub> emissions consequences, but in total, less than space heating.

### 7.3.5 Water heating overall outcomes

For water heating, it appears that a move to more cost-reflective pricing will, on average, make controlled electric options more attractive to households compared to the current pricing structure. This is because off-peak electricity is comparatively low cost.

Further, from an economic whole-of-New-Zealand perspective, the sunk nature of gas network costs (and significant spare capacity) means that gas-fired water heating options are likely to be least-cost in most situations (the incremental cost of a unit of gas being lower than an additional unit of electricity). However, it is not clear that gas networks will move to fully cost reflective pricing as the high fixed daily charge that this would require may affect consumer's perceptions of cost-effectiveness of gas for many users.

Electric water heating CO<sub>2</sub> emissions are relatively high (but less than space heating and lighting) as even controlled HWCs are on during some peak periods – this is because networks only tend to use ripple (and other) peak demand controls when demand is close to the network peak. At other peak demand times over winter, hot water cylinders may be on during the evening peak demand in many cases.



## 8 Lighting, refrigeration, and other electricity-consuming consumer technologies

### 8.1 Lighting

#### 8.1.1 Introduction

The need for lighting services (on average) across the residential sector is mainly driven by the time of day and time of year (i.e. obviously mainly correlated to the hours of darkness). This means lighting is very highly correlated to peak electricity demand.

There are a variety of lighting technologies each capable of providing a similar lighting service, the main ones considered here are incandescent, compact fluorescent (CFL), and Light Emitting Diodes (LED)

Within a typical home, lamps in different rooms are used for a different number of hours per year (on average), for example:

- Kitchen/living areas >3 hrs/day (annual average)
- Bedrooms <2 hrs/day (annual average)
- Utility areas (e.g. laundry) < 1 hrs/day (annual average)

#### 8.1.2 Cost

Each lighting technology<sup>39</sup> has a different profile of electricity consumption, cost, and lifetime.

LED technology is still evolving (efficiencies are improving and costs are reducing)

Recessed down-lights are a special category of lights that are particularly inefficient. These 'reflector' type lamps themselves can be half as efficient as normal incandescent lamps, but they also significantly compromise the ceiling insulation.

Most older incandescent recessed downlights typically allow air-flow between the room and the ceiling cavity. There is also a gap in the ceiling insulation around the light fitting required to minimise fire risk. The combined effect is that where there is a high number of down lights, any ceiling insulation is significantly compromised.

These types of downlight fittings are no longer allowed; however, many still exist across New Zealand. LED replacement light fittings significantly improve the insulation characteristics of the ceiling (precluding air flow and allowing insulation to abut, or entirely cover the downlight fitting)

**Table 1 - Typical assumptions for the lighting analysis**

	Electricity consumption	Indicative cost	Life
Incandescent	100 Watts	\$0.75	1-2 years
CFL	23 Watts	\$5	2-6 years
LED lamp	15 Watts	\$18	7-10 years
LED downlight (including install cost)	10 Watts	\$45	7-10 years

<sup>39</sup> For this section, considering the residential sector, we look at lighting 'technologies', not the lighting 'service'. This is because efficiency options such as daylight harvesting and sensor lights are more applicable to commercial settings. The technologies also make simpler examples for consumers to understand.

### 8.1.3 Benefits

#### Public

Lighting is used at peak times, so greater use of efficient lighting results in lower electricity network costs, and lower peaking generation costs, in the long run. Efficient lighting (e.g. LED) is generally economic when use is greater than 0.25 hours/day on average<sup>40</sup>. This is for a simple lamp that can be replaced by the householder.

In the case of recessed downlights (which typically require an electrician to re-fit), these are generally economic to replace where the lights are used more than about 0.75 hour per day on average. Therefore, LED lighting is typically economic in the majority of circumstances (all except the lowest-use illumination areas).

Note that LED downlight replacement fittings are generally sealed, and many can be insulated over. Therefore, they are not only more efficient from a lighting viewpoint, but can also significantly improve ceiling insulation. We have not counted this improved insulation effect in our analysis.

#### Private

Efficient lighting reduces electricity consumption, and thus has a private benefit when the savings outweigh the additional cost of the lamp (typically where lamps are used for more than 0.75 hours/day).

In the case of recessed downlights (which typically require an electrician to re-fit), these generally provide a private benefit where the lights are used more than about 1.25 hours per day.

We can therefore see that there are situations where LED lighting will be economic (good for NZ), but it won't happen because the current electricity pricing results in no private benefit to the householder. The current 'flat' electricity pricing structure under-rewards efficient lighting. Efficient lighting would be expected to be more cost-effective for consumers under more cost-reflective electricity pricing.

### 8.1.4 Emissions consequences

Lighting is on at peak times, so greater use of efficient lighting results in lower emissions. Given that lighting is highly correlated with peak demand (and thus fossil fuel use), and that it is cost-effective in many cases in its own right, it is a very low-cost (in fact, almost always a negative 'cost') source of CO<sub>2</sub> abatement. This can be seen in Table 2 below. This analysis allows for the typical variability in lamp life, and cost, as well as other lesser sources of uncertainty.

**Table 2- Estimated cost of carbon abatement for various LED lighting scenarios**

	LED lamp only (quality lamp replaced by householder, incremental cost of \$25/lamp)	LED downlight (quality lamp, many replaced so incremental cost of electrician is low, at about \$45/lamp)	LED downlight (quality lamp, only a small number replaced so incremental cost of electrician is high, at about \$60/lamp)
Low use (about 1 hr/day)	-250 \$/tCO <sub>2</sub> to -350 \$/tCO <sub>2</sub>	+50 \$/tCO <sub>2</sub> to -100 \$/tCO <sub>2</sub>	+300 \$/tCO <sub>2</sub> to +100 \$/tCO <sub>2</sub>
Medium use (about 2 hrs/day)	-450 \$/tCO <sub>2</sub> to -500 \$/tCO <sub>2</sub>	-300 \$/tCO <sub>2</sub> to -350 \$/tCO <sub>2</sub>	-150\$/tCO <sub>2</sub> to -250 \$/tCO <sub>2</sub>

<sup>40</sup> There is significant variability due to lamp costs, and life time, but this is a typical figure.

High use (about 3 hrs/day)	-500 \$/tCO <sub>2</sub> to -550 \$/tCO <sub>2</sub>	-400 \$/tCO <sub>2</sub> to -450 \$/tCO <sub>2</sub>	-300 \$/tCO <sub>2</sub> to -400 \$/tCO <sub>2</sub>
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## 8.2 Domestic refrigeration

### 8.2.1 Introduction

The need for domestic refrigeration services (on average) is relatively constant across the day and across the year. There are typically only small changes arising from seasonal temperature differences<sup>41</sup>, and from the times of day refrigerators are used (i.e. opened and closed, and items placed inside that require additional cooling).

While there are a variety of types of refrigerator configuration (freezer at bottom, freezer at top, side by side etc), the technology for fridge-freezers is largely the same. The variations in efficiencies is due to configuration, and the quality of the refrigerator's thermal envelope.

### 8.2.2 Cost

A refrigerator is a mature product that has had decades of development. Further, because refrigerators use a lot of electricity, they are subject to Minimum Energy Performance Standards (MEPS) in many countries including New Zealand. This has resulted in all refrigerators currently being sold in New Zealand being relatively efficient, regardless of price, brand or configuration.

### 8.2.3 Benefits

#### *Public*

While fridge-freezers use a lot of electricity over a year (about 12%, see Figure 59 ), they only make a very small contribution to peak electricity demand. Therefore, the savings arising from a more efficient refrigerator are small (i.e. comprised of energy costs, but not network costs).

Therefore, there is only a very small net public benefit (if any) arising from investing in more efficient refrigeration (e.g. the additional expense of more insulation) outweighs the energy savings.

#### *Private*

In contrast, under the current flat electricity tariff structure, consumers do typically see a net-benefit from investing in more efficient refrigeration. This is because the consumers are given a greater incentive than is warranted by the high variable electricity tariff component.

The benefit would be much less (possibly non-existent) under more cost-reflective pricing.

### 8.2.4 Emissions consequences

Domestic refrigeration is not biased towards peak demand, and thus typically has a very small, or negligible, emissions benefit in the long term. As discussed in Section 4, where the electricity use profile is relatively flat over the year, this demand can be met most cost-effectively by new low-carbon generation in future (i.e. wind or geothermal plant).

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<sup>41</sup> Due to New Zealand's poorly insulated houses, and the tendency to under-heat our homes, the outdoor seasonal temperature differences are also experienced indoors (but to a lesser degree). In very extreme cases, indoor room temperatures can be lower than the inside of the homes refrigerator, albeit briefly (e.g. overnight in winter in some student flats in the South Island).

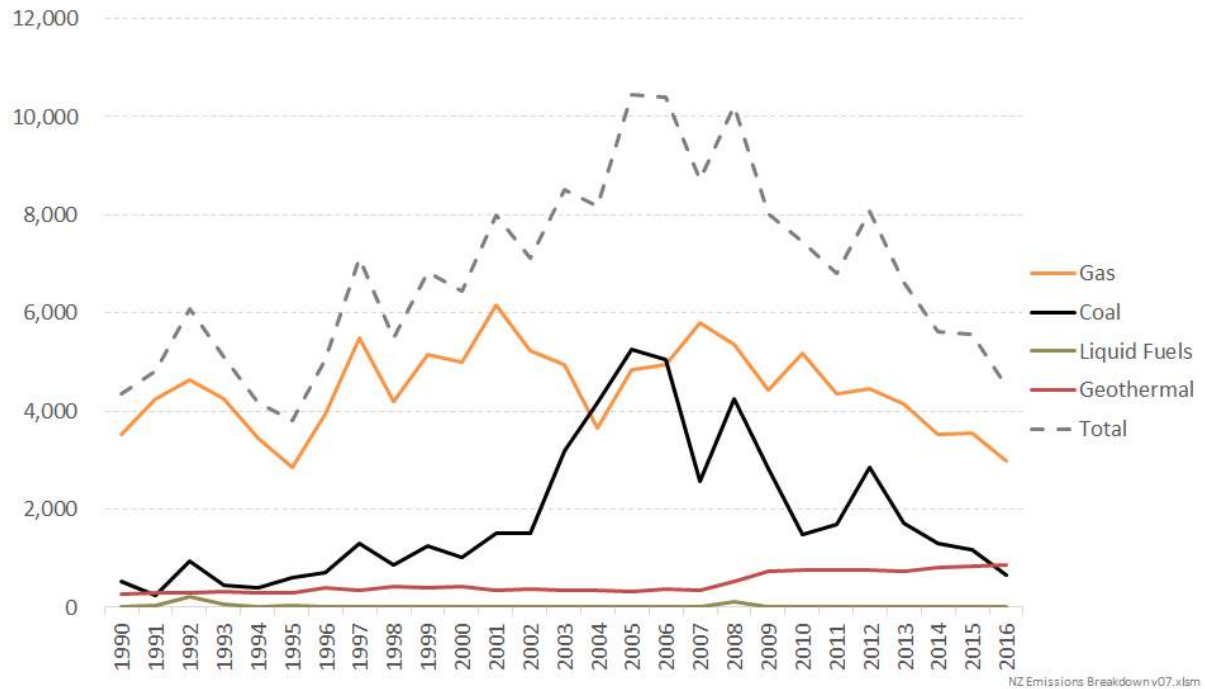
## Part C - Appendices

## Appendix A. Analysis of electricity sector drivers

### Understanding the drivers behind the historical change in power generation emissions

Figure 60 below (reproduced from Figure 14 in the main section) shows that greenhouse emissions from the power sector rose steadily from 1990 to 2005/6, but have declined a similar amount since then. It also shows that there has also been significant variation between coal and gas-fired plant within this time, and significant year-on-year variation.

**Figure 60: Historical power sector emissions by power station fuel (ktCO<sub>2</sub>-e)**

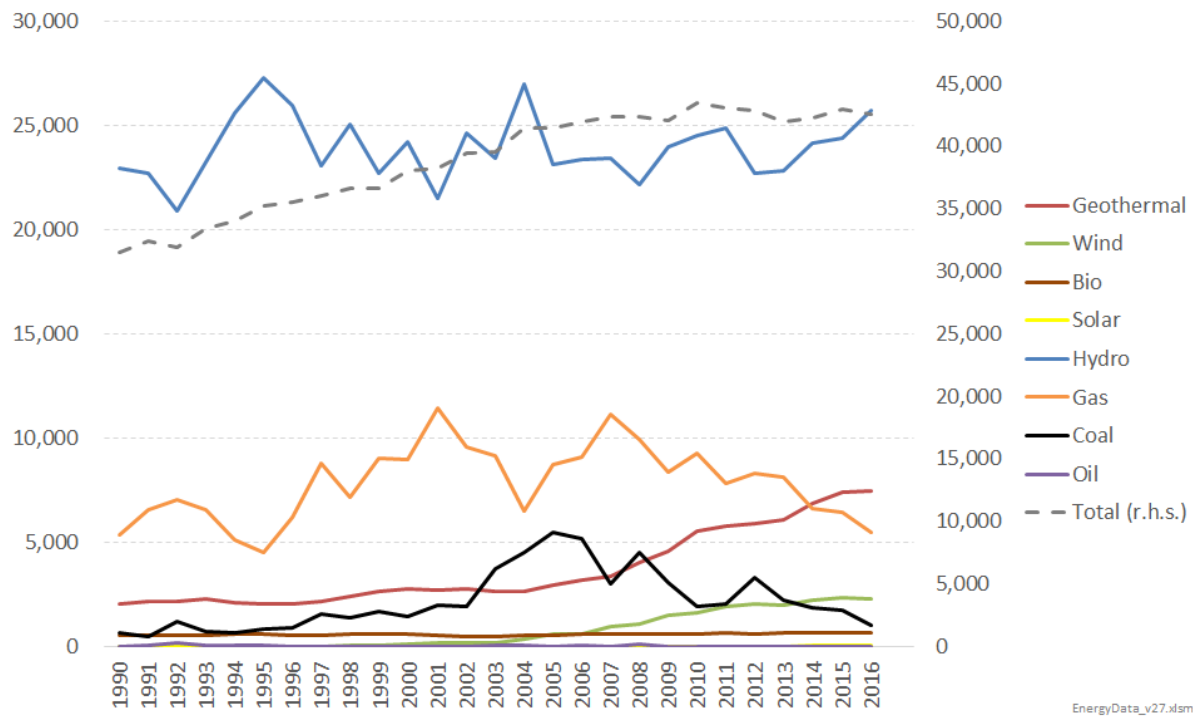


Source: Concept analysis of MBIE data

Part of the year-to-year variation in fossil generation output is due to year-to-year variations in hydro generation. As Figure 61 below shows, these are significant, with the variation in hydro

generation between the wettest and driest year over this period being equivalent to approximately 14.5% of average annual generation over this period.

**Figure 61: Historical generation by plant type**



Source: Concept analysis of MBIE data

In order to better discern the underlying ‘structural’ changes in generation over this period, Figure 62 below attempts to correct for hydrological variation by showing derived generation patterns if hydro output each year were at mean hydro generation levels, with fossil generation adjusting to these pseudo-mean levels.<sup>42</sup>

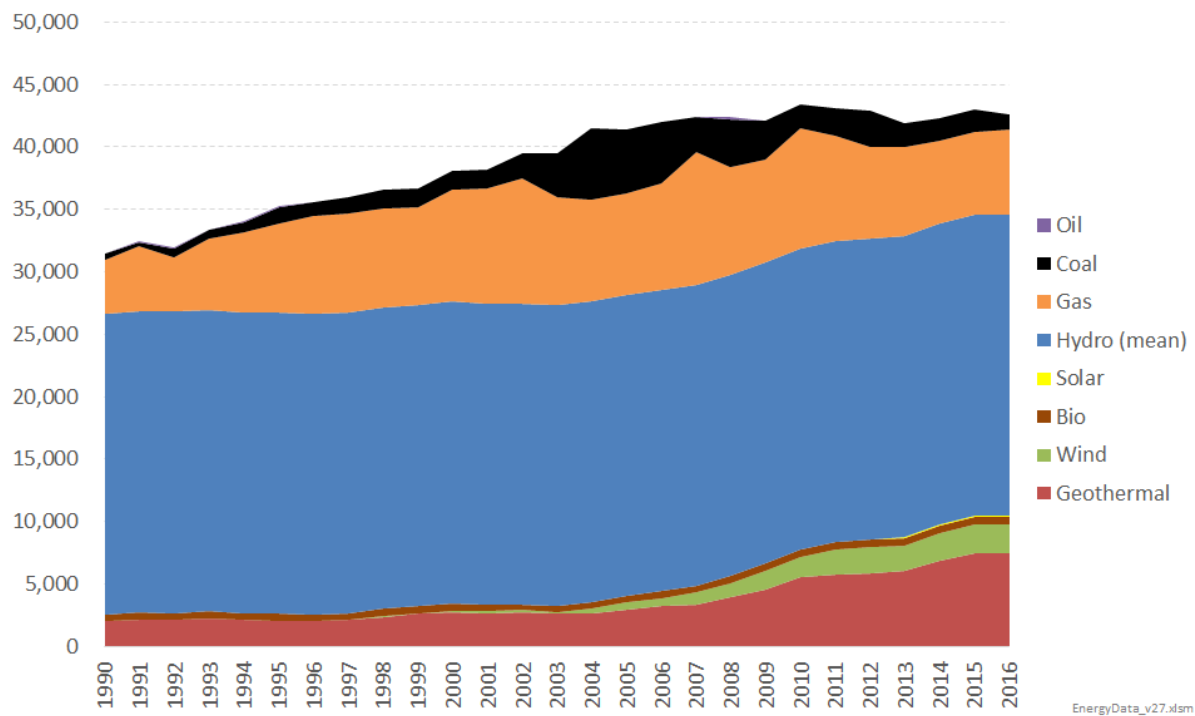
This is believed to be a very good representation of total fossil generation in mean years, but only a reasonable first-order representation of the split between coal and gas for such mean years – given that different fossil plant play a greater-or-lessor role in hydro balancing.

However, despite this caveat on the extent of split between coal and gas, this representation is good for discerning the underlying structural drivers in power generation outcomes.

<sup>42</sup> i.e. for a given year:

- Derived fossil generation = Total actual generation – actual non-hydro-renewables – mean hydro generation.
- Gas-generation share of fossil generation = Derived fossil generation \* Gas % of actual fossil generation.

**Figure 62: Historical generation by plant type, correcting for mean hydrology (GWh)**



Source: Concept analysis of MBIE data

This, and other, analysis reveals the following key structural trends in electricity generation over the past 25 years.

- **1990 to 2005**

- **Fossil generation predominantly meets demand growth.** Fossil generation was the principal form of generation developed to meet growth in electricity demand. In the early part of this period this was from increasing output at the Huntly and New Plymouth ‘Rankine’ power stations<sup>43</sup>, but from the late 1990s, this was also from the building of new, high-efficiency, combined-cycle gas turbine (CCGT) power stations.
- **Some switching between gas and coal.** In the early 2000’s, gas prices in New Zealand rose significantly following the re-determination downwards of the reserves at the Maui gas field – the largest gas field in NZ at the time, responsible for almost 60% of NZ reserves just prior to the re-determination. This led to an increase in coal burn in the dual-fuelled Huntly Rankine power station, which can switch between coal or gas (or a blend) for its fuel. More recently, (in the last five years), gas prices have fallen again, with coal prices rising slightly, resulting in some of this trend reversing.

<sup>43</sup> Rankine-cycle thermal power stations raise steam in a boiler, with the steam used to turn a turbine that drives an electricity generator. These achieve fuel efficiencies of approximately 33%. Combined-cycle gas turbines (CCGTs) burn gas in a gas turbine (very similar to aero-jet engines). The waste-heat from the gas turbine is then used to raise steam which drives a steam turbine. Both the gas and steam turbines drive an electricity generator. These are considerably more fuel efficient than the Rankine stations, achieving fuel efficiencies of close to 50%. Open-cycle gas turbines (OCGT) only have the initial gas-turbine to drive a generator. These achieve efficiencies of approximately 38%.



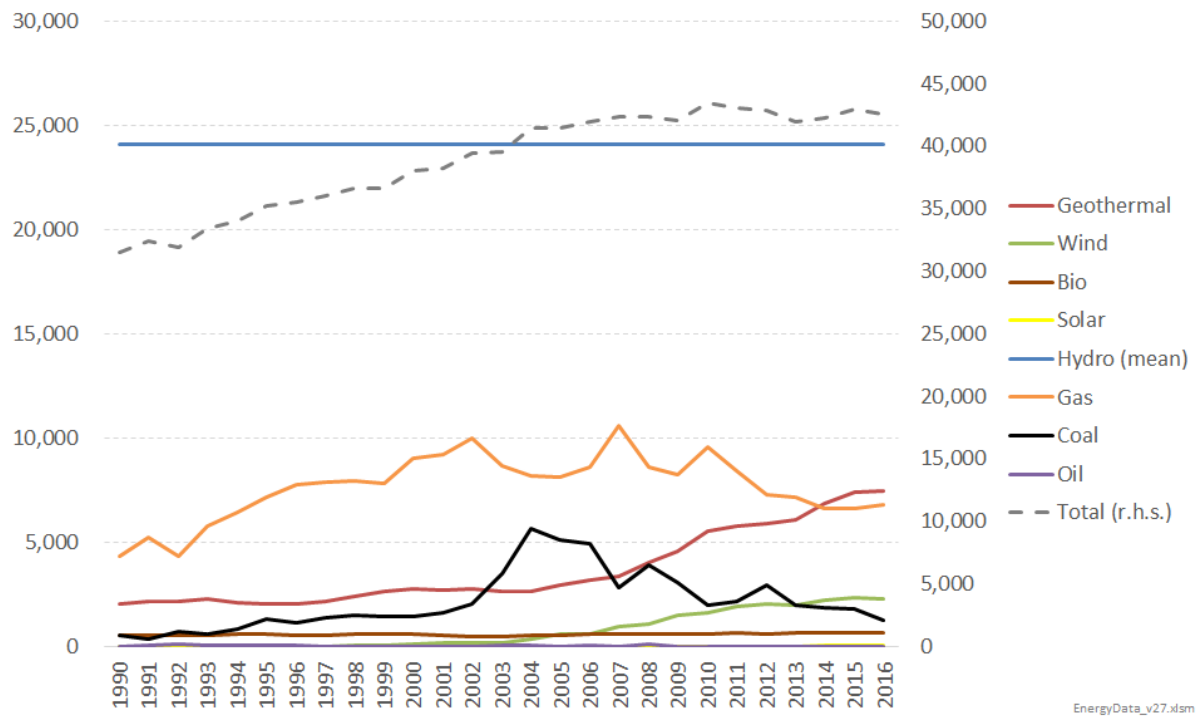
- **2005 to 2010**
  - ***New renewables start to be developed to meet demand growth.*** From the mid-2000s, new renewables (principally geothermal and wind) started to be developed following significant falls in the costs of such technologies (particularly wind), and the aforementioned significant increase in the cost of gas. Only one new gas-fired power station was built in this period – the e3p CCGT (also known as Huntly unit 5), located at the Huntly site. This was commissioned in 2007, but committed to much earlier.
  - ***Some old thermals start to be retired.*** The development of new renewables and new gas-fired power stations meant that some of the older thermals – particularly the New Plymouth and Huntly Rankine stations started to be squeezed out. In particular, the New Plymouth power station started to be progressively retired, a unit at a time, over the period from the early 2000s to 2008 when it was finally closed. Like the Huntly Rankine station, it too was dual-fuelled, but gas and *oil* (rather than coal), so couldn't take advantage of the cheaper coal prices that Huntly could.
- **2010 to present**
  - ***Demand starts to decline.*** After fairly steady average annual growth of 1.5% for the previous 20 years, a number of factors meant that electricity demand actually started to decline from 2010: The global financial crisis, the closure of a major paper mill, the Christchurch earthquake, and energy efficiency improvements. In the same way as fossil generation alters output to meet variations in hydro generation, it was fossil generators who predominantly reduced output in response to this decline in demand. This is because the variable costs of existing renewable generation are much lower than that of fossil generators (who incur a fuel cost), and thus variations in demand are met by variations in high variable-cost fossil generation.
  - ***Some new renewable stations continue to be built.*** Despite demand falling, some new geothermal and wind stations continued to be built and commissioned. These were committed to several years' earlier when expectations of demand growth were much higher than actually transpired.
  - ***More thermal stations are retired.*** This combination of falling demand, and continued renewable build resulted in fossil stations being increasingly squeezed, and the market as a whole having significant surplus generating capacity above its requirements. This resulted in several more fossil generators being retired. Two of the four Huntly Rankine units (one retired and one put into long-term storage) were retired in 2012 and 2015, respectively. The Otahuhu B CCGT was retired in 2015 (only 16 years after it was first commissioned), and the Southdown CCGT was retired in 2016.

## Consideration of possible future changes to greenhouse-emitting power stations in New Zealand

Looking forward, the key questions are will the recent trends of the past five years (illustrated in Figure 63 below) continue? In particular, will renewables continue to be built, not just to meet

demand growth (as occurred in 2005 to 2010), but to continue to displace existing fossil stations (as has occurred from 2006).

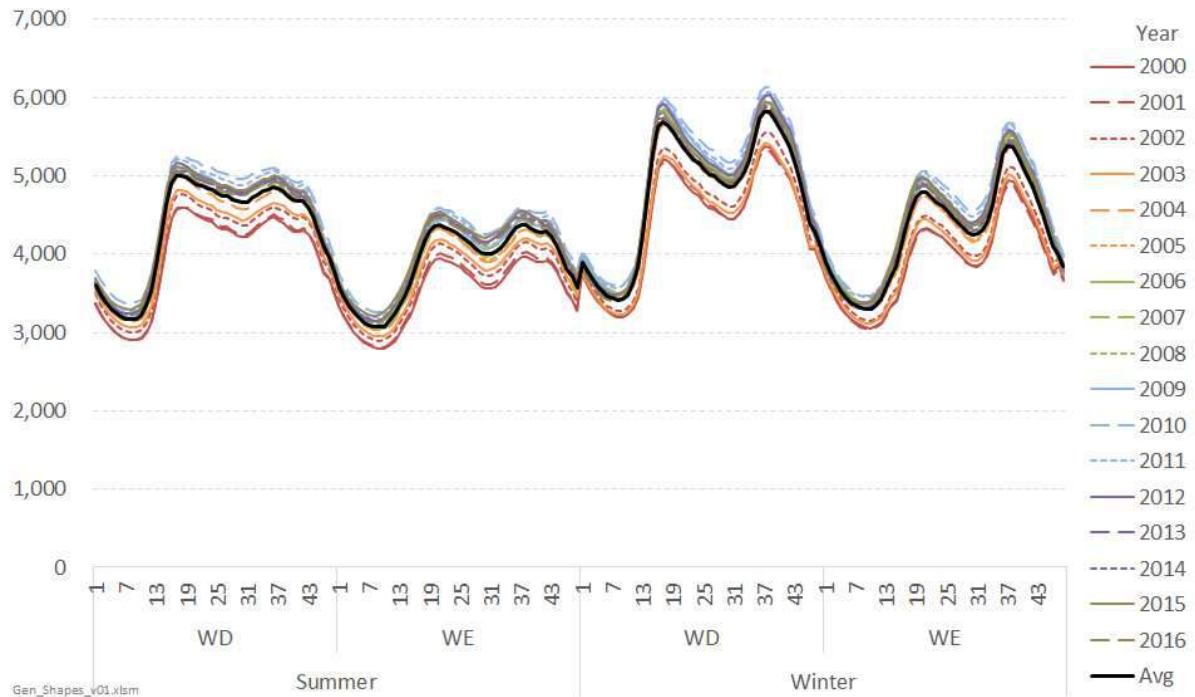
**Figure 63: Historical generation by plant type, correcting for mean hydrology (GWh)**



*To consider this, it is necessary to understand that electricity is an unusual product in that production and consumption must be exactly matched every minute of the day. When combined with the fact that electricity demand varies significantly on a within-day/week and within-year basis (as illustrated in*

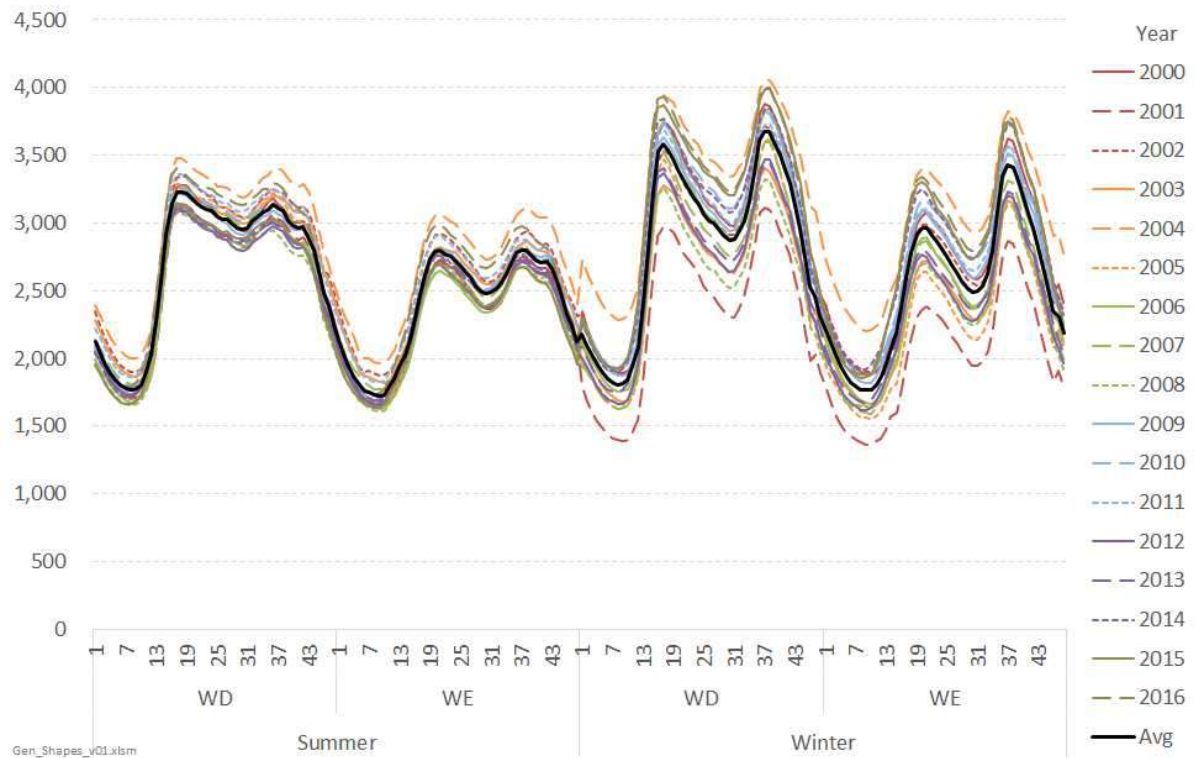
Figure 64 below), this gives rise to a need for some generating capacity to only operate relatively infrequently, when demand is high.

**Figure 64: Average within-day/week and within-year 'shape' of electricity demand (MW)**



New Zealand’s hydro storage lakes have the ability to ‘sculpt’ a lot of hydro generation into these peak demand periods, as illustrated by Figure 65 below.

**Figure 65: Average within-day/week and within-year hydro generation profiles (MW)**



However, there are limits to the ability of New Zealand's hydro fleet to perfectly sculpt their generation into high demand periods:

- There is an upper limit, being the physical capacity of the hydro power stations
- There are significant minimum-flow requirements on the rivers on which all significant hydro generators operate, resulting in an effective minimum generation requirement which much occur, even at times when demand is low.
- Storage capacity is limited for all hydro schemes.
  - For some, so-called 'run-of-river' schemes there is very little storage capacity such that hydro generation varies on a day-to-day basis depending on natural variation in inflows. Depending on the scale of what storage there is, some schemes can perform limited sculpting on a within-week basis (i.e. to generate more on weekdays than weekends), while other can only do limited within-day sculpting (i.e. limited storage overnight for release during the day).
  - A few schemes have seasonal storage (i.e. storage of a scale to enable water to be stored during summer – when demand is low – to be released in winter), but the only scheme with material amounts of seasonal storage is the Waitaki scheme in the South Island.
  - No scheme has storage large enough to handle year-to-year variation in inflows. This contrasts with countries such as Norway which have reservoirs large enough to handle year-on-year variations.
  - These storage limitations, coupled with significant variation in inflows, means that at times hydro generates when demand is relatively low (due to high inflows which can't be stored), and at other times has relatively low generation even when demand is high (due to sustained low inflows which, coupled with minimum flow requirements, results in limited ability to store water for release in high demand periods).

These limitations mean that the hydro fleet can't perfectly sculpt its generation into high demand periods, such that the 'residual' demand for non-hydro generation (i.e. electricity demand minus hydro generation) is flat. Box 1 at the end of this appendix provides further analysis which suggests that hydro generators are limited in their ability to provide significantly more seasonal and within-day/week peaking.

Further, as also illustrated in Figure 65, the significant year-to-year variation in hydro generation gives rise to its own requirement for infrequently-used generation to perform 'hydro-firming' duties.

This results in a residual demand for non-hydro generation which still has a significant amount of variability. This is illustrated in Figure 66 below which shows that there is a residual demand for some non-hydro generation to operate relatively infrequently at times of high demand – i.e. more in winter than in summer, more in weekdays than in weekends, and more during the day than the night – plus also to operate more during sustained dry periods.

**Figure 66: Average residual demand for non-hydro generation (MW)**

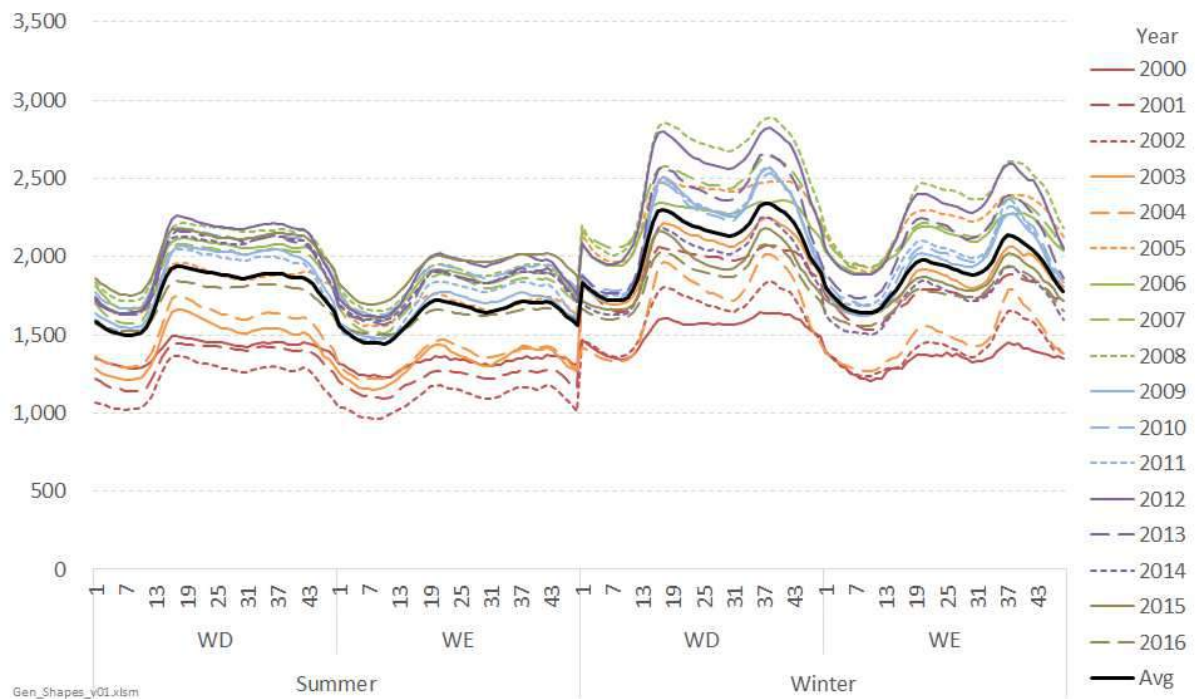
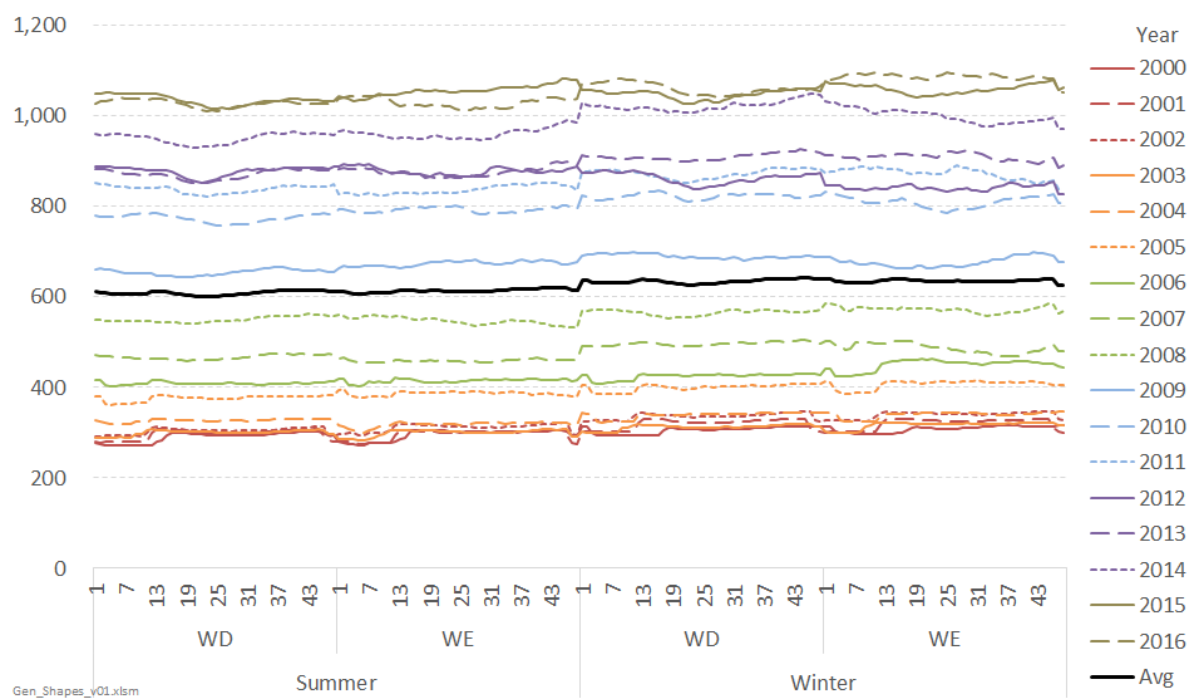


Figure 67 below shows that the other main types of non-hydro renewable generation (geothermal and wind) have made virtually no contribution to meeting this residual demand for *flexible* non-hydro generation – i.e. generation which will vary its output to meet changes in demand and/or hydro generation.

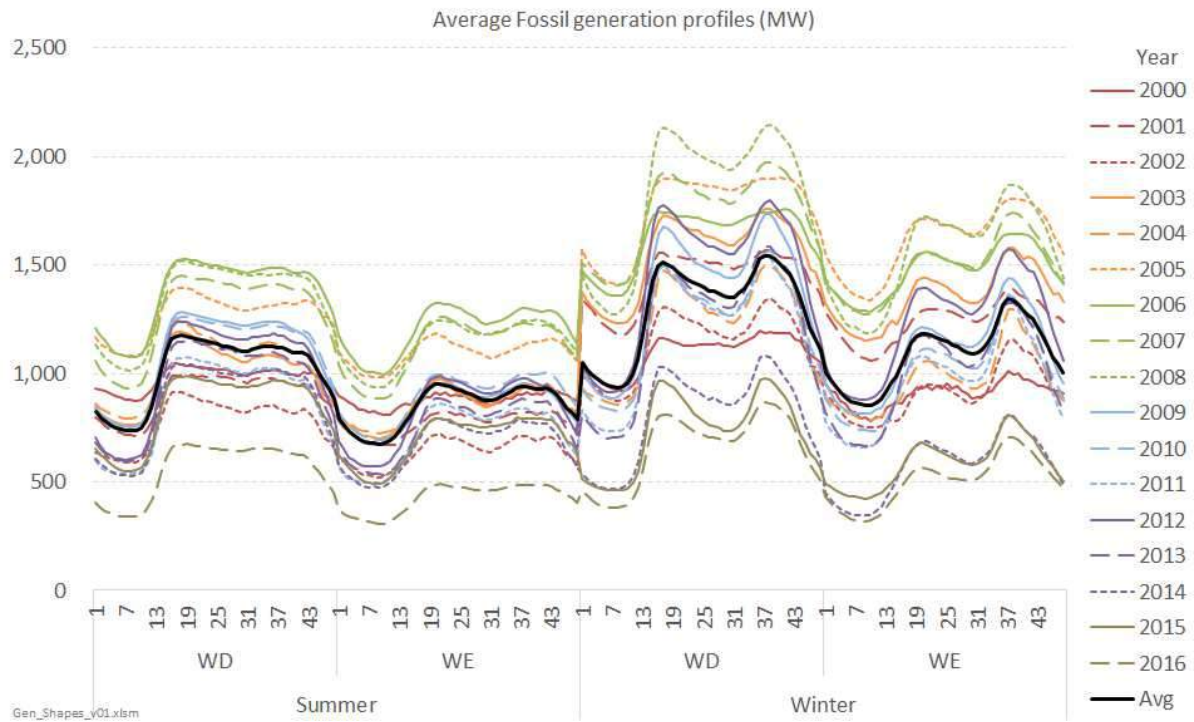
**Figure 67: Average Geothermal + Wind generation profiles (MW)**



Instead, as shown in Figure 68 below, this requirement for flexible non-hydro generation has almost entirely been met by fossil generators



**Figure 68: Average fossil generation profiles (MW)**



Indeed, Figure 68 shows a more benign picture of the need for flexible non-hydro generation than is actually the case. While Figure 68 shows the average within-day/week and within-year requirement for non-hydro generation, it doesn't show the even greater variation that occurs due to demand being greater or less on particular days, as well as day-to-day (and hour-to-hour) variation in output from hydro and wind plant.

This is best illustrated by a duration curve. Figure 69 below stylistically illustrates what a duration curve is. It also illustrates how the different types of plant operation can be given broad classifications: 'Baseload' for plant which operates almost all the time (i.e. 90% to 100%), 'Peaking' for plant which only operates very infrequently (i.e. only 10% or so) at times of greatest demand, and 'Mid-merit' for plant which operates between these two extremes.<sup>44</sup>

<sup>44</sup> There is no hard and fast definition of the capacity factors that apply to these three types of operation. However, the concepts are useful to understand the economics of power station development and operation.



**Figure 69: Illustration of a duration curve**

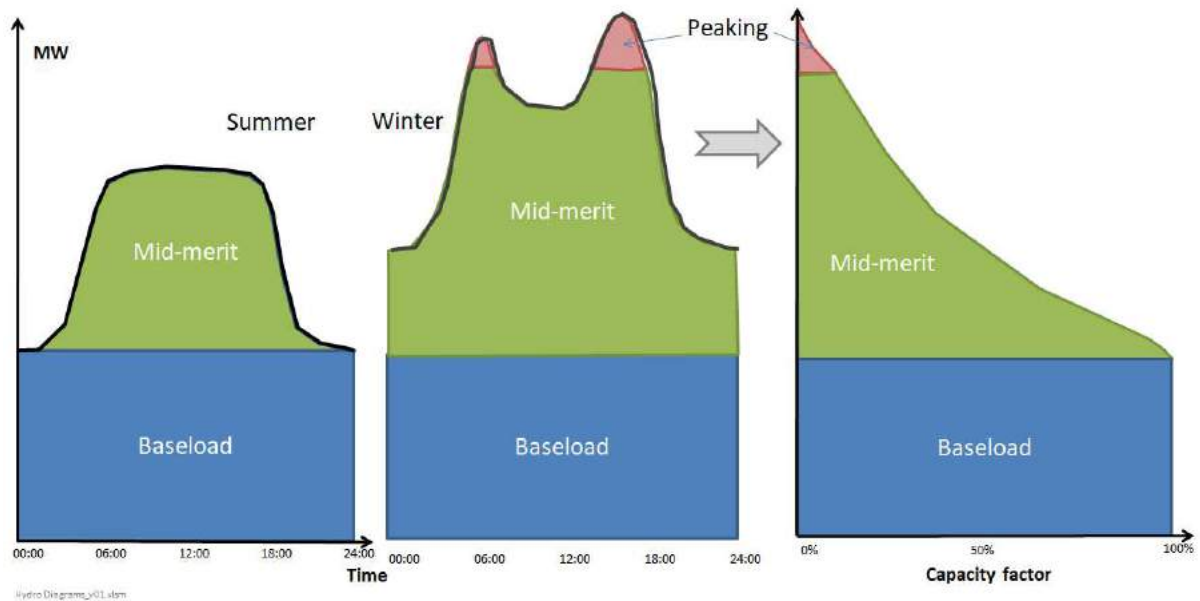
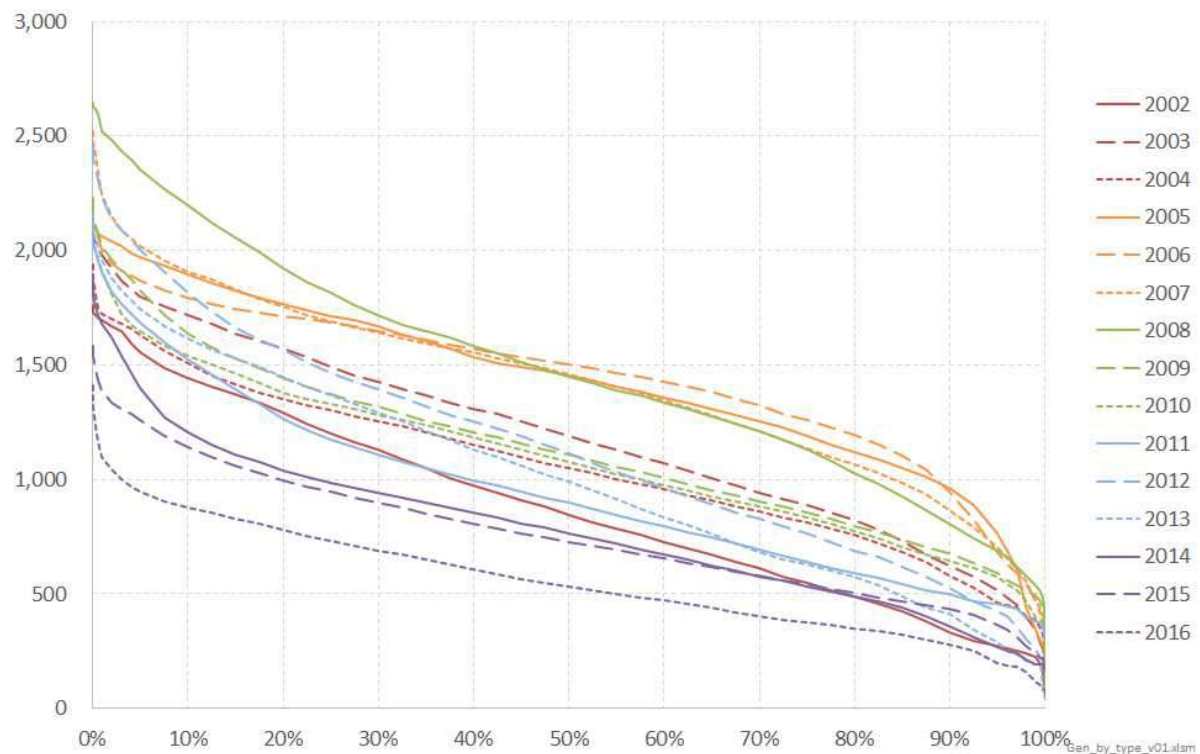


Figure 70 below shows the within-year duration curves of fossil generation. It shows that in 2016 there was a baseload fossil requirement of only  $\approx 200$  MW, but a peaking requirement (i.e. the quantity of generation above the 10% capacity factor level) of approximately 500 MW, and a further 1,000 MW of fossil generation operating at capacity factors between this level.

**Figure 70: Within-year duration curves of fossil generation (MW)**



This figure, and Figure 71 below, also show that while the overall amount of fossil generation required has varied significantly – in particular, a steady reduction from 2006 onwards in the requirement for baseload generation, the requirement for flexible fossil generation (being the mid-merit and peaking fossil generation which doesn't operate all the time), has not changed by as much.

**Figure 71: Comparison between baseload and flexible GWh for all fossil generation**

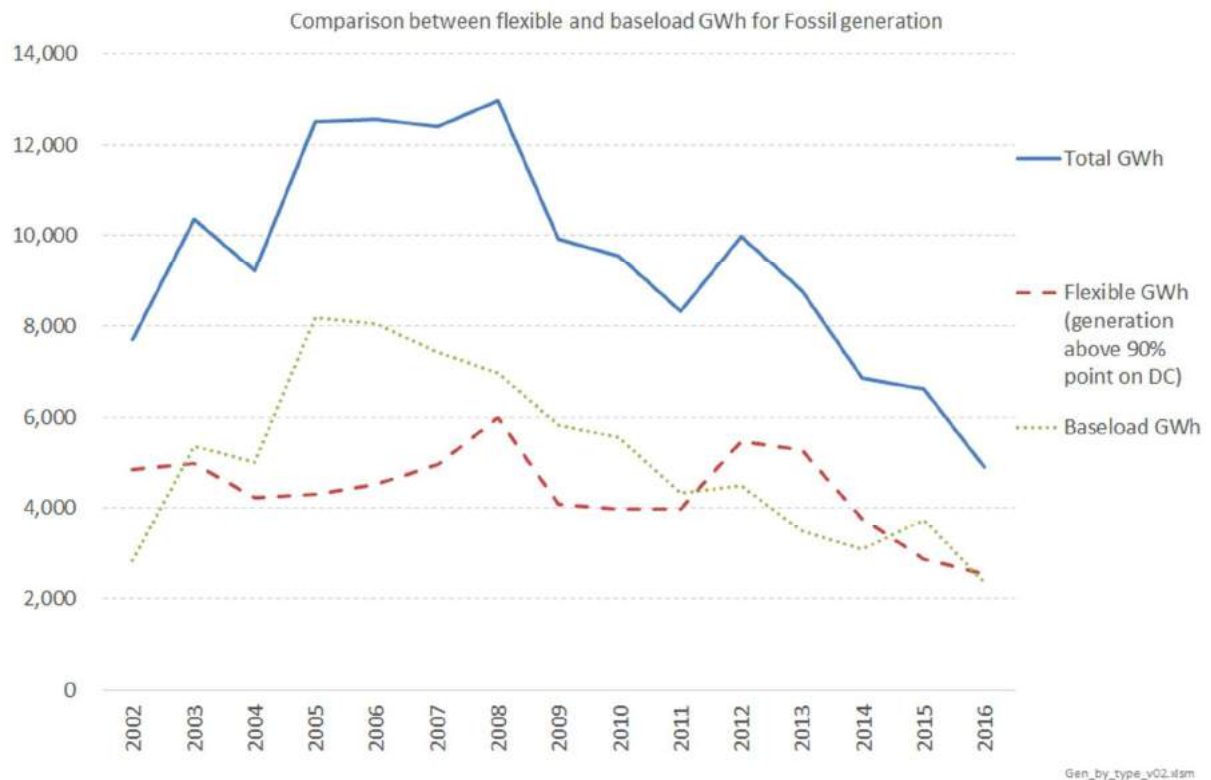


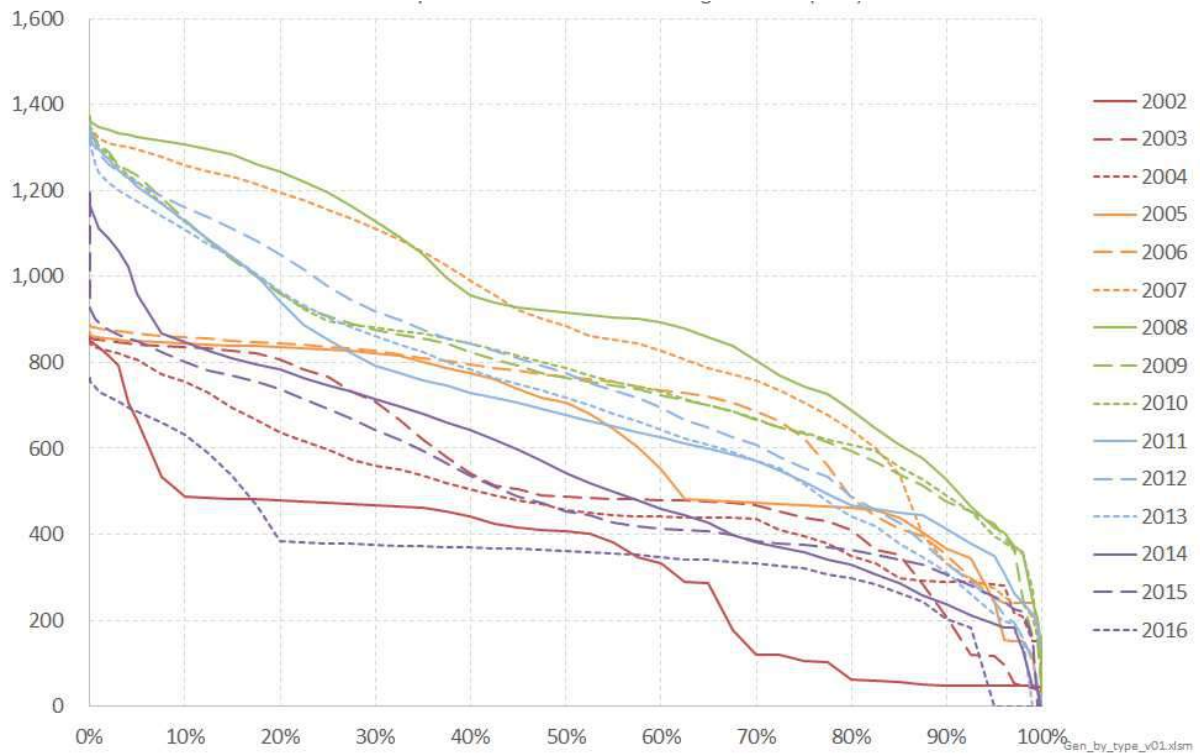
Figure 70 and Figure 71 also illustrate that if significant new renewables are built, and there is no new demand growth, fossil generation will be entirely displaced from baseload operation (i.e. operating all the time), and instead the entire fossil fleet will be operating solely to provide flexible generation – i.e. to meet the periods of high demand that can't be met by hydro 'sculpting', and also to provide 'hydro-firming' services to balance dry / wet periods.

It is also important to understand that there are three main types of fossil generation (the Huntly Rankine units, the CCGTs, and the OCGTs), and that the pattern of generation has been very different between these units.

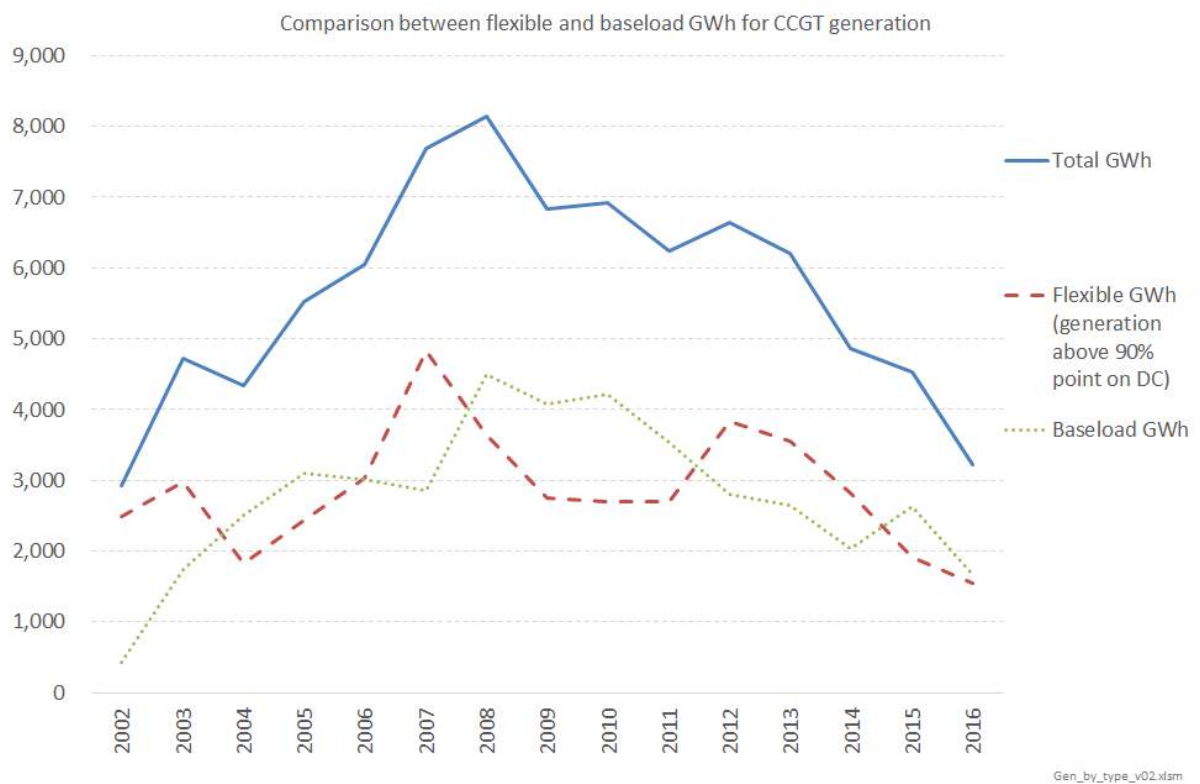
Figure 72 to Figure 77 on the following pages show that

- CCGTs are the only type of fossil generation to continue to provide baseload operation (i.e. some proportion of output operating the entire year), but that in (the relatively wet) year of 2016 it was close to zero. It should be noted that there are two remaining CCGTs, the 400 MW e3p station (a.k.a. Huntly Unit 5) and the 380 MW TCC station.
- The Huntly Rankine units last operated baseload in 2009, and have provided a progressively declining quantity of flexible generation
- OCGTs have never provided baseload generation, but have been progressively increasing the quantity of flexible generation they provide since 2010 – a significant amount of which is 'taking' flexible operation away from CCGTs and the Huntly Rankine units.

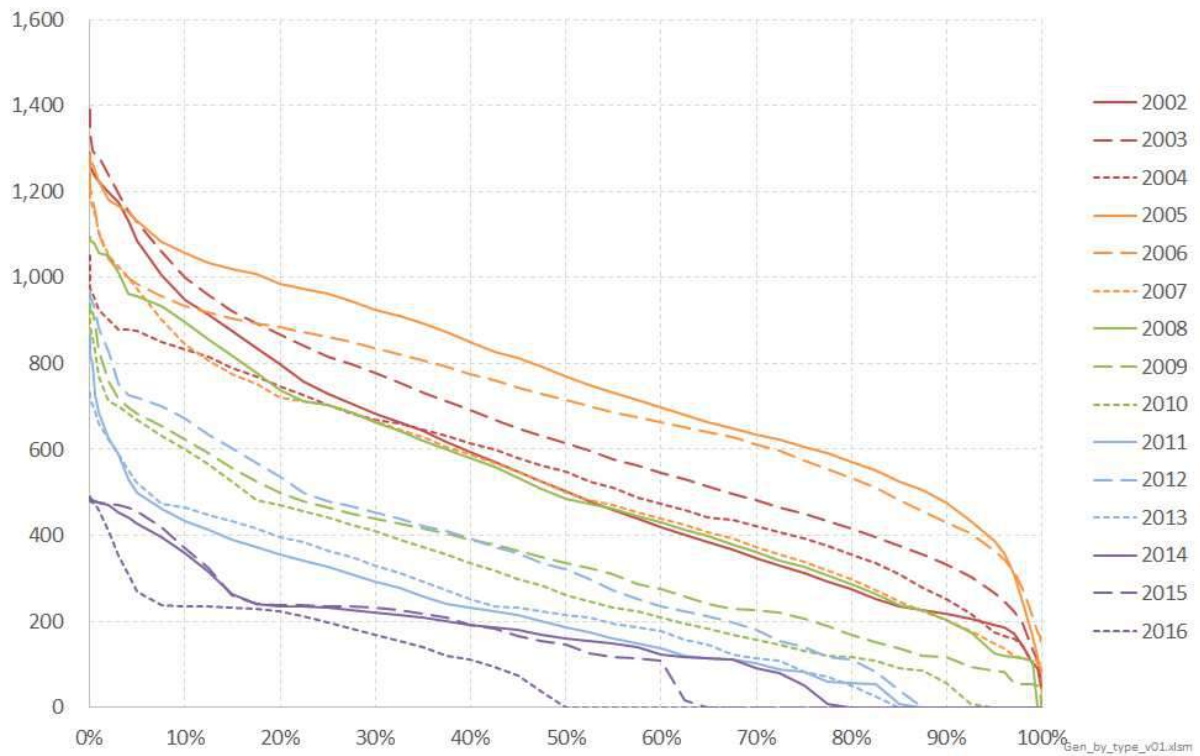
**Figure 72: Within-year duration curves for CCGT generation (MW)**



**Figure 73: Comparison between baseload and flexible GWh for CCGT generation**



**Figure 74: Within-year duration curves for Rankine generation (MW)**



**Figure 75: Comparison between baseload and flexible GWh for Rankine generation**

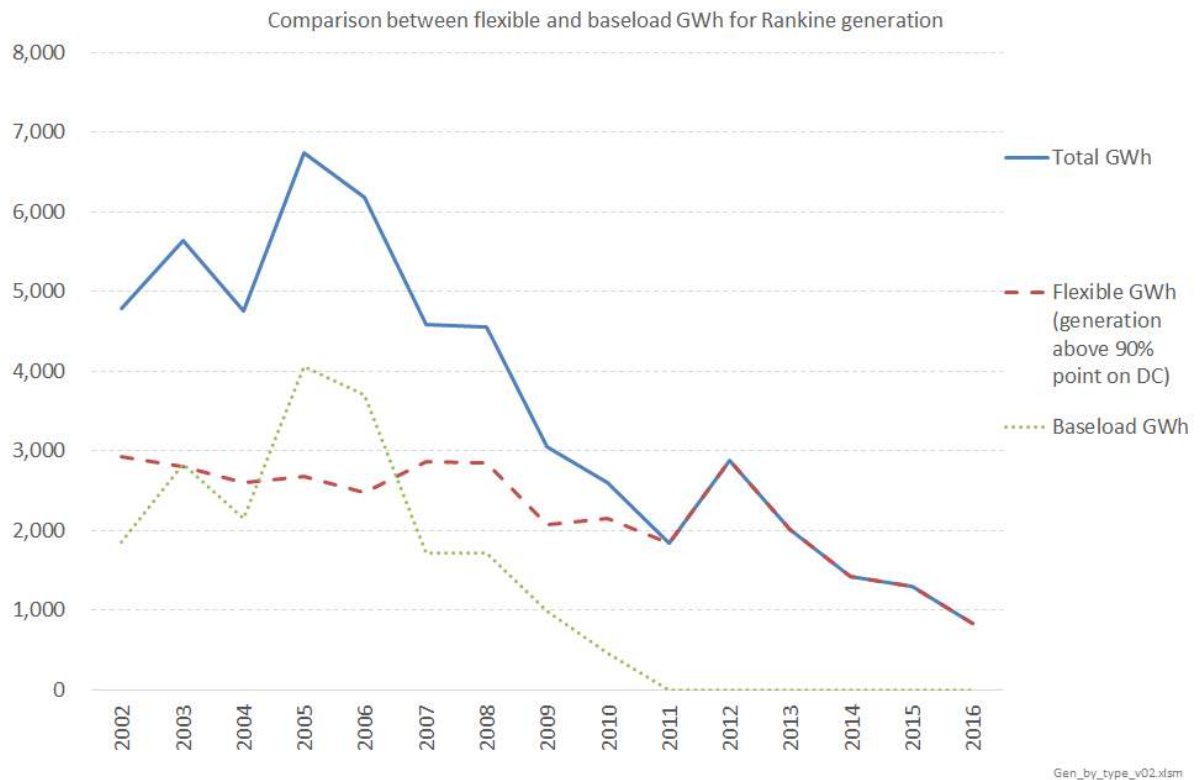




Figure 76: Within-year duration curves for OCGT generation (MW)

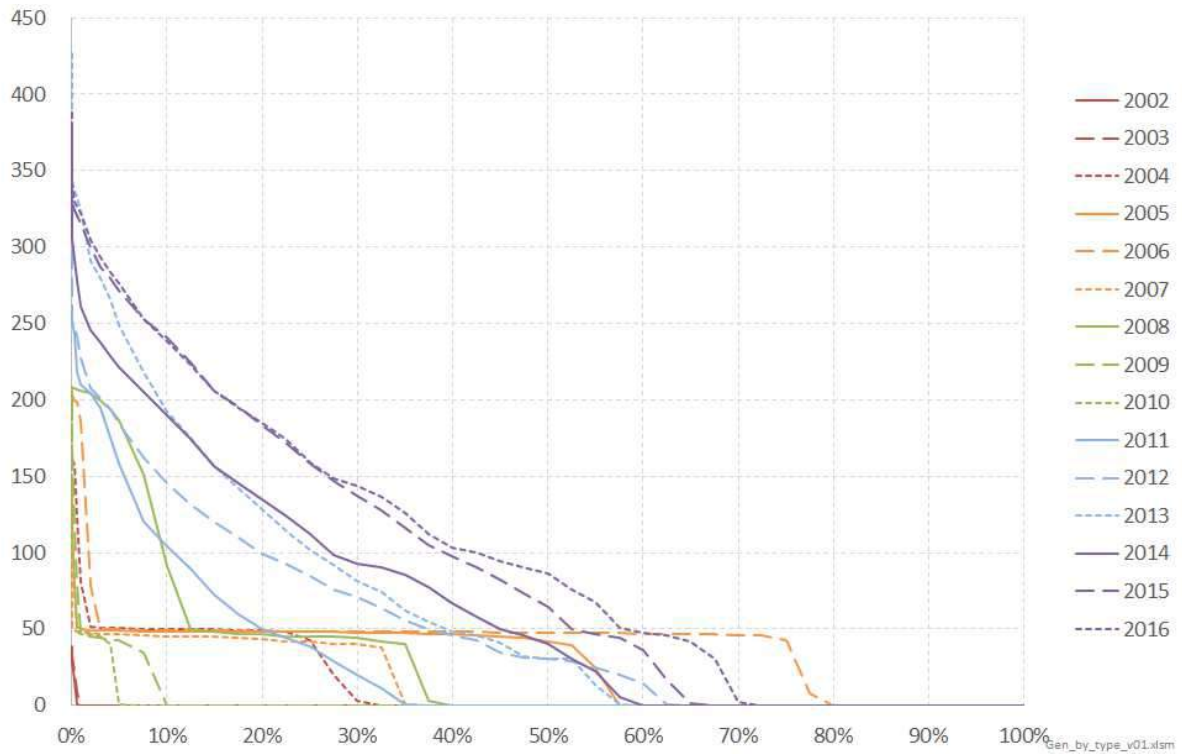
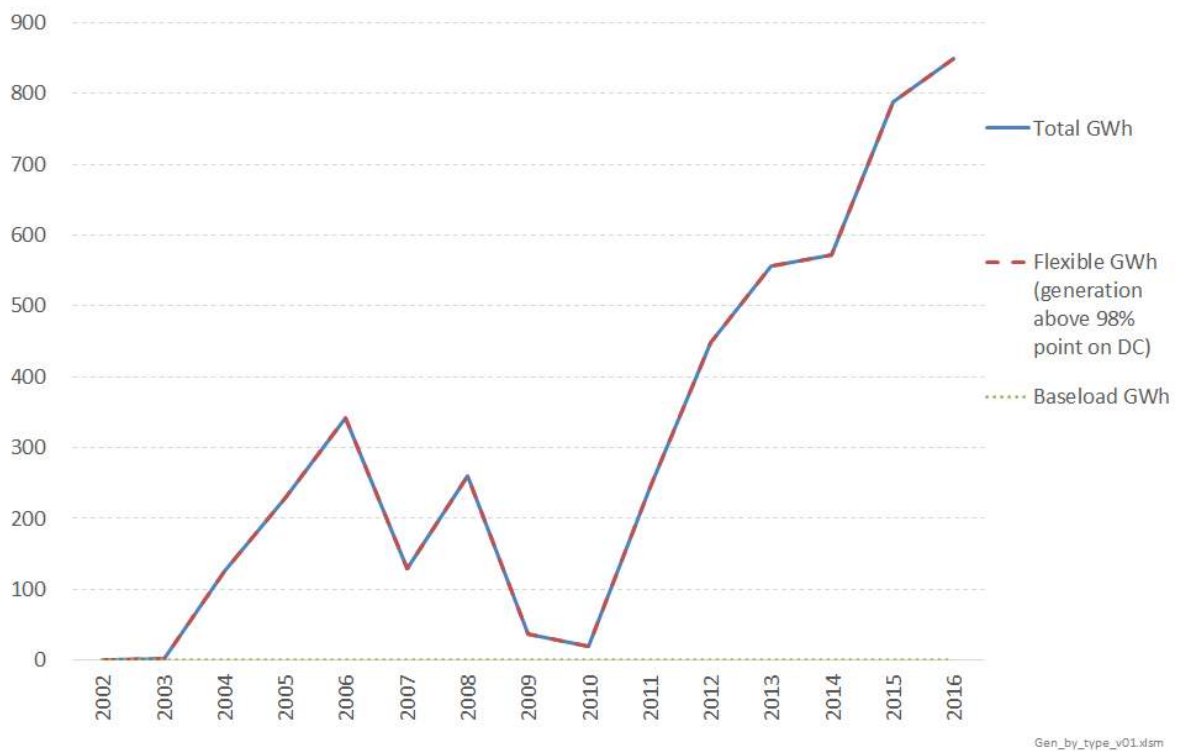


Figure 77: Comparison between baseload and flexible GWh for OCGT generation



The above analysis shows that the level of new renewable build that has occurred over the past six years, coupled with no material demand growth, has resulted in extensive displacement of existing fossil generation, but this displacement has been predominantly from baseload modes of operation.

This displacement has reached the point where only one CCGT (the e3p station) is now operating in a close-to-baseload mode of operation. All the other fossil plant (the TCC CCGT, the remaining two Huntly Rankine units, and the OCGTs) are operating in mid-merit-to-peaking modes for a range of low-capacity factor duties (seasonal peaking, within-day/week peaking, and hydro firming).

If New Zealand is to further reduce greenhouse emissions from the power sector it will be necessary to build more low-carbon power stations to displace existing fossil generation.

With reference to Figure 70 above, absent any demand growth:

- The first 3-400 firm<sup>45</sup> MW of new renewable power stations will be displacing the remaining e3p CCGT from baseload operation.
- Subsequent new renewable power stations will be progressively displacing fossil plant from progressively lower capacity factor operations. i.e.
  - the next 100 firm MW of new renewable plant will only be effectively operating<sup>46</sup> for approximately 85% of the time
  - the next 100 firm MW of new renewable plant will only be effectively operating for approximately 75% of the time
  - and so on.

---

<sup>45</sup> 'Firm' MW refers to the fact that some renewables have only operate for part of the time (e.g. only when the wind is blowing or sun is shining). Thus, over a year, a 10 MW wind farm may only produce as much electricity as a 4.45 MW generator operating full time, and a 10 MW solar farm may only produce as much electricity as a 1.5 MW generator operating full time.

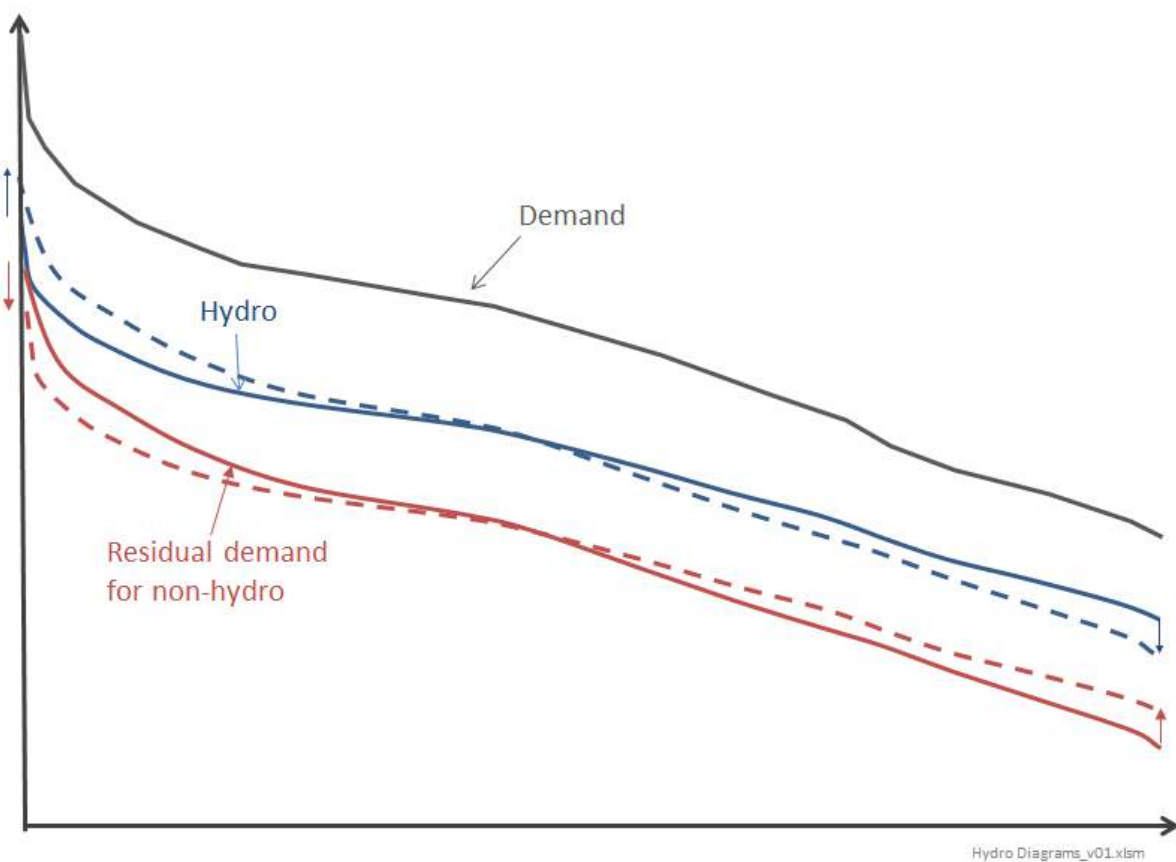
<sup>46</sup> The phrase 'effectively operating' means that for other times, the energy the plant will be producing will be surplus to requirements and will be 'spilt' (or will cause some other renewable station to spill its energy). This assumes that the existing hydro fleet is unable to materially alter the pattern of storage and release decisions to sculpt even more water away from low demand periods, and into high demand periods. This is based on analysis presented in Box 1 on page 35.

**Box 1: Can hydro generators do materially more sculpting?**

As mentioned previously, one of the constraints on the development of additional renewables is that their capital intensity makes them relatively expensive options (compared to relatively low capital cost fossil plant) to operate at low capacity factors.

One potential option to accommodate more must-run renewables (e.g. wind, geothermal and solar) is to ‘sculpt’ hydro generation even more away from periods of low demand into periods of high demand, thereby flattening the residual demand curve for non-hydro generation, and increasing the proportion of the residual demand for non-hydro generation which could be met by high capacity-factor generation. This is illustrated in Figure 78 below.

**Figure 78: Schematic representation of effect of ‘sculpting’ more hydro generation away from periods of low demand to periods of high demand**



However, as set out on page 93, there are significant limitations on the ability of hydro plant to store water at times of low demand to release at times of high demand:

- Physical generation capacity limits
- Minimum flow requirements on rivers
- Limited storage volumes
- Significant variations in hydro inflows

As such, it appears that hydro generators are already operating their schemes in such a way as to optimise the storage and release to sculpt water away from periods of low demand into high demand.



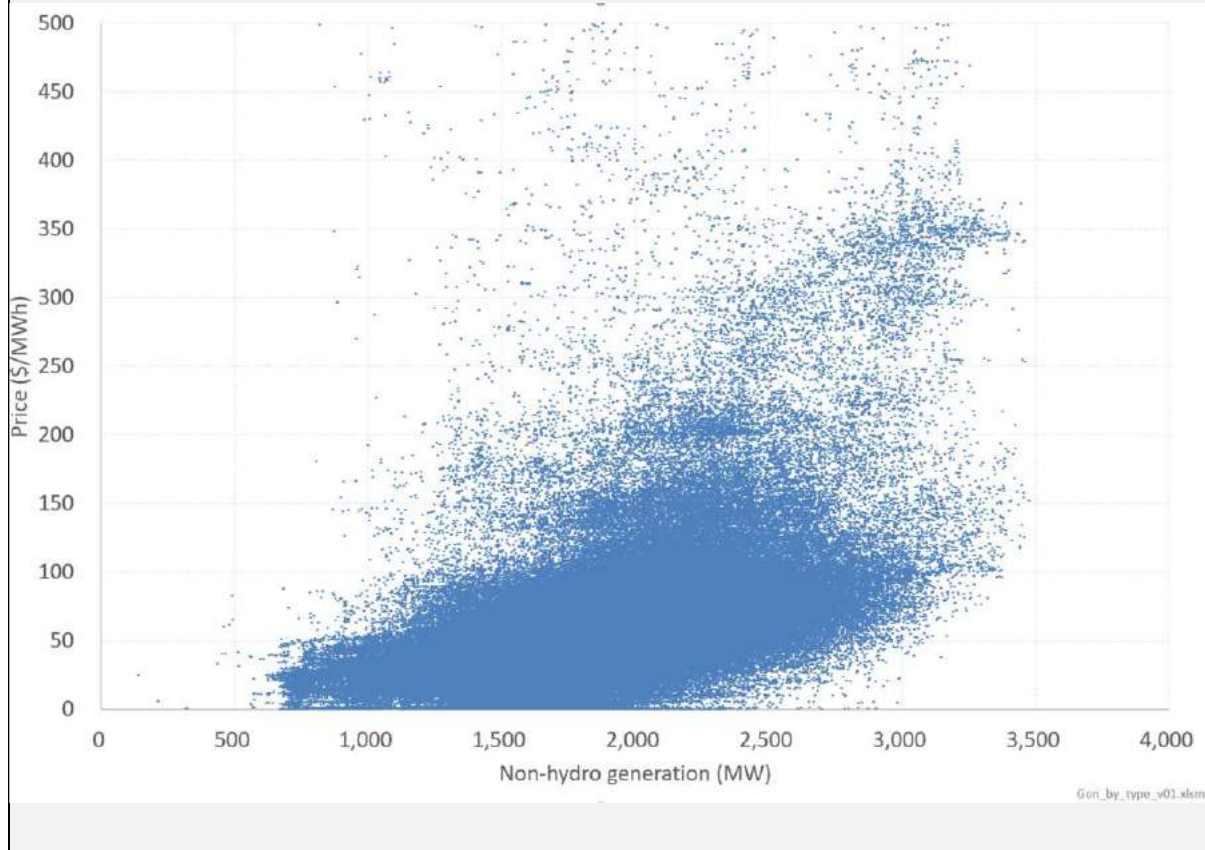
Therefore, it is considered there is little prospect of hydro generators being able to store more in summer for release in winter, or store more overnight for release during the day and peak, than they are already doing.

This is indicated by the persistent observed price differentials between periods of relatively high residual demand for non-hydro generation and periods of relatively low residual demand for non-hydro generation. This is shown in Figure 79 and Figure 80 below.

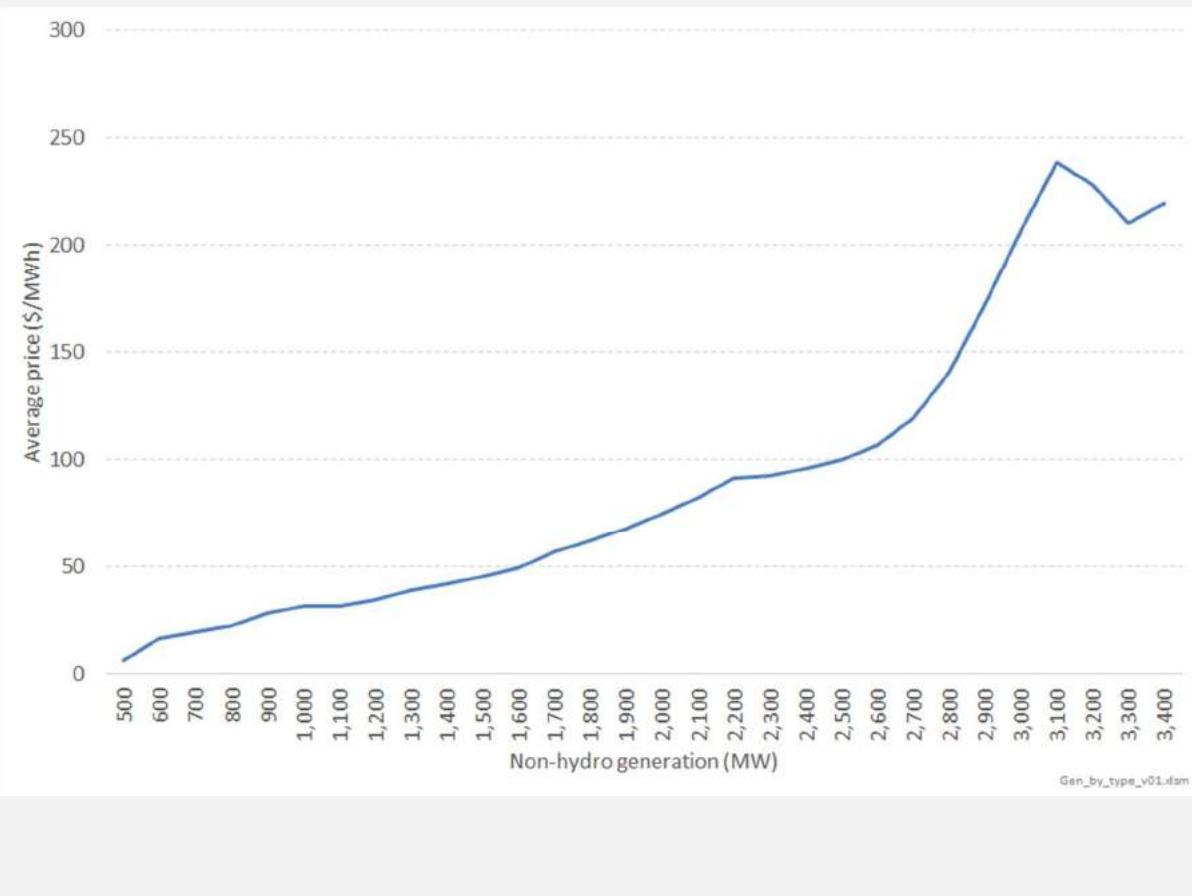
Thus, if hydro generators were unconstrained in their ability to store water in order to release at times of highest value, you would not see the pattern shown in Figure 79 and Figure 80. Instead, there would be little relationship between the residual demand for non-hydro generation and wholesale prices, as the optimal storage and release decisions would arbitrage such price differentials away.

However, the fact that there are these persistent, significant price differentials is indicative of the constraints hydro generators face to materially optimise their storage and release decisions any more than they are already doing.

**Figure 79: Historical pattern of wholesale prices in relation to the residual demand for non-hydro generation for the period 2000 to 2016**



**Figure 80: Average relationship between residual demand for non-hydro generation and wholesale prices for the period 2000 to 2016**



## Appendix B. Costs of land transport

### Transport externalities.

Key externalities in the provision of transport services are:

- Global warming – to the extent that the societal costs of greenhouse gas emissions (principally CO<sub>2</sub>) are not reflected in the fuel costs of the different transport options
- Human health.
  - Respiratory illness and mortality arising from local air quality degradation from other combustion-engine emissions (particularly NO<sub>x</sub>, CO, and particulates).
  - *Positive* human health benefits from cycling and walking, (e.g. reduced obesity, and general cardio-vascular health improvements).
- Congestion. There are two key congestion externalities:
  - The costs of road-building to provide peak network capacity not being directly passed-on to those users of the road network at such times and in those geographic locations. Instead, these costs are generally smeared across all road users through petrol excise duty / RUCs (in the case of state highways) and local rates (in the case of regional roads).
  - Reduced productivity due to people and goods taking longer to move from place to place.
- Land cost. For example, residents parking allowances not reflecting the true cost of the land associated with providing these parking spaces.
- Noise from traffic reducing the quality of life for people living or working close to major roads.
- Accidents from vehicles causing injury or death.

Each of these costs are considered below.

### *Greenhouse externalities*

Although New Zealand has an emissions trading scheme with a cost of CO<sub>2</sub> that now flows through to fuel prices, it is generally considered that the level of this cost is substantially lower than the ‘true’ societal cost of CO<sub>2</sub> emissions:

- At the very least, the one-for-two requirement<sup>47</sup> under the current emissions trading scheme effectively halves the cost of CO<sub>2</sub> seen by end-users who consume petroleum fuels.
- Even once the one-for-two requirement is removed (as is currently planned by the government), it is potentially the case that the price of NZUs is substantially lower than the ‘true’ societal cost of greenhouse emissions. Thus, NZUs currently cost approximately NZ\$16.5/tCO<sub>2</sub>-e (≈ US\$12/tCO<sub>2</sub>-e). This contrasts with various international studies which put the societal cost of CO<sub>2</sub> anywhere between US\$40 to US\$220/tCO<sub>2</sub>-e (NZ\$55 to NZ\$300/tCO<sub>2</sub>).<sup>48</sup>

Taking the combined effect of both the one-for-two factor, plus the current low price of NZUs, price of CO<sub>2</sub> faced by transport users needs to rise anywhere between 9 and 50 times in order to reflect the true societal cost of their emissions.

This range of CO<sub>2</sub> prices is used in the analysis to estimate the cost of greenhouse emissions from the various modes of transport.

<sup>47</sup> Fuel suppliers must surrender one New Zealand emissions unit (NZU) for every two tonnes of CO<sub>2</sub>-e in the fuel they supply.

<sup>48</sup> For example, refer: <http://news.stanford.edu/2015/01/12/emissions-social-costs-011215/>

## Human health externalities

### Respiratory conditions

There is growing awareness of the respiratory illnesses associated with degraded local air quality from exhaust emissions. Four pollutants are considered to cause respiratory illness: Carbon monoxide (CO), hydrocarbons (HC), Nitrous oxides (NO<sub>x</sub>), and particulates (PM<sub>10</sub>). Increasingly, it appears that greatest harm arises from PM<sub>10</sub> emissions.<sup>49</sup>

The two most significant studies of the human health costs of transport emissions are:

- “Updated Health and Air Pollution in New Zealand Study”, March 2012. This study estimated the human health costs of transport emissions to be \$950m per year.
- Surface Transport Costs and Charges Study, March 2005. This study estimated the human health costs of transport emissions in 2001/2 to be \$600m per year.

If both estimates are updated to a ‘present value’, taking into account increases in population and CPI since the estimates were calculated, this gives rise to a 2015/16 estimate of \$1.1bn and \$1.3bn, respectively. For the purposes of this study, a central estimate of \$1.2bn/year is used.

This cost has been simply apportioned between petrol and diesel vehicles in proportion to their relative emissions of PM<sub>10</sub>. According to Ministry of Transport data on median PM<sub>10</sub> emissions from light vehicles in Auckland<sup>50</sup>, diesel vehicles emit approx. 6.5 times more PM<sub>10</sub> than petrol vehicles.

Using this factor, and reported land transport diesel and petrol consumption for 2015, this gives rise to a health cost of 7 c/litre for petrol, and 44 c/l for diesel.

Using average fuel economies for petrol and diesel light passenger vehicles this gives rise to a respiratory health cost of 0.7 and 5.1 c/km, respectively.

Although this is relatively high-level and simplistic, it is considered a reasonable approach for producing first-order estimates of this health externality.

### Improved human health from exercise

New Zealand’s health sector is facing increasing costs associated with obesity and poor cardio-vascular health. Lack of exercise has been identified as a significant contributory factor.

Walking or cycling instead of using motorised transport has been identified as significantly improving individuals’ weight and cardio-vascular health, and is starting to be considered internationally in cost-benefit analyses for cycling and walking infrastructure developments.

For example, one study in London estimated that if every Londoner switching to walking for trips under 2 km, and to cycling for trips of 2-8 km, the share who got enough exercise to remain healthy simply by getting around would rise from 25% to 60%.<sup>51</sup> i.e. the number of people not getting enough exercise to remain healthy would halve.

In New Zealand, a recent study by the University of Auckland has estimated that obesity costs the country approximately NZ\$800m/year in health and productivity costs.<sup>52</sup>

<sup>49</sup> For example, the 2012 study “Updated Health and Air Pollution in New Zealand Study” states that “the majority of health effects in New Zealand are associated with this pollutant”.

<sup>50</sup> <http://www.transport.govt.nz/ourwork/tmif/publichealth/ph002/>

<sup>51</sup> The Economist, 5-Sep-2015.

<sup>52</sup> <https://www.fmhs.auckland.ac.nz/en/faculty/about/news-and-events/news/2012/12/11/the-cost-of.html>

Ministry of Transport statistics indicated that 38% of road-based trips of less than 2km are undertaken on foot, but only 2% of road-based trips of less than 5 km are undertaken by bicycle.<sup>53</sup>

Using the above statistics as building blocks, a high-level estimate is that approximately 25% of the obesity-related costs in New Zealand are from individuals driving a car, rather than walking or cycling.<sup>54</sup>

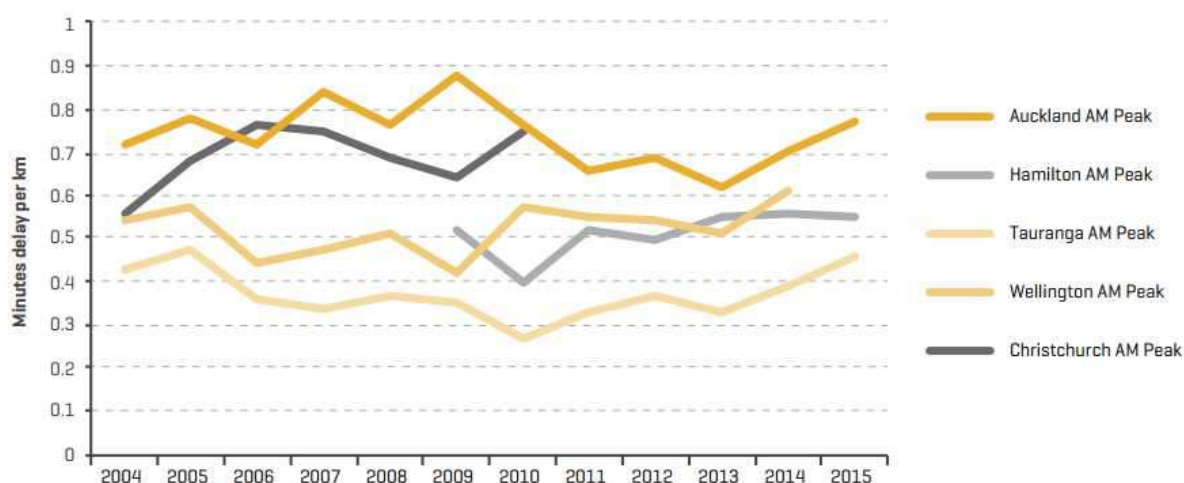
Dividing this \$200m cost by the estimated number of kilometre travelled by private vehicles for trips < 6 km long<sup>55</sup> gives a 'lack-of-exercise' cost of approximately 1.2 c/km for driving a car when the journey could have been undertaken on foot or by bicycle. (0.6 c/km across all kilometre driven by cars)

### Congestion externalities

Congestion imposes costs on society through delaying the transport of people and goods. A 2005 study for the Ministry of Transport<sup>56</sup> estimated the lost productivity and value of time for individuals and commercial vehicles stuck in traffic was \$1bn in 2001/2.

The most recent Ministry of Transport statistics indicated that the levels of congestion (as measured by minutes delay per kilometre during peak morning periods) have broadly remained stable, as shown in Figure 81 below.

Figure 81: AM peak congestion - minutes delay per kilometre



Source: Ministry of Transport Annual report 2015/16

Although minutes delay per kilometre has broadly remained stable over the past 15 years, both population and CPI have increased by a significant amount over that time. Updating for these factors gives a 'present value' congestion cost of approximately \$1.7bn.

In terms of attempting to project future congestion costs, a very simple approach has been taken:

- The \$1.7bn estimated costs of congestion for 2016 was divided by observed total VKT for 2016 to give a congestion cost per kilometre

<sup>53</sup> <http://www.transport.govt.nz/research/travelsurvey/data-and-spreadsheets-household-travel-survey/>

<sup>54</sup> Public Transport is not included in this, as Ministry of Transport data indicates that people who regularly use public transport walk twice as far as those who never use public transport.

<sup>55</sup> Household travel survey data indicates 48% of driver trip chains are < 6 km long.

<https://www.nzta.govt.nz/assets/resources/travel-planning-toolkit/docs/resource-1-facts-and-figures.pdf>

<sup>56</sup> "Surface Transport Costs and Charges", Ministry of Transport, March 2005

- This per kilometre congestion cost is multiplied by projected total VKT for future years.

This approach will reward mode shifts that reduce the number of vehicles on the road (e.g. increased public transport, walking, cycling, and car sharing), but not be affected by fleet changes to electric vehicles.

### *Land cost*

A significant amount of urban land area is given over to the motor vehicle. A significant proportion of this is taken up by parking.

While users of some types of parking may face close to the full economic cost of such parking (e.g. users of a commercial multi-storey car-park will pay fees which include the land cost of such a facility), much of the on-street parking is provided at considerably below cost.

This is particularly the case for residents parking.

Metered parking in Wellington city costs approximately \$4/hr, both for kerbside and for many commercial car parks in flat open parking lots. Assuming such parks are filled from approximately 10 hrs per day, this gives a cost of \$40/day.

This contrasts with resident parking permits of \$115/yr (30 cents/day). This is 125 times less than the cost charged for metered parking in Wellington.

Another simple calculation looking at land values for properties in Wellington suburbs suggests that the land associated with a residents parking space is worth \$1,000/yr.

Assuming the population-weighted average land cost is 2/3 of that in Wellington, this gives a land cost associated with residential parking of \$500/year/car. This is considered conservative, given that land cost in Auckland is higher than that of Wellington.

Taken together, this suggests that residents parking is being significantly under-priced.

This matters for two reasons.

- Firstly, the availability of 'cheap' residential car parking encourages excessive car use beyond—for example, as evidenced by Japan where residents parking is charged based on market rates, and where rates of car ownership and use are much less; and
- Secondly, in many cases residential parking is frustrating the development of far more efficient uses of scarce road space, such as bus lanes or cycle lanes.

### *Noise*

In its March 2009 report, "Understanding transport costs and charges: Phase 2 – Social and environmental costs", the Ministry of Transport estimated the social costs from traffic noise (in terms of reduced quality of life from living and working near to roads, and the costs of mitigation) in 2003 was \$101 million. It further presented data which indicated that the noise cost from heavy fleet vehicles (trucks and buses) was five times greater on a per kilometre driven basis than that from light vehicles.

Using this data, and reported VKT for both the heavy and light fleet for 2003, an estimated noise cost per kilometre travelled was calculated for both heavy and light vehicles. This value was used to estimate the noise cost for future years, based on projections of VKT, and CPI-adjusting to 2016 dollars.

This approach will reward mode shifts that reduce the number of vehicles on the road (e.g. increased public transport, walking, cycling, and car sharing).



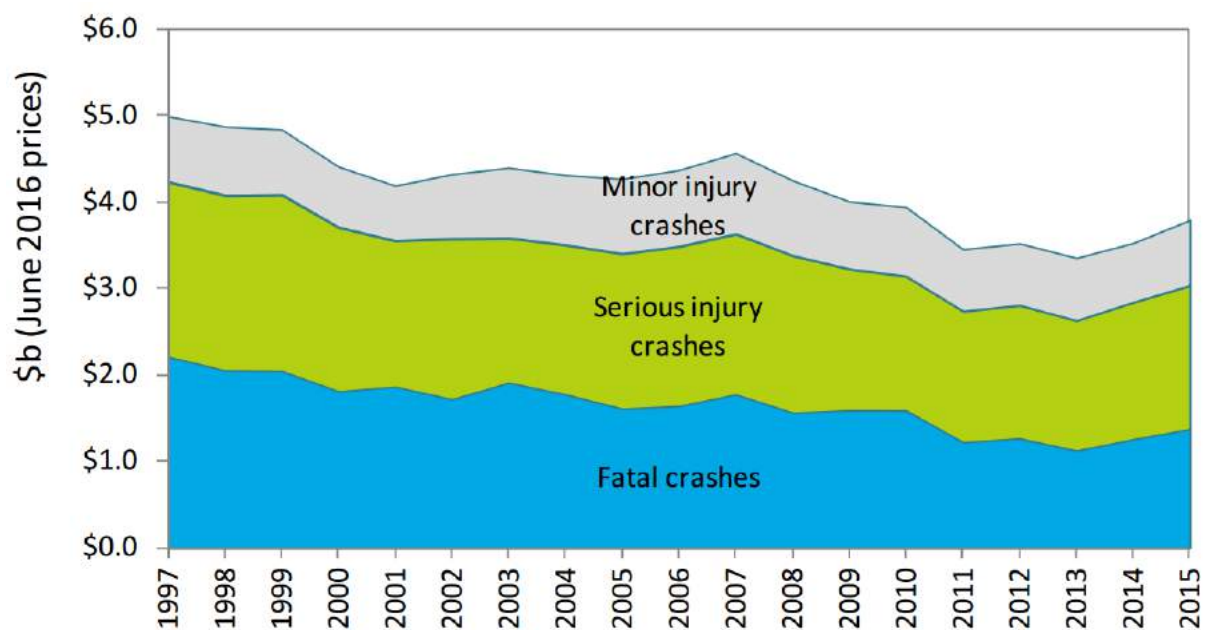
The fact that electric motors are quieter than combustion engines was taken into account by factoring the noise per kilometre cost for EVs to be 75% of that for internal combustion engine-driven vehicles.

### Accidents

In its March 2017 report, “Social cost of road crashes and injuries – 2016 update”, the Ministry of Transport estimated the total social cost of crashes involving injury in 2015 to be \$3.79 billion. Approximately \$1.3 billion was from crashes involving fatalities, \$1.7 billion from serious injury crashes, and a further \$0.8 billion from minor injury crashes.

As the following graph from this report indicates, this was a higher cost than in the previous two years, but significantly lower than from seventeen years’ ago.

**Figure 82: Estimated annual total social cost of injury crashes, by crash severity (\$ billion, at June 2016 prices)**



The detail of this report indicates that only 4.8% of this cost was due to vehicle damage, with the majority of cost being due to the value of lost life and reduced quality of life from those individuals suffering injury.

This report further indicated that there was an additional \$0.66 billion of cost from non-injury crashes – presumably due to vehicle damage – with the report noting that there were many non-injury crashes than injury crashes.

In terms of projecting this likely cost going forward, a simple approach has been taken:

- an accident cost per VKT was estimated (being the reported 2015 cost of accidents, divided by the reported total VKT across all motorised modes of road transport)
- this value was then used to project the cost in future years based on the projected VKT for future years.

This approach will reward mode shifts that reduce the number of vehicles on the road (e.g. increased public transport, walking, cycling, and car sharing), but not be affected by fleet changes to electric vehicles.



### *The social dimension of transport externalities*

Many of the above aspects of car travel, have a regressive social dimension, in that the externality costs fall disproportionately on poorer individuals. This is because, as shown in XX below, people in the lowest income decile are significantly less likely to own a car than those in the higher income decile.

Thus, they suffer the externalities caused by others owning and driving vehicles – particularly local air pollution affecting health, travel delays caused by congestion, and the costs of road space being taken up for parking which could be more productively used for public transport or cycling.

## Appendix C. Solar PV

### Introduction

Unlike the other technologies evaluated in this study, solar panels are not an energy *service* per se, but rather provide an alternative means of *generating* the electricity (which can then be used to provide an end service).

This section compares the cost and emissions consequences of rooftop solar panels versus the principal alternative means of supplying consumers with electricity – i.e. grid-scale generation supplied over the transmission and distribution networks.

The information in this appendix is drawn largely from Concepts earlier work on solar PV across three studies looking at the economic, environmental, and social impacts of new technologies.<sup>57</sup>

### The cost of solar PV

There are four main components to the up-front costs of a rooftop PV system for consumers:

- The costs of the panels
- The costs of the inverter used to convert the direct current (DC) power generated by the panel into the alternating current (AC) power that is supplied into consumers' homes.
- The costs of installing the system. This includes the cost of labour and other materials (cabling and metering), and the costs of getting council and electricity network company approvals.
- Goods and services tax (GST).

Most of these costs broadly scale with the size of system, while some (e.g. council approvals, and some aspects of the labour costs) don't vary much with the size of the system. Figure 83 shows the estimated overall cost to consumers of installing different-sized rooftop PV systems, based on current prices. The fact that some costs are fixed means that there are economies of scale with rooftop solar PV – as indicated by the downward sloping nature of the curve which expresses the costs on a \$ per Watt basis.

The 'replacement inverter' cost item is to take account of the fact that most systems will need their inverter replacing approximately half-way through their life. The replacement inverter cost is the estimated 'present value' of this cost which is likely to occur in ten years' time.

The cost estimates shown below are based on advertised retail costs for so-called 'grid-tie' PV systems. These costs include an estimate of the installation and inspection fees charged in most regions when installing solar PV.

As well as evaluating solar PV based on current costs, we have considered the benefits of installing solar PV in future years given that solar PV costs are expected to continue to decline. Our central estimates for further cost reductions are:

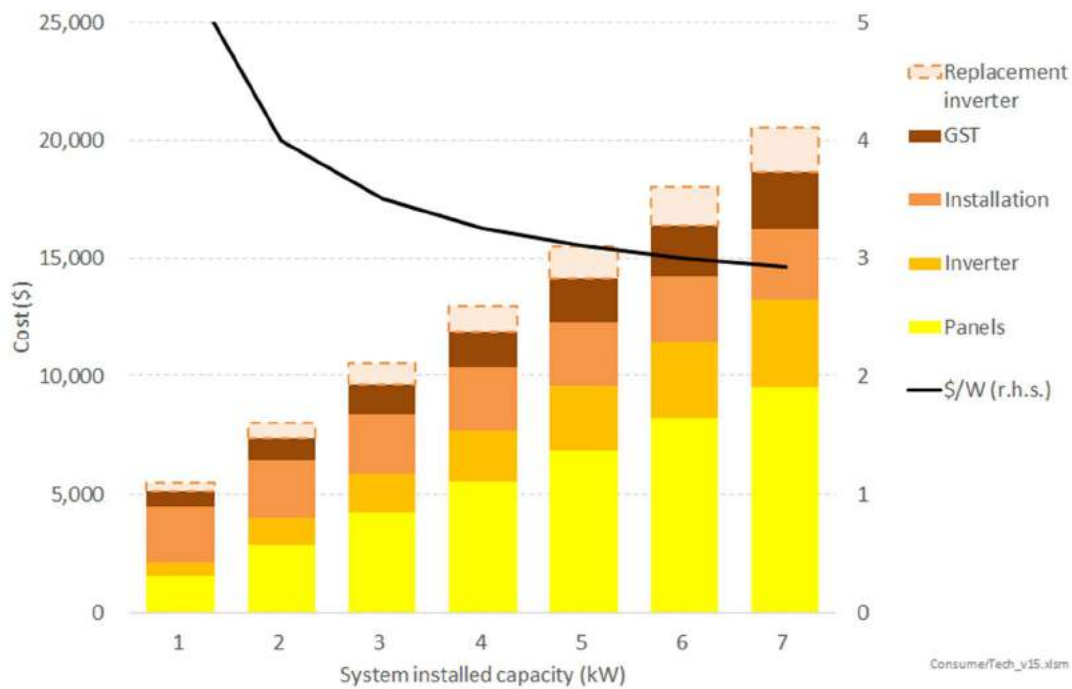
- Panels = 7% p.a.<sup>60</sup>
- Inverters = 3% p.a.
- Installation = 3.5% p.a.

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<sup>57</sup> These reports are available at:

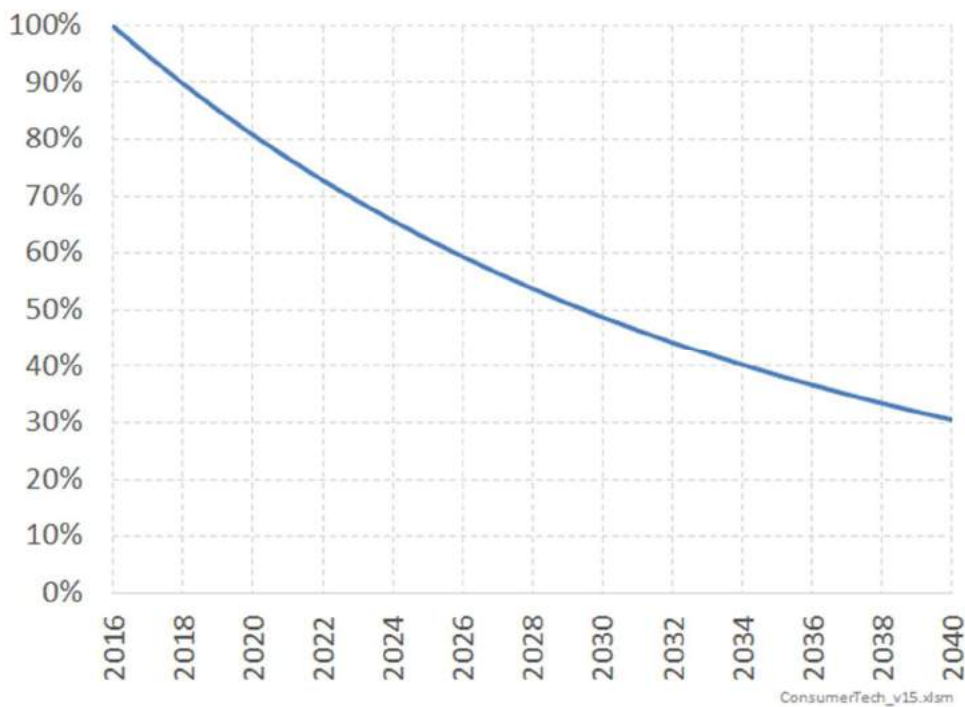
[http://www.concept.co.nz/uploads/2/5/5/4/25542442/new\\_technologies\\_economic\\_report\\_v2.0.pdf](http://www.concept.co.nz/uploads/2/5/5/4/25542442/new_technologies_economic_report_v2.0.pdf), and  
[http://www.concept.co.nz/uploads/2/5/5/4/25542442/new\\_technologies\\_emissions\\_report\\_final.pdf](http://www.concept.co.nz/uploads/2/5/5/4/25542442/new_technologies_emissions_report_final.pdf)

**Figure 83: Estimated 2016 up-front costs of rooftop solar PV systems**



As shown in Figure 84, these assumptions mean that the cost of a rooftop solar panel installed in ten years' time (i.e. in 2027) could be about 40% less than the cost of a panel installed this year<sup>58</sup>, and will roughly halve by 2030.

**Figure 84: Estimated (real) rate of decline of costs of installed rooftop solar PV systems**



<sup>58</sup> This is consistent with independent PV cost reduction estimates in Transpower's 'Transmission Tomorrow' document.

## The benefit of solar PV

### Private benefits

Solar PV is different to grid-scale generation because it is installed behind the customer's electricity meter. Therefore, solar PV can offset the household's electricity demand, and/or inject electricity back into the distribution network (pending the relative magnitude of demand and generation at any one time).

When the solar PV generation is offsetting household electricity use, the household is saving the full electricity tariff that they would otherwise pay (i.e. to meet their electricity demand from the grid).

Most householders currently have a flat electricity tariff (i.e. face the same price of electricity regardless of time of day or year), the solar PV generation that offsets the households demand receives a relatively high price, regardless of the value of that electricity to the wider system.

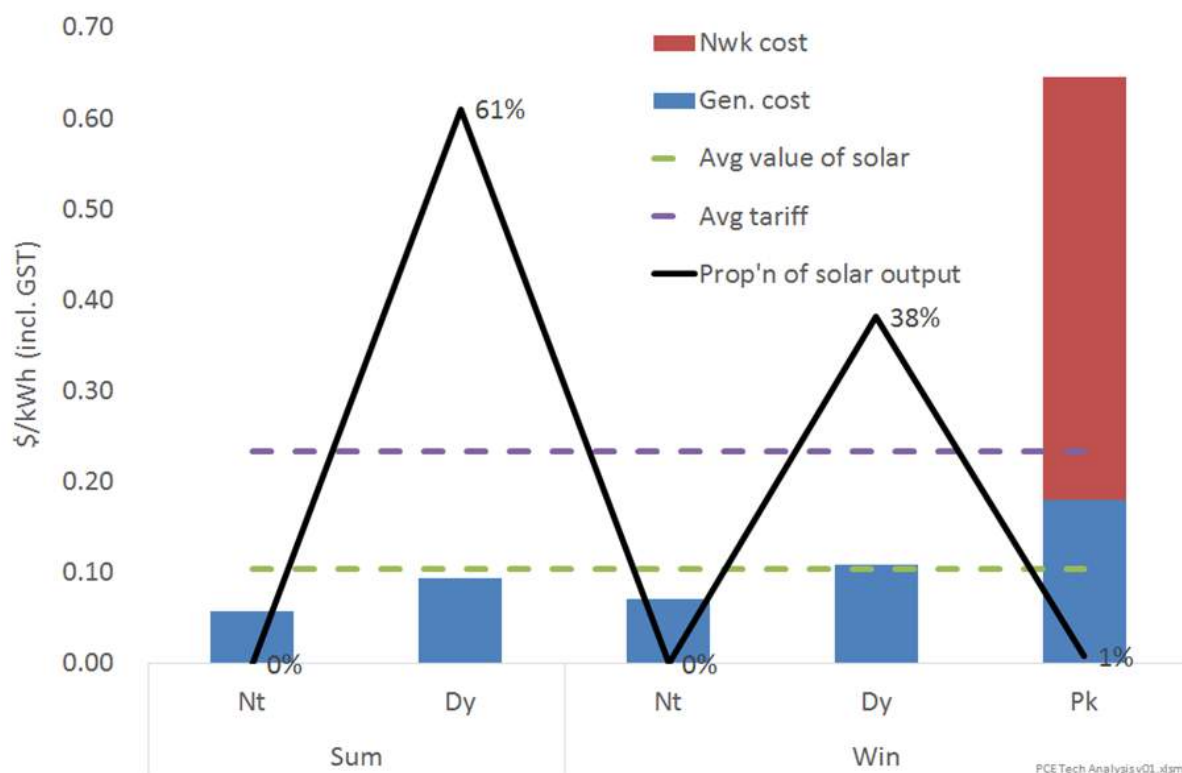
Note that the majority of the solar PV generation occurs in summer, and that the costs of supplying electricity are lowest in summer (due to generation costs being lower, and a lower need for distribution capacity).

We can therefore see that the current electricity tariff structure causes households with solar PV to be paid much more than the value of the solar PV generation. This is highlighted graphically in Figure 85 below.

We can see that solar PV does not offset any of the network costs – these are driven by peak demand on winter evenings when solar PV output is zero. We can also see that the output of solar PV is strongly biased towards the times that grid generation costs are lowest.

Therefore, the current residential electricity tariff structure inefficiently over-rewards investment in solar PV.

**Figure 85 - The cost of grid electricity supply by season**



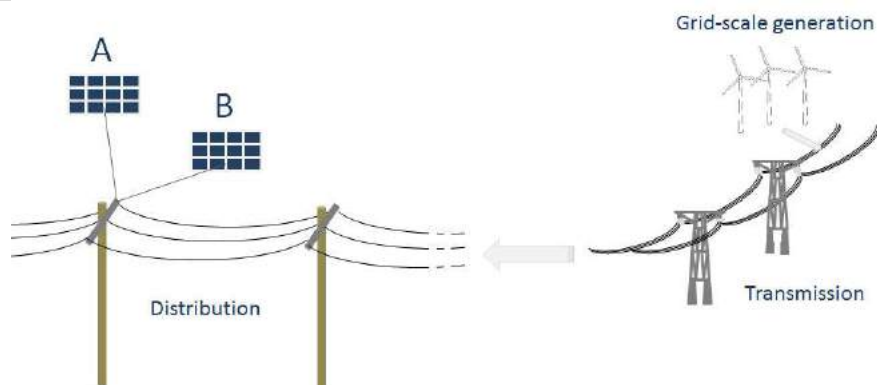
## Public benefits

The public benefit of solar PV is purely a function of cost and timing of the output of the solar system. It is not materially affected by how the PV system is connected to the electricity network<sup>59</sup> (i.e. whether behind the meter, or to the local distribution network). In terms of the connection configuration, consider the ‘thought experiment’ below.

### Box 2: Thought experiment – is rooftop solar PV being rewarded properly?

To test whether solar PV is being over-paid under the current residential electricity tariff structures—consider a hypothetical example: two identical 3kW solar panels, “A” and “B”, that are located 10 metres apart and each connected into the same part of the low voltage distribution network (but each with their own connection).

Figure 86: Solar PV thought experiment - Part 1



Electrically, they make an identical contribution to avoiding:

- grid-scale generation costs: i.e. displacing a lot during summer days, much less during winter days, and none during nights; and
- transmission and distribution ‘lines’ costs: i.e. no impact on reducing the need for lines networks – and potentially *increasing* costs if they are installed in an LV network with a lot of solar PV.

Further, neither is reducing the amount of retail cost-to-serve costs (i.e. metering, billing, call centres, advertising, etc.).

The question is: “What should each of these panels be paid?”

The right answer from New Zealand’s perspective is that they should each be paid an identical amount, being the value of the costs they avoid for New Zealand, i.e.: avoided grid generation (taking into account any avoided network losses) – less an amount to take account of any network cost increases they impose.

This is the basis on which other generation (large transmission-connected, or small distribution-connected) is paid, and is a framework which ensures that only the cheapest generation (taking into account any costs they impose on the system) is built and used (i.e. dispatched).

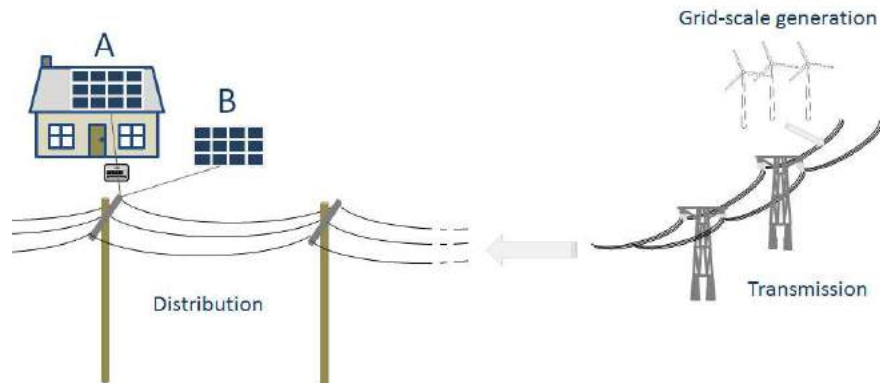
However, at the moment in our hypothetical example, panel A is effectively getting paid close to two-and-a-half times the amount of panel B – some \$9,000 extra over the life of the panel in present value terms.

<sup>59</sup> There are very minor differences in benefits pending where PV is located due to losses. However this is a very small factor and is allowed for in our analysis.

Why is this?

As you will have probably guessed, and as Figure 87 reveals, it is purely because panel A is sitting on a householder's roof and is located behind the household's meter, whereas panel B is not connected behind a household meter.

Figure 87: Solar PV thought experiment - Part 2

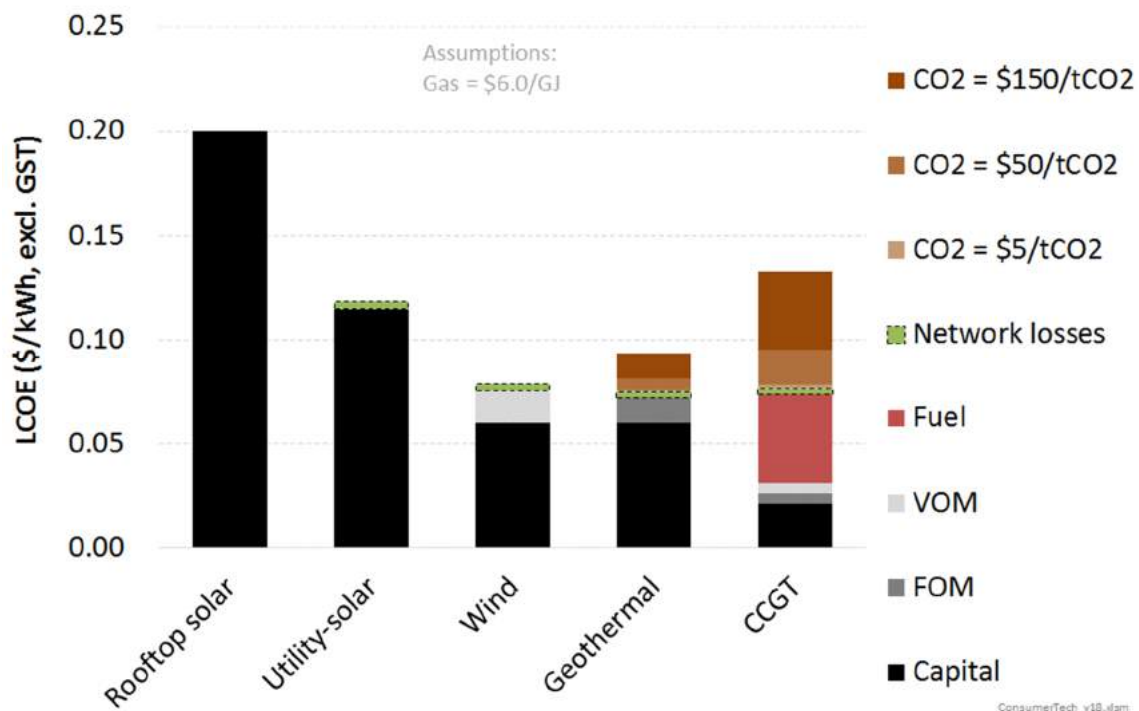


As such, because of the simplistic structure of current domestic electricity prices, panel A is enabling the householder to avoid paying for lines and retail costs, even though the solar panel is not reducing such costs for New Zealand.

### Costs of solar PV

It is important to consider the economic costs of solar PV relative to other generation options. If solar PV is sufficiently low-cost, it wouldn't matter that it mainly generated in summer (as opposed to winter when most needed).

Figure 88 - Costs of solar PV relative to grid-scale generation options



In Figure 88 above we can see the results of our cost analysis. Solar PV is significantly more expensive than grid scale generation when compared on a levelised cost basis. This includes allowing for losses that rooftop solar will avoid. Rooftop solar PV is still much more expensive when relatively high CO<sub>2</sub> prices are included for the relevant generation technologies.



## Appendix D. Biofuels

This appendix summarises the approach used to estimate the cost of producing second generation (advanced) biofuels from woody biomass.

The method used to assess the indicative cost of second generation biofuels is a 'bottom-up' calculation that estimates the main cost components, namely:

- Base wood fuel costs
- Woody biomass transport costs
- Biofuels plant capital recovery cost
- Biofuels plant efficiency

The numbers derived from this analysis are broadly consistent with Scion's various analyses.

### *Woody biomass fuel cost*

We have estimated the raw fuel cost of woody biomass for several different methods:

- Collection of existing forest residues
- The price of existing lowest grade logs, and
- New short rotation cropping

The first approach is to assume that landing or forest residues are collected. In this case, the wood itself has little cost, it's just the cost of collecting and gathering the woody biomass to bring it to a central point (for onward bulk transportation to biofuels plant).

We estimate the wood biomass landing and forest residues collection cost to be between \$20/tonne and \$40/tonne (i.e. at the landing site). This equates to about \$2.7/GJ - \$5.4/GJ. This cost is mainly for labour and light machinery. This is an average cost – some residues could be collected at lower cost, and some higher cost (i.e. harder to access residues). Over time, this cost could reduce as new systems and equipment improve the efficiency of the extraction of forest residues.

The second approach to estimating this fuel cost is to look at the commercial fuelwood and low-quality log value. Various sources indicate that the costs of chip or fuel wood (low quality and unusable lengths) is of the order of \$45/tonne, but varies by location. The value of the lowest grade logs varies between \$50 and \$90/tonne (including transport) pending demand for pulp.

Various sources indicate that short rotation cropping would have a cost of about \$75/tonne (e.g. on marginal land)<sup>60</sup>.

Overall, this indicates that a significant biomass resource is available at a delivered cost (see transport below) of about \$8/GJ - \$12/GJ.

In terms of volume of the forest/landing residues resource, it can currently be estimated as about 10% of the total recoverable volume<sup>61</sup>, (TRVIB was 26.5 million cubic metres in 2015)<sup>62</sup>, or about 2.6 million cubic metres (or about 10 PJ/year in energy terms)<sup>63</sup>. This means that any large-scale biofuel production (or biomass use) will require purpose grown fuel crops. Therefore, the higher end of the price range for biomass resource cost is more applicable. As noted in various Scion reports, New Zealand has significant areas of marginal land (much of which has a current land use value of

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<sup>60</sup> Scion, "Volume and cost analysis of large scale woody biomass supply", 2010.

<sup>61</sup> Ibid.

<sup>62</sup> [http://www.nzfoa.org.nz/images/stories/pdfs/ff\\_2016\\_web.pdf](http://www.nzfoa.org.nz/images/stories/pdfs/ff_2016_web.pdf)

<sup>63</sup> [http://ieabioenergytask43.org/wp-content/uploads/2013/09/IEA\\_Bioenergy\\_Task43\\_PR2012-04.pdf](http://ieabioenergytask43.org/wp-content/uploads/2013/09/IEA_Bioenergy_Task43_PR2012-04.pdf)

less than \$200/hectare), which could be planted in forests to produce all of our road transport fuel needs.<sup>64</sup> However, this would almost triple the size of our plantation forest estate<sup>65</sup> and thus have significant land-use and social impacts in regional New Zealand.

### ***Woody biomass transport cost***

The next part of the cost estimation is for the transportation of woody biomass from a skid site in a forest through to the biofuels plant. We have done a bottom-up estimate of these transport costs that looks at the truck capital, fuel, and other (driver and maintenance) operating costs. We estimate the transport costs as about \$16/tonne (\$2.1/GJ) for a 50 km distance (100 km return trip). The costs scale broadly with distance, which starts to significantly impact on the economics of biofuel sourced from a forestry location quite a distance from the wood processing facility. This cost estimation is broadly in alignment with other data, such as Scion's work in this area.<sup>66</sup>

There are some areas where transport costs could be lower. For example, the transportation of wood residues within a large forest on private roads may allow specialised over-dimension vehicles to be used. This is a consideration when optimising the fuel supply process, including determining where to chip the wood residues etc. While this is a valid consideration now in our larger forests (e.g. most have a network of private roads), it is more relevant if large scale afforestation is undertaken in New Zealand.

### ***Biofuels plant capital recovery cost***

Using published sources, we have estimated the capital cost of a biofuels plant, for a given production capacity (e.g. the Z Energy 'Stump to Pump' analysis). This information suggests that the plant capex will be the main cost component of biofuels, about \$20/GJ. This is a significant uncertainty in the analysis as there is very little published data because most information is commercially sensitive.

### ***Biofuels plant efficiency***

The plant is assumed to be 50% efficient – i.e. for every 2 GJ of wood waste entering the process, 1 GJ of processed biofuel is produced. This is based on the Fischer-Tropsch process for renewable diesel production.

### ***Summary biofuel cost***

The overall cost of biofuels (with a significant margin of uncertainty) is about \$35/GJ. While this seems very high, even small improvements in the bio-refining process, or the addition of revenue streams from additional products (i.e. other saleable chemicals etc) will reduce these costs.

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<sup>64</sup> <https://www.bioenergy.org.nz/documents/resource/IEA39-Opportunities-for-biofuels-NZ.pdf>

<sup>65</sup> [https://www.bioenergy.org.nz/documents/resource/Reports/Bioenergy-Options\\_Situation-Analysis\\_Scion.pdf](https://www.bioenergy.org.nz/documents/resource/Reports/Bioenergy-Options_Situation-Analysis_Scion.pdf)

<sup>66</sup> <https://www.usewoodfuel.org.nz/documents/resource/EECA-transport-of-wood-residue-guide.pdf>

## Appendix E. Hydrogen

This appendix summarises the assessment of hydrogen as a possible transport fuel.

Hydrogen can be produced from renewable electricity in New Zealand at a cost of about \$35/GJ.<sup>67</sup> These costs will reduce slightly as electrolyser efficiencies increase, and as capital costs of electrolysers reduce. The likely future lowest cost of hydrogen as a 'standalone' bulk fuel is expected to be about \$30/GJ. This is because costs reductions are limited by the need to use electricity as an input energy source, and the inherent efficiency loss of electrolysis process when separating water into hydrogen and oxygen.

While currently uneconomic, it may be economic to use hydrogen for 'return to base' type transportation in future (as a standalone fuel) if the cost of carbon increases to about \$100/tCO<sub>2</sub>. The 'return to base' aspect of the transport is essential as it reduces the fuel distribution costs (these are not included above).

Hydrogen uptake would be very dependent on the economics of hydrogen relative to competing fuels (primarily advanced biofuels and existing fossil fuels with a carbon price).

Existing biofuels (derived from tallow and waste oil) are not a direct competitor to hydrogen in the medium term because bio-diesel is a very limited resource and can only meet a small proportion of the current transport energy demand.

Hydrogen is already economic in niche applications in some countries (e.g. fuelling forklifts used in clean-air environments such as warehouses) where it has a considerable advantage over battery-electric vehicle technology. This is because battery-electric vehicles have limited travel range and recharging times can be significant. Hydrogen fuelled vehicles can achieve a much higher asset utilisation than electric vehicles. The downtime of charging battery electric vehicles can represent a material cost for high utilisation vehicles such as taxis (or forklifts) that are used on multiple shifts (i.e. the taxi on the road nearly 24 hours a day, but with different drivers).<sup>68</sup>

Further, hydrogen has an advantage over battery-electric vehicles where payload capacity is important (e.g. the majority of the heavy vehicle fleet). The weight of the batteries further reduces the payload capacity of these vehicles, thus adversely affecting the economics of battery electric heavy vehicles.<sup>69</sup>

We can therefore see that hydrogen and advanced biofuels are the main options for reducing emissions in the majority of the heavy vehicle fleet. This is because the vehicle's range (kilometres per day), and payload capacity, are often very important factors underpinning the economics of transporting goods.

The above discussion assesses hydrogen production from a standalone viewpoint – i.e. electrolysis plant is built solely for the production of hydrogen. However, it is much more likely that hydrogen production would be integrated into a wider industrial process. At the very least, the oxygen 'waste' product from the process is likely to be utilised (e.g. where a very pure oxygen source is required). This would help in reducing costs attributable to hydrogen production, as the capital and operating costs of the electrolysis process would be shared across various product streams.

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<sup>67</sup> This assumes an electricity input cost of about \$70/MWh, electrolyser efficiency of about 75%, and capital costs being about 20% of the operating costs (on a \$/GJ basis).

<sup>68</sup> Even with fast charging technologies, battery electric vehicles are expected to be unsuitable in many roles.

<sup>69</sup> Heavy electric vehicles do have a role for short-range transport and for volume-based goods (i.e. where weight is less of an issue). However, our initial analysis indicates that about 70% of heavy vehicle transport may be unsuitable for battery electric vehicles.