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Summary insights on energy-related carbon-abatement opportunities

Prepared for the Parliamentary Commissioner for the Environment

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About Concept

Concept Consulting Group Ltd (Concept) specialises in providing analysis and advice on energy-related issues. Since its formation in 1999, the firm's personnel have advised clients in New Zealand, Australia, the wider Asia-Pacific region and Europe. Clients have included energy users, regulators, energy suppliers, governments, and international agencies.

Concept has undertaken a wide range of assignments, providing advice on market design and development issues, forecasting services, technical evaluations, regulatory analysis, and expert evidence.

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Contents

1 Introduction

1.1 Purpose of study

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.

In conducting this analysis Concept used a suite of different models, including its electricity and gas market models, its New Zealand land transport forecasting model, its model of industrial process heat economics, and a variety of other tools to examine specific issues.

The results of this modelling were provided to the Commissioner as a set of technical working papers. The Commissioner has also asked that Concept prepare this public summary paper which draws out the key insights from this work.

1.2 Background: Our energy-related carbon emissions are increasing

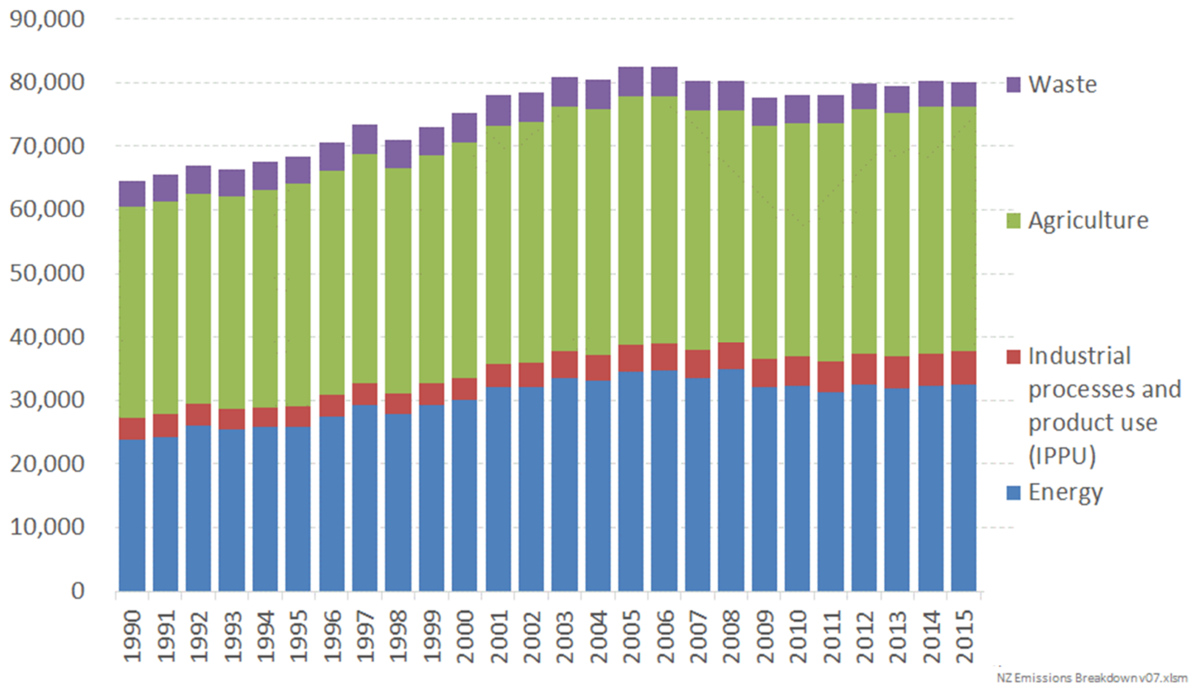
New Zealand has set targets to reduce its greenhouse emissions as part of an international response to global warming. For example, our Paris commitment is for our 2030 'net' emissions (i.e. gross emissions less carbon sequestration from forestry) to be at least 30% below our 2005 gross emissions. Also, in 2011 the Government introduced a self-imposed target of our 2050 net emissions to be 50% below our 1990 gross emissions.

However, as Figure 1 below shows, New Zealand's gross emissions have not started to materially reduce. Indeed, after a temporary reduction following the Global Financial Crisis, New Zealand's gross emissions have started to grow again.

Further, the current level of forest planting (which has carbon sequestration benefits) is significantly below the levels required if we were to meet our net emissions targets through this means.

Accordingly, if New Zealand is to meet these targets, it will need to implement measures to significantly reduce future gross emissions.

Figure 1: New Zealand's historical gross greenhouse gas emissions (ktCO$_2$-e)



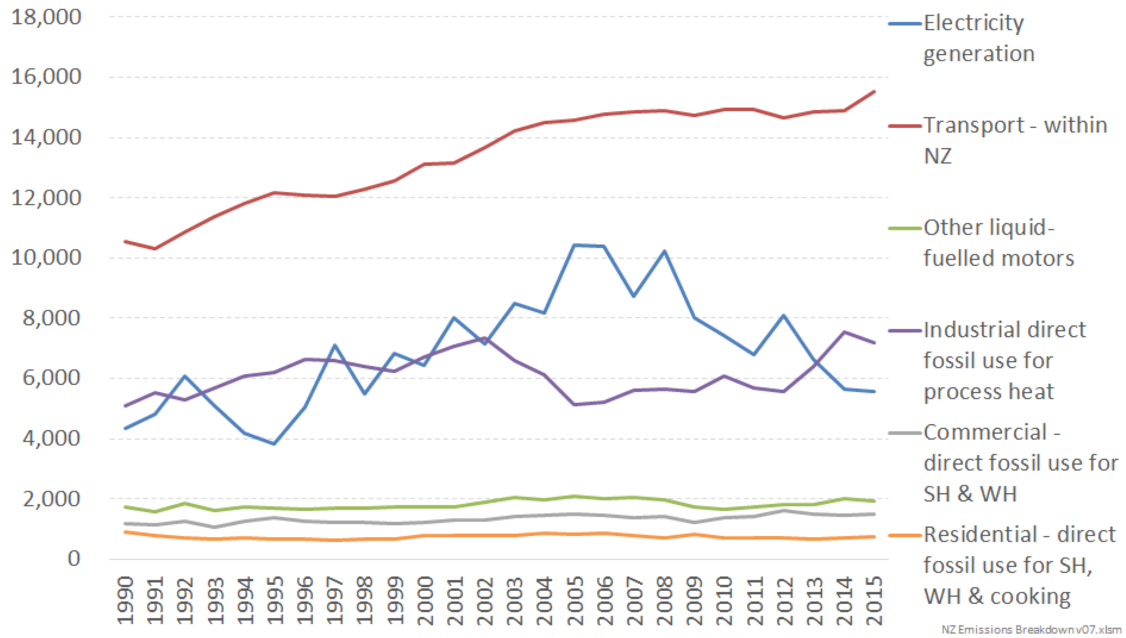
Source: Concept analysis of MfE data

Figure 1 also shows that energy-related emissions are the second largest source of emissions in New Zealand after agricultural emissions (corresponding to 40% and 48% of our total gross emissions, respectively). It also shows that these energy emissions have been growing in recent years (albeit very slowly).

Figure 2 shows a breakdown of these energy-related emissions into the main end-use sectors.

It highlights that it is primarily the transport and industrial process heat sectors that have contributed to the increase in gross energy sector emissions over the last decade, and that electricity generation emissions, while they have declined significantly over the past decade, are still responsible for more than one-sixth of New Zealand's energy-related emissions. Together, these three types of energy use account for approximately 85% of New Zealand's energy-related emissions.

Figure 2: New Zealand's historical energy-related greenhouse emissions by end use (ktCO_2-e)



Source: Concept analysis of MBIE data

Sections 3 to 6 in this report address each of the sectors shown in Figure 2 and:

- Analyse what has been driving the historical changes in emissions; and
- Assess what cost-effective opportunities may exist in the future to significantly reduce energy-related emissions.

However, section 2 first summarises some key insights about the economics of greenhouse gas abatement which are relevant to all parts of the energy sector.

2 General insights about the economics of greenhouse abatement

Insight 1. Most energy end uses (e.g. space heating, industrial process heat, refrigeration, transport) are capital intensive. This significantly affects the carbon-cost-effectiveness of different options. It particularly means that least-cost abatement generally requires investing in lower-emissions plant at the time of natural asset replacement (i.e. end of economic life), not scrapping higher-emissions plant with significant remaining economic life.

Most energy-using appliances (e.g. industrial boiler, fridge, vehicle etc.) have a significant up-front capital cost. Recovery of this capital cost comprises a significant proportion of the overall cost per kWh of useful heat/cooling, or per kilometre of distance travelled (in some cases it is the majority of the cost).

This capital intensity of energy use gives rise to significant variation in the carbon-cost-effectiveness of low-carbon options for a given energy use, depending on:

- How often the energy appliance will be used
  - For example, the carbon abatement from an electric vehicle will be lower-cost for a vehicle that is driven a lot over its lifetime, compared to a vehicle that is not driven much. The same is also true for lightbulbs, space and water heaters, and industrial process heat boilers. In other words, replacing higher utilisation assets results in lower-cost abatement.
- Whether there is a need to invest in a new appliance anyway (e.g. replacing an old appliance which is worn out), or whether a low-carbon option would be replacing an existing higher-carbon appliance which still has many years' life left in it.
  - Replacing assets that have plenty of useful life remaining is a lot more expensive than in situations where there is a need to invest in new assets anyway. In other words, the lowest cost abatement arises when new capital is anyway required – e.g. building homes, buying new cars, investing in a new factory – rather than scrapping an existing asset.[i]

This also means that the abatement cost curve over the medium-to-long-term, will have a much greater volume of cheaper options (as over the medium-to-long-term the general capital replacement cycle will give plenty of low-cost opportunities), than an abatement cost-curve solely looking at actions that could be taken today (which will require scrapping existing capital in the majority of cases).

This variation in cost-effectiveness means that in all parts of the energy sector (e.g. transport, electricity generation, heat) there will likely be a significant chunk of options which are very cheap (in many cases a negative abatement cost) coinciding with 'natural' capital investment decisions, as well as some which are much more expensive. Therefore, assessments which solely focus on the average abatement cost for a sector risk missing some very cost-effective abatement opportunities.

Insight 2. The capital intensity of most energy uses also means they tend to be long-lived assets. This means that: 'Bad' carbon-intensive capital investment decisions taken today, will stay with us for decades; and, even if we start making 'good' investments in low-emission assets now, the timescale of the capital replacement cycle will mean it will take a long time to replace our whole 'fleet' (of vehicles, boilers, houses, etc)

Things that have a high upfront cost (i.e. are capital intensive), tend to last a long time. This means that if there aren't good policy and price settings to enable good decisions, we will have a lot of high-carbon assets entering our economy which will remain for a very long time. For example:

- New cars entering New Zealand in 2016 will likely still be on New Zealand's roads until the mid-2030's.
- A fossil-fuelled industrial boiler built today could still be operational in the 2050's.
- A geothermal power station could be around for another 50 or so years (e.g. until 2070). This is relevant because geothermal stations emit CO_2 – albeit less than a fossil-fuelled power station, but a lot more than a wind farm.

This capital intensive, long-lived nature of most energy uses means that our energy economy is like a super-tanker which needs early and sustained action to gradually 'turn the ship around'.

This is clearly illustrated by our current housing stock – about 70% of New Zealand's housing stock was built prior to 1990[ii], and are now considered to be significantly under-insulated, having no (or negligible) wall insulation. Houses last a very long time, so this legacy will still be with us for many decades to come. Wall insulation can be retrofitted, but it is very expensive unless the wall linings are being replaced anyway (e.g. as part of a renovation).

Insight 3. Low-carbon options tend to be significantly more capital intensive than high-carbon options. This makes firm future expectations of higher carbon costs (i.e. certainty and sufficiency of the carbon price signal) critical to influence the decisions of parties making a capital investment towards low-carbon options.

Low-carbon options tend to be significantly more capital intensive than high carbon options – i.e. the energy service (e.g. transport, heating, lighting) is achieved through more capital, rather than ongoing consumption of a fossil fuel.

Because there is a significantly higher up-front cost, this means that if we want the parties making capital investment decisions to choose a low-carbon option – e.g. the board of a company considering a multi-million-dollar investment in an industrial boiler, or a household deciding whether to purchase an electric vehicle – they need to have a reasonable expectation that the financial benefits they will enjoy from not facing higher carbon costs will outweigh the higher up-front cost.

To-date, lack of certainty about future carbon prices has been a significant barrier to parties making investments in low-carbon assets.

It is our view that current carbon prices in New Zealand (approximately NZ\$18/tCO_2, but reduced to NZ\$12/tCO_2 given the staged exit from the 'one-for-two' arrangement under the ETS) are significantly lower than that which would reflect the cost to New Zealand society from global warming – not just local effects (e.g. sea-level rise affecting coastal New Zealand cities and infrastructure), but broader global geo-political instability from sea-level rise and impacts on food and water availability in many parts of the world.

In this we note a growing number of international studies which indicate that global carbon prices will need to be significantly higher in order to prevent global temperatures rising above 2°C – the level at which some of the significant adverse impacts mentioned above have been identified as starting to become particularly significant. For example, the International Energy Agencies scenario for limiting global temperature rise to 2°C has carbon prices rising to NZ\$225/tCO_2 by 2050.

In this report, we have focussed on measures which are likely to be cost effective at prices below NZ\$100/tCO_2.

Insight 4. Other pricing distortions and barriers are also significantly frustrating investment in low-carbon options, including lack of cost-reflective electricity tariffs, and many other externalities in road transport (human health, road pricing, etc.)

Even if there was an adequate carbon price that reflected the true societal cost of emissions, we would not see the optimum level of abatement. This is because of a variety of other barriers that currently affect consumers' and businesses' capital expenditure and operating decisions. Different barriers apply to different sectors.

In electricity:

- Consumer electricity tariffs are not cost-reflective. Currently most consumers pay the same electricity tariff whenever they use electricity, whether at peak times in winter, or off-peak in mid-summer. This is the case, even though it is much more expensive and, more to the point, fossil-intensive to provide electricity at peak times, compared to off-peak times.[iii] The consequences of this mis-pricing are:
  - There is under-investment in efficient space heating (and insulation) and lighting technologies which, because they would be used predominantly over winter, would generally displace fossil-generation used to meet winter-peaking demand.
  - There is inefficient over investment in technologies such as more efficient refrigeration, and solar photovoltaics, that have a negligible impact on emissions (as they are not biased towards winter peak demand)[iv], and
  - The mis-pricing also reduces the incentive for 'fuel switching' to less CO_2 intensive fuels such as using a wood burner for space heating instead of electricity, or using an electric vehicle for transport (instead of an internal combustion engine vehicle).

In process heat:

- There is the additional complication of a carbon price on NZ industry risking carbon leakage (due to New Zealand production being less competitive internationally). Aside from the economic costs to New Zealand, this could cause a net increase in global emissions if New Zealand's production (e.g. of methanol, steel, or milk powder) is more carbon-efficient overall compared to that overseas.

In transport:

- There is the under-pricing of respiratory human health consequences of exhaust emissions (particularly from diesel vehicles, which is of most relevance in the main cities)
- There has been a tendency to under-price private transport (e.g. lack of congestion pricing, little internalisation of human health (accidents[v] and obesity) externalities, under-pricing of land-space allocated for private benefit (e.g. parking a vehicle on the road)). This causes a bias favouring private vehicles over other transport modes (e.g. walking, cycling, and public transport). While it can be argued that this is a minor effect because only a small portion of people are close enough to amenities/work to cycle or walk, there is a long-term urban design issue here whereby the bias towards vehicles has also likely contributed to a bias towards lower-density urban areas than would otherwise be optimal.

For the main energy amenities (space and water heating, and lighting):

- There are principal / agent barriers whereby the main decision-maker about a capital investment decision will not be the party paying the energy bills. This relates to tenant / landlord situations, and also property development situations.

3 Electricity generation insights

Insight 5. Displacing existing base-load gas-fired electricity generation with new low-carbon generation represents one of the largest, carbon-displacement opportunities. However, displacing fossil generation from providing seasonal and within-day peaking, and dry-year reserve, will be a lot more expensive.

Although New Zealand's electricity supply is, on average, highly renewable (80% is generated from low[vi] or zero-carbon generation technologies), we still have a significant amount of existing fossil generation capacity: some of it operating baseload (i.e. all the time), but much of it being relatively under-utilised and used infrequently to meet within-day/week and seasonal peaks in demand, and also to providing hydro 'firming' during low-rainfall periods when the hydro storage lakes fall to low levels.

Given this situation, we estimate that electricity generators need to face a price of carbon of approximately NZ$50-60/t$CO_2$ to:

- stop growth in electricity demand being met by increased baseload operation of currently under-utilised existing gas-fired generation plant; and
- to provide sufficient incentive to develop additional low-carbon generation to displace that gas-fired generation which is operating in baseload mode.

We estimate this will save approximately 2,900 ktCO_2/year over the medium term. New Zealand already has enough consented wind generation (over 2,000 MW) to displace this fossil fuel generation. New Zealand also has extensive additional wind potential, l as yet undeveloped.

After all the existing fossil generation has been displaced from baseload generation, progressively higher carbon prices are required to displace the remaining existing fossil generation from providing lower capacity-factor duties (i.e. operating less often), such as daily through to seasonal peaking operation.

This is because the additional low-carbon generation will need to operate at progressively lower capacity factors, and effectively 'spill' generation for ever-increasing amounts of time. Put another way, it is expensive to build a wind-farm only to operate in winter, or in a dry-year, say, rather than use an existing fossil generator to only operate for such infrequent periods.[vii]

Even with high carbon prices, there will continue to be material amounts of greenhouse emissions from geothermal generation, and the existing fossil-fuelled industrial co-generators.

Insight 6. Ironically, it is New Zealand's hydro generation fleet which is prolonging the life of the coal-fired Huntly Rankine station, as coal is much cheaper than gas for providing large amounts of energy during relatively rare dry-year events. Switching from coal to gas for hydro-firming is likely to be a 'medium' cost abatement option.

Approximately 57% of New Zealand's electricity is from hydro generation. However, this is subject to significant year-on-year variation – with the difference in generation between the 'driest' and 'wettest' of the past 25 years equivalent to 14% of New Zealand's total generation.

This requires having some generation in reserve to be available for dry years. As well as having the spare power station capacity (which incidentally makes renewables such as wind a very expensive dry year option), this requires having the fuel available to call upon as required. Providing fuel flexibility from coal is relatively low cost as it can be achieved with a combination of a coal stockpile and calling upon the international coal spot market as required. In contrast dry-year gas flexibility will need to either come from over-sizing production capacity in upstream gas & oil fields, or diverting gas from methanol production to power generation – both of which are relatively expensive.[viii]

We estimate that switching from coal to gas for dry-year energy could deliver savings of approximately 600 ktCO_2/year, and cost approximately \$70-100/tCO_2.

Insight 7. Geothermal energy, while less emissions intensive than fossil power stations, emits greenhouse gases. Building new wind instead of new geothermal stations to meet future demand could avoid material emissions.

Extracting geothermal fluid to power a geothermal power stations also releases CO_2 from within the fluid. The effective tCO_2/MWh emissions intensity of most geothermal stations is less than a third of a gas-fired power station, but still material. (Indeed, 2016 was the first year where emissions from geothermal power stations overtook those of coal-fired power stations).

On average, we estimate that every NZ\$10/tCO_2 will increase the cost of geothermal power by \$1.2/MWh.

If future carbon prices are relatively low, it is likely that a significant proportion of demand growth will be met by building new geothermal power stations. Once built, it is likely they will continue to operate for many decades.

However, if carbon prices were to be approximately \$50 to \$70/tCO_2 it is more likely that new wind farms would meet demand growth. We estimate that building wind instead of geothermal would save approximately 360 ktCO_2/year over the long-term.

Insight 8. Consumer scale generation technologies (solar PV and batteries) do not offer cost-effective abatement compared with utility-scale low-carbon generation (particularly wind).

Consumer-scale generation technologies (rooftop solar and batteries) are likely to continue to be much higher cost abatement options than utility-scale low-carbon generation (wind and geothermal) delivered over the grid. This is the case even noting the decreasing costs of solar photovoltaics and battery technology.

In particular, rooftop solar is a very expensive form of generation compared to grid-scale low-carbon generation alternatives. Even with very high carbon prices and significant solar PV cost reductions it is not economic compared to grid-scale wind generation. Indeed, the uptake of (higher cost) solar will largely displace (lower-cost) wind generation that would otherwise be built.

Even if batteries significantly reduce in cost, rooftop solar is still not economic, as the most cost-effective use of distributed storage batteries is filling up with much lower-cost grid-scale renewable generation at times of surplus, rather than higher-cost rooftop solar.

Consumer stand-alone batteries are also likely to be higher cost options than utility-scale batteries because of the economies of scale, and the ability to more cost-effectively target these batteries at parts of the grid facing capacity constraints. Further, batteries in electric vehicles may be cheaper than either consumer or utility-scale stand-alone batteries, but deliver fundamentally the same benefit.

There will be limits to the extent to which batteries can cost-effectively displace fossil generation. In particular, for the foreseeable future they will be uneconomic for displacing fossil generation that is used to provide seasonal generation. This would require filling up a battery once in the summer, for release once in the winter, which while technically feasible is economically ‘challenging’. It is even less economic to use batteries for hydro-dry-year firming (e.g. filling up once in a 1-in-10-year wet year, for release once in a 1-in-10-year dry year).

Insight 9. The grid is a key enabler for de-carbonising our economy, particularly to support development of renewable-powered electric vehicles and industrial process heat.

Overall, the grid is a key enabler of moving to a low-carbon energy economy:

- It enables the cheapest low-carbon generation schemes to be developed (which tend to be grid-scale generation) – particularly of a scale to deliver the amount of electricity required to power EVs and for future electrification of industrial process heat; and
- It enables the balancing of renewable generation and demand variations to be achieved at much lower cost than would be incurred from developing significant battery storage to enable such balancing to occur at a much more local level. In particular, the grid provides access to the diversity[ix] of generation and demand which enables balancing of demand and renewable supply at much lower cost.

While there is much talk of 'disruption' from new technologies, the New Zealand electricity grid provides significantly lower-cost and lower-emission electricity compared to households supplying their own electricity (e.g. from solar PV and batteries).

4 Consumer energy insights

Insight 10. There is economic greenhouse abatement potential in the demand-side of the energy sector – particularly efficient technologies for those end-uses that are greatest in winter and/or heavily focused in morning & evening peak periods.

Although New Zealand's electricity is, on average, largely from renewable resources, this does not mean that we should be complacent in our electricity use. As set out in the previous section, there is a material volume of avoidable greenhouse gas emissions caused by fossil electricity generation (i.e. as used to meet winter demand and morning & evening 'peak' periods).

Thus, the most fossil intensive consumer end-uses are space heating and lighting, (both of which are used more in winter and have a morning and evening peak profile). These are followed by cooking and water heating (which have a largely flat within-year profile but a morning & evening peak profile). Conversely, residential refrigeration (which is flat throughout the day and year) is predominantly met by renewable electricity generation.

Gas is also used for space and water heating by some consumers. Given the fossil-intensive nature of electricity generation to meet space heating in particular (i.e. because it is a peak-related demand), the greenhouse emissions from gas appliances are generally lower than resistance electric options, but higher than heat pump electric options.

Given the above, it follows that reducing the higher winter electricity demand will have the greatest impact on reducing electricity emissions. The most likely candidates are:

- Residential and commercial space heating
- Residential lighting[x]

There are a wide variety of options to reduce electricity or gas demand for these services, for example:

- Fuel switching
  - A wood burner replacing electric space heating (residential)[xi]
- Improved efficiency
  - Heat pumps replacing resistive heating
  - Thermal insulation reducing heat loss
  - Double glazing reducing heat loss
  - Draught proofing reducing heat loss (predominantly residential dwellings)
  - LED lighting replacing CFL, or incandescent lighting (or lighting controls in commercial buildings, and simply turning off lights when not in use)

Some of these options are cost-effective in terms of energy savings alone (e.g. LED replacing incandescent lighting), and thus can result in abatement at 'negative cost'.

However, given the capital intensity of most energy end-uses, many options are only cost-effective if a new appliance is being purchased anyway (e.g. a new-build situation, or replacing a worn-out appliance). In many situations, if the low-carbon option requires scrapping an existing working appliance (e.g. an existing heater, or existing single-glazed window) the cost of carbon-abatement achieved can be very high.

This has some important implications:

- The ability to substantially and cost-effectively reduce carbon emissions from heating and lighting will be affected by the timing of the general capital replacement cycle for such appliances. This is not such an issue for replacing bulb replacements, but may be more an issue for where costs are higher and asset life-times longer.
- Bad choices made today, will still be with us in several decades time – particularly in relation to space heating. (e.g. under-insulating a home when it is first built, or the design of commercial building heating systems).

We estimate that more than 1 $MtCO_2$ of cost-effective emissions reduction from consumer end-use could be achieved over the next 20 years.

Insight 11. There are a number of distortions / barriers which mean that these abatement options which are cost-effective for New Zealand may not be realised. The most significant is a lack of cost-reflective electricity prices, but there also some significant 'behavioural' and principal / agent barriers which frustrate good decision making.

There are five main issues, which are explored below:

- Current electricity pricing is not cost-reflective

  The current approach to consumer electricity pricing discourages consumers from making economic investments that will result in emission reductions. This is because the current predominant pricing structure (i.e. a flat tariff) under-signals the cost of peak electricity demand, and over-signals the cost of off-peak electricity use. Further, the current low-fixed charge regulations will tend to exacerbate these price distortions.

  This is increasingly an issue as more technologies become economic (such as LEDs), and as other energy services can economically switch to electricity as a cleaner fuel (e.g. electric vehicles).

  There are alternative price structures (for example pricing that reflects the time-of-use of electricity) that better signal the costs of providing electricity at peak times[xii]. The industry is starting to consider these alternative pricing structures, but there are many hurdles to overcome before these are likely to be introduced.

- The carbon price appears to be lower than the societal cost of climate change

  This is a simple price effect, but can be a discerning factor between a higher and lower emission appliance option.

- Principal- agent issues

  Principal/agent issues arise when the party making the decisions about a property (e.g. what appliances to fit, and whether to retrofit insulation) is not the party that will pay the fuel bills for the property. This is particularly in relation to: developers specifying heating and insulation for new-build properties; and landlords making decisions as to whether to install insulation or more efficient appliances in a property (e.g. LED downlights). Principal /agent issues particularly arise for space heating, but also for lighting and water heating.

  Cost-effective measures to address principal / agent issues include:

  – Building regulations. It is not clear that the current building regulations are at a sufficient level to ensure the thermal performance of new buildings (or buildings being renovated) is adequate
  – Mandates on landlords to meet certain minimum energy performance requirements for their properties

– Building energy rating schemes – providing information on the energy performance of a property for a potential tenant or property purchaser. However, the transaction costs in administering these schemes means that their cost-effectiveness varies hugely depending on the nature of the property. Generally, they are only cost-effect for certain types of commercial property, and not cost-effective for residential housing.

- Information barriers

  Information barriers are also significant to consumers making good decisions. The most cost-effective measure for addressing such barriers tend to be minimum energy performance schemes (MEPS) applying to appliance sales (akin to building regulations). Information provision can sometimes be cost-effective, but this will not always be the case.

- Behavioural aspects of consumer's decision making

  In addition to the above, all decision makers (businesses and households) are subject to the inherent biases and 'behavioural' effects that result in investment decisions being 'imperfect' compared to the economically rational outcome. This is due to many compounding effects such as:

  – People are generally busy, and have many competing priorities, therefore they often do not devote much time to decision making

  – There are also known status-quo biases that can dissuade people against newer technologies

  – They are also subject to a lot of partisan marketing information

By way of example, the tables below show the abatement potential (i.e. magnitude and cost of reductions) of residential LED lighting.

Table 1 - Estimated cost of carbon abatement for various LED lighting scenarios (a negative carbon cost implies that it is worth replacing the lamp to save money, let alone the carbon saving)

	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 $/t$CO_2$ to -350 $/t$CO_2$	+50 $/t$CO_2$ to -100 $/t$CO_2$	+300 $/t$CO_2$ to +100 $/t$CO_2$
Medium use (about 2 hrs/day)	-450 $/t$CO_2$ to -500 $/t$CO_2$	-300 $/t$CO_2$ to -350 $/t$CO_2$	-150$/t$CO_2$ to -250 $/t$CO_2$
High use (about 3 hrs/day)	-500 $/t$CO_2$ to -550 $/t$CO_2$	-400 $/t$CO_2$ to -450 $/t$CO_2$	-300 $/t$CO_2$ to -400 $/t$CO_2$

Table 2 - Estimated cost of abatement for residential space heating (health benefits are not included here[xiii])

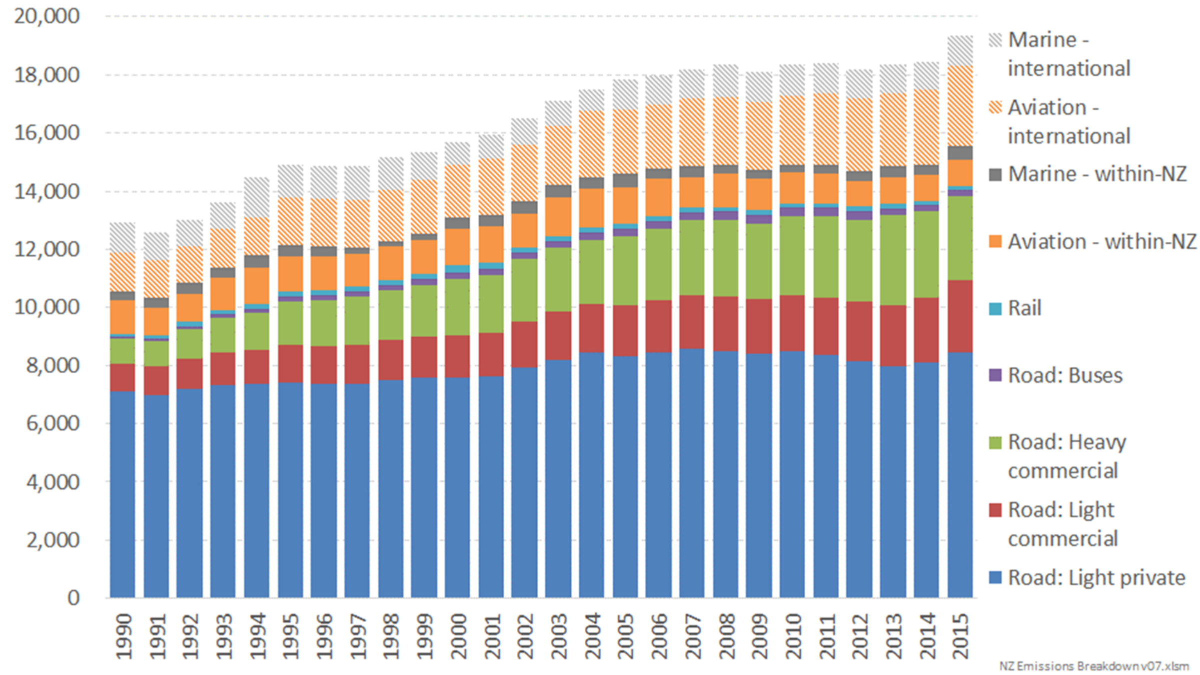
	Heat pump replacing resistive heating	Ceiling insulation (resistive heating)
Low use (about 1 hr/day)	+500 $/tCO_2$ to +200 $/tCO_2$	+200 $/tCO_2$ to +100 $/tCO_2$
Medium use (about 2 hrs/day)	-50 $/tCO_2$ to -200 $/tCO_2$	-50 $/tCO_2$ to -250 $/tCO_2$
High use (about 3 hrs/day)	-250 $/tCO_2$ to -350 $/tCO_2$	-200 $/tCO_2$ to -350 $/tCO_2$

5 Transport insights

Figure 2 previously showed that transport-related emissions dominate New Zealand's energy-related emissions, accounting for approximately half of our total. It is also the sector which has seen the highest growth of emissions since 1990 – and is continuing to grow.

Figure 3 below shows that our transport emissions are dominated by road transport – with light private vehicles (i.e. cars) being the dominant source of such emissions. Road transport emissions have also grown strongly, with particularly fast growth for heavy commercial (i.e. trucks) and light commercial (i.e. vans).

Figure 3: Historical disaggregated transport-sector emissions (ktCO$_2$-e)



Insight 12. Electric vehicles are the most attractive abatement option for light passenger and light commercial travel – and the largest abatement opportunity across our whole economy. However, lack of a societal carbon price and many other barriers will significantly frustrate their uptake.

By far the most significant low-carbon option to reduce light vehicle fleet emissions (private vehicles and light commercial vehicles) is electric vehicle (EV) technology[xiv]. Our increasingly low-carbon electricity generating fleet means that increased electricity demand to charge EVs will predominantly be met by increased development of wind and geothermal power stations (particularly if the societal cost of carbon is appropriately signalled to generation investors, as noted above).

To highlight the potential scale of impact of EVs, we have modelled the scenario of EVs making up 100% of all new light vehicles entering the NZ fleet by 2030.

Given that there will still be existing petrol and diesel vehicles which have yet to be scrapped, this corresponds to 41% of the total light fleet being EVs at 2030, rising to 58% at 2035, 70% at 2040, 79% at 2045, and 85% by 2050. Table 3 below gives the projections of the light vehicle emissions in MtCO$_2$/yr.

Table 3 -The magnitude of emission reductions ($MtCO_2$/yr) from a 'high EV uptake' scenario

	2015	2020	2025	2030	2035	2040	2045	2050
BAU	10.9	11.2	11.5	11.3	10.2	8.3	6.2	4.4
High EV uptake	10.9	11.1	9.6	7.0	5.1	3.6	2.6	1.7
Difference	0.0	0.2	2.0	4.3	5.1	4.6	3.6	2.6

At the moment, EVs have higher up-front capital costs than internal combustion engine (ICEs) vehicles. However, the fuel costs of running EVs are a lot less (electric motors are three-times more efficient than a combustion engine, plus electricity can be delivered via an existing distribution infrastructure[xv]), plus EV maintenance costs are expected to be less. Based on current prices, this means that, *from a New Zealand Inc perspective*, the lifetime carbon-abatement cost of choosing EVs rather than ICEs for a significant proportion of light passenger vehicles coming in to New Zealand is relatively low (i.e. < NZ$25/t$CO_2$) or even negative. As EV costs decline further, the economics will continue to improve, increasing the proportion of vehicles coming into New Zealand which would cost-effectively be EVs rather than ICEs.

However, due to a number of pricing distortions and other barriers, the lifetime ownership cost of EVs relative to internal-combustion engine vehicles seem much more expensive for vehicle owners than the 'true' cost difference for New Zealand Inc. Key factors creating this distortion are:

- Lack of a carbon price in petrol/diesel prices at a level that reflects the societal cost of global warming
- Non-cost-reflective electricity prices which substantially increase the cost of charging an EV overnight relative to the 'true cost'
- Internal-combustion engine vehicle owners are not paying for the significant respiratory health costs of exhaust emissions (particularly for diesel for light commercial vehicles)

Additionally, the current lack of public charging infrastructure for refuelling EVs away from home is likely to be a barrier for some vehicle buyers.

A key factor affecting the rate of EV uptake is that it is generally not cost-effective to scrap an internal-combustion engine vehicle with ten or fifteen years of useful life left in it. This means that the transition to low-carbon EVs will take several decades, even when all barriers are removed. This is simply because new internal-combustion engine vehicles are entering the fleet today (and will do so for years to come), and these vehicles are likely to have an economic life of about 20 years (i.e. this is the average age of light vehicles in New Zealand when they are scrapped).

Given this timing, and taking account of projected cost improvements in EVs, we estimate that over half of light private and commercial emissions can be cost-effectively removed by EVs within 20 years. This will reduce light fleet emissions by approximately 5.5 Mt CO_2/year compared with current light fleet emissions.

Much smaller, but nonetheless important, volumes of emission reductions in the light fleet can be achieved by using biofuel blends e.g. E10 from Gull (10% ethanol) and B5 from Z Energy (5% bio-diesel). In terms of scale, the new Wiri biodiesel facility is estimated to offset approximately 0.05 $MtCO_2$/yr.

These fuels are one of the relatively rare opportunities where abatement is available without any capital cost for end-users – the fuels are compatible with the existing vehicle fleet. However, these fuels are limited in volume as they are made from wastes or residues from other industries (e.g. ethanol from the dairy sector, and tallow from the meat processing sector).

Insight 13. Unless action is taken now, New Zealand will be locked into a high-emission vehicle light fleet for the next few decades

If the distortions and other barriers highlighted above are not addressed, our initial projections are that New Zealand's light fleet transport emissions will continue to grow for another decade (and then only decline slowly). This is because of population growth, and the additional new internal-combustion engine vehicles entering the fleet in the near future (approximately 300,000 light vehicles every year at present) staying with us for decades. There will be some uptake of EVs (growing in later years), but less than is economic.

Insight 14. Mode-shifting light passenger travel to walking, cycling, car sharing, and public transport[xvi] offers some additional (albeit materially smaller) cost-effective abatement opportunities. However, these too are being frustrated by barriers

There are opportunities to cost-effectively shift the mode of travel from private cars to walking, cycling, car sharing, and (perhaps less-cost-effectively)[xvii] public transport.

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.

However, given the generally shorter distances of journeys suitable for such modes of transport, the potential emissions savings are significantly less than for EVs, but nonetheless still material. 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%.

It is potentially the case that increased car-sharing could deliver more significant savings than many of these other mode-shifting opportunities. However, we haven't looked in detail at the scale of this potential.

Insight 15. Achieving abatement in the heavy vehicle fleet is much higher cost, because EV technology is less suitable (due to range and battery weight considerations), and biofuel and hydrogen technologies are high cost

While some of the heavy vehicle fleet can be replaced with electric vehicles (initial analysis indicates this may be as low as 30%), the issues of daily driving range and weight of the batteries (i.e. reducing net payload capacity) are more pronounced and make heavy-fleet EVs much more costly than light fleet EVs.

There are currently no low-cost options to decarbonise the majority of the heavy fleet that can't be 'electrified'. It is likely that some road-to-rail freight switching would be cost-effective, but provisional analysis indicates that this will not facilitate major emissions reductions[xviii].

While hydrogen and advanced biofuels are technically feasible (and don't have the truck weight penalty of batteries), they are high-cost. Initial estimates put the cost at about NZ$100/t$CO_2$ at US$100/bbl oil price and NZ$250/tCO_2 for US$50/bbl oil prices). However, given the infant nature of these technologies, these estimates are subject to some uncertainty, and costs are expected to reduce as technology improves.

Further, it is likely that New Zealand's limited biomass resource[xix] would be more cost-effectively used initially to displace coal-fired industrial process heat emissions (where biomass is lower cost than electrification of heat plant) than heavy-fleet diesel.

Achieving heavy-fleet emissions reductions is likely to rely on further technology improvements (whether in batteries, advanced bio-fuels, or hydrogen), plus addressing the same externalities facing EVs relative to ICEs in the light fleet. We provisionally estimate that the uptake of electric vehicles for heavy goods vehicles will be 20 years behind the uptake for light vehicles. However, this is subject to significant uncertainty.

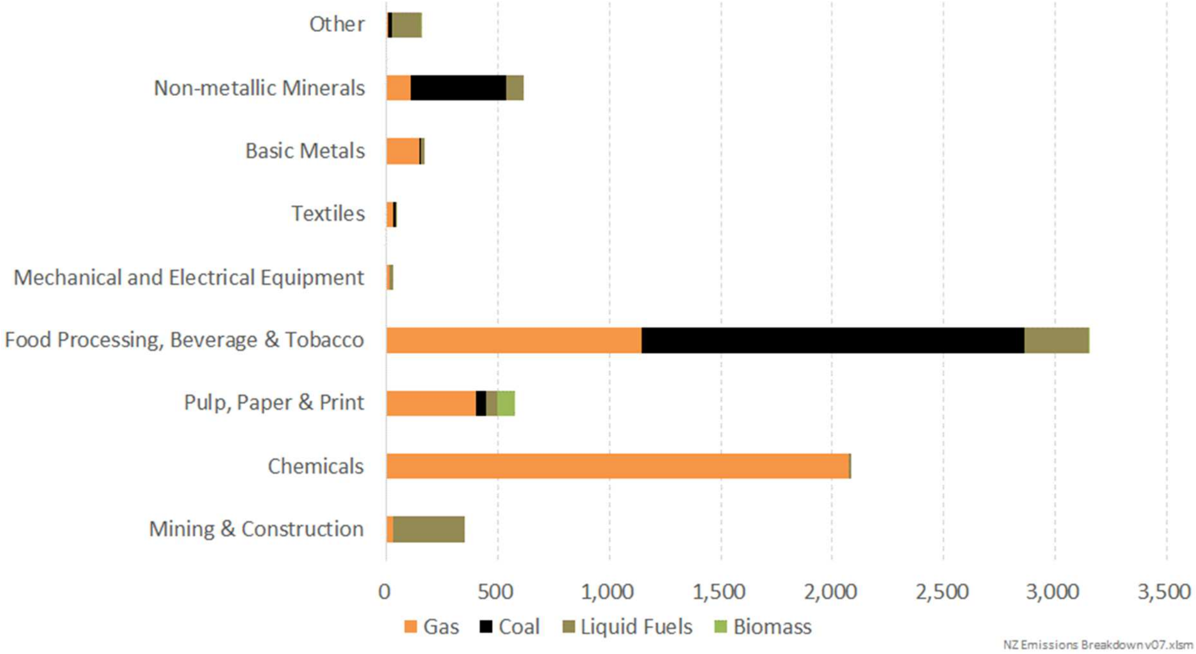
6 Process heat insights

Figure 2 previously shows that emissions from industrial process heat raised by fossil fuels has grown significantly over recent years, to the point where it has now overtaken emissions from electricity generation.

Many industries need heat for their industrial processes. As illustrated in Figure 4 below, the biggest heat requirements are:

- to provide the energy for the chemical transformation of gas to create methanol and urea
- for dairy, meat, and other food processing
- for drying in wood, pulp, and paper production
- to raise heat for steel and other metal production.

Figure 4: 2015 process heat emissions by industrial sector



Source: Concept analysis of MBIE data

Insight 16. Industrial process heat emissions are highly concentrated amongst a subset of the heat plant, and an even smaller number of companies (primarily in the chemicals, and food processing industries).

Industrial process heat emissions are dominated by a relatively small number of super-large heat plant fuelled by coal and gas (i.e. it is estimated that over 90% of the emissions come from less than 5% of the heat plant). These plant are dominated by boilers to raise intermediate temperature process heat for the dairy, meat and other food processing industries, and also heat-raising plant for methanol and urea production.

These industries have also seen the greatest growth in emissions, driven most significantly by the growth in New Zealand's dairy production, and also by a recent resumption of methanol production to full capacity. In 2015, Taranaki was the world's largest methanol production location.

Insight 17. Abatement is slow to achieve because boilers are long-lived plant, but a significant amount of abatement could be possible with a carbon price of the order of \$70 to \$100/tCO_2 (through switching to lower-carbon fuels such as electricity or biomass).

A key factor for this sector is that boilers are very long-lived plant – a boiler installed today could still be burning coal or gas in 2040-2050. So, making the right decisions now is important.

In terms of abatement opportunities in the process heat sector, we note that:

- There can be some cost-effective abatement opportunities through 'boiler tuning' (i.e. efficiency increases), but these are relatively small (EECA has run programmes in this area in the past)
- The potential for using electricity for some process heat plant warrants further investigation. While the average \$/GJ fuel cost of electricity is about five times that of coal (absent a price of CO_2), electricity prices vary strongly by season due to seasonal variations in demand, hydro inflows and wind generation. This may give opportunities for heat-loads which are anti-

correlated with winter (e.g. dairy processing). This could significantly reduce the cost of electric solutions for such plant, potentially giving a sub \$100/tCO_2 abatement cost.

- There are some cost-effective opportunities to switch from coal to gas in the North Island (with the main barriers to such switching being a lack of a cost-reflective carbon price, and having to wait for existing boilers to reach the end of their economic lives), but there are no such opportunities in the South Island due to no natural gas supply being available. Likewise, there may be some opportunities to switch to geothermal power, but these opportunities are very site specific and currently limited to the Taupo-Rotorua-Kawerau region[xx].
- Fuel switching to woody biomass is a technically feasible option, but it can double the delivered energy costs (i.e. including higher boiler and fuel handling capital costs) compared to using coal for large scale plant. On average, we estimate this equates to a cost of carbon of about \$60 to \$70/tCO_2 for the lowest-cost biomass resources.

  However, the cost of biomass is very situation-specific. It depends on the type of biomass residues (which affects collections costs), and the distance between the biomass source and the process heat requirement. It is expensive to transport biomass long-distances because freshly harvested biomass has a low energy density due to its high moisture content. This means there are likely to be some relatively low-cost opportunities – and equally some very high cost options.[xxi]

  There may be 'option value' in paying higher capital costs for a boiler than can burn either coal and woody biomass, such that in the years ahead it can be switched to woody biomass at much lower cost as soon as it becomes cost-effective (rather than waiting until the boiler needs replacing).
- In the long-term, it is likely that new technologies (or at least highly tailored applications of existing technologies such as electric boilers) will be required to cost-effectively de-carbonise industrial process heat. This is because the sector is very price-sensitive (being trade-exposed), and due to the very different energy demand across the sector (even within the dairy processing sector, drying milk has a different energy demand to other dairy products). This will require research investment which may require government involvement.

Insight 18. While the principal barrier to the uptake of low-carbon process heat is a lack of carbon price, industrial process heat faces an additional challenge in terms of competition from overseas producers who don't face a cost of carbon.

The principal externality limiting the uptake of low-carbon process heat opportunities is lack of a carbon price that reflects the cost of global warming to New Zealand society. A higher carbon price wouldn't just increase the cost of fossil fuels, but would increase the availability (and reduce the cost) of woody biomass residues due to increased forest planting.

However, unlike most other energy-related carbon-emitting sectors, introducing a carbon price for industrial process heat raises some particular additional challenges: these energy-intensive process heat users are also those who are most likely to be exposed to competition from overseas producers who don't face a cost of CO_2. As a result, there is a real risk of 'carbon leakage' whereby a price of carbon causes a New Zealand manufacturer to shut down, only for its output to be replaced by increased production from an overseas producer. This overseas producer may be more carbon-intensive than the New Zealand producer it has displaced (for example, coal-based methanol production in China).

This will require continuation of the Industrial Allocation mechanism, or something equivalent, to prevent such outcomes while providing an incentive to switch to lower-carbon alternatives.

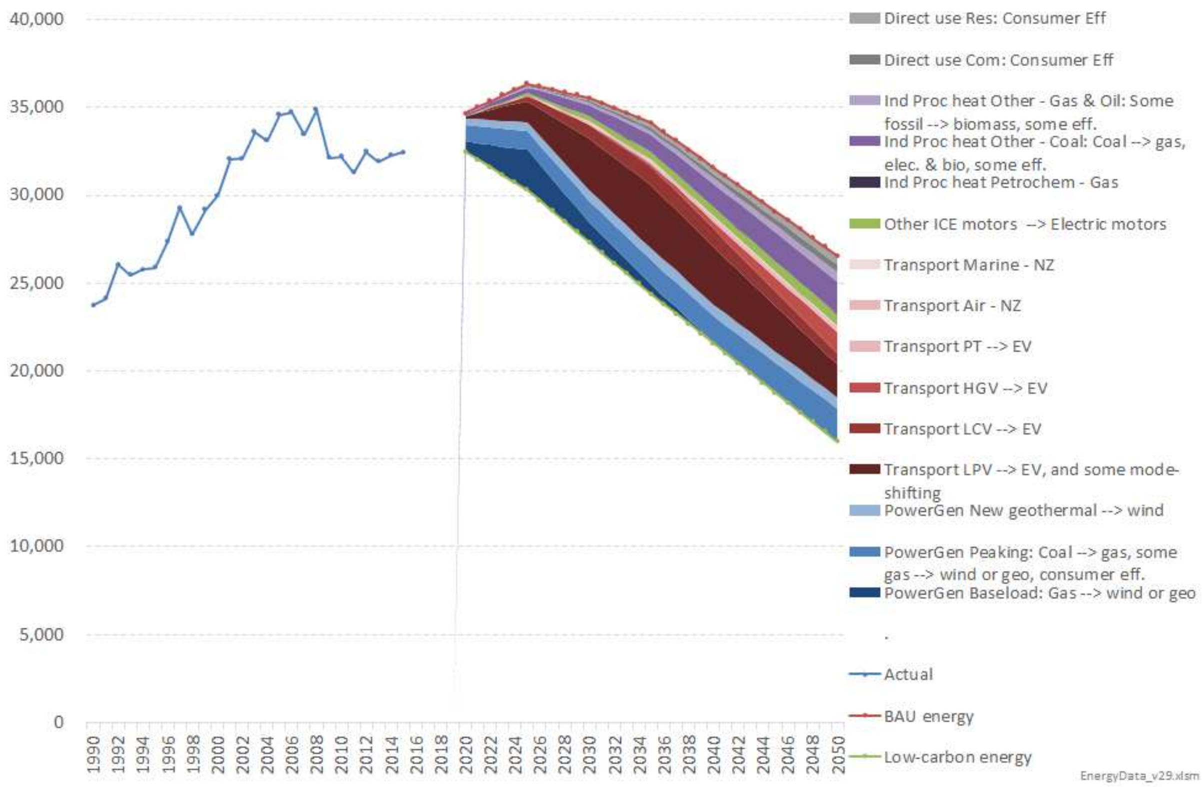
7 Summary

7.1 Projections of low-carbon emissions savings

We have undertaken an initial 'first-pass' at drawing together this analysis and producing projections of the likely scale of emissions reductions that could be achieved from measures which are likely to be cost-effective for carbon prices of approximately NZ$100/t$CO_2$ or less. These 'low-carbon' projections were compared with our projections of energy-related emissions on a 'business-as-usual' (BAU) basis – i.e. based on projections of population and GDP growth, and with a continuation of current low carbon prices, and other barriers to uptake of low-carbon energy options.

These projections are shown in Figure 5. The lines show the absolute total emissions ('Actual', and the 'BAU Energy' and 'Low-carbon energy' projections), with the shaded areas indicating what is projected to make up the difference between the BAU and low-carbon lines.

Figure 5: Projected gross energy-related greenhouse emissions (ktCO2-e)



There are some considerable inherent uncertainties over projections out to this time frame – for example, future fossil fuel prices and the future rate of technology improvement in low-carbon technologies (particularly batteries and wind power) will both have a major bearing on future outcomes, but are both subject to major inherent uncertainties.

Nonetheless, we believe our analysis presents a reasonable first-order estimate of the likely nature and scale of carbon abatement opportunities.

As can be seen, we are projecting that BAU energy emissions will start to decline at some point in the future anyway due to general technology improvement and other changes. In particular:

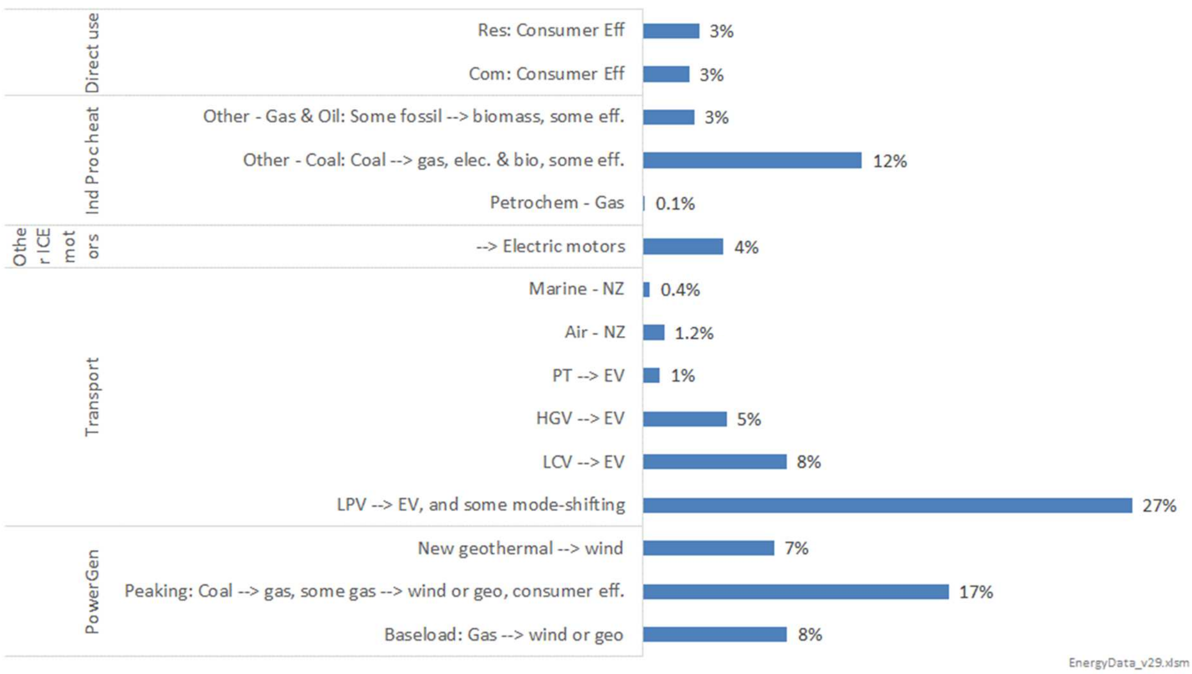
- The inherently superior energy-conversion efficiency of electric motors compared to combustion engines means we believe it is a question of when, not if, EVs start to significantly displace petroleum-fuelled vehicles.

- At some point in the future the existing baseload CCGTs will anyway be retired and replaced by wind or geothermal, given that new wind and geothermal power stations are already cheaper in New Zealand than new fossil stations for baseload power, even without a price of CO2, and the cost of renewable technologies (particularly wind) continues to decline.

However, if barriers to low-carbon initiatives are not removed, we project that our BAU energy emissions will continue to grow for another decade or so before this turn-around starts to occur.

Figure 6 below gives a summarised breakdown of where we project these sub NZ\$100/tCO_2 low-carbon energy savings are likely to come from. These assess the total savings from each sector out to 2050 (i.e. the total of the shaded area for each sector in Figure 5 above) – noting that we project some sectors may deliver early savings but not later savings (e.g. early displacement of baseload fossil stations which we project will retire anyway within this period), and vice versa for sectors such as de-carbonisation of heavy goods vehicles.

Figure 6: Breakdown of low-carbon energy greenhouse savings



As can be seen, there is a wide range of different opportunities, spanning a range of different energy-using sectors. However, in descending order of importance, we believe the key opportunities are:

- ***Electric vehicles & motors*** – particularly for light passenger travel (i.e. private cars), but also for commercial vehicles and some other motors (e.g. agricultural equipment), and (at the back-end of our projections) also for heavy goods vehicles
- ***Wind power*** to displace existing fossil generation (particularly baseload gas-fired generation), but also to displace geothermal stations that would otherwise be built to meet demand growth.
  - We note that consumer self-generation options (solar PV & batteries) are not considered cost-effective relative to wind (and other grid-scale renewables) delivered over the grid. We believe the grid is a critical enabler for de-carbonising our economy.
- ***Coal to electricity fuel switching:*** In the longer-term, we believe it could be economic to convert some of the large South-Island coal-fired dairy processing plant to electricity for carbon prices less than \$100/tCO_2.

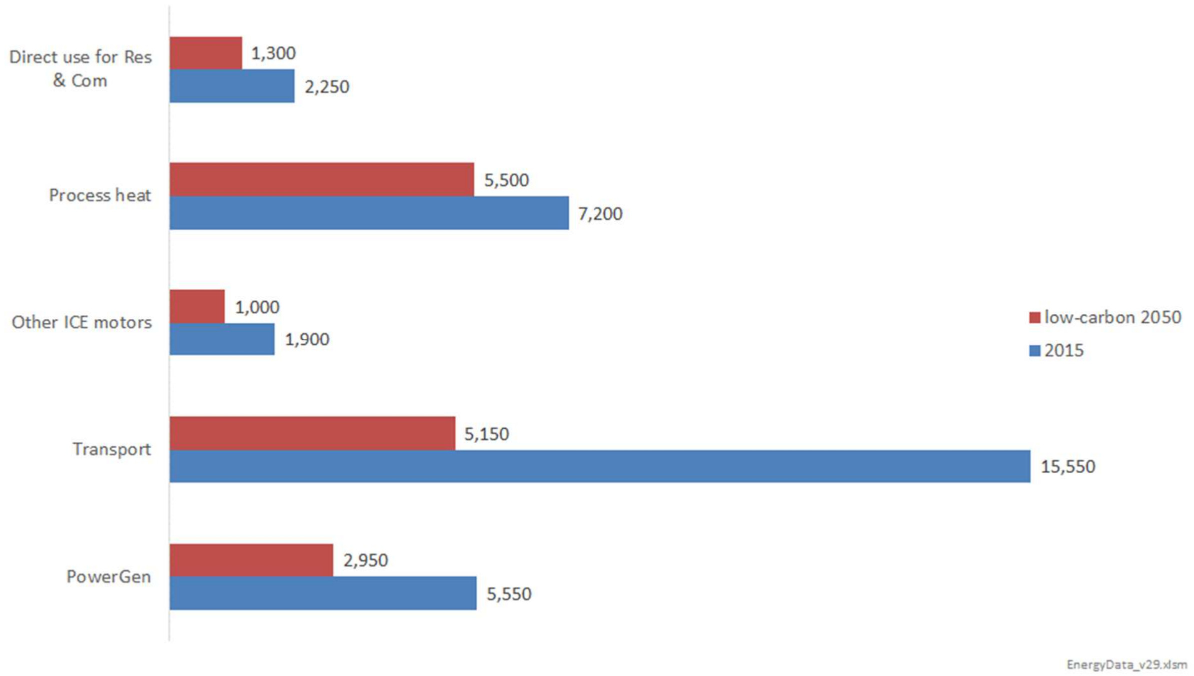
- ***Coal to gas fuel switching:*** In particular, displacement of coal in the Huntly Rankine power stations, but also some opportunities for industrial process heat in the North Island.
- ***Consumer efficiency:*** A range of opportunities from large industrials to households, covering process heat, space and water heating, and lighting.

However, as the main sections in this summary report highlight, achievement of sub NZ\$100/tCO_2 savings is not going to happen without action to address the various barriers to greenhouse gas abatement in each of the different areas of energy use. These include:

- The lack of a NZ\$100/tCO_2 price faced by the various decision-makers making fuel and appliance investment choices
- Many other externalities in the transport sector which favour private travel generally, and also combustion engines specifically (e.g. human health, congestion, land-pricing)
- Consumer electricity prices not reflecting the very high cost of supply at times of peak demand, and the low-cost at other times
- Other barriers for consumer energy (such as lack of information, behavioural barriers, principal / agent barriers)

Further, even with these cost-effective options taken up, we will still be left with a significant portion of our energy emissions which will be challenging to de-carbonise. This is illustrated in Figure 7 below:

Figure 7: The 'hard stuff' - projected remaining 2050 energy-related emissions



These more stubborn emissions sources are:

- Electricity generation used for peaking purposes (i.e. fossil fuel generation used for dry-year support, and seasonal peaking), plus existing geothermal power stations.
- Transport: Heavy vehicles, where the abatement is impeded by the daily driving range being outside the capability of battery technology, or the weight of batteries reducing the effective payload capacity of the vehicles.

- Gas-fired process heat: Cost-effective alternatives to gas to deliver the large quantities of high-temperature heat required.
- Residential and commercial space heating provided by direct use of gas. Even where the heating demand can be met by electricity, this still causes emissions as per the first bullet point above. Further, improving heating and insulation options in particular will take time because of the slow capital replacement cycle, and consumer energy is the area facing the greatest behavioural and principal / agent barriers to efficient energy uptake.

Many of the above issues will require either research and technology development beyond what is available today, or a price on carbon above \$100/tCO_2.

7.2 Summary of key insights

We have drawn together each of the key insights set out in the main body of this report:

General insights

Insight 1. Most energy end uses (e.g. space heating, industrial process heat, refrigeration, transport) are capital intensive. This significantly affects the carbon-cost-effectiveness of different options. It particularly means that least-cost abatement generally requires investing in lower-emissions plant at the time of natural asset replacement (i.e. end of economic life), not scrapping higher-emissions plant with significant remaining economic life.

Insight 2. The capital intensity of most energy uses also means they tend to be long-lived assets. This means that: 'Bad' carbon-intensive capital investment decisions taken today, will stay with us for decades; and, even if we start making 'good' investments in low-emission assets now, the timescale of the capital replacement cycle will mean it will take a long time to replace our whole 'fleet' (of vehicles, boilers, houses, etc)

Insight 3. Low-carbon options tend to be significantly more capital intensive than high-carbon options. This makes firm future expectations of higher carbon costs critical to influence the decisions of parties making a capital investment towards low-carbon options.

Insight 4. Other pricing distortions and barriers are also significantly frustrating investment in low-carbon options, including lack of cost-reflective electricity tariffs, and many other externalities in road transport (human health, road pricing, etc.)

Electricity generation insights

Insight 5. Displacing existing base-load gas-fired electricity generation with new low-carbon generation represents one of the largest, carbon-displacement opportunities. However, displacing fossil generation from providing seasonal and within-day peaking, and dry-year reserve, will be a lot more expensive.

Insight 6. Ironically, it is New Zealand's hydro generation fleet which is prolonging the life of the coal-fired Huntly Rankine station, as coal is much cheaper than gas for providing large amounts of energy during relatively rare dry-year events. Switching from coal to gas for hydro-firming is likely to be a 'medium' cost abatement option.

Insight 7. Geothermal energy, while less emissions intensive than fossil power stations, emits greenhouse gases. Building new wind instead of new geothermal stations to meet future demand could avoid material emissions.

Insight 8. Consumer scale generation technologies (solar PV and batteries) do not offer cost-effective abatement compared with utility-scale low-carbon generation (particularly wind).

Insight 9. The grid is a key enabler for de-carbonising our economy, particularly to support development of renewable-powered electric vehicles and industrial process heat.

Consumer energy insights

Insight 10. There is economic greenhouse abatement potential in the demand-side of the energy sector – particularly efficient technologies for those end-uses that are greatest in winter and/or heavily focused in morning & evening peak periods.

Insight 11. There are a number of distortions / barriers which mean that these abatement options which are cost-effective for New Zealand may not be realised. The most significant is a lack of cost-reflective electricity prices, but there also some significant 'behavioural' and principal / agent barriers which frustrate good decision making.

Transport insights

Insight 12. Electric vehicles are the most attractive abatement option for light passenger and light commercial travel – and the largest abatement opportunity across our whole economy. However, lack of a societal carbon price and many other barriers will significantly frustrate their uptake.

Insight 13. Unless action is taken now, New Zealand will be locked into a high-emission vehicle light fleet for the next few decades

Insight 14. Mode-shifting light passenger travel to walking, cycling, car sharing, and public transport offers some additional (albeit materially smaller) cost-effective abatement opportunities. However, these too are being frustrated by barriers

Insight 15. Achieving abatement in the heavy vehicle fleet is much higher cost, because EV technology is less suitable (due to range and battery weight considerations), and biofuel and hydrogen technologies are high cost

Process heat insights

Insight 16. Industrial process heat emissions are highly concentrated amongst a subset of the boiler plant, and an even smaller number of companies (primarily in the chemicals, and food processing industries).

Insight 17. Abatement is slow to achieve because boilers are long-lived plant, but a significant amount of abatement could be possible with a carbon price of the order of $70 to $100/tCO_2$. New technology is likely required to deliver significant emissions reductions in the long-term

Insight 18. While the principal barrier to the uptake of low-carbon process heat is a lack of carbon price, industrial process heat faces an additional challenge in terms of competition from overseas producers who don't face a cost of carbon.

Endnotes

[i] Note that we are thinking here in economic terms (i.e. scrapping an asset means it is no longer used in New Zealand). We are not talking about an individual's private situation where they might buy a new appliance (e.g. a new car), but the old appliance is on-sold and stays in-use somewhere else in New Zealand.

[ii] Some of the older houses will have been renovated and wall insulation added. However, even houses built in the 2000s have been subsequently found to have no insulation (even though the code requires this).

[iii] Electricity is more expensive to supply at peak times because much of the need to invest in distribution and transmission network assets to provide sufficient capacity for the relatively few periods of peak demand. Likewise, there is the need to invest in some infrequently-used generation to provide generation at times of peak demand.

[iv] For analysis on the extent to which solar PV does (or does not) reduce emissions in New Zealand, see the first volume in our 'New Technologies' study, available for download here: http://www.concept.co.nz/publications.html

[v] The ACC levy to cover accidents is less than the estimated total societal cost of accidents.

[vi] While a renewable resource, geothermal energy still produces CO_2 emissions which can be material. On average across all geothermal generation, these are approximately a third of the amount per MWh of a gas-fired power station. However, some specific fields give rise to emissions that are higher than for a gas-fired power station.

[vii] This is because existing hydro generation has little additional ability to use storage 'sculpt' its generation from summer to winter any more than it currently is doing. Plus, by definition, hydro generation cannot be used to meet infrequent dry-year requirements.

[viii] Although the Ahuroa gas storage facility is ideally sized to provide seasonal flexibility, it is not large enough to provide sufficient energy to meet the demand for dry-year firming.

[ix] There is diversity of generation type (e.g. hydro, wind and solar), geography (e.g. if it is calm / cloudy / dry in one part of the country it may be windy / sunny / wet in another). It also realises the benefits of diversity of consumer demand, leading to a much flatter average demand profile, such that lower-emission generation technologies can be used (i.e. less thermal peaking generation).

[x] Note that while a lot of commercial lighting is on at peak times, it is also used all year round. Therefore, only a small proportion of the commercial lighting results in higher emissions. In contrast. Most of residential lighting is during winter evenings when electricity related greenhouse gas emissions are at their highest.

[xi] The uptake of wood burners, which emit particulates, would have an air quality (and hence health) cost that would need to be factored into any cost-benefit analysis.

[xii] This should not be confused with 'spot pricing' (i.e. wholesale market prices). Peak electricity demand is higher because both the network and generation costs of meeting peak demand are higher. Cost reflective pricing would seek to signal these higher costs for electricity used at peak times of the day and year.

[xiii] Note that where homes are under-heated, there are health costs arising from respiratory illnesses, particularly amongst children and the elderly. Analysis associated with the 'Warm Up New Zealand' government insulation retrofit programme found that the benefits of insulation were four times greater than the costs, primarily due to improved health (e.g. fewer doctor's visits and hospitalisations). These benefits have not been factored into this analysis. The abatement costs for insulation are indicative only, given the large number of variables that can affect the analysis.

[xiv] This may be a mix of battery-electric, and plug-in hybrid vehicles, pending the vehicles use (particularly the maximum daily trip length).

[xv] This requires managed off-peak charging of EVs, which can be done, but does require more cost-reflective electricity pricing.

[xvi] Some public transport options (e.g. urban buses) are very cost-effective – particularly where they address congestion and avoid the need for road investment. However, others (e.g. new rail investment, some other

buses) are likely to be quite high cost options for transport de-carbonisation. However, there are likely other social-good aspects to some public transport (particularly buses) – e.g. social access for individuals who cannot afford private vehicles.

[xvii] The economic challenge with public transport is that it is sized to transport passengers at peak times, but is often operating largely empty at much of the rest of the time. This can be cost-effective where public-transport eases congestion and avoids new roading investment. However, if it itself requires significant investment (e.g. for new rail) the economics can become prohibitive.

[xviii] Mode-shifting to a combination of rail (or coastal shipping) and electric heavy vehicles may be feasible as a low-carbon option to replace some existing heavy transport, but this causes significant additional handling. Similarly, first-generation biofuels will allow blended biofuels to reduce some emissions in the near term, but the quantum of this blended fuel is limited by the availability of the 'waste' streams (e.g. tallow and used vegetable oil etc).

[xix] We note that Scion have done significant research on the potential of woody biomass for liquid fuels (via afforestation of marginal land across New Zealand), which would allow enough advanced biofuels to be produced for our entire transport fleet. However, given the current high cost of advanced biofuels, we have not explored this high afforestation scenario in detail.

[xx] Other geothermal heat sources exist around New Zealand, (e.g. along the West Coast near the Alpine Fault), but these resources have yet to be quantified in detail.

[xxi] Oven-dried wood has a similar energy density to mid-grade coal (~19MJ/kg), whereas freshly cut wood has an energy density of only about 7.5MJ/kg.