Emissions Reduction Roadmap

Pathway to Science Based Targets – scenarios for Queenstown Lakes District

Prepared for Queenstown Lakes District Council (QLDC)

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Glossary

Abbreviation	Stands for
AFOLU	Agriculture, Forestry and Other Land Use
BEV	Battery Electric Vehicle
CAP	Climate Action Plan
ETS	Emissions Trading Scheme
HW	Hot Water
LCOE	Levelised Cost of Energy
LULUCF	Land Use, Land Use Changes and Forestry
MAC	Marginal Abatement Cost
MACC	Marginal Abatement Cost Curve
MBIE	New Zealand Ministry of Business, Innovation and Employment
MfE	New Zealand Ministry for the Environment
MoT	New Zealand Ministry of Transport
QLDC	Queenstown Lakes District Council
SBTi	Science Based Targets Initiative
WWTP	Wastewater Treatment Plant

Executive summary

The objective of this report is to describe an emissions reduction roadmap – and relevant associated costs – for the Queenstown Lakes District Council (QLDC) in order to inform QLDC about the pathways for achieving net zero carbon emissions by 2050 across the whole district. Further, this report also outlines feasibility of achieving Science Based Targets for the 1.5°C and well-below 2°C scenarios.

Three key scenarios have been considered for this Emissions Reduction Roadmap:

1. Business as Usual – No further behavioural or technological changes to reduce emissions. This is designed to illustrate how the emissions in the region would change with a changing population, based on 2019 emissions intensity metrics. This essentially locks in carbon reduction opportunities already implemented and assumes continued equivalent installations – this effectively means no focus on carbon reduction.
2. Modest Change – Modest behavioural changes and modest technological changes to reduce emissions. This scenario includes projected changes that will occur with current plans, including projects that QLDC are looking at implementing and pathways based on current information regarding projected uptake of various low carbon options. In essence this assumes the current effort in regards to reducing carbon is continued.
3. High Change – High behavioural changes and high technological changes to reduce emissions. This scenario assumes that significant and effective action is taken to realise all savings opportunities across all sectors of the region. This scenario includes very ambitious targets which are currently beyond what will be achieved with current efforts.

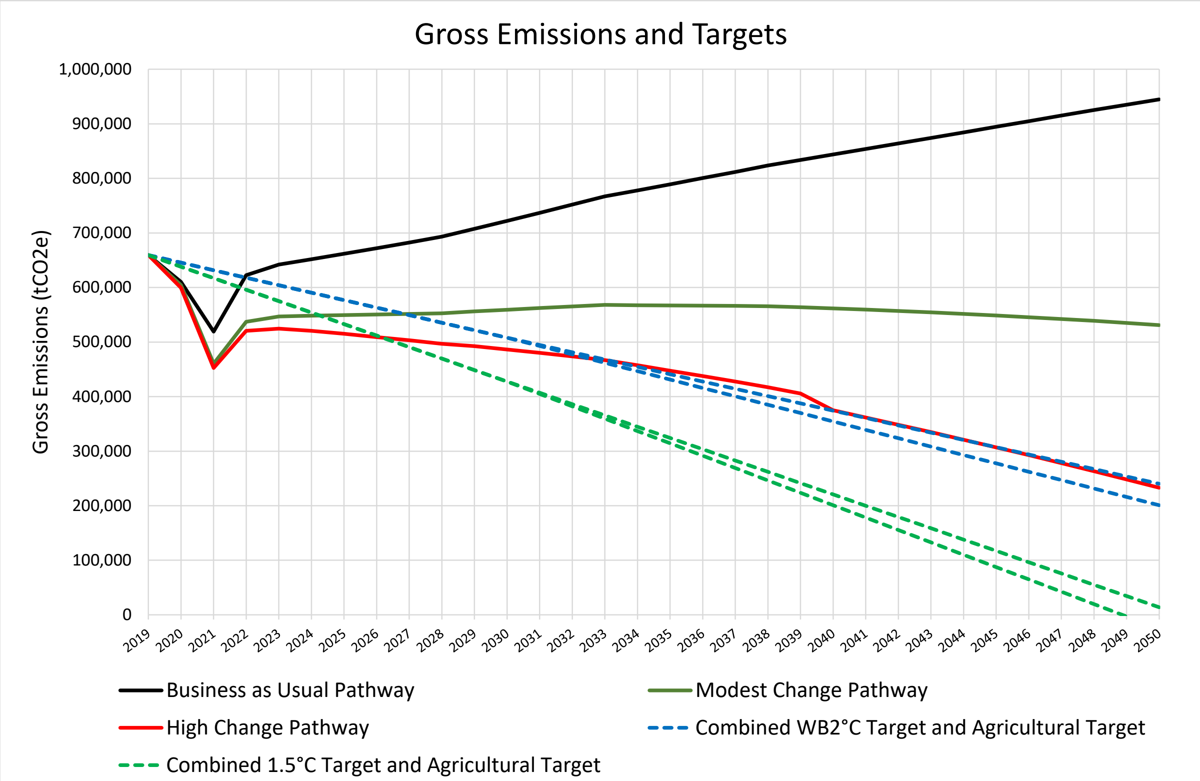
While it is not possible to accurately predict what will happen across the district over the next 30 years, we expect that the actual emissions for the region will fall somewhere between the bounds of the Moderate Change and High Change pathways.

We have used marginal abatement cost estimates to inform our assumptions on start date and uptake rate of key technology options in the transport, electricity, LPG and waste sectors. The estimates cover shorter and longer time-frames, allowing us to capture future technology cost reductions.

The following targets have been set within the Climate Action Plan to align with the NZ Government targets:

1. Reduce all greenhouse gases (except biogenic methane) to net zero by 2050
2. Reduce emissions of biogenic methane within the range of 24–47% below 2017 levels by 2050 including to 10% below 2017 levels by 2030.

The emissions reduction roadmap resulting from the three pathways, and compared to the Climate Action Plan targets, is illustrated on the next page.



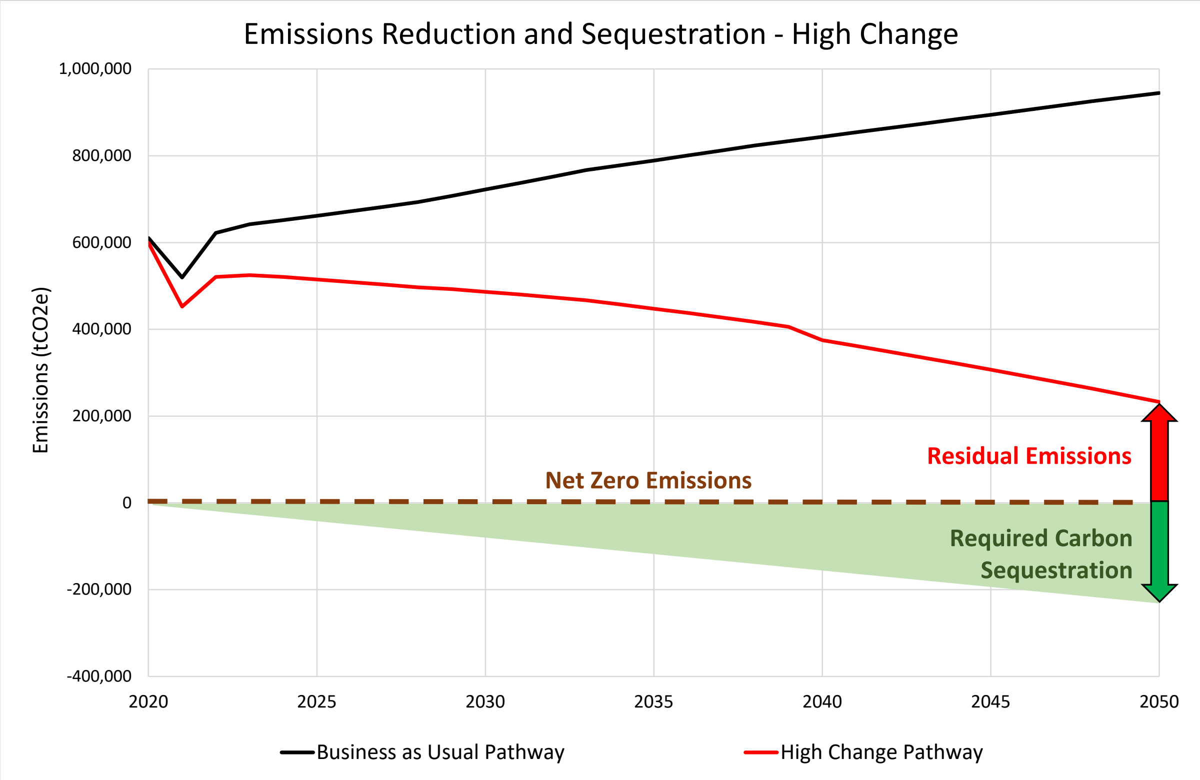
As can be seen, gross emissions for the whole Queenstown Lakes district, although significantly reduced, remain positive through to 2050 for both of the Modest Change and High Change pathways.

Even with significant behavioural and technological changes to low carbon alternatives, very few of the transition options are zero-carbon. Hence a target of net zero by 2050 cannot solely be met through emissions reduction.

A Sequestration Study has been performed in conjunction with this report, highlighting key areas for further investigation and with a focus on carbon sequestration opportunities across the District including both biological sequestration and technical sequestration.

Bearing in mind the land areas, climate and landscape values of the region, a number of opportunities were explored. The analysis showed that it is technically feasible to offset the remaining pathway emissions via sequestration. However, this will involve significant land use change and community buy in will be required in order to facilitate the changes required to achieve net zero emissions.

If the whole Queenstown Lakes district commits to net zero by 2050 (including biogenic methane) then, under the High Change pathway, 233 ktCO_2e/year of GHG emissions will need to be sequestered in order to achieve net zero emissions, as illustrated on the next page.



Modelling performed in the Sequestration Study illustrates that, based on the protocols adopted, plantings of around 17,320 ha of land (the majority with high carbon sequestration vegetation) has potential to sequester over 400 ktCO_2e/year by 2050. This figure is greater than the 233 ktCO_2e/year of residual emissions in 2050 from the High Change pathway, so, based on the modelling assumptions, net zero emissions could be achieved. This planting of around 17,320 ha is less than 2% of the land area of the region, however, it should be noted that this will entail significant challenges regarding the natural landscape of the area and land ownership.

It should also be noted that there are strong synergies between carbon reduction options, biological sequestration and technical sequestration. The Sequestration Study has identified both anaerobic digestion of mixed waste streams to biomethane and pyrolysis of purpose grown biomass to biochar as opportunities worthy of examination. Further assessment is needed to establish whether there is a sufficient business case for further investment; but irrespective such opportunities underlines the value of an integrated holistic approach to emissions reduction across the district.

Both the Modest and High Change pathways have significant gross emissions associated with them and therefore sequestration will provide a key mechanism to achieving net zero. All available reduction options should be pursued aggressively (High Change pathway) including, where appropriate, carbon sequestration.

The majority of emissions reduction options in this report are technically focussed, as these can be more easily quantified with existing data sets. However, following either pathway will require QLDC to influence stakeholders, communities and partners to change emission behaviours of the population at large – transport and waste are two key areas where behavioural changes will have significant impacts and will make a material difference to emissions. QLDC will need to utilise multiple levers, particularly regulatory, policy and community engagement in order to meet the ambitious targets that have been set. Specific actions around these levers will need to be formulated, discussed, implemented and reviewed.

1. Introduction

1.1 Purpose

QLDC wishes to identify ways in which the District can reduce its carbon emissions as a key action towards mitigating and adapting to the effects of climate change. As a first step it is seeking to develop an Emissions Reduction Roadmap with science-based targets and a plan that assesses the various means for sequestering carbon available to the District.

QLDC engaged Sapere to undertake both the Emissions Reduction Roadmap and Sequestration Study. This report provides a summary of the scenarios and pathways developed for the Emissions Reduction Roadmap. The analysis and cost estimation set out in this report will form the key inputs to QLDC strategic decision making.

The sequestration study is addressed in a separate report, although is referenced here, where appropriate.

1.2 Climate Action Plan

The Queenstown Lakes District Council (QLDC) adopted a Climate Action Plan (CAP) in March 2020, which identifies ways that QLDC can reduce emissions and sets a strategic direction for adapting to and mitigating the effects of climate change across the district.

One of the priority actions in the CAP is to develop an Emissions Reduction Roadmap with science based targets, along with a Sequestration Study. This roadmap will inform some of the strategic decisions made by QLDC and will help to set a direction for community response to climate change. Based on this information, QLDC will determine its own organisation emissions targets.

1.3 Project goals

The aim of this report is to provide QLDC with a roadmap to achieving net zero carbon emissions by 2050 across the whole district. The scope for both the Emissions Reduction Roadmap and Sequestration Study therefore includes all activities occurring within QLDC's administrative boundary.

2. Existing carbon emissions

2.1 Greenhouse gas emission inventory

QLDC commissioned Tonkin & Taylor Ltd to assist in the development of a high-level Greenhouse Gas (GHG) Emission Inventory[1] for the QLDC administrative area. The most recent inventory was carried out in November 2020 for the 2019 calendar year. The QLDC GHG inventory follows the guidance outlined in the *Global Protocol for Community-Scale Greenhouse Gas Emissions Inventories* and summarises the total GHG emissions by relevant subsectors. As noted in the Tonkin & Taylor report, the inventory is a high-level assessment and was limited by the availability and quality of data for the district.

The sectors and subsectors included within the GHG inventory are summarised in Table 1.

Table 1 Included sectors and subsectors for community GHG emissions

Sector	Subsector
Stationary Energy	Electricity consumption
	LPG use
Transportation	Road transportation
	Aviation
Waste	Landfill solid waste disposal
	Septic tanks
	Wastewater treatment and discharge
Agriculture, Forestry and Other Land Use (AFOLU)	Agriculture
	Land use, land use change, forestry (LULUCF)

[1] Tonkin & Taylor (2020), Greenhouse Gas Community Inventory – 2019 Update for the Queenstown Lakes District

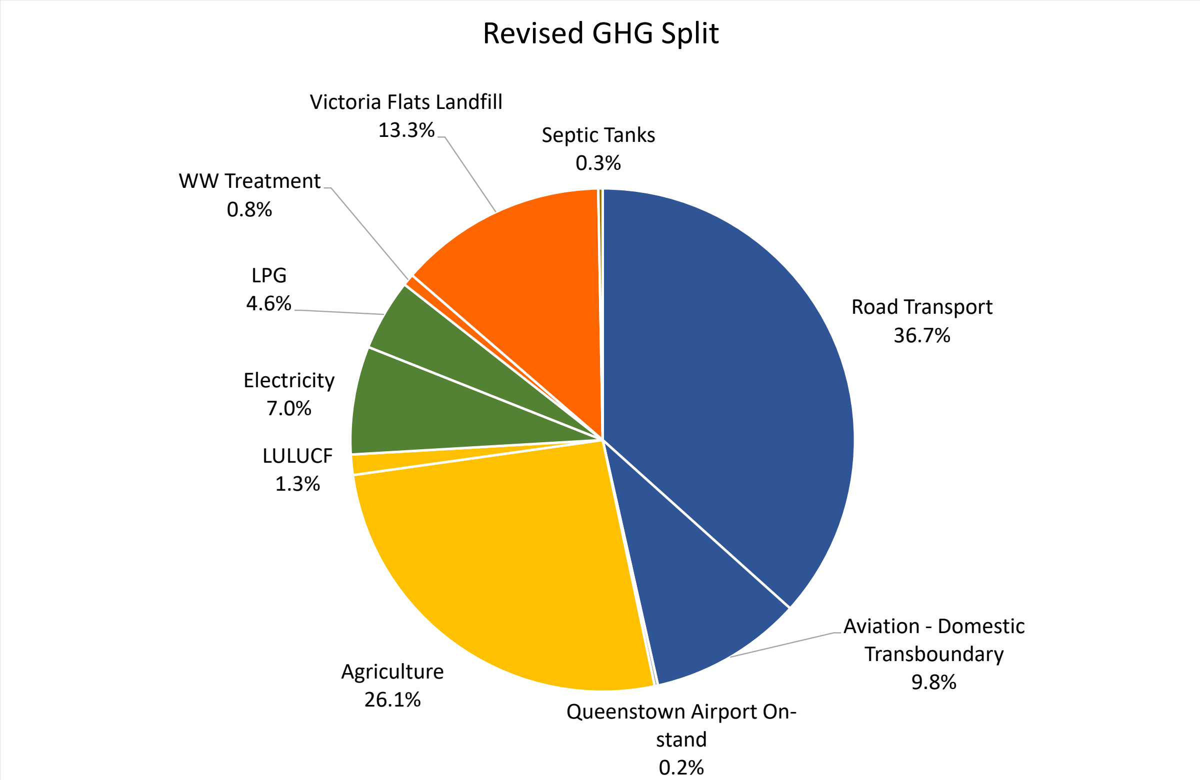
2.2 GHG emissions for 2019

A summary of the gross emissions for the Queenstown Lakes district in the 2019 calendar year is provided in Table 2 (Tonkin & Taylor, 2020). The GHG split is shown in Figure 1.

Table 2 Summary of the gross emissions for the district in 2019

	2019 Emissions	
Sector	**tCO_2e**	**%**
Transport	**307,844**	
Road Transport	241,755	36.7%
Aviation - Domestic Transboundary	64,670	9.8%
Queenstown Airport On-stand	1,419	0.2%
Agriculture, Forestry and Other Land Use	**180,537**	
Agriculture	171,923	26.1%
LULUCF	8,614	1.3%
Stationary Energy	**76,022**	
Electricity	45,822	7.0%
LPG	30,200	4.6%
Waste	**94,871**	
WW Treatment	5,008	0.8%
Victoria Flats Landfill	88,011	13.3%
Septic Tanks	1,852	0.3%
TOTAL	**659,274**	100%

Figure 1 GHG split for the district



We worked with Tonkin & Taylor and Beca to refine assumptions made in earlier emissions reports. In particular, this applied to the reported emissions for the Victoria Flats landfill, Wakatipu wastewater treatment plant and Wanaka wastewater treatment plant.

2.2.1 Landfill emissions

Emissions from solid waste are a significant portion of the total emissions within the district and a breakdown of the waste streams was required to inform the emissions reduction plan.

The following methodology was applied to inform the landfill emissions calculations:

- QLDC recorded 55,691 t of total waste to the Victoria Flats landfill in 2019. Note that this figure includes waste from both QLDC and Central Otago District Council (CODC).
- We have used the total waste figure of 55,691 t for 2019, since this activity is undertaken within the Queenstown Lakes district. The contract for the Victoria Flats Landfill is a joint contract between QLDC, CODC and Scope Resources Ltd.
- This total waste figure was split into separate waste streams based on the fractions provided on Page 8 of the 2020 SWAP[2]. The SWAP was only performed on QLDC waste, so excludes analysis of the waste streams sent to Victoria Flats from the CODC. Based on the 2020 SWAP, waste from QLDC accounted for 76% of all waste sent to Victoria Flats. Therefore, we have assumed that the CODC waste composition split is the same as for QLDC in order to calculate the total tonnes of waste sent to the Victoria Flats landfill for each waste stream.

[2] Waste Not Consulting, Interim Results of February 2020 SWAP Survey of Queenstown RTS, 2020

- Carbon emissions were calculated for each waste stream based on specific emission factors from MfE (refer to Table 25 in Appendix A)

Please refer to Table 5.1 in the Tonkin & Taylor report (2020) for a full breakdown.

2.2.2 Wakatipu WWTP emissions

Beca has undertaken a carbon emissions assessment at the Wakatipu WWTP and has re-baselined the current operations. Beca have also calculated the emissions from the plant after the ponds are decommissioned.

The following estimates were provided by Beca and include emissions from the biosolids[3], based on disposal at landfill with gas capture:

- Emissions factor for operations pre-upgrade = 0.00102 tCO_2-e/m^3 +/-40% (2019 baseline assessment)
- Emissions factor for operations post-upgrade = 0.00097 tCO_2-e/m^3 +/-40%

These emissions factors have been used for this study. Note that they include Scope 1, 2 and 3 emissions.

Beca and ourselves recommend that the uncertainty is reduced through the development of a biosolids specific emissions factor that considers the:

1. Biosolids composition.
2. Information about the landfill operations.

2.2.3 WWTP and biosolids emissions

Biosolids from the Wakatipu and Wanaka WWTPs are sent to the AB Lime landfill in Winton, which is outside of the Queenstown Lakes region. Previously, the emissions from these biosolids were not included in the earlier GHG inventory, since only the waste material being disposed of at the Victoria Flat landfill was included. Rather than having these biosolids emissions exported outside of the region, and after consultation with QLDC and Tonkin & Taylor, these emissions have now been included within the latest GHG inventory update from Tonkin & Taylor (2020).

Please refer to Section 5.2 and Appendix B the Tonkin & Taylor report (2020) for further detail.

Note that:

- The tonnes of biosolids disposed of at the AB Lime facility in 2019 were based on interpolation from Table 2.5 in the QLDC Organics Modelling Report, 2019:
    - o 2,525 t biosolids from Wakatipu in 2019
    - o 1,596 t biosolids from Wanaka in 2019

[3] Email correspondence with Caroline Hope, Beca, 1/9/2020

- An emissions factor of 0.32 tCO2e/t for biosolids at Wakatipu was applied, based on information provided by Beca (including landfill gas capture, which is installed at AB Lime). This factor has been used in this report.
- The biosolids emissions factor for Wanaka was assumed to be the same as for Wakatipu.
- The total emissions from the Wakatipu WWTP emissions are for Scope 1, 2 and 3 emissions, which will include biosolids emissions. The Wanaka WWTP emissions includes our estimate for biosolids, based on the assumptions stated above. These figures require confirmation.

We believe that significant uncertainty is likely to be attached to these emissions factors, due to the range of different data sources, varying time periods and underlying assumptions. We recommend that a detailed wastewater GHG analysis and report is performed for the WWTPs to provide more robust emissions data for the district GHG inventory.

3. Pathways to 2050

3.1 Scenarios

Three key scenarios have been considered for this Emissions Reduction Roadmap (these are outlined further in Section 4):

4. Business as Usual – No further behavioural or technological changes to reduce emissions. This is designed to illustrate how the emissions in the region would change with a changing population, based on 2019 intensity metrics. This essentially locks in carbon reduction opportunities already implemented and assumes continued equivalent installations – this essentially means no focus on carbon reduction.
5. Modest Change – Modest behavioural changes and modest technological changes to reduce emissions. This scenario includes projected changes that will occur with current plans, including projects that QLDC are looking at implementing and pathways based on current information regarding projected uptake of various low carbon options. In essence this assumes the current effort in regards to reducing carbon is continued.
6. High Change – High behavioural changes and high technological changes to reduce emissions. This scenario assumes that significant and effective action is taken to realise all savings opportunities across all sectors of the region. This scenario includes very ambitious targets which are currently beyond what will be achieved with current efforts.

For illustrative purposes, these three scenarios have been mapped in Figure 2.

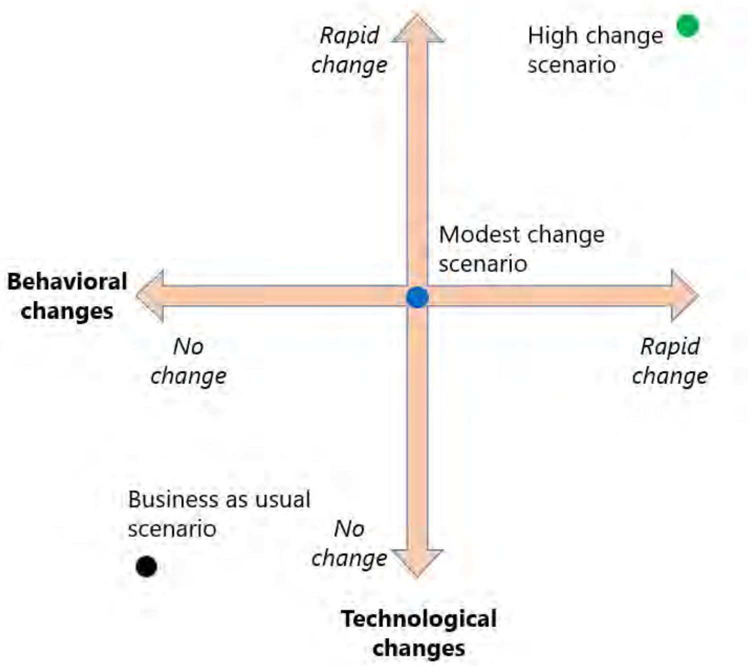


Figure 2 Illustrative mapping of behavioural changes against technological changes that drive the uptake in emissions reduction

3.2 Population projections

Three population projections have been provided by QLDC for the Emissions Reduction Roadmap:

1. Change the path (different journey to 2018 projections but same endpoint)
2. 5-year lag (from 2018 projections)
3. 10-year lag (from 2018 projections)

The "Change the path" projection is preferred by QLDC and has been used as the base-case option within the modelling. All three projections assume that there will be a sharp fall in total population (including both residents and average visitors per day) from 2019 to 2021 due to Covid-19. The total population for all three projections is assumed to increase steadily from 2021 to 2023 and grow at a steady rate through to 2050. The population projections are summarised in Table 3.

Table 3 Total population (average day) projections for the district

Scenario	2019	2021	2023	2030	2040	2050
Change the path	69,670	50,552	69,012	82,973	101,976	117,281
5-year lag	69,670	51,373	66,706	79,876	97,059	110,944
10-year lag	69,670	47,718	60,818	70,989	87,788	103,214

3.3 Modelled pathways

Combining the three emissions reduction scenarios with the three population projections provides nine potential pathways for the Queenstown Lakes district. These pathways are summarised in Table 4.

Table 4 The nine modelled pathways

Number	Scenario	Population Projection	Pathway Name
1	Business as Usual	Change the path	BAU-0
2	Business as Usual	5-year lag	BAU-5
3	Business as Usual	10-year lag	BAU-10
4	Modest Change	Change the path	Modest-0
5	Modest Change	5-year lag	Modest-5
6	Modest Change	10-year lag	Modest-10
7	High Change	Change the path	High-0
8	High Change	5-year lag	High-5
9	High Change	10-year lag	High-10

3.4 Emissions reduction targets

Two emissions reduction targets have been considered for this study: Climate Action Plan and Science Based Targets.

3.4.1 Climate Action Plan targets

The following greenhouse gas reduction targets have been set out in QLDC's Climate Action Plan for 2019-2022:

- Reduce all greenhouse gases (except biogenic methane) to net zero by 2050
- Reduce emissions of biogenic methane within the range of 24–47% below 2017 levels by 2050 including to 10% below 2017 levels by 2030.

These figures align with the New Zealand Government's domestic greenhouse gas emissions reduction targets[4].

3.4.2 Science Based Targets

The Science Based Targets initiative is a collaboration between CDP, World Resources Institute (WRI), the World Wide Fund for Nature (WWF), and the United Nations Global Compact (UNGC). It uses a science-based target methodology to define the transition required to achieve a low-carbon economy.

Targets adopted by companies to reduce greenhouse gas emissions are considered "science-based" if they are in line with what the latest climate science says is necessary to meet the goals of the Paris Agreement – to limit global warming to well-below 2°C above pre-industrial levels and pursue efforts to limit warming to 1.5°C.

The Science Based Targets initiative (SBTi) is currently focusing on private sector companies but are looking to include cities and local governments in future. However, the science-based targets methodologies provided by SBTi are still applicable for cities and local governments and can be adapted for use.

The most recent SBTi criteria and recommendations (v4) came into effect in October 15th 2019. The minimum annual emissions reduction for these scenarios are shown in Table 5:

Table 5 Science Based Targets

Scenario	Minimum annual emissions reduction[5]
1.5 degrees	4.2%
Well-below 2 degrees	2.5%

[4] https://www.mfe.govt.nz/climate-change/climate-change-and-government/emissions-reduction-targets/about-our-emissions

[5] As per https://sciencebasedtargets.org/wp-content/uploads/2019/04/target-validation-protocol.pdf

Both these SBT scenarios have been modelled within this Emissions Reduction Plan.

3.5 Emissions factors

Please refer to Appendix A for the emissions factor assumptions used in the pathways.

3.6 Technical assumptions

Please refer to Appendix B for the technical assumptions used in the pathways.

3.7 Model

A model for the emission reduction pathways has been developed using Excel and accompanies this report. The model is called "QLDC Emissions Reduction Model.xlsx"

4. Business as usual scenario

In order to assess how effective decarbonisation options would be at reducing carbon emissions, the projected future emissions must be calculated for the Queenstown Lakes district. This section outlines the methodology and results of this part of the project.

4.1 Methodology

QLDC have performed emissions assessments in the past. These have provided a good base of information but have been focussed on existing emissions, rather than forecast emissions. The revised GHG inventory from Tonkin & Taylor for the 2019 calendar year has been used as the foundation for the modelled projections (refer to Section 2.2 for details on the revisions).

As a starting point for the Emissions Reduction Roadmap, district emissions have been projected through to 2050 based on the Business as Usual scenario where there are no further behavioural or technological changes to reduce carbon emissions from the 2019 baseline. This is effectively the worst-case scenario that ignores any future improvements or actions by individuals, communities, businesses, Council or Government. This scenario puts an upper bound on future emissions.

Two key underlying assumptions for this Business as Usual scenario are:

1. Agricultural stock numbers and emissions factors remain constant (further detail below).
2. The per capita emissions for all other subsectors remain constant (further details below).

The following methodology has been applied to produce the Business as Usual gross emissions projection:

- Agricultural animal numbers in the district have declined gradually by 0.68% per year from 2002 to 2019[6]. Most of this decline is due to reducing sheep numbers. Based on this, we have assumed that the number of sheep, beef cows, dairy cows and deer remains constant from 2019 to 2050 with no change in GHG emissions.
- Emissions from the remaining subsectors (road transport, aviation, LULUCF, electricity, LPG, wastewater and septic tanks, landfill) have been divided by the total average population for the district (residents and visitors) to provide GHG emissions metric based on 2019 data.
- This metric for 2019 emissions has been scaled linearly with QLDC's population forecasts. Therefore, if the population increases, emissions rise (and vice versa).
- The Business as Usual scenario assumes that there is no change in GDP per capita, since this is the worst-case scenario and 30-year economic projections for the district are not available.
- All future emissions factors remain the same as the 2019 figures from MfE, except for electricity emissions.
- MBIE has forecast that the emission factor per kWh of grid-connected electricity will fall from 2020 to 2035 then remain constant, due to additional renewable electricity generation being

[6] As per http://archive.stats.govt.nz/browse_for_stats/industry_sectors/agriculture-horticulture-forestry/2012-agricultural-census-tables/livestock.aspx#gsc.tab=0

added to the market[7]. These forecast emission factors have been included in the modelling across all pathways.

4.2 Business as usual modelling results

The gross carbon emission profile resulting from the Business as Usual scenario is shown in Figure 3. Based on the methodology outlined in Section 4.1, the emissions from agriculture remain constant through to 2050, while the other sectors see an increase in emissions by 2050 due to population growth.

The decrease in emissions in 2021 is due to the anticipated reduction in visitor numbers and resident population as a result of the fallout from Covid-19.

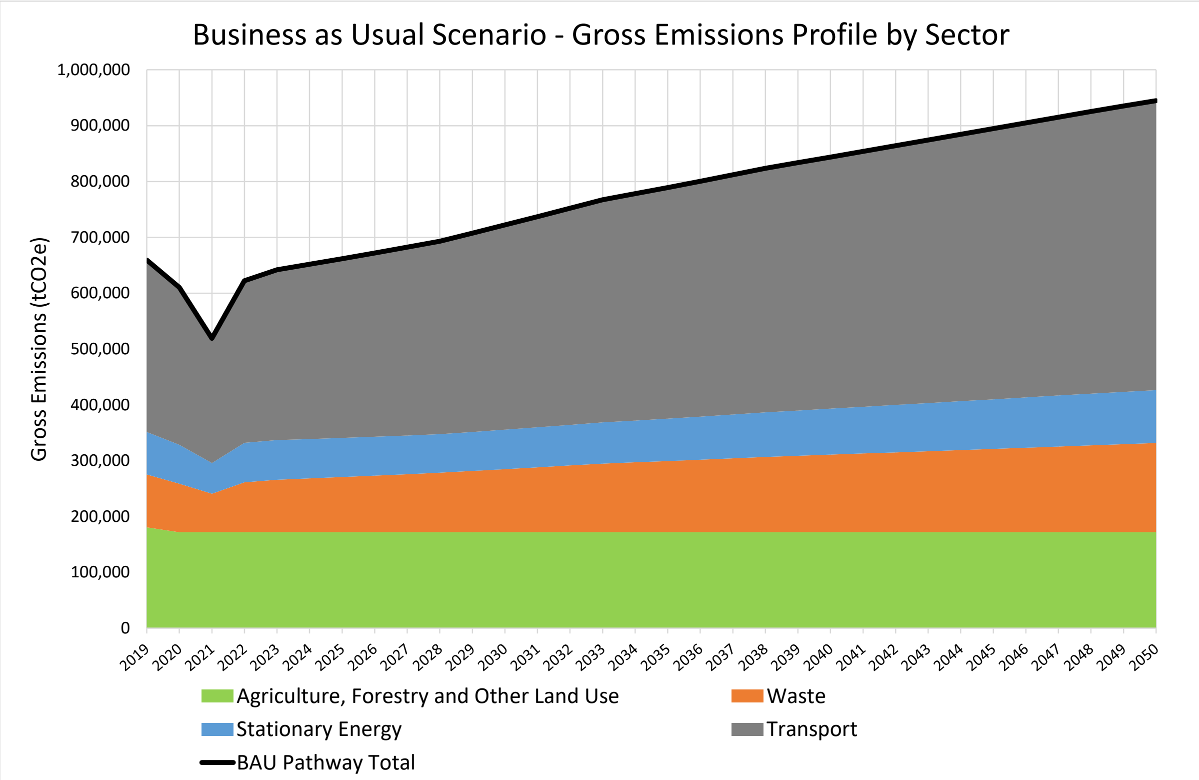


Figure 3 Gross CO_2e emissions profile by sector for the Business as Usual scenario with "Change the path" population projections (BAU-0)

[7] As per https://www.mbie.govt.nz/assets/Data-Files/Energy/e5813268d9/electicity-insight-global-low-carbon.xlsx

4.3 Population sensitivity

The total population for the district (including both residents and visitors) will have an impact on carbon emissions. A sensitivity analysis was undertaken to compare the carbon emissions associated with the BAU-0, BAU-5 and BAU-10 pathways. The figure below illustrates the modelling for these three pathways through to 2050. As can be seen, lower rates of population increase will result in fewer carbon emissions being emitted due to less travel, economic activity, and overall consumption.

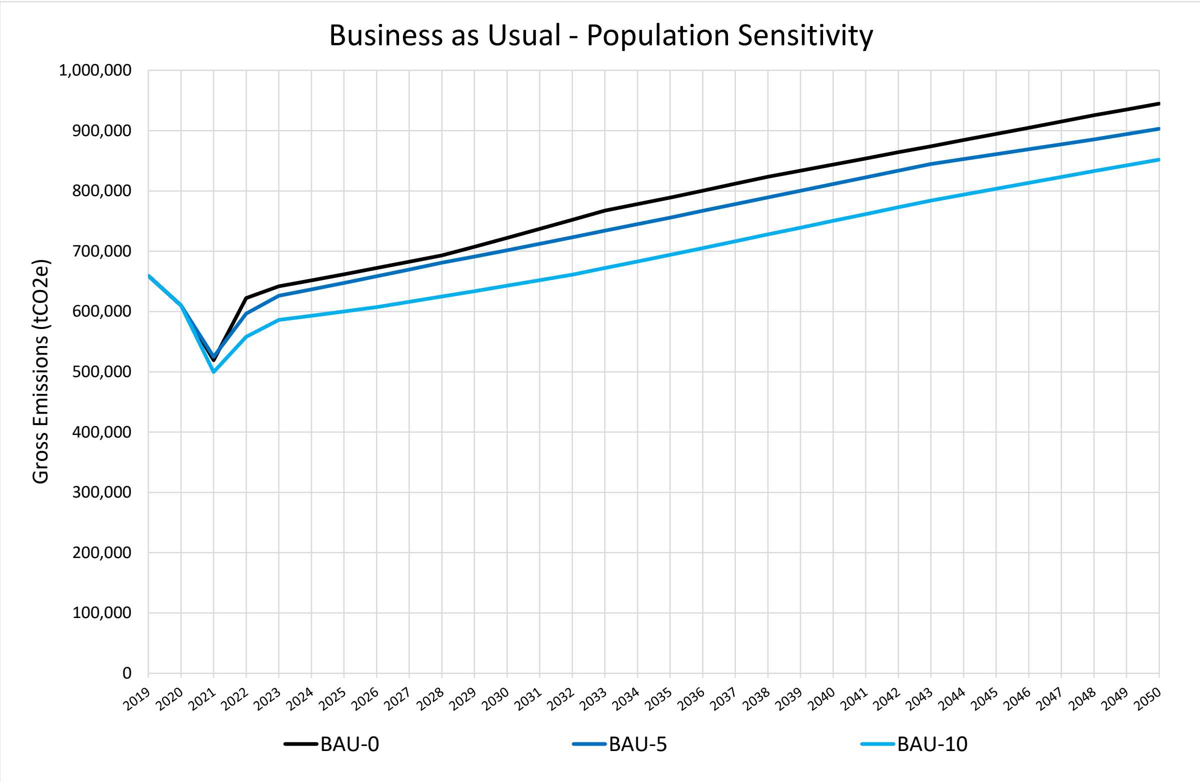


Figure 4 Population sensitivity for the Business as Usual pathway

Further population sensitivity analysis has been undertaken in Section 9 for the Moderate Change and High Change pathways.

5. District emissions reduction options

High-level emissions pathways to 2050 have been developed for each subsector. Two pathways have been modelled based on Modest Change and High Change. While it is not possible to accurately predict what will happen across the district over the next 30 years, we expect that the actual emissions for the region will fall somewhere between the bounds of the Modest Change and High Change pathways.

The carbon emission reduction options that have been investigated and modelled are discussed in the following sections for each subsector. The reduction charts for the Modest Change and High Change pathways in each subsector have been presented side-by-side for ease of comparison.

All of the charts presented in this section are for the Modest/High Change-0 pathways using the "change the path" population projections, to illustrate the potential scenario for the district to reduce gross carbon emissions based on activities that have already been planned and other behavioural and technological changes.

The high-level options to reduce carbon emissions are wide-ranging and collaboration with communities, partners and stakeholders will be essential in order to achieve the desired outcomes. As outlined in the CAP[8], QLDC's specific role depends on its ability to act in three spheres of influence:

- Sphere of Control – QLDC operations and policy
- Sphere of Influence – QLDC relationships and advocacy
- Sphere of Interest – Wider social, cultural, environmental and economic factors

QLDC will need to use all three of these spheres of influence to achieve the emissions mitigation options presented in the following sections.

Further, there will be a mixture of behavioural and technological changes required to implement these options. An indicative summary of these relative ratios is provided in Table 6, based on the total amount of carbon emissions reduction by 2050 under the Modest-0 pathways. Approximately 80% of the options will require the uptake of existing and future low-carbon technologies.

Table 6 Changes required to implement Modest-0

Changes	Net tCO2e Savings vs BAU	Percentage of Net Reduction
Behavioural	29,200	7%
Behavioural & Technological	56,600	14%
Technological	327,900	79%

The modelling has been performed using readily available information. Further refinements can be achieved by improving the underlying data, assumptions, and forecasts, especially for behavioural changes. Recommended modelling improvements for each subsector are summarised in Section 11.

[8] QLDC, Climate Action Plan 2019-2022

5.1 Road transport

The following emissions reduction options have been modelled for the road transport sector:

- Public transport and ride sharing for journeys taken on SH6A, between Frankton and Queenstown – Increase the number of journeys taken on public transport or ride sharing, rather than travelling via private vehicles. Traffic volumes along this stretch of road are highest in the district, providing a good opportunity for transport mode shifting.
- Convert from petrol light passenger vehicles and light commercial vehicles to battery electric – BEVs emit fewer emissions per kilometre travelled compared to internal combustion engines and the technology is commercially available. Charging infrastructure will be required.
- Convert from diesel light passenger vehicles and light commercial vehicles to battery electric – BEVs emit fewer emissions per kilometre travelled compared to internal combustion engines and the technology is commercially available. Charging infrastructure will be required.
- Heavy vehicle driver training and telemetrics – Ensuring truck drivers are operating the trucks as efficiently as possible and routes are optimised.
- Heavy vehicle efficiency – Annual improvement in energy efficiency through incremental design improvements.
- Trucking collaboration – Collaboration between companies to minimise empty space in trucks, including empty return trips. Could occur via middle freight forward companies or directly.
- Convert heavy diesel vehicles to battery electric – Purchase new BEV, or convert existing fleet. Given battery density, charge time and charging infrastructure, only a relatively small portion of heavy vehicles are projected to be suitable for this upgrade (such as buses).
- Convert heavy diesel vehicles to 100% renewable biodiesel (G2) – Retain existing trucking fleet and operate on 2nd generation biodiesel – this fuel is able to be blended up to 100% in engines. Currently unavailable in NZ, but projected to become more readily available.
- Convert heavy diesel vehicles to hydrogen fuel cells – Upgrade trucks and operate on hydrogen. Currently limited opportunities for this, but availability is expected to increase significantly in the future
- Behaviour Change – Information around the effects that behavioural change (outside of the above items) will have on the pathway is currently very limited, however we realise that this will be a key aspect for future savings. As such, we have included a place holder opportunity which will allow QLDC to modify the modelling outputs once additional input and results data is available.

The figures on the next page show the net emissions reduction options in the road transport sector for both the Modest Change and High Change pathways, based on the key inputs from Table 7.

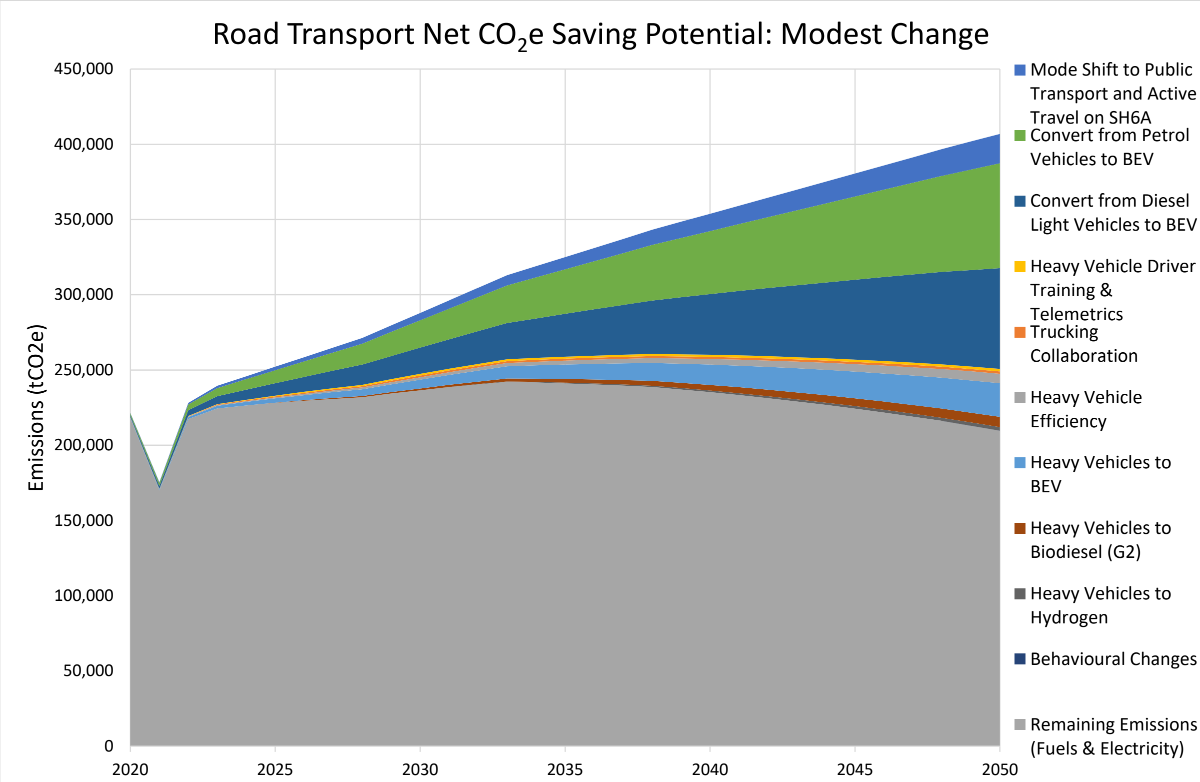


Figure 5 Net CO_2e saving potential for road transport under the Modest Change pathway (Modest-0)

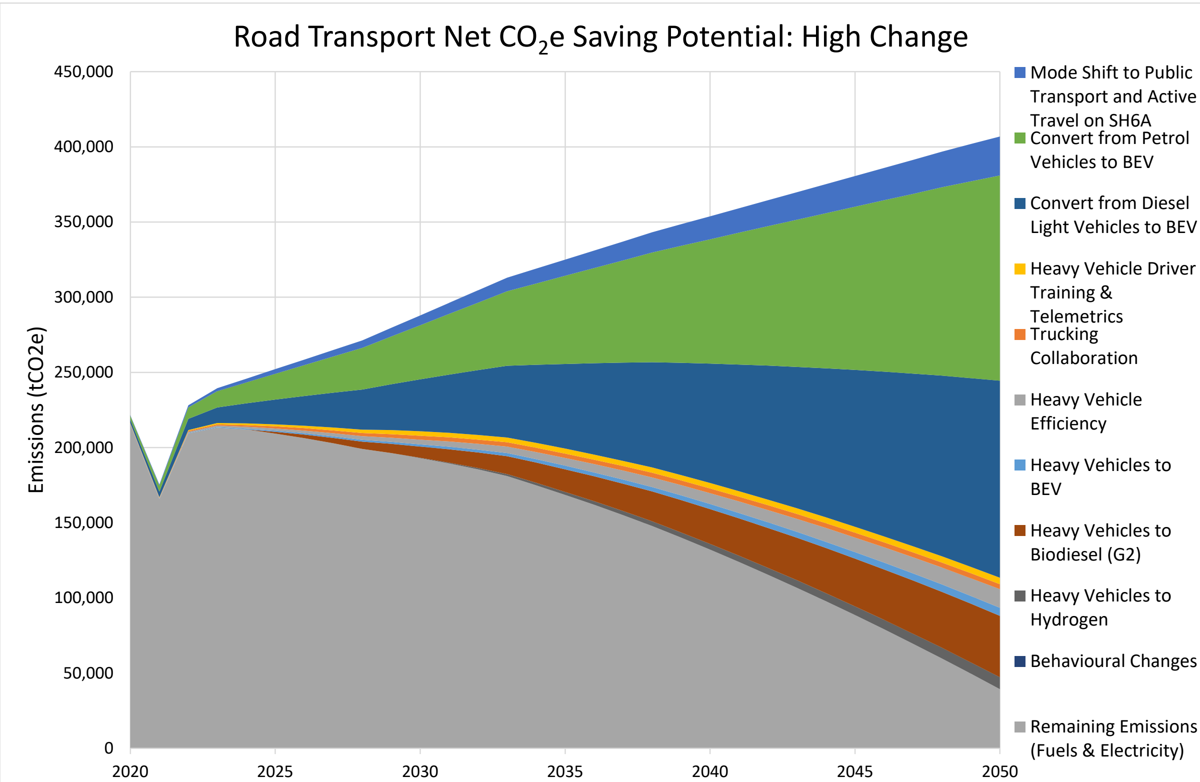


Figure 6 Net CO_2e saving potential for road transport under the High Change pathway (High-0)

The main points emerging from these figures are:

- Increasing the shift of transport modes from private vehicles to public transport, ride-sharing and cycling will provide modest emissions savings for the district.
- Light passenger vehicles and light commercial vehicles have been estimated to account for approximately 79% of the total road transport emissions within the district (petrol and diesel). Therefore, switching from fossil fuel power internal combustion engines to battery electric vehicles will provide the greatest emissions savings for the road transport sector.
- The remaining emissions include residual fossil fuel use for vehicles that have not switched to other fuels (such as electricity) and the electrical emissions resulting from charging the BEVs and creating hydrogen fuel.

Table 7 Key modelling inputs for road transport

Opportunity	Modest Change Pathway	High Change Pathway
Mode Shift to Public Transport and Active Travel for SH6	60% mode shift by 2050 for journeys taken on SH6A between Frankton and Queenstown, based on the MoT base case used in the Abley transport model[9]	80% mode shift by 2050 for journeys taken on SH6A between Frankton and Queenstown
Convert from Petrol Vehicles to BEV	50% fleet conversion to battery electric vehicles by 2050, based on the MoT base case used in the Abley transport model[9]	100% fleet conversion to battery electric vehicles by 2050
Convert from Diesel Light Vehicles to BEV	50% fleet conversion to battery electric vehicles by 2050, on the MoT base case used in the Abley transport model[9]	100% fleet conversion to battery electric vehicles by 2050
Heavy Vehicle Driver Training & Telemetrics	Net savings of 2% by 2030, maintained through to 2050	Net savings of 5% by 2030, maintained through to 2050
Heavy Vehicle Efficiency	Annual savings of 0.25% per year	Annual savings of 0.5% per year
Trucking Collaboration	Net savings of 2% by 2030, maintained through to 2050	Net savings of 5% by 2030, maintained through to 2050
Heavy Vehicles to BEV	36% fleet conversion to battery electric vehicles by 2050, inferred from the Abley transport model[9]	10% fleet conversion to battery electric vehicles by 2050, starting in 2020

[9] Abley (2020), QLDC Road Transport Emissions Assessment

Opportunity	Modest Change Pathway	High Change Pathway
Heavy Vehicles to Biodiesel (G2)	10% fleet conversion to renewable biodiesel (G2) by 2050	70% fleet conversion to renewable biodiesel (G2) by 2050, starting in 2025
Heavy Vehicles to Hydrogen	5% fleet conversion to hydrogen fuel cell vehicles by 2050	20% fleet conversion to hydrogen fuel cell vehicles by 2050, starting in 2030
Behavioural Changes	Net savings of 0% by 2050	Net savings of 0% by 2050

Under the High Change pathway, if all light passenger vehicles and light commercial vehicles are battery electric by 2050 then approximately 280 GWh/year of electricity would be required to charge these vehicles. For comparison, Queenstown used 261 GWh of electricity in 2019 with a control period demand of 63 MW. 280 GWh/year for vehicle charging could equate to 70 MW of additional peak demand (133 MW in total), depending on when the vehicles are charged. Note that these figures exclude other electrification options considered in this study.

5.2 Aviation

The following emissions reduction options have been modelled for the aviation sector (including on-stand emissions from Queenstown Airport):

- Aircraft efficiency – Incremental efficiency improvements achieved as airlines upgrade to newer, more fuel-efficient aircraft. This includes advancements such as more fuel-efficient engines, reduced aircraft weight, more seats per aircraft improved flight plans, and increased aerodynamic efficiency.
- Biofuel for aircraft – Operate aircraft with biofuel rather than Jet A1. The International Energy Agency (IEA) anticipates that biofuels will cover 10% of aviation fuel demand by 2030 and 20% by 2040. Currently biofuel accounts for 0.1% of aviation fuel[10].
- Electric aircraft – Operate electrically-powered aircraft rather than fossil fuel powered aircraft. The International Air Transport Association (IATA) anticipates that electric aircraft may be available from 2040[11].
- Electric vehicles for the airport – Convert airport ground handling vehicles and equipment from fossil fuels to battery electric.
- Biodiesel vehicles for the airport – Convert airport ground handling vehicles and equipment from fossil fuels to biofuel.
- Hydrogen vehicles for the airport – Convert airport ground handling vehicles and equipment from fossil fuels to hydrogen fuel cells.
- Behaviour Change – Information around the effects that behavioural change (outside of the above items) will have on the pathway is currently very limited, however we realise that this will be a key aspect for future savings. As such, we have included a place holder opportunity which will allow QLDC to modify the modelling outputs once additional input and results data is available.

The figures on the next page show the net emissions reduction options in the aviation sector for both the Modest Change and High Change pathways, based on the key inputs from Table 8. The main points emerging from these figures are:

- Aircraft fuel efficiency improvements and converting to 100% renewable biofuel are projected to provide significant carbon emission reductions over the next 30 years. Based on the assumptions made in the model, gross emissions in 2050 would be very similar to 2019 emissions, even with increased aviation travel demand in 2050.
- The gross on-stand emissions from ground handling vehicles and equipment at the airport are much smaller than for aviation fuel consumption for the district, so the fuel switching options for these vehicles will only provide modest savings.

[10] IEA (2018), Renewables 2018, IEA, Paris, https://www.iea.org/reports/renewables-2018
[11] IATA, Aircraft Technology Roadmap to 2050

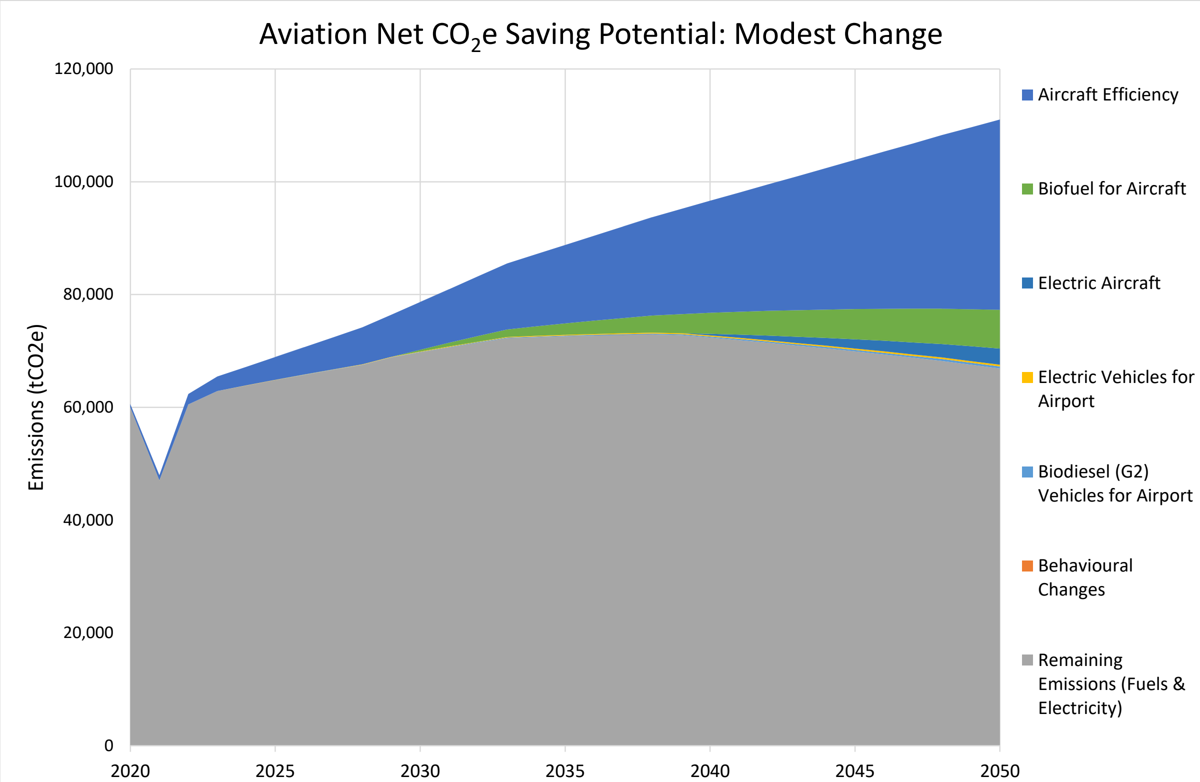


Figure 7 Net CO_2e saving potential for aviation under the Modest Change pathway (Modest-0)

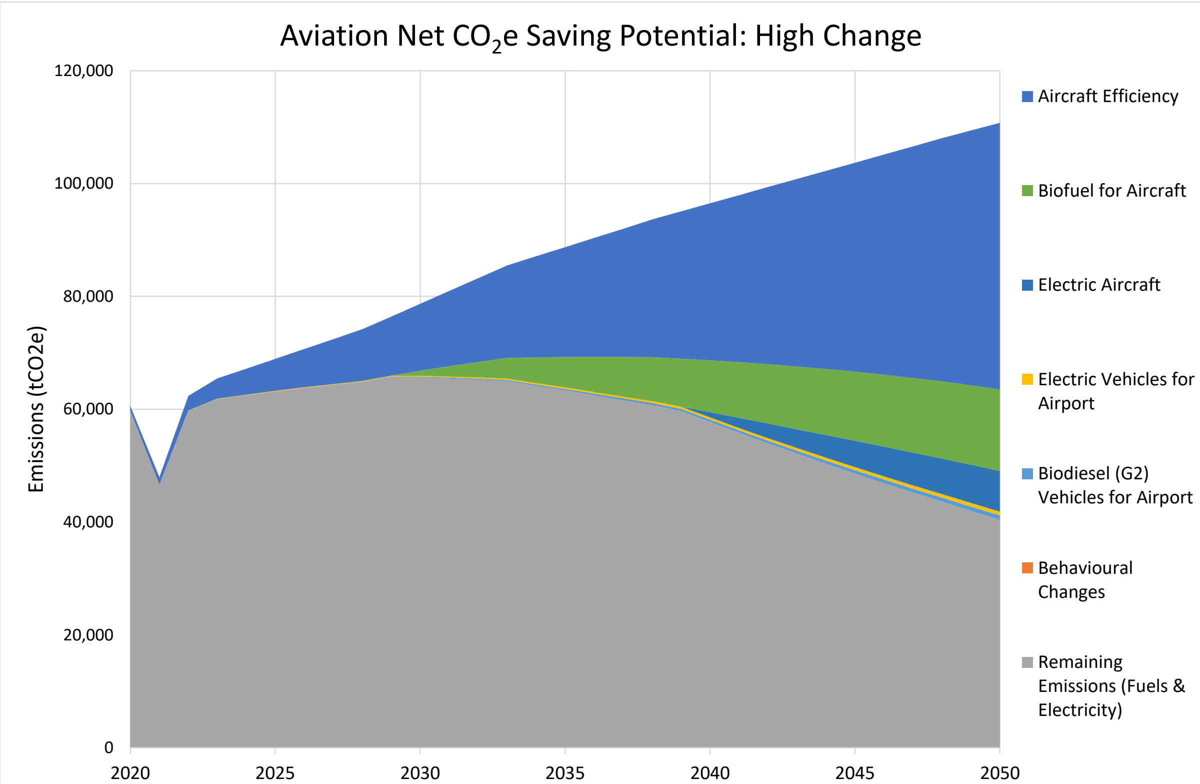


Figure 8 Net CO_2e saving potential for aviation under the High Change pathway (High-0)

Table 8 Key modelling inputs for aviation

Opportunity	Modest Change Pathway	High Change Pathway
Aircraft Efficiency	1.0% constant annual efficiency gain	1.4% constant annual efficiency gain, based on IPCC forecast
Biofuel for Aircraft	10% fleet conversion to renewable biofuel by 2050, starting in 2030	30% fleet conversion to renewable biofuel by 2050, starting in 2030
Electric Aircraft	5% fleet conversion to electric aircraft by 2050, starting in 2040	20% fleet conversion to electric aircraft by 2050, starting in 2040
Electric Vehicles for Airport	15% fleet conversion to electric vehicles by 2050, starting in 2040	33% fleet conversion to electric vehicles by 2050, starting in 2040
Biodiesel Vehicles for Airport	15% fleet conversion to renewable biodiesel (G2) by 2050	33% fleet conversion to renewable biodiesel (G2) by 2050, starting in 2025
Hydrogen Vehicles for Airport	15% fleet conversion to hydrogen fuel cell vehicles by 2050	33% fleet conversion to hydrogen fuel cell vehicles by 2050, starting in 2030
Behavioural Changes	Net savings of 0% by 2050	Net savings of 0% by 2050

5.3 Agriculture

The following emissions reduction option has been modelled for the agricultural sector:

- Agricultural mitigation programme – This is a broad package of emissions mitigation options based on work undertaken by the New Zealand Agricultural Greenhouse Gas Research Centre (NZAGRC)[12] and includes enhanced animal performance, low-methane breeding, fertiliser management, farm management and low-emissions feeds. The report predicts that GHG emission savings of 1.01% per year could be achieved based on maximum assumptions about efficacy and adoption rate for each mitigation option. This has been applied to the High Change pathway. We have assumed that savings of 0.5% per year are achieved under the Modest Change pathway.
- Behaviour Change – Information around the effects that behavioural change (outside of the above items) will have on the pathway is currently very limited, however we realise that this will be a key aspect for future savings. As such, we have included a place holder opportunity which will allow QLDC to modify the modelling outputs once additional input and results data is available.

The figures on the next page show the net emissions reduction options in the agricultural sector for both the Modest Change and High Change pathways, based on the key inputs from Table 9. Note that the target diverges as the NZ goal is to reduce emissions by 10% below 2017 levels by 2030, and then by 24%-47% by 2050. This is instead of a hard target.

[12] NZAGRC (2018), Future options to reduce biological GHG emissions on-farm: critical assumptions and national-scale impact

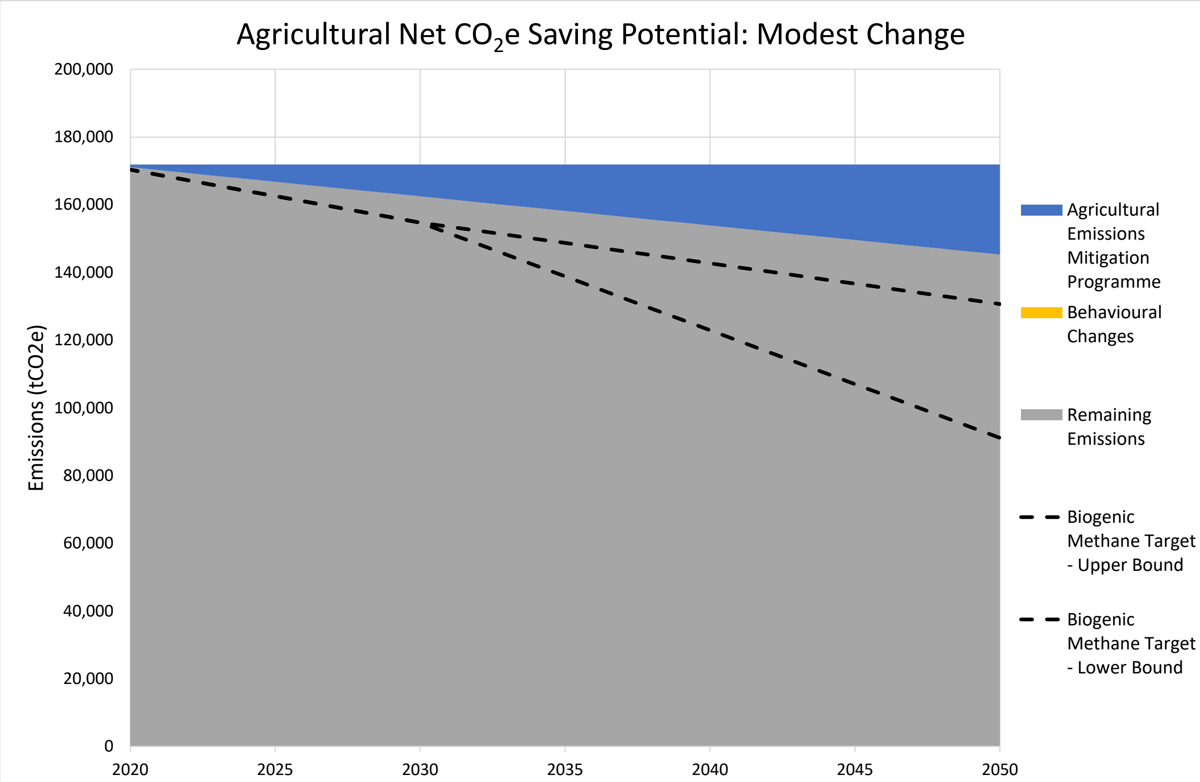


Figure 9 Net CO_2e saving potential for agriculture under the Modest Change pathway (Modest-0)

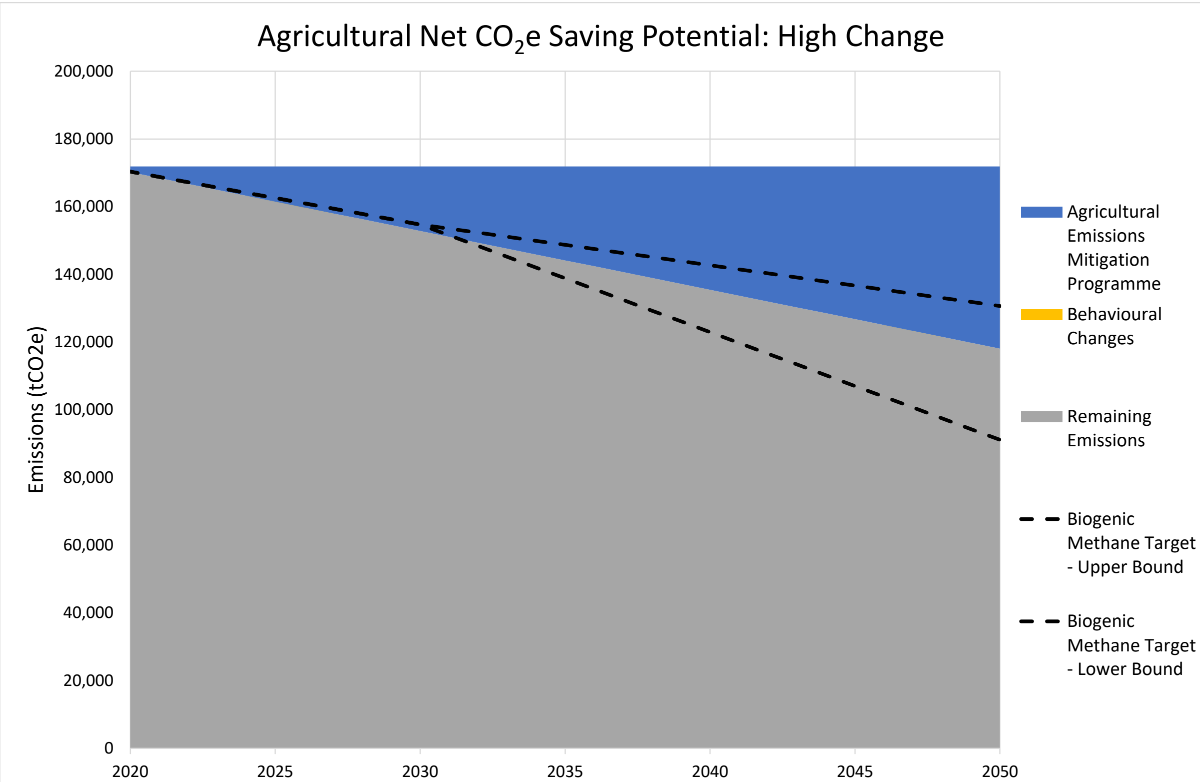


Figure 10 Net CO_2e saving potential for agriculture under the High Change pathway (High-0)

The main points emerging from these figures are:

- GHG emissions from agriculture are projected to decline at a modest rate from 2020 to 2050.
- If annual savings of 0.5% are made, the savings will be insufficient to achieve the biogenic methane targets.
- Significant residual GHG emissions will remain in 2050.

Table 9 Key modelling inputs for agriculture

Opportunity	Modest Change Pathway	High Change Pathway
Agricultural Emissions Mitigation Programme	0.5% constant annual savings per year	1.01% constant annual savings per year
Behavioural Changes	Net savings of 0% by 2050	Net savings of 0% by 2050

5.4 Electricity

The following emissions reduction options have been modelled for electricity end users:

- Reduce hot water demand for small users – Install low flow tap and shower fixtures in residential houses and small commercial buildings to reduce hot water consumption, therefore reducing heating demand.
- Hot water heat pumps for small users – Convert from direct electric heating hot water heating to hot water heat pumps.
- Heat pumps for space heating for small users – Convert from direct electric space heating to heat pumps. Note that conversion to biomass heating (e.g. firewood or wood pellets) is also an option which would result in slightly larger emissions reductions than a heat pump conversion.
- Insulation & glazing upgrades for existing small users - Retrofit insulation and double glazing to existing housing stock. Increase the insulation performance standards for new houses.
- Energy efficient housing for new builds - Mandate that the energy performance standards for new houses must be above a certain star rating or be constructed using passive housing design principles.
- Solar PV for small users – Install 3 kW solar PV systems (without batteries) on residential and small commercial properties, offsetting internal consumption and exporting excess electricity back into the grid.
- Building energy efficiency for medium users – Perform energy audits at key sites with medium energy consumption (e.g. hotels etc), implement efficiency opportunities and share the learnings with others in the sector to increase uptake
- Solar PV for medium users – Install 10 kW solar PV systems (without batteries) on commercial properties, offsetting internal consumption and exporting excess electricity back into the grid.
- Energy efficiency for large users – Perform energy audits at key sites with high energy consumption (e.g. ski fields, QAC etc), implement efficiency opportunities and share the learnings with others in the sector to increase energy efficiency.
- Behaviour Change – Information around the effects that behavioural change (outside of the above items) will have on the pathway is currently very limited, however we realise that this will be a key aspect for future savings. As such, we have included a place holder opportunity which will allow QLDC to modify the modelling outputs once additional input data is available.

The figures on the next page show the net emissions reduction options in the electricity sector for both the Modest Change and High Change pathways, based on the key inputs from Table 10.

The main points emerging from these figures are:

- There is a pronounced decrease in the overall electricity emissions profile from 2023 to 2032 due to the forecast reduction in grid electricity emissions by MBIE as the percentage of renewable generation increases.
- Status quo emissions are projected to increase linearly from 2035 to 2050, based on a constant grid electricity emissions factor and steady population growth within the district.
- Implementing all of the options listed above for the Modest Change pathway would only provide savings of 16% in 2050 compared to the Business as Usual pathway.

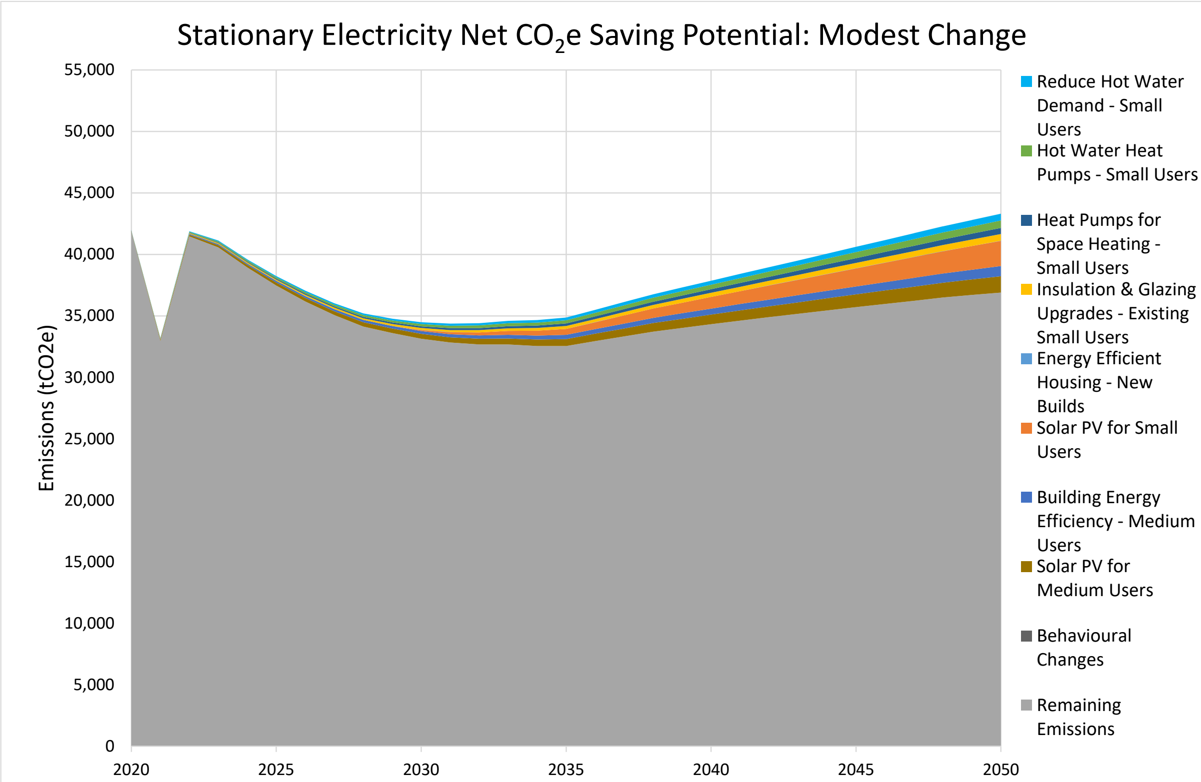


Figure 11 Net CO_2e saving potential for electricity under the Modest Change pathway (Modest-0)

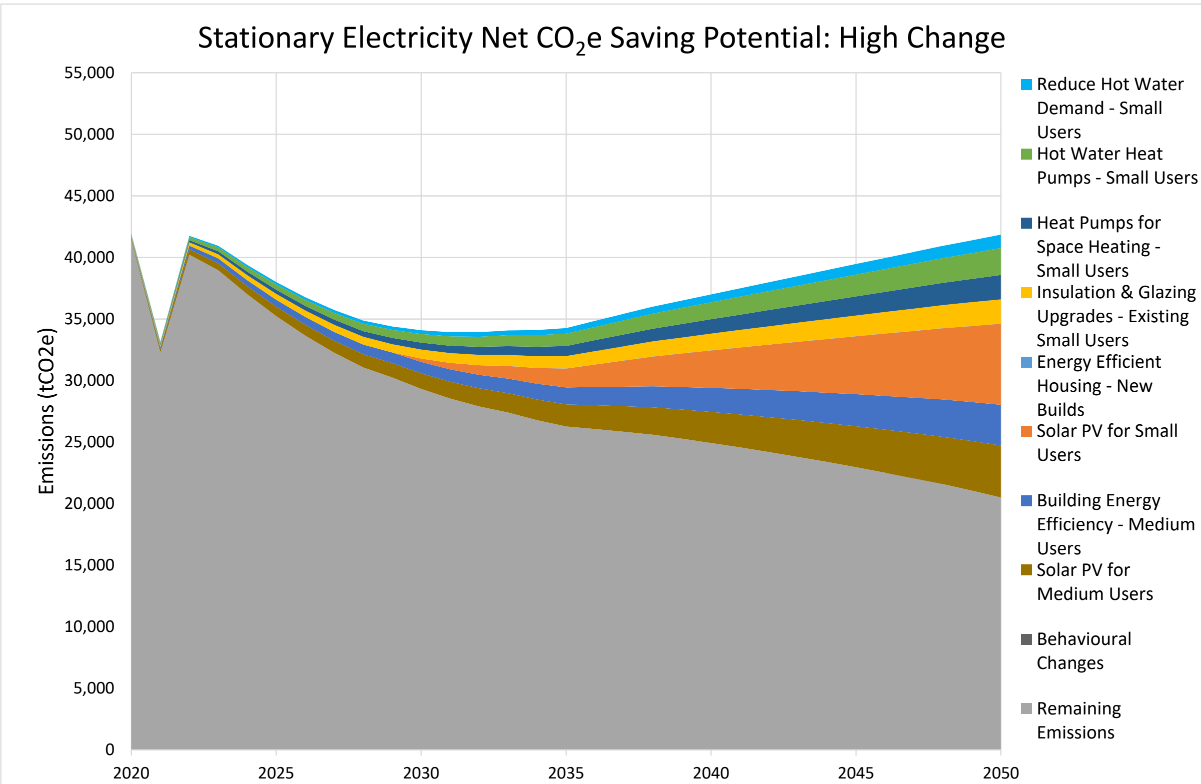


Figure 12 Net CO_2e saving potential for electricity under the High Change pathway (High-0)

Table 10 Key modelling inputs for electricity

Opportunity	Modest Change Pathway	High Change Pathway
Reduce Hot Water Demand - Small Users	10% reduction in hot water demand across households by 2050	20% reduction in hot water demand across households by 2050
Hot Water Heat Pumps - Small Users	25% conversion of hot water cylinders from direct electric to hot water heat pumps by 2050	100% conversion of hot water cylinders from direct electric to hot water heat pumps by 2050
Heat Pumps for Space Heating - Small Users	25% conversion of direct electric space heating to heat pumps by 2050	100% conversion of direct electric space heating to heat pumps by 2050
Insulation & Glazing Upgrades - Existing Small Users	10% energy savings achieved for households by 2050	50% energy savings achieved for households by 2050
Energy Efficient Housing - New Builds	10% energy savings achieved for all new houses constructed from 2025 to 2050	50% energy savings achieved for all new houses constructed from 2025 to 2050
Solar PV for Small Users	25% of households install a 3 kW solar PV system (without batteries) by 2050, starting in 2030	80% of households install a 3 kW solar PV system (without batteries) by 2050, starting in 2030
Building Energy Efficiency - Medium Users	5% reduction in electricity use by 2050 through energy efficiency improvements	20% reduction in electricity use by 2050 through energy efficiency improvements
Solar PV for Medium Users	25% of commercial buildings install a 10 kW solar PV system (without batteries) by 2050, starting in 2020	80% of commercial buildings install a 10 kW solar PV system (without batteries) by 2050, starting in 2020
Energy Efficiency - Large Users	10% reduction in electricity use by 2050 through energy efficiency improvements	30% reduction in electricity use by 2050 through energy efficiency improvements
Behavioural Changes	Net savings of 0% by 2050	Net savings of 0% by 2050

5.5 LPG

The following emissions reduction options have been modelled for LPG end users:

- Phase out residential LPG cooktops and ovens – Convert to electric.
- Reduce residential hot water demand – Install low flow tap and shower fixtures in residential houses to reduce hot water consumption, therefore reducing heating demand.
- Residential hot water heat pumps – Convert from direct electric hot water heating to hot water heat pumps.
- Residential heat pumps for space heating – Convert from LPG space heating to heat pumps. Note that conversion to biomass heating (e.g. firewood or wood pellets) is also an option which would result in slightly larger emissions reductions than a heat pump conversion.
- Phase out commercial LPG cooktops and ovens – Convert to electric.
- Reduce commercial hot water demand – Install low flow tap and shower fixtures in commercial buildings to reduce hot water consumption, therefore reducing heating demand.
- Commercial hot water heat pumps – Convert from LPG fired hot water heating systems to electric hot water heat pumps. Note that conversion to biomass is also an option which would result in slightly larger emissions reductions than a heat pump conversion.
- Commercial heat pumps for space heating – Convert from LPG-fired space heating systems to electric heat pumps. Note that conversion to biomass is also an option which would result in slightly larger emissions reductions than a heat pump conversion.
- Behaviour Change – Information around the effects that behavioural change (outside of the above items) will have on the pathway is currently very limited, however we realise that this will be a key aspect for future savings. As such, we have included a place holder opportunity which will allow QLDC to modify the modelling outputs once additional input and results data is available.

The figures on the next page show the net emissions reduction options in the LPG sector for both the Modest Change and High Change pathways, based on the key inputs from Table 11.

The main points emerging from these figures are:

- Partially switching away from LPG heating and cooking systems to equivalent electric or biomass systems will not provide significant emissions savings by 2050 under the Modest Change pathway.
- Aggressive switching to low-carbon alternatives under the High Change pathway will almost reduce LPG emissions to zero.

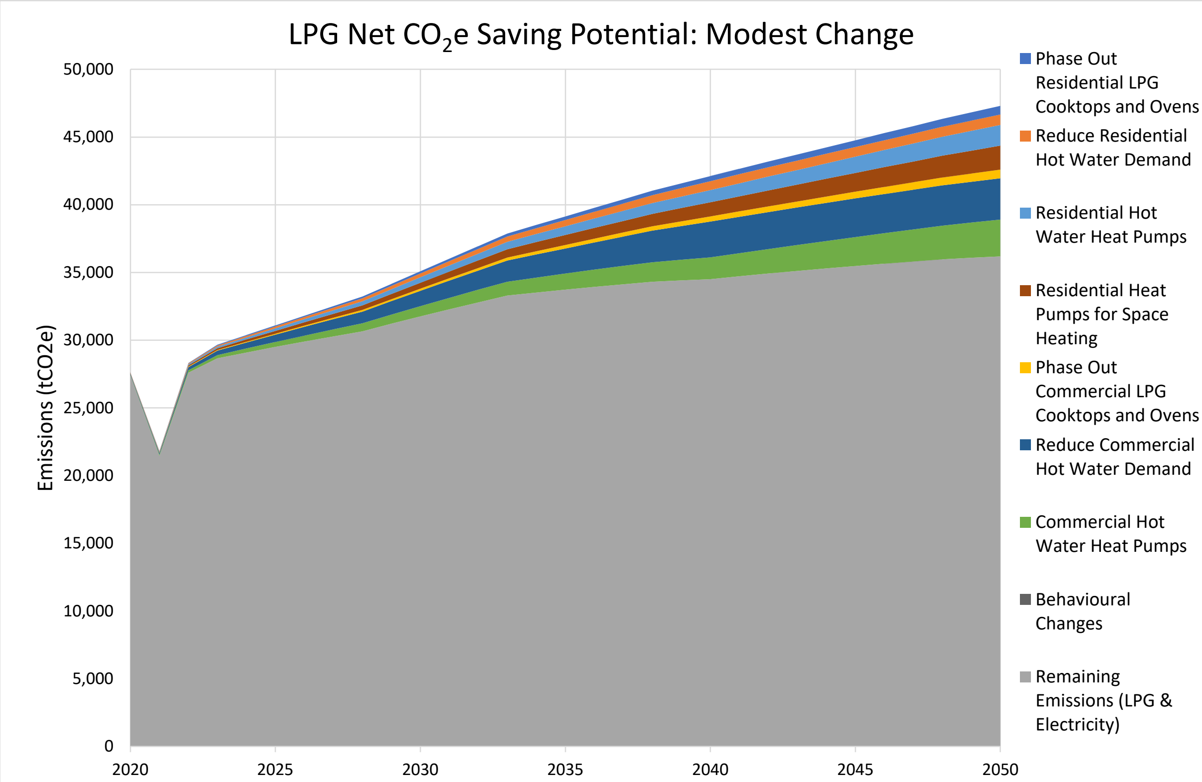


Figure 13 Net CO_2e saving potential for LPG under the Modest Change pathway (Modest-0)

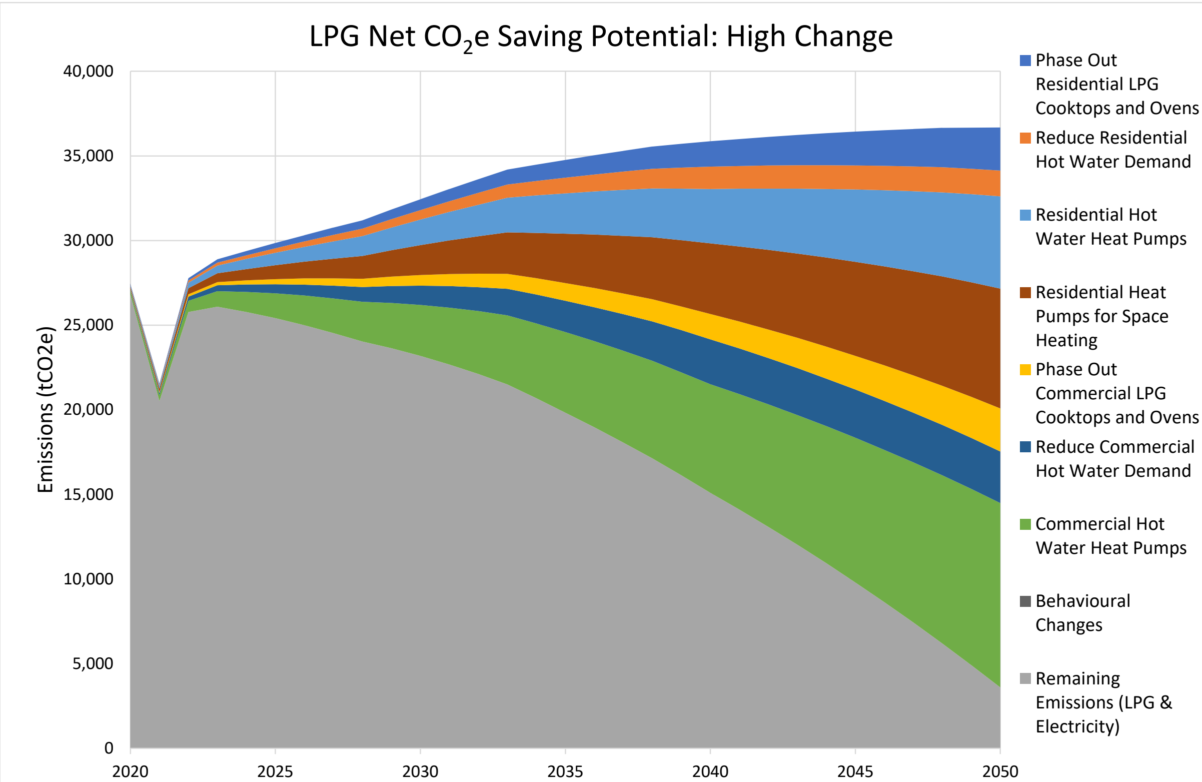


Figure 14 Net CO_2e saving potential for LPG under the High Change pathway (High-0)

Table 11 Key modelling inputs for LPG

Opportunity	Modest Change Pathway	High Change Pathway
Phase Out Residential LPG Cooktops and Ovens	25% conversion to electric by 2050	100% conversion to electric by 2050
Reduce Residential Hot Water Demand	10% reduction in hot water demand across households by 2050	20% reduction in hot water demand across households by 2050
Residential Hot Water Heat Pumps	25% conversion of hot water systems from LPG to hot water heat pumps by 2050	100% conversion of hot water systems from LPG to hot water heat pumps by 2050
Residential Heat Pumps for Space Heating	25% conversion from LPG space heating to heat pumps by 2050	100% conversion from LPG space heating to heat pumps by 2050
Phase Out Commercial LPG Cooktops and Ovens	25% conversion to electric by 2050	100% conversion to electric by 2050
Reduce Commercial Hot Water Demand	10% reduction in hot water demand across businesses by 2050	20% reduction in hot water demand across businesses by 2050
Commercial Hot Water Heat Pumps	25% conversion of hot water systems from LPG to hot water heat pumps by 2050	100% conversion of hot water systems from LPG to hot water heat pumps by 2050
Commercial Heat Pumps for Space Heating	25% conversion from LPG space heating to heat pump space heating by 2050	100% conversion from LPG space heating to heat pump space heating by 2050
Behavioural Changes	Net savings of 0% by 2050	Net savings of 0% by 2050

5.6 Wastewater

The following emissions reduction options have been modelled for wastewater and septic tanks:

- Wakatipu WWTP pond decommissioning – The ponds at the Wakatipu WWTP are in the process of being decommissioned and the wastewater currently going to the ponds will be treated by an MLE process. This work is due to be completed in 2022. Based on the carbon emissions provided by Beca in Section 2.2 of this report, the emissions from the WWTP will reduce by 5% once the ponds are decommissioned.
- Convert Hawea ponds to mechanical WWTP – The default MfE emissions factor for a mechanical WWTP is 0.447 $kgCO_2e/m^3$, which is 22% lower than the pond emissions factor of 0.57 $kgCO_2e/m^3$ from the Tonkin & Taylor report. This indicates that converting from ponds to a mechanical WWTP will provide emissions savings. QLDC has proposed budget in the next Long Term Plan to move the Lake Hawea Township (~750 connections) from a pond based system to a mechanical treatment in 2022/23[13].
- Convert septic tanks to mechanical WWTPs – From the Tonkin & Taylor report, there were approximately 3,526 septic tanks within the district in 2019. Septic tanks have a higher emissions factor than mechanical WWTPs, so converting to a mechanical system will provide emissions reductions. This would be applicable for the townships of Kingston and Glenorchy. If other clusters can be connected, the savings will increase.
- Behaviour Change – Information around the effects that behavioural change (outside of the above items) will have on the pathway is currently very limited, however we realise that this will be a key aspect for future savings. As such, we have included a place holder opportunity which will allow QLDC to modify the modelling outputs once additional input and results data is available.

The figures on the next page show the net emissions reduction options in the wastewater sector for both the Modest Change and High Change pathways, based on the key inputs from Table 12.

The main points emerging from these figures are:

- Decommissioning the Wakatipu WWTP ponds will reduce emissions from the plant, based on figures provided by Beca.
- Only very modest savings will be achieved by connecting Hawea, Kingston and Glenorchy townships to a mechanical WWTP system.

[13] Email correspondence with Mark Baker, QLDC

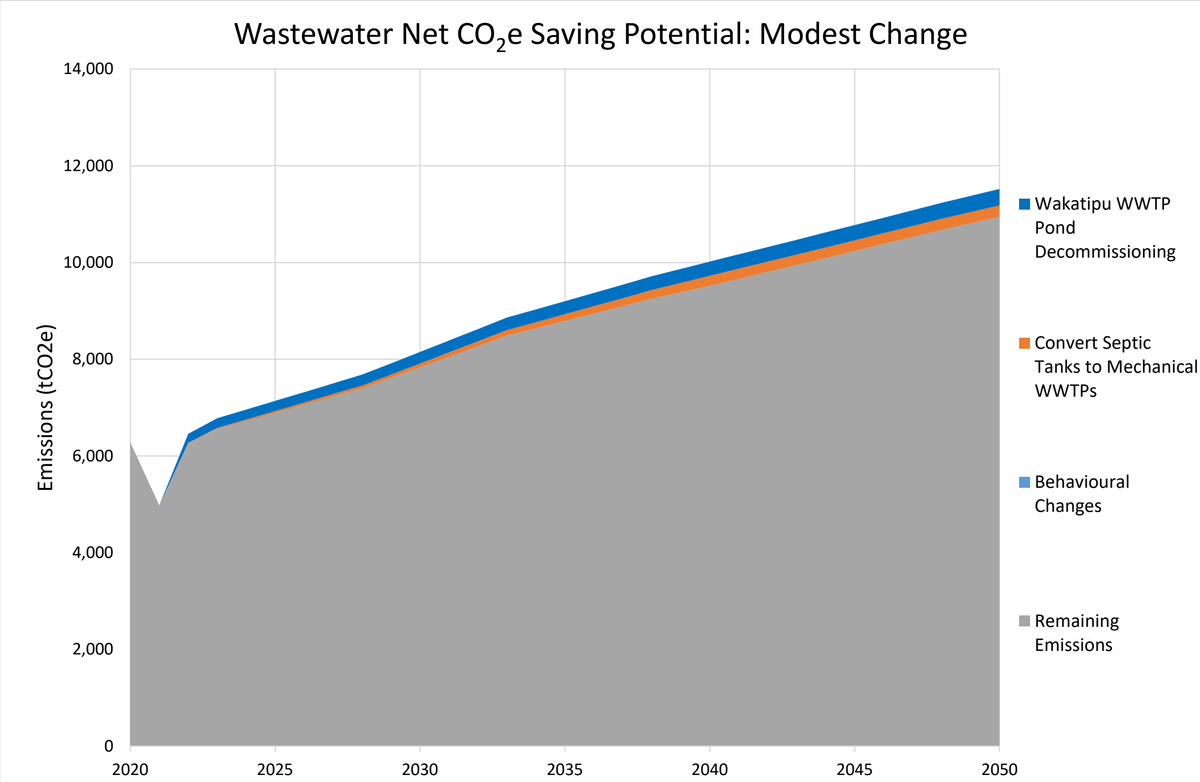


Figure 15 Net CO_2e saving potential for wastewater under the Modest Change pathway (Modest-0)

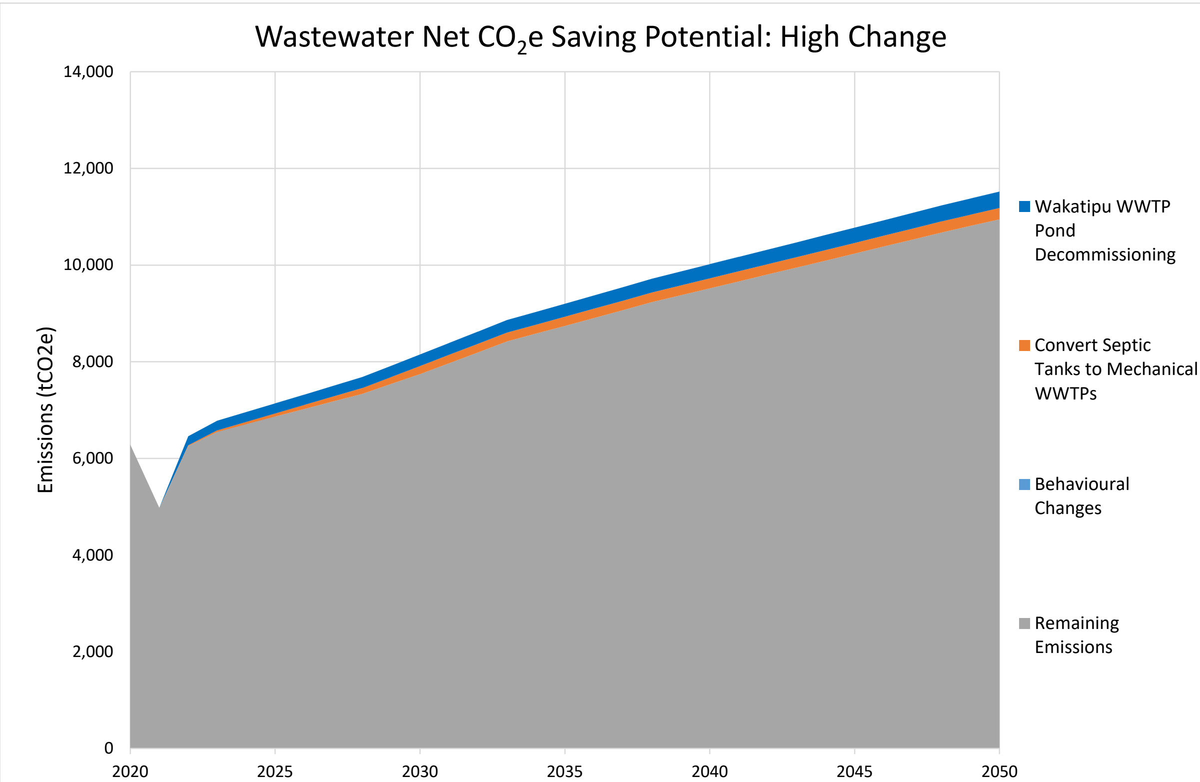


Figure 16 Net CO_2e saving potential for wastewater under the High Change pathway (High-0)

Table 12 Key modelling inputs for wastewater and septic tanks

Opportunity	Modest Change Pathway	High Change Pathway
Wakatipu WWTP Pond Decommissioning	5% reduction in emissions factor (inlcuding biosolids) based on information from Beca, starting in 2022	5% reduction in emissions factor (inlcuding biosolids) based on information from Beca, starting in 2022
Hawea - Convert from Ponds to Mechanical WWTP	22% reduction in emissions factor based on defualt MfE figures, starting in 2022	22% reduction in emissions factor based on defualt MfE figures, starting in 2022
Convert Septic Tanks to Mechanical WWTPs	10% conversion (approximately 350 houses) of existing septic tanks to mechanical WWTPs, starting in 2022 and finishing in 2040	10% conversion (approximately 350 houses) of existing septic tanks to mechanical WWTPs, starting in 2022 and finishing in 2030
Behavioural Changes	Net savings of 0% by 2050	Net savings of 0% by 2050

5.7 Landfill

The following emissions reduction options have been modelled for the Victoria Flats landfill:

- Waste reduction and behavioural changes – Reduce the amount of waste being sent to the Victoria Flats landfill across all waste streams, via community initiatives, education, and behavioural changes.
- Divert food waste and green waste from landfill – Divert this waste from landfill to a dedicated organic waste treatment facility. SLR[14] have assessed the diversion of organics waste and provided recommended next steps to QLDC. Please refer to their report for further information on this option.
- Divert timber waste from landfill – Divert this waste from landfill for reuse and recycling. SLR[15] have assessed the diversion of timber and provided recommended next steps to QLDC. Please refer to their report for further information on this option.
- Landfill gas capture and flaring – Install a landfill gas capture and flaring system to reduce emissions at the Victoria Flats landfill. This is already underway and will commence operation in 2021. Landfill gas is a by-product from the decomposition of organic waste found in landfills. Landfill gas is typically made up of 30-50% of methane, 30% carbon dioxide and trace amounts of other gases. Methane gas has a higher global warming potential compared to carbon dioxide. The methane from the landfill would be collected and combusted to produce carbon dioxide and water, therefore reducing emissions compared to the existing situation.
- Biochar and electricity via pyrolysis – This is not currently part of QLDC's long term planning and has been excluded from the Modest Change scenario. However, for completeness, we have included a pyrolysis plant within the High Change model. Pyrolysis plants can receive organic waste streams and produce biochar (which can be sequestered in agricultural soils), bio-oil (for electricity generation, motive fuel or thermal fuel) and bio-gas (re-used in within the pyrolysis plant combustion process). Organic waste supplied to the pyrolysis plant will have net zero emissions, since the carbon can be sequestered in the biochar. For reference, a case study on a pyrolysis plant is included within the Sequestration study.

The figures on the next page show the net emissions reduction options in the landfill sector for both the Modest Change and High Change pathways, based on the key inputs from Table 13.

[14] SLR, Organic Waste Mass Balance Modelling, 2019
[15] SLR, Organic Waste Mass Balance Modelling, 2019

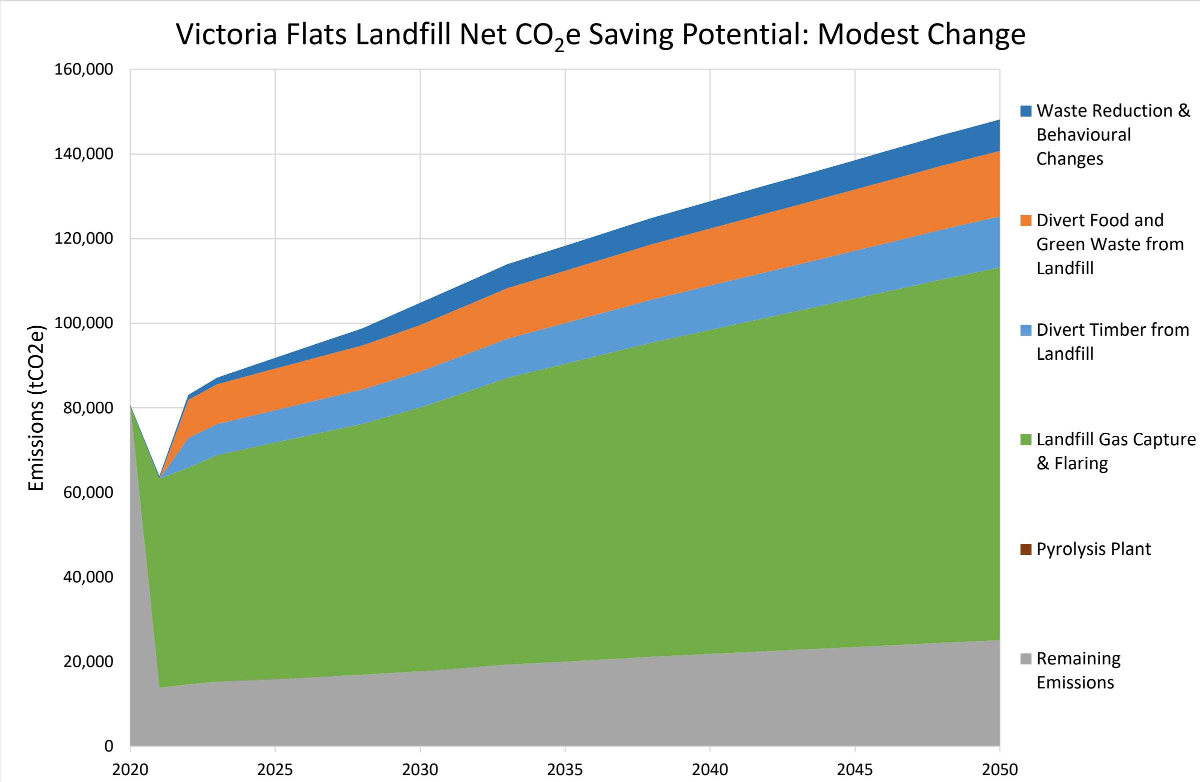


Figure 17 Net CO_2e saving potential for landfill under the Modest Change pathway (Modest-0)

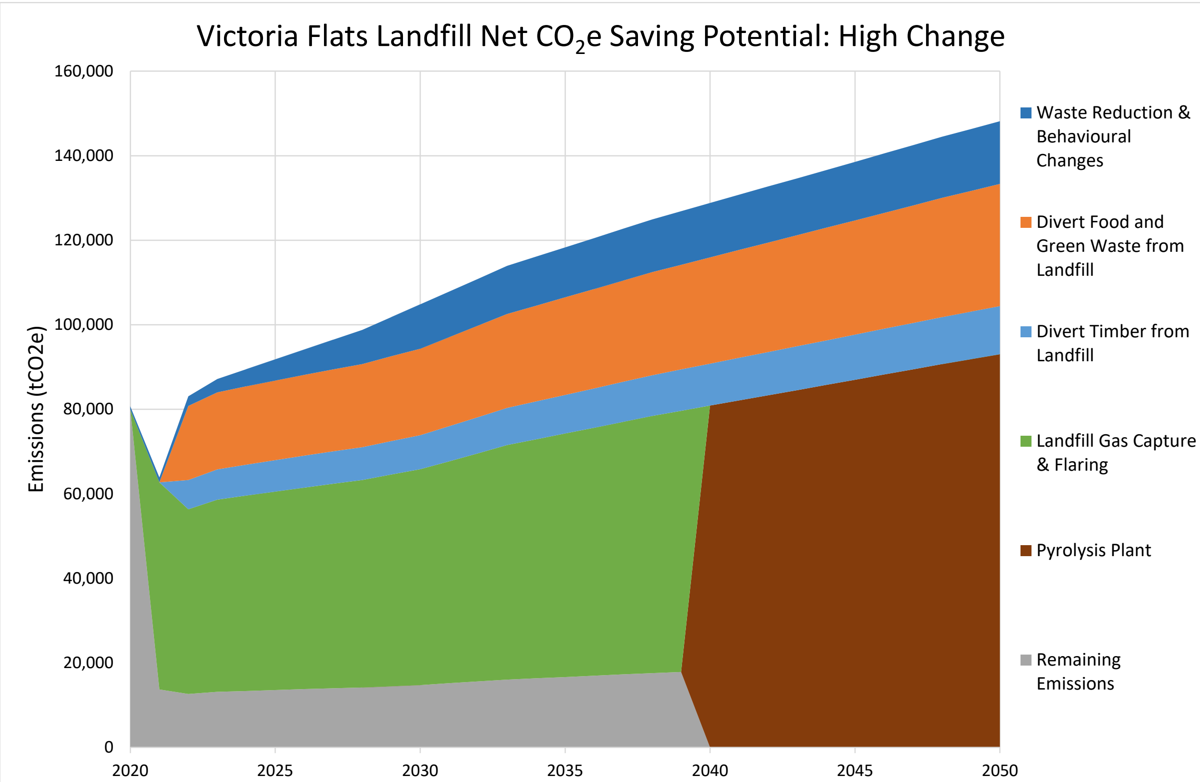


Figure 18 Net CO_2e saving potential for landfill under the High Change pathway (High-0)

The main points emerging from these figures are:

- Waste reduction initiatives and diverting food scraps, green waste and timber from landfill will provide significant emissions savings[16].
- A landfill gas capture and flaring system is unable to fully eliminate GHG emissions, although it will provide a large reduction in emissions.
- A pyrolysis plant producing biochar and biofuel from residual organic waste would allow QLDC to achieve net-zero carbon emissions from landfill (included in the High Change pathway).

Table 13 Key modelling inputs for landfill

Opportunity	Modest Change Pathway	High Change Pathway
Waste Reduction	5% reduction in all waste types to landfill by 2030	10% reduction in all waste types to landfill by 2030
Divert Food and Green Waste from Landfill	44% diversion of food and green waste from landfill, based on work by SLR[17] and applied to both QLDC and CODC waste streams	100% diversion of food and green waste from landfill
Divert Timber from Landfill	19% diversion of timber waste from landfill, based on work by SLR[18] and applied to both QLDC and CODC waste streams	19% diversion of timber waste
Landfill Gas Capture & Flaring	Installation in 2021 (already underway)	Installation in 2021 (already underway)
Biochar and Bio-oil via Pyrolysis Plant	Not installed by 2050, as this option does not feature in QLDC's long term planning	Installation in 2040, with all non-diverted food scraps, green waste, timber, paper and sanitary paper supplied to the pyrolysis plant

[16] We also refer to the Sequestration Study analysis which has examine a dry anaerobic digestion plant as alternative means for treatment of these wastes. The analysis contained there shows that a plant sized for 30,000 tonnes per year mixed landfill waste/biomass feed, would be capable of supplying up 68,400 GJ/year biomethane (either as pipeline gas or as feed to renewable electricity generation). The estimated capital cost of the precursor biogas/electricity plant (without methanation) was estimated at $NZ 8.1 million with an IRR of 23% at 6% WACC
[17] SLR, Organic Waste Mass Balance Modelling, 2019
[18] SLR, Organic Waste Mass Balance Modelling, 2019

6. QLDC direct energy emissions reduction

6.1 QLDC direct energy consumption

QLDC has not performed a full carbon footprint yet, so detailed information on Scope 1, 2 and 3 emissions were not available. However, QLDC was able to provide information on its direct energy consumption (electricity, petrol, diesel and LPG) for buildings and vehicles within its control.

Direct energy consumption by QLDC resulted in emissions of 2,661 t CO_2e for 2019, based on data from CarbonEMS eBench and LPG invoices supplied by QLDC. This equates to 0.4% of the total emissions within the whole Queenstown Lakes district. Although this is a small portion, QLDC has direct control over its energy emissions and has the ability to lead by example.

The following emissions reduction options have been modelled for QLDC's direct energy consumption:

- Convert from fossil fuel vehicles to BEV - QLDC is already moving to a more sustainable fleet, replacing part of the existing fleet vehicles for 100% EVs. QLDC will have a total of 13 EVs in its fleet by December 2020, with further EVs being added to end up with 30 EVs in the fleet by mid-2022.
- Increase electrical efficiency for buildings and equipment – Perform energy audits to assess efficiency opportunities and implement the findings. Replace existing equipment with energy-efficient models.
- Convert Alpine Aqualand water heating from LPG to heat pumps – Replace the existing LPG heating system with electric heat pumps. Note that conversion to biomass is also an option which would result in slightly larger emissions reductions than a heat pump conversion.
- Convert Wanaka Recreation Centre water heating from LPG to heat pumps – Replace the existing LPG heating system with electric heat pumps. Note that conversion to biomass is also an option which would result in slightly larger emissions reductions than a heat pump conversion.
- Solar PV – Install solar PV panels on QLDC buildings to offset imported electricity consumption.
- Behaviour Change – Information around the effects that behavioural change (outside of the above items) will have on the pathway is currently very limited, however we realise that this will be a key aspect for future savings. As such, we have included a place holder opportunity which will allow QLDC to modify the modelling outputs once additional input and results data is available.

These options are high-level and further work is required to develop a full carbon reduction strategy for QLDC's operations.

The figures on the next page show the net emissions reduction options at QLDC for both the Modest Change and High Change pathways, based on the key inputs from Table 14.

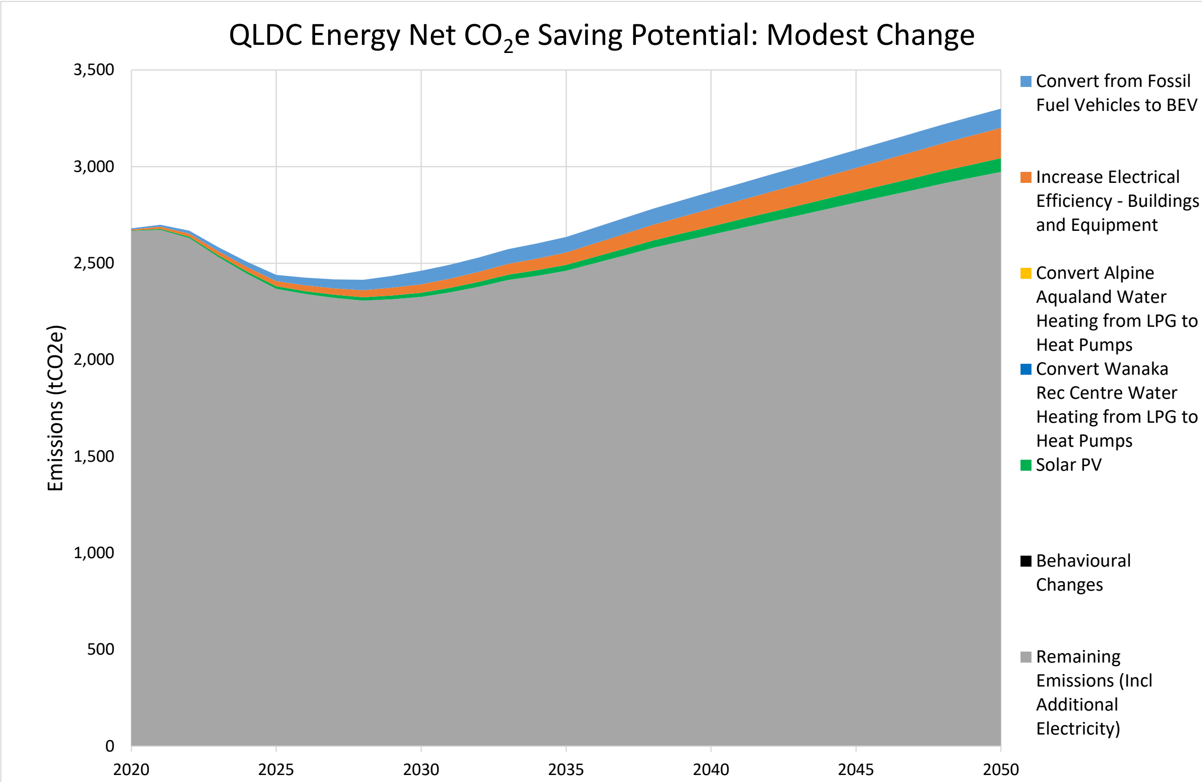


Figure 19 Net CO_2e saving potential for QLDC's energy consumption under the Modest Change pathway (Modest-0)

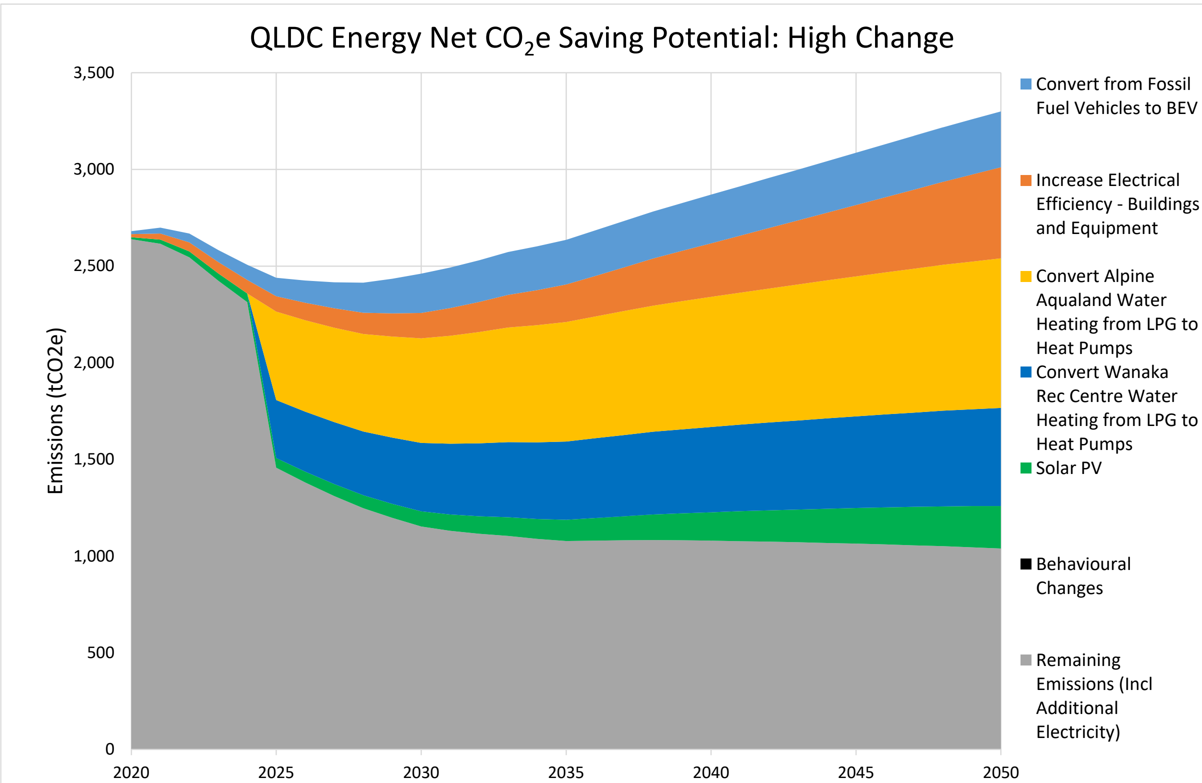


Figure 20 Net CO_2e saving potential for QLDC's energy consumption under the High Change pathway (High-0)

The main points emerging from the High Change pathway are:

- The modelled carbon emission mitigation options will achieve significant savings for QLDC under the High Change pathway.
- Electricity represented 61% of QLDC's energy emissions in 2019 (based on the available data). There are few alternatives available to switch from electricity to lower-carbon fuels, so the residual emissions from QLDC's energy consumption is forecast to remain fairly steady from 2030 to 2050 under the High Change pathway.
- These options are only indicative and further work needs to be done in a separate study to develop a thorough low-carbon roadmap for QLDC's internal activities.

Table 14 Key modelling inputs for QLDC direct energy consumption

Opportunity	Modest Change Pathway	High Change Pathway
Convert from Fossil Fuel Vehicles to BEV	34% fleet conversion to battery electric vehicles by 2030	100% fleet conversion to battery electric vehicles by 2030
Increase Electrical Efficiency - Buildings and Equipment	10% reduction in electricity use by 2050 through energy efficiency improvements	30% reduction in electricity use by 2050 through energy efficiency improvements
Convert Alpine Aqualand Water Heating from LPG to Heat Pumps	No conversion of hot water heating from LPG to heat pumps by 2050	100% conversion of hot water heating from LPG to heat pumps by 2025
Convert Wanaka Recreation Centre Water Heating from LPG to Heat Pumps	No conversion of hot water heating from LPG to heat pumps by 2050	100% conversion of hot water heating from LPG to heat pumps by 2025
Solar PV	Solar panels are installed gradually between 2020 and 2050, generating 5% of QLDC's stationary electricity by 2050	Solar panels are installed gradually between 2020 and 2050, generating 20% of QLDC's stationary electricity by 2050
Behavioural Changes	Net savings of 0% by 2050	Net savings of 0% by 2050

7. Emissions reduction pathways

7.1 Modest change pathway

Figure 21 below shows the emissions reduction pathway for Modest Change given the (i) district growth assumptions, and (ii) carbon reduction opportunities described in Sections 3, 4 and 5.

The key points emerging from this figure are:

- Over the long-term, most of avoided emissions come from the following top-five sectors in a decreasing order of emissions avoided:
  - o Road transport
  - o Landfill
  - o Aviation
  - o Agriculture
  - o LPG
- If all of the options are implemented as we have projected, this will result in emissions savings of 44% by 2050 compared to the Business as Usual pathway.

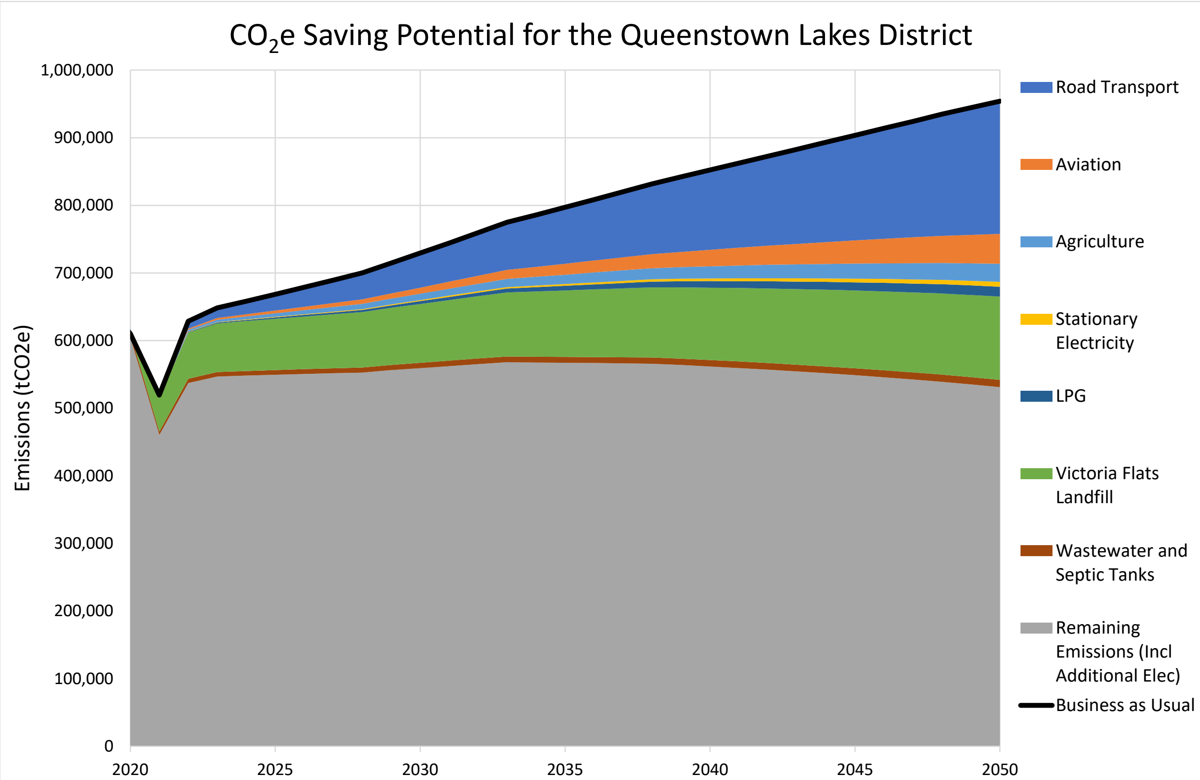


Figure 21 Emissions reduction pathway under the Modest Change pathway

Figure 22 illustrates the gross residual emissions under the Modest Change pathway. There are significant residual emissions, particularly for the road transport and agricultural sectors.

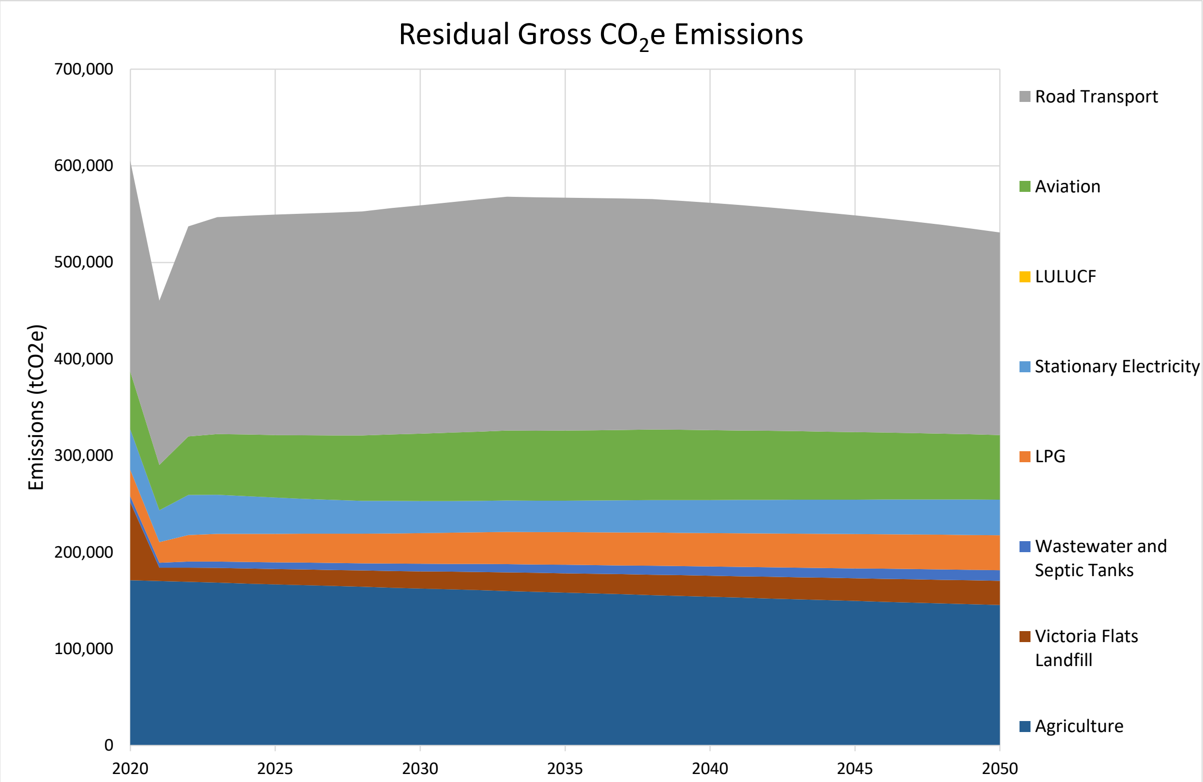


Figure 22 Residual gross emissions under the Modest Change pathway

7.2 High change pathway

Figure 23 shows the emissions reductions for High Change pathway. This pathway has increased behavioural and technological changes compared to the Modest Change pathway, resulting in significant decreases in emissions by 2050.

The road transport sector has the largest potential for emissions reductions, followed by landfill and then agriculture.

The step change in 2040 for the High Change pathway is due to the assumption that a pyrolysis plant is installed to produce biochar and bio-oil from food scraps, green waste, timber, paper and sanitary paper that is unable to be diverted from landfill.

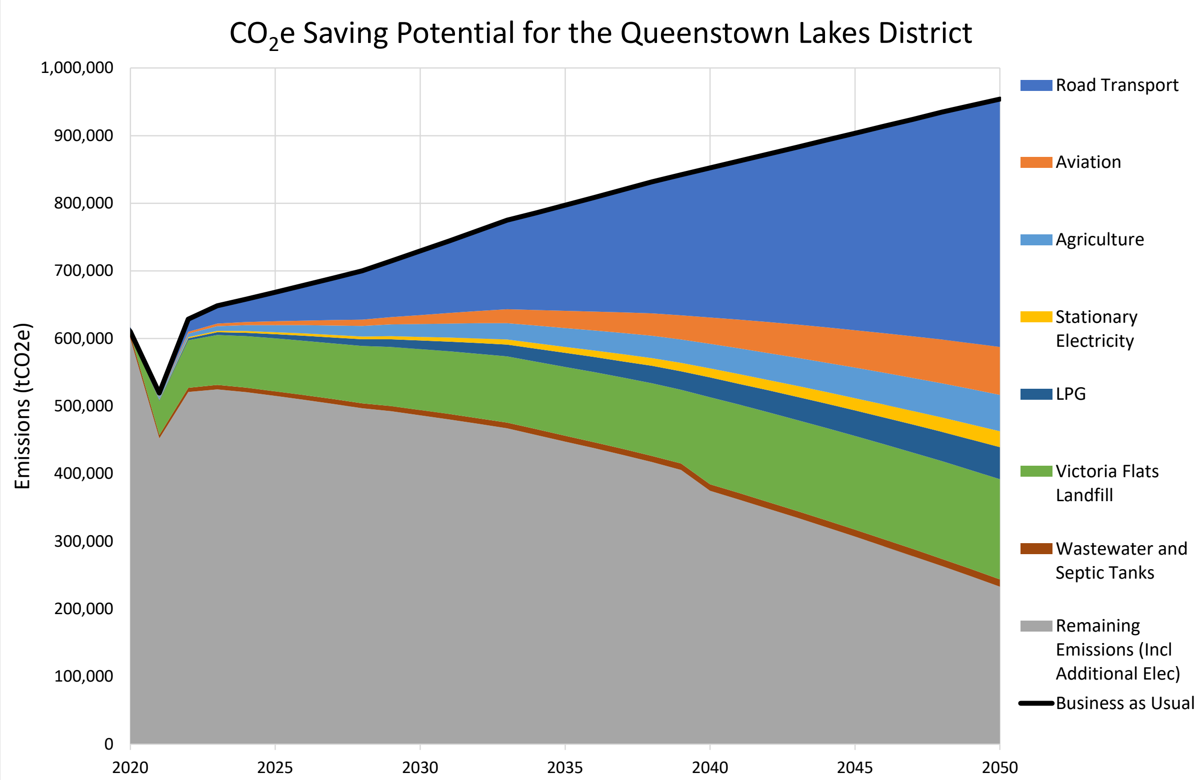


Figure 23 Emissions reduction pathway under the High Change pathway

Figure 24 illustrates the gross residual emissions, which are significantly lower than the Modest Change pathway.

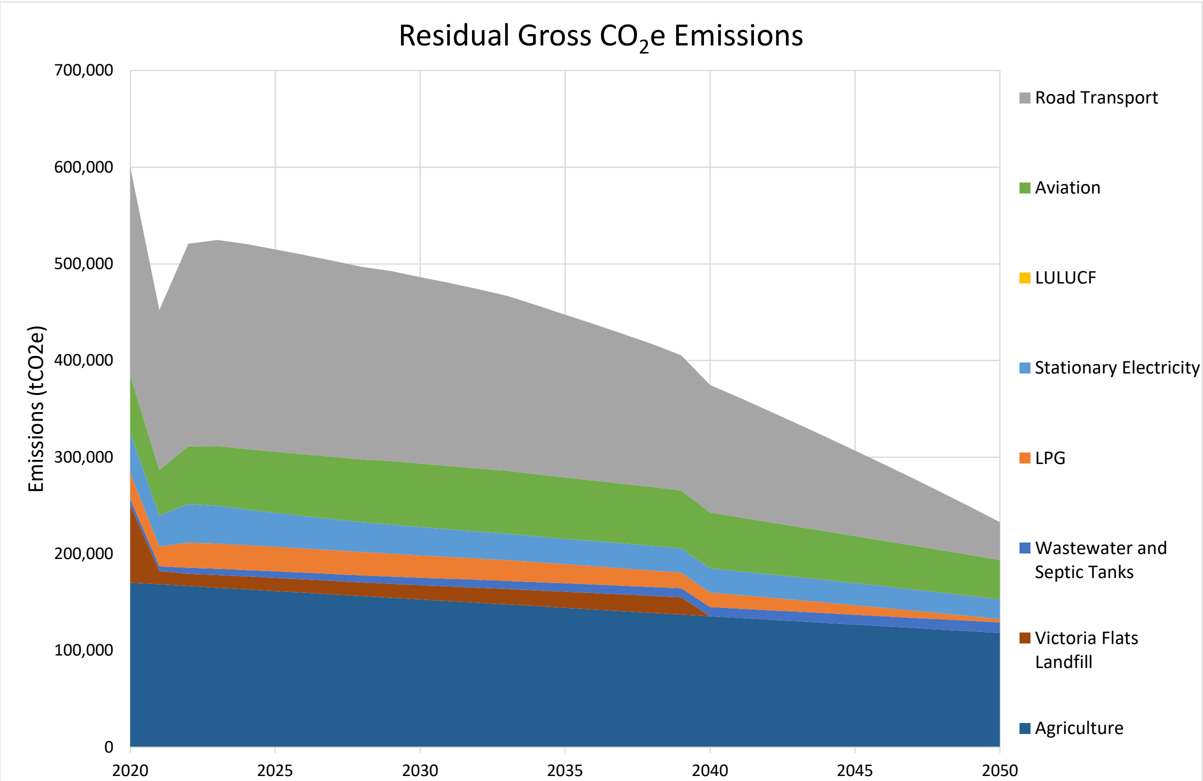
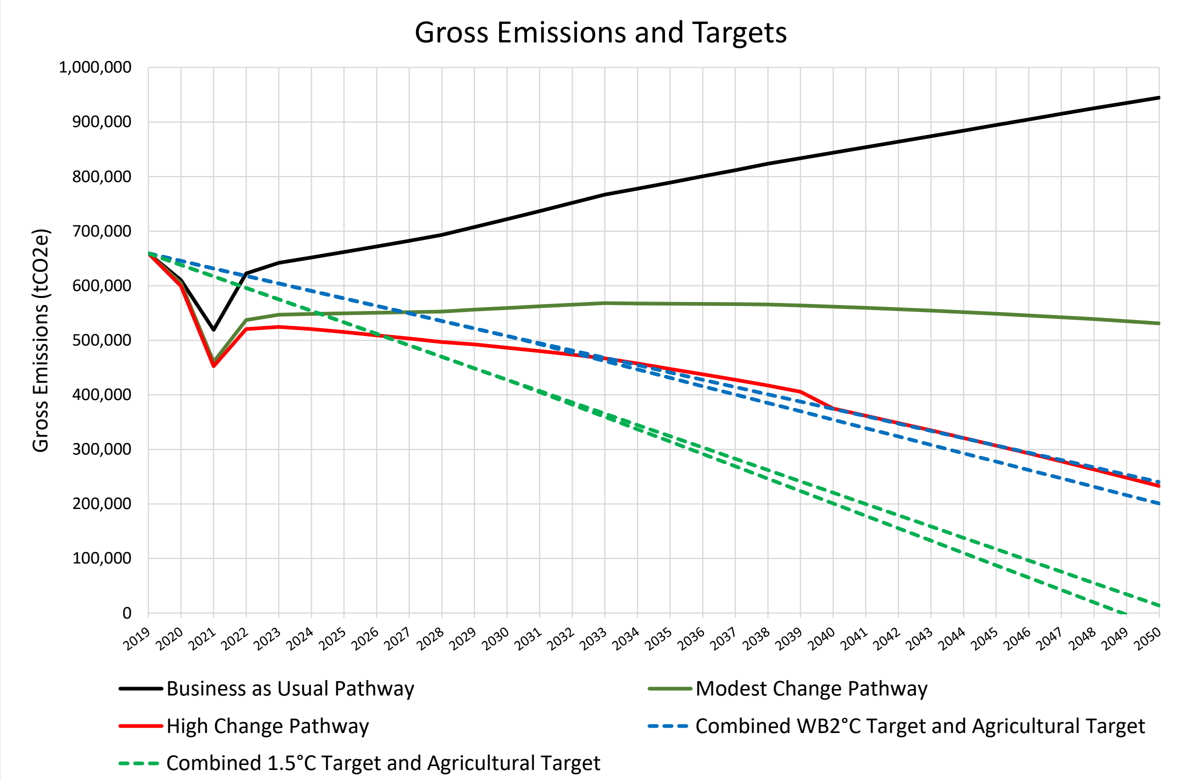


Figure 24 Residual gross emissions under the High Change pathway

7.3 Pathway comparison

A comparison is provided in Figure 25 for the Modest Change and High Change pathways versus the emissions reduction targets.

Figure 25 Comparison between the Modest Change and High Change pathways



The following can be observed from this chart:

- The High Change pathway will provide significantly more carbon savings compared to the Modest Change pathway, however it will only just achieve the combined well-below-2°C Science Based Target and biogenic methane target.
- The combined 1.5°C Science Based Target and biogenic methane target is aggressive and will not be achieved by either pathway.

7.4 Carbon budgets

District-wide carbon budgets have been generated based on the outputs from the modelling for each of the key pathways. These budgets are presented in Table 15 and Table 16.

Table 15 District emissions budgets (tCO_2e/year) for the Modest Change pathway (Modest-0)

Emissions Source	2020	2025	2030	2035	2040	2045	2050
Road Transport	217,901	228,108	236,494	241,120	235,268	224,317	209,729
Aviation	59,918	64,839	69,772	72,618	72,374	69,929	66,894
Agriculture	171,063	166,765	162,467	158,169	153,871	149,573	145,275
LULUCF							
Electricity	41,796	37,475	33,143	32,557	34,318	35,712	36,906
LPG	27,363	29,500	31,759	33,731	34,505	35,479	36,188
WW and Septic Tanks	6,282	6,899	7,833	8,793	9,519	10,238	10,947
Landfill	80,223	15,920	17,753	20,041	21,819	23,469	25,094
Total	604,545	549,506	559,221	567,028	561,674	548,717	531,033

Table 16 District emissions budgets (tCO_2e/year) for the High Change pathway (High-0)

Emissions Source	2020	2025	2030	2035	2040	2045	2050
Road Transport	215,290	209,313	192,928	168,551	132,125	88,577	39,315
Aviation	59,675	63,166	65,612	63,331	57,733	48,602	40,405
Agriculture	170,186	161,504	152,822	144,140	135,458	126,776	118,094
LULUCF							
Electricity	41,383	35,232	29,319	26,275	24,932	22,960	20,502
LPG	26,771	25,415	23,181	19,829	15,094	9,799	3,596
WW and Septic Tanks	6,282	6,865	7,745	8,743	9,519	10,238	10,947
Landfill	79,856	13,562	14,741	16,640	-	-	-
Total	599,443	515,056	486,348	447,510	374,860	306,952	232,858

7.5 Climate Action Plan budget mapping

From the pathways that have been developed, the emissions reduction options have been mapped out based on the CAP's five outcomes, in order to determine areas where the emissions roadmap can inform the setting of quantitative and qualitative KPIs for the CAP.

The five outcomes within the CAP are:

- Outcome 1 – The community looks to QLDC for leadership and action
- Outcome 2 – Queenstown Lakes has a low carbon transport system
- Outcome 3 – Built environment and infrastructure climate responsiveness
- Outcome 4 – Communities are climate conscious and resilient
- Outcome 5 – Our economy and natural environment thrive together

The carbon budgets for the five CAP outcomes are provided in Table 17 for the Modest Change pathway and in for the High Change pathway. Please refer to Appendix C for information on how the emissions reduction options within each subsector were mapped to the five CAP outcomes. Note that the 2020 and 2050 are sourced directly from the model, with the budgets for the intervening years determined via linear interpolation.

Table 17 CAP emissions budgets (tCO_2e/year) for the Modest Change pathway (Modest-0)

CAP Outcome	2020	2025	2030	2035	2040	2045	2050
1 – Leadership	2,700	2,750	2,800	2,850	2,900	2,950	3,000
2 – Transport	307,800	302,620	297,430	292,230	287,030	281,820	276,600
3 – Buildings/infra	88,800	87,450	86,100	84,750	83,400	82,050	80,700
4 – Communities	88,000	77,520	67,040	56,560	46,080	35,590	25,100
5 – Economy	171,900	167,470	163,040	158,610	154,180	149,740	145,300

Table 18 CAP emissions budgets (tCO_2e/year) for the High Change pathway (High-0)

CAP Outcome	2020	2025	2030	2035	2040	2045	2050
1 – Leadership	2,700	2,440	2,170	1,890	1,600	1,300	1,000
2 – Transport	307,800	269,790	231,780	193,760	155,740	117,720	79,700
3 – Buildings/infra	88,800	79,300	69,800	60,290	50,770	41,240	31,700
4 – Communities	88,000	73,350	58,700	44,040	29,370	14,690	-
5 – Economy	171,900	162,950	154,000	145,040	136,070	127,090	118,100

8. Costs to implement the pathway

This section presents marginal abatement costs of key mitigation options across the sectors investigated. These costs are based on our own estimates and on estimates by the Ministry for the Environment in their recent report on NZ marginal abatement cost curves (MfE, 2020).[19]

A marginal abatement cost measures the additional cost required to reduce an additional ton of CO2e emission, and provides a useful metric for prioritising mitigation activities from least to highest cost over a certain period of time. The costs are derived on a net-present-value basis (using a 6% discount rate) and include total asset lifetime costs.

Our roadmap is over a long-term horizon which allows capturing future technology cost reductions at points of capital replacement. However, we also include an intermediate 2020-2030 time horizon, which is the period over which MfE costs are estimated. The shorter time-frame allows us to identify options that are already, or will become, economic over the next ten years. The longer time-frame allows us to capture significant cost reductions that are expected beyond the next decade – e.g. BEV and FCHV costs for heavy freight transport, and solar PV costs for distributed electricity generation. By adjusting the timeframes in this way, we are able to make high-level assumptions on an economically feasible start date and uptake for a technology.

The purpose of our marginal abatement cost analysis, therefore, is mainly to inform our emissions reduction roadmap, and is used to compare between options at different points in time.

We have focused our MAC analysis on the key options that have the potential to deliver most of the emissions reduction, i.e. switch away from fossil fuel consumption in the transport and energy sectors, waste minimisation and landfill emissions reduction. Because New Zealand electricity already has low-emissions electricity, we have not focussed on assessing costs for improving the energy efficiency of uses that are already electrified.[20]

We have not included agriculture in this analysis as – for the purpose of the emissions reduction roadmap – we simply adopt the emissions reduction estimates for a broad package of emissions mitigation options based on the work undertaken by the New Zealand Agricultural Greenhouse Gas Research Centre.

We also exclude the wastewater treatment plant, as we determine that decommissioning the ponds will provide modest emissions savings.

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[19] Note that the MfE estimates as reported here are approximate based on graphs in the MfE report.
[20] E.g. switch from direct electric cylinder to electric heat pumps.

8.1 The transport sector

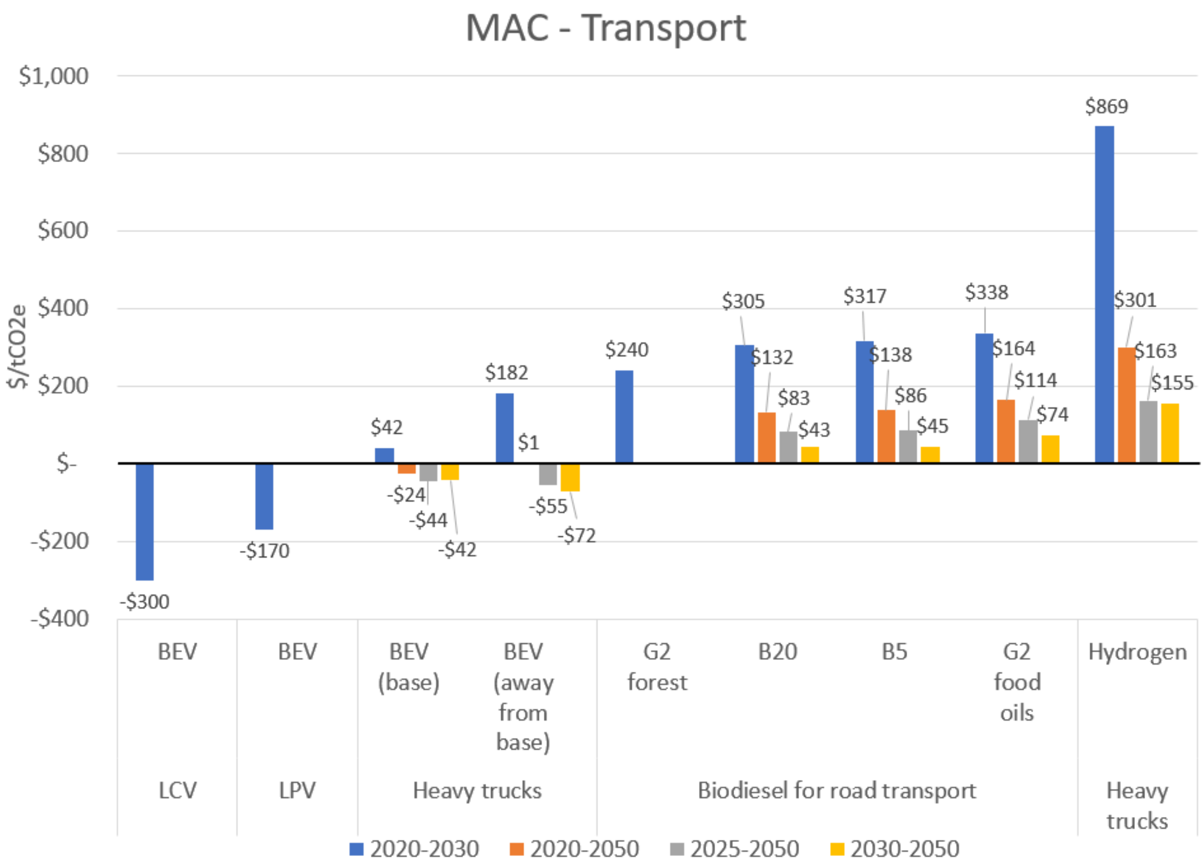
The table below lists the transport emissions reduction activities for which MACs have been estimated (right-hand-side column). The left-hand-side column maps these activities to the high-level emissions reduction options in the roadmap. The table is then followed by Figure 26 which illustrates the marginal costs for the transport sector.

We have used our own modelling to estimate the MACs for some activities, and have adopted MfE's estimates for others (e.g. BEV LCV and LPV, and G2 forestry biodiesel). We note that there is a difference in the approach we have taken for the transport sector compared to MfE's approach: whereas MfE's estimates reflect changes through time across the entire vehicle fleet, our estimates are on a per-vehicle basis. The latter approach means that our estimates, all else constant, could potentially be more conservative than if we modelled the entire fleet. This is because the latter would allow accounting for emissions reductions being achieved by the portion of the fleet that had already been converted to low-carbon technologies. Overall, we do not think the difference in approaches is material for the purpose of informing the roadmap – the estimates together give us a good picture of the relative costs amongst vehicle uses and fuel technologies.

Table 19 Transport emissions reduction activities for which MACs are estimated

High-level options in the emissions reduction roadmap	Specific activity for which costs are estimated in Figure 26
Convert petrol/diesel vehicles to BEVs, electric vehicle for airport	BEV light commercial vehicles (LCV) and light passenger vehicles (LPV)
Heavy vehicles to BEV	Heavy vehicles to BEV, with charging at base and away from base
Heavy vehicles to biodiesel (G2), biodiesel (G2) vehicles for airport and biofuel for aircraft	G2 from forestry products, G2 from food oils
Heavy vehicles to hydrogen, with findings applicable to hydrogen vehicles for airport	Hydrogen trucks

Figure 26 Marginal abatement costs for the transport sector



LCV = light commercial vehicles; LPV = light passenger vehicles; BEV = battery electric vehicles; G2 = Generation 2 biodiesel (drop in); G1 = Generation 1 biodiesel (blends); B20 = 20% biodiesel + 80% diesel blends; B5 = 5% biodiesel + 95% diesel blends.

Source: (MfE, 2020) estimates for LCV, LPV, and G2 forestry; own estimates for the other solutions

For some of the emissions reduction activities, the figure above presents multiple time horizons. This was mainly done to understand how technology cost reductions affect the estimates depending on when the capital investments are made.

The following sections provide a summary of the analysis and findings. The specific assumptions used to determine the costs are presented in Appendix D:.

Electrification of light passenger (LCV) and commercial vehicles (LPV)

MfE estimates that the marginal abatement cost of electrifying LCV and LPV are around -$300/tCO2e and -$170/tCO2e respectively over the 2020-2030 time horizon (MfE, 2020). This suggests that electrification of light vehicles is a cost-effective option to be pursued over the next decade. The MACs in these cases are negative mainly because of lower operating and maintenance costs of BEV options compared to their ICE counterparts.

On this basis, we have assumed that the uptake of electric LCV and LPV increases by 3% p.a., starting at 3% in 2020, and reaching 35% and 100% by 2035 and 2050 respectively.

Heavy truck electrification

Electrification of heavy trucks has a lower MAC if investments are made later rather than sooner during the next decade, mainly because of the higher capital cost of the BEV trucks relative to an ICE truck currently. We assume that current BEV heavy vehicle cost is 143% higher than that of a diesel counterpart (as per (Concept, 2019)), and estimate the capital costs to reach parity by 2040. We also assume that BEV trucks incur performance penalties due to battery weight or longer recharge time. For short-haul trucks charging at base during idle time we assume a battery weight penalty of 9% as per (MfE, 2020). For long-haul trucks needing to recharge at stations, we assume both a battery weight and a recharge penalty, 9% each.[21] On a TCO basis adjusted for these penalties, we find that cost parity with diesel trucks is reached by 2035.[22]

The costs over the longer time horizons are lower than those over the next decade because the former capture significant technology cost reductions and operational cost savings that improve capital cost recovery when viewed over the long-term. We have therefore assumed that the uptake of heavy BEV trucks will start slow at 1% in 2020, and increase by 1% every year (in High Change scenario).

Figure 26 presents two marginal cost estimates for the electrification of heavy trucks: those travelling shorter distances and therefore can charge at base, and those travelling longer distances, requiring charging away from base. The latter case is relatively more expensive because longer distances means less discretion on the timing of the battery re-charge, and therefore on the ability to avoid peak electricity charges. We have assumed the following with the regards to the electricity tariffs:

- Off-peak commercial electricity prices are used to estimate electricity cost for BEV trucks charging at base. The wholesale price component for off-peak cost is the average wholesale electricity price above multiplied by a factor of 0.8. This factor reflects the average ratio of off-peak/average wholesale prices based on 2015-2019 EMI data.[23]
- Daytime commercial electricity prices are used to estimate electricity cost for BEV trucks charging away from base. The wholesale price component for off-peak cost is the average wholesale electricity price above multiplied by a factor of 1.13. This factor reflects the average ratio of morning peak/average wholesale prices based on 2015-2019 EMI data.

Note that both of these estimates are higher than the approximate $160/tCO2 marginal abatement cost reported by (MfE, 2020) over the 2020-2030 time horizon.

Biodiesel

Biodiesel can play an important role in meeting emissions reduction targets, particularly in sectors that are difficult to de-carbonise, such as aviation and long-haul road freight.

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[21] The total productivity penalty drop to 6% by 2039 as per (Concept, 2019)..
[22] This is later than 2029 reported by (McKinsey, 2019), although it is unclear if McKinsey estimates include penalties.
[23] https://www.emi.ea.govt.nz/

We present two MAC estimates for G2 biodiesel: using forestry products as feed and using waste food oils. The first estimate of $240t/CO2e is from (MfE, 2020), and echoes Scion's finding that there are credible large-scale biofuel production pathways in New Zealand, particularly using forestry grown on arable land (Scion, 2018). The estimates for G2 biodiesel from food oils is based on our previous work investigating renewable diesel production abroad, suggesting a current price of $2.53 per litre.

Although the abatement cost for G2 biodiesel remains positive through to 2050, in our work we have found that biodiesel is an integral part of the technology set required to de-carbonise the transport sector. Policy levers will be required to support the uptake. For our purposes, we assume that the uptake of G2 biodiesel for road transport and airport vehicles starts with some delay (i.e. in 2025), and is slow – 1% p.a. reaching 33% by 2050 (in the High Change scenario). For aircraft, we assume that biofuel starts to be used 5 years later (in 2030), in line with IEA forecasts and also assuming that the establishment of a domestic supply market will be gradual.

In our emissions reduction roadmap, we have focused on G2 biodiesel (drop-in fuel). In Figure 26 we also present costs for G1 B5 and B20 biodiesel for illustration only to provide the context of the current market in New Zealand. Until recently, Z Energy was producing B5 biodiesel at its plant in Wiri (in South Auckland) using inedible tallow, a by-product from New Zealand's meat industry.[24] Production at this plant, however, has been shut down due to the cost increase of tallow feed as a result of demand competition from foreign biodiesel producers. This has raised the B5 premium to 8c/litre of diesel, making it more costly compared to G2 biodiesel from a MAC perspective.

Hydrogen

The high early MAC estimates for hydrogen heavy trucks reflect both relatively high capex and opex costs. We assume a current of $500k for a hydrogen-fuelled heavy truck, dropping to $347k and $206k by 2050, based on international research on cost reduction rates.[25]

The relatively high opex is explained by significant energy losses in the overall well-to-wheel energy chain, starting with the electrolysis process through to the conversion of hydrogen to electricity in the electric drive train. By some estimates (see Figure 29 in Appendix D:), the overall efficiency is 22%: some 56% of energy is lost in the wheel-to-tank stage, from electrolysis to the transport and distribution of hydrogen, and some further 57% is lost in the electric drive train. In our model, we assume improvements in fuel cell efficiency (tank-to-wheel) from 51% today to 75% by 2050.

After 2040, fuel costs for hydrogen trucks drop below those for diesel trucks due to declining hydrogen production costs combined with improved fuel cell efficiency, and increasing diesel costs as a result of increasing carbon prices.

For our estimates, we assume a delivered cost of hydrogen of $12.44/kg, $10.95/kg and $10.68/kg today, by 2030 and by 2050 respectively. This includes a service station overhead of $1.30/kg as per (Castalia, 2020). These estimates are based on our previous work, reflecting our assumptions on electricity price, and electrolyser and fuel cell efficiencies. We note that these estimates are higher

[24] https://z.co.nz/assets/Biodiesel/Z-biodiesel-plant.pdf

[25] See (Moultak, 2017)

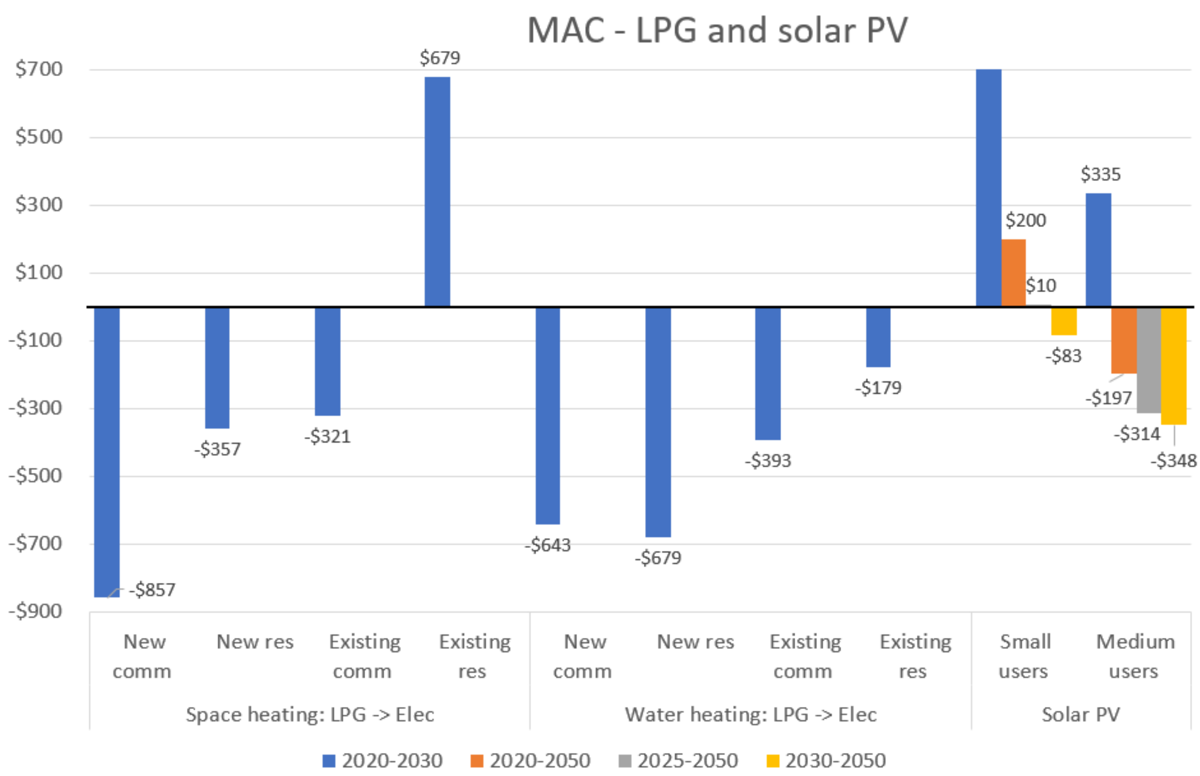
than Concept's current price of $11.3/kg (Concept, 2019), and Castalia's price of $7.23 by 2035 (Castalia, 2020)[26]

On the basis of the above, our High Change scenario assumes that the uptake of hydrogen-powered heavy trucks doesn't start until 2030, and grows by 1-2% p.a. to reach 33% by 2050. Similarly, the uptake of hydrogen-powered vehicles for airport doesn't start until 2030, but the ramp-up is slower reaching 20% by 2050.

8.2 LPG and solar PV

This section covers the MACs for replacing LPG use for space and water heating with electric heat pumps, and solar PV for small users (3 kW - residential) and medium-size users (10 kW - commercial).

Figure 27 Marginal abatement costs for LPG and solar PV



LPG=liquefied petroleum gas; PV = photovoltaics

Source: (MfE, 2020) and own estimates for solar PV

[26] The numbers are converted from USD4.77 for wind only production, liquefication and transport over 200km, excluding station overhead.

Space and water heating

For space and water heating, we use MfE's preliminary estimates of electrification options (MfE, 2020), which cover the lifetime costs for providing useful heat. Although MfE caution that the preliminary results are highly uncertain, they still provide useful insights with regards to the relative positioning of the different MAC blocks, in particular:

- Except for existing residential LPG use for space heating, switching away from LPG use in both space and water heating in existing commercial and new builds is very cost-effective due to the high price of LPG.
- By contrast, if LPG appliances have significant remaining economic lifetime over the next decade, then switching away from existing residential LPG use is very costly. This is because the switch would entail an appliance replacement cost sooner than otherwise.
- On that basis, it is generally much more expensive to replace an existing appliance that has a significant remaining economic life. Except for residential space heating, it is much more cost-effective to switch to an electric appliance in new builds or where the existing one needs to be replaced.
- Switching away from existing residential LPG use is very costly over the next decade.
- It is generally more cost-effective for commercial users to switch to the electric option than for residential users because of the higher load factor in the former case.

Although our roadmap does not explicitly distinguish between existing and new builds, on the basis of the above we can assume that the earlier switch from LPG to electric heat pumps will mainly cover new residential and commercial users, whereas for space heating of existing builds this will take place after 2030.

Solar PV

Drawing on domestic market quotes, we assume a current capital cost for a 3 kW and 10 kW PV system to be $2,667/kW and $2,100/kW respectively (see (My Solar Quotes, 2020a). [27] We assume these costs to decline by 4.6% p.a. to 2035, and by 1.3% p.a. thereafter, in line with (NREL, 2019) estimates.

For small users, we have assumed that 40% of the 3,800 kWh generated by a 3kW solar PV system is for self-consumption, and the rest is exported to the grid. We assume that, in the absence of a battery to store generation, households cannot consume the entirety of their solar PV generation because the generation profile does not entirely coincide with their load profile. Generally, a higher rate of own consumption implies a lower MAC, because the avoided cost of electricity in this case would also include a network charge, whereas the retailers' solar power buy-back rates generally only reflect the energy component.

The solar buy-back rate in 2020 is assumed to be $0.08/kWh based on (My Solar Quotes, 2020b). Cost savings from self-consumption of solar PV generation in 2020 are $0.29/kWh, based on MBIE's electricity cost and price monitoring date for Queenstown for February 2020 (MBIE, 2020a).

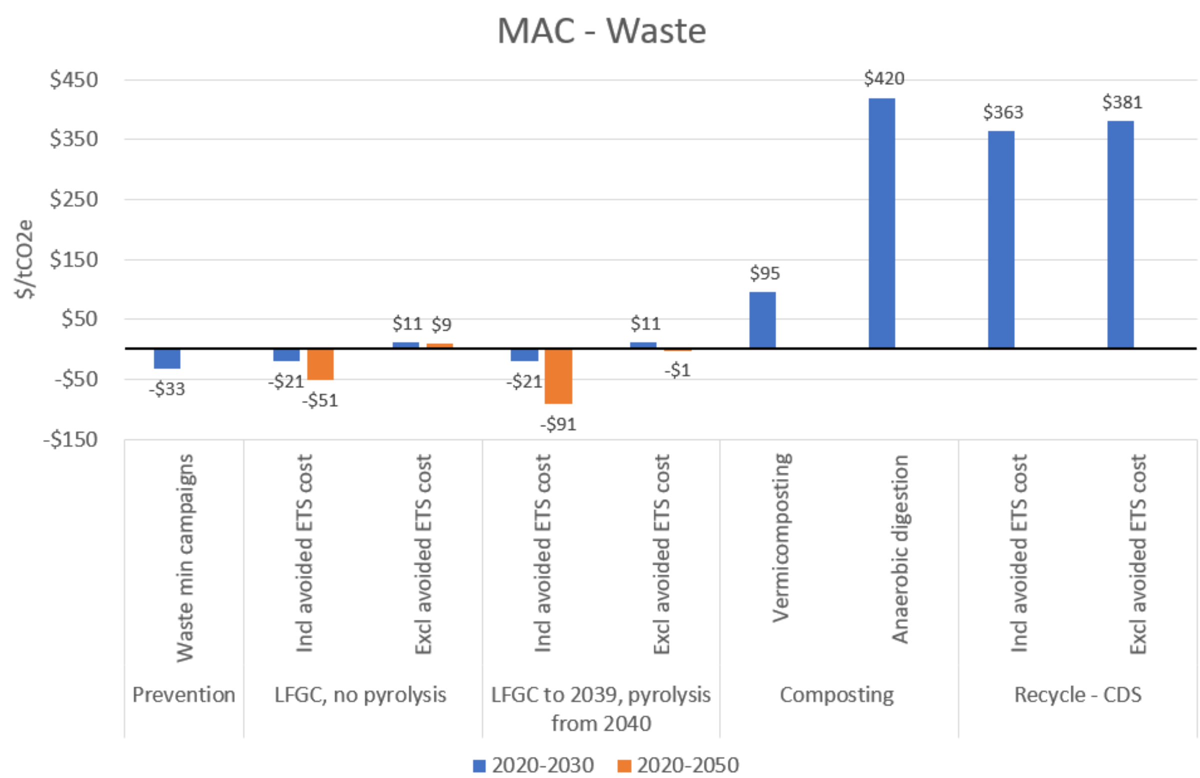
[27] https://www.mysolarquotes.co.nz/about-solar-power/residential/how-much-does-a-solar-power-system-cost/

The estimated MACs suggest that for small users, installing PV systems becomes cost-effective from 2030 onwards. We therefore assume that the transition to residential solar PV systems starts in 2030.

For medium users, we assume that all of the 12,667 kWh solar PV generation is for own consumption, as the solar generation profile is more likely to coincide with the commercial demand profile. In 2020, the avoided cost of electricity is $0.18/kWh, assuming that commercial tariffs are 63% of the residential tariffs based on MBIE historical electricity data (MBIE, 2020b). The analysis suggests that the transition to medium-scale solar PV is already cost-effective as a longer-term investment.

8.3 The waste sector

Figure 20 Marginal abatement costs for the waste sector



LFGC = landfill gas capture and flare; CDS = container deposit scheme

Source: Sapere analysis and (MfE, 2020) estimates for waste minimisation campaigns

Waste minimisation

In the roadmap, emissions reduction due to waste minimisation are as a result of community initiatives, education and behavioural changes. Marginal abatement costs would be very specific to the programs implemented, and because these programs are still being assessed by QLDC, we have not been able to determine the associated costs.

Notwithstanding, we provide two examples of costs for waste diversion activities, to show that the range of possible costs can be large.

For example, the Council may decide to pursue specific campaigns to raise awareness about the size of the waste problem and how community members can be part of the solution. Analysis commissioned by MfE suggests that reducing the amount of food waste generated by households by targeting them with a communications campaign is cost-effective, having a negative MAC of -$44/tCO2e.

By contrast, recycling schemes can prove to be expensive, especially if they result in unintended consequences, such as no net improvement in, or even increased transport emissions as a result of the way the waste is diverted.[28] A recent cost-benefit analysis of a proposed container deposit scheme in Auckland (see (Davies, 2017)), suggests that the MAC for such a program can be very high – over $350/tCO2e.[29]

Composting and AD

We understand that QLDC is currently assessing options for diverting green waste from landfill, based on recommendations from a recent report by SLR (SLR, 2019). We have not estimated costs for any of these options, but note that Eunomia estimates of waste MACs for MfE suggest that the costs for vermicomposting or anaerobic digestion of food waste are $84/tCO2e and $409/tCO2e respectively (see Table 4 in (MfE, 2020)).

Landfill gas capture and flare

We understand that a landfill gas capture and flare (LFGC) plant will become operative at the Victoria Flats Landfill by the end of this year. For the purpose of the MAC estimates, we used a capital cost of $2.6m, and operating costs of $0.27m p.a. based on data from the QLDC LFGC business case. We assume an economic lifetime of 20 years.

We provide two estimates, including and excluding avoided ETS liability, where the former case uses a carbon price of $34 in 2020, rising to $175 in 2050 based on (Prod Comm, 2018). The analysis shows that the ETS liability has a significant impact on the marginal costs.

LFGC costs are provided separately for a Modest Change scenario, where the LFGC plant continues to operate through to 2050, and for a High Change scenario, where the LFGC plant is replaced with a pyrolysis plant in 2040. In the Modest Change scenario, the 2040 capital replacement cost ($71.2/ton) of the LFGC plant reflects a larger footprint required to handle increased waste volumes.

Pyrolysis plant

A pyrolysis plant is assumed to be operation in 2040 in the High Change scenario, with capital and operating costs of $5.8m and $0.2m p.a. respectively. We also assume a containerised GE genset will produce electricity from the bio-oil resulting from the pyrolysis process. The capex and opex of the generator are of $1.5m/MW and $25/MWh respectively. We assume that all generated electricity replaces grid imported electricity at a current price of $0.10/kWh. The other value streams are biochar, for which we assume a price of $5/GJ, and biogas, which we assume to replace LPG as feedstock for

[28] E.g. more smaller trips by households to dispose of recyclable waste, or longer trips to a recycling facility.
[29] This was estimated based on the reported costs and benefits, excluding welfare benefits as measured by consumer surplus / willingness to pay.

industrial process heat at a current price of $10/GJ. Appendix E: provides other assumptions used in the calculations.

The cost of waste disposal (excl. ETS cost and levies) is assumed to be the same between the landfill and the pyrolysis plant. Avoided ETS costs are a marginal benefit. We have not included avoided levies as these are being reviewed,[30] and it is unclear how they would change over the long time-horizon.

Our estimates suggest that the MACs for the Modest Change scenario of an LFCG plant through to 2050, and a High Change scenario where the LFCG plant is replaced with a pyrolysis plant in 2040 are similar when ETS costs are included. Our baseline roadmap assumes the Modest Change scenario with no pyrolysis.

8.4 Summary

For road transport

- Electrification of light passenger and commercial vehicles is already a cost-effective abatement option that should be pursued.
- Heavy truck electrification will become a cost-effective abatement over the next five years. In the roadmap, we assume that the uptake of heavy BEV trucks will start slowly at 1% in 2020, and increase by 1% every year.
- Although all biodiesel options will have positive abatement costs throughout the timeframe investigated, we have found that biodiesel is an integral part of the technology set required to de-carbonise the transport sector, and policy levers will be required to support the uptake. In the roadmap, we assume that the uptake of G2 biodiesel for road transport and airport vehicles starts in in 2025, and grows slowly at 1% p.a. We also assume that sustainable aviation fuel is taken up from 2030.
- The abatement cost for hydrogen trucks also stays positive through to 2050. Notwithstanding, hydrogen is an indispensable abatement option for road transport, similar to biodiesel. We assume that the uptake of hydrogen-powered heavy trucks starts in 2030, and grows by 1-2% p.a.

For space and water heating

- The high price of LPG means that switching away from LPG in existing commercial and new builds is already cost-effective from an abatement perspective. However, this is not the case for households where existing LPG appliances are relatively new.
- Compared to residential users, it is generally more cost-effective for commercial users to switch to the electric option due to the higher load factor in the latter case.
- On the basis of above, we assume that the earlier switch from LPG to electric heat pumps will mainly cover new residential and commercial users, whereas for space heating of existing builds this will take place after 2030.

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[30] https://www.odt.co.nz/regions/queenstown/multimillion-dollar-plan-landfill

For solar generation

- We assume that the transition to residential solar PV systems starts in 2030, as that is it when this becomes cost-effective from an abatement perspective.
- The transition to medium-scale solar PV is already cost-effective as a longer-term investment.

For the waste sector

- There is evidence that waste minimisation campaigns can reduce emissions at a negative marginal cost, but these costs would be very specific to the programs implemented. We have used MfE MAC estimates, and separate analysis should be conducted of QLDC-specific programs once these are developed.
- Replacing the LFCG plant with a pyrolysis plant starting with 2040 does not bring abatement cost savings, so our baseline roadmap assumes the LFCG plant operates through to 2050 (however the pyrolysis plant is included in the High Change scenario to show the step change in emissions).

9. Sensitivity analysis

9.1 Population projections

The total population for the district (including both residents and visitors) will have an impact on carbon emissions. The figure below illustrates all modelled pathways to 2050, based on different levels of change and varying population projections as detailed in Section 3. As can be seen, lower rates of population increase will result in fewer carbon emissions being emitted due to less travel and economic activity. However, as the pathways become more aggressive (from the Business as Usual pathway through to the High Change pathway) the sensitivity to population decreases. This is due to the agricultural emissions being modelled without any influence from population changes.

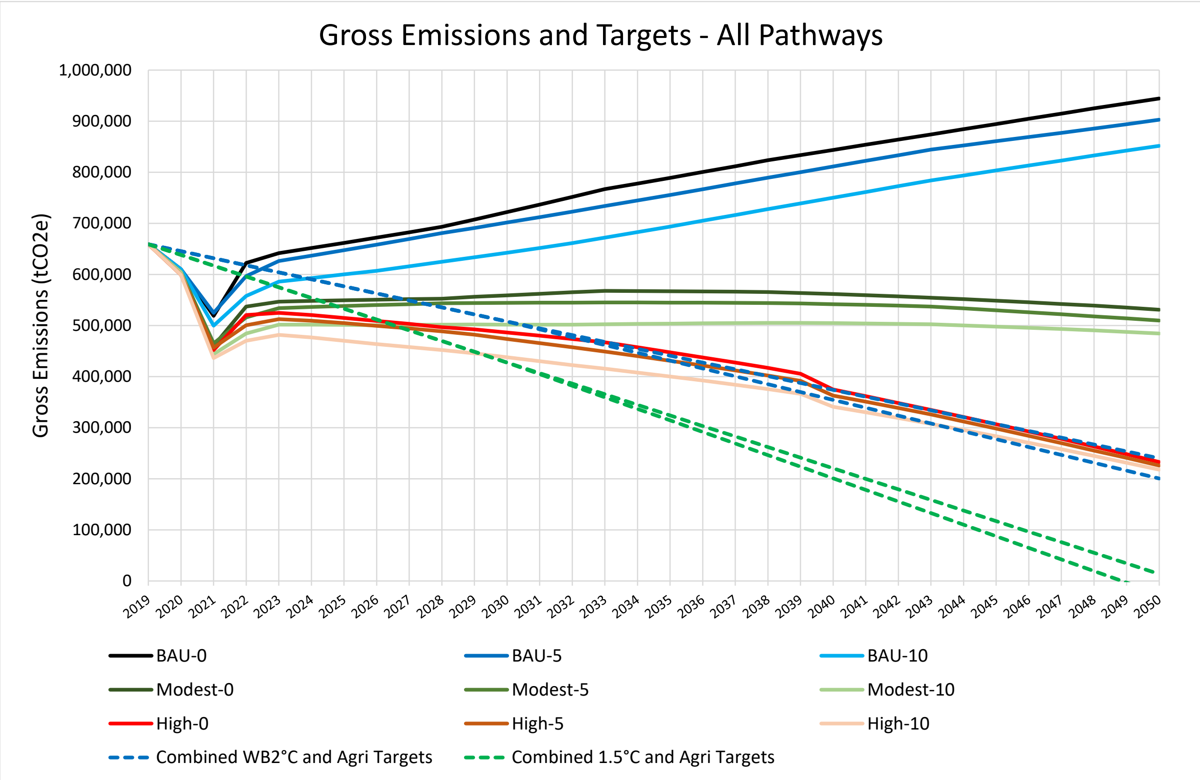


Figure 28 Gross district emissions for all pathways

As shown in the sensitivity above, the key drivers for reducing carbon emissions in the Queenstown Lakes district are behavioural and technological changes, rather than population changes.

10. Emissions reduction and sequestration

Behavioural and technological changes alone will not be sufficient for the Queenstown Lakes district to achieve net zero emissions by 2050. Carbon sequestration will be required to offset the residual emissions and reach the net-zero goal.

A Sequestration Study for QLDC has been developed independently, and in parallel, to this Emissions Reduction Roadmap without constraints to achieve specific carbon sequestration. The Sequestration Study provides an overview of biological and technical sequestration opportunities within the District and concludes that there is good opportunity for the cropping of high yield biomass crops for use in bioenergy / biochar manufacture as well as potential for significant biological sequestration, including expansion of current native forest restoration efforts as well as new plantings within pastoral lease areas below 700m in some of the less sensitive parts of the District.

Modelling performed in the study illustrates that, based on the protocols adopted, plantings of around 17,320 ha of land (the majority with high carbon sequestration vegetation) has potential to sequester over 400 ktCO_2e/year by 2050. This planting is less than 2% of the land area of the region, however, it should be noted that this will entail significant challenges in reference to:

- The natural landscape of the area – decisions will need to be made regarding what lands would be planted with vegetation as any planting will result in a change in landscape.
- Land ownership – the QLDC is a relatively small landowner and to make a material effect on net emissions the sequestration will need to be much wider than just QLDC.

It will not be easy and there are many challenges that will need to be overcome. Significant community buy in will be required in order to enable the land change required for any substantial biological sequestration contributions.

Please refer to the plan for details on how the information above was developed.

11. Next steps

The carbon reduction options discussed in this report are wide-ranging and long-term. While it is not possible to accurately predict what will happen across the district over the next 30 years, we expect that the actual emissions for the region will fall somewhere between the bounds of the Modest Change and High Change pathways. However, even the Modest Change scenario needs significant intervention from all parties to ensure it is met as it is a large divergence from status quo.

We hope that QLDC will be bold and ambitious, aiming for the High Change pathway in order to mitigate the effects of climate change.

Achieving this High Change pathway will require QLDC to influence stakeholders, communities and partners across all three spheres of influence and QLDC will need to utilise multiple levers, particularly regulatory, policy and community engagement in order to meet the ambitious targets that have been set. Specific actions around these levers will need to be formulated, discussed, implemented and reviewed.

The table below summarises the recommended next steps for each sub-sector.

Table 21 Subsector recommendations

Subsector	Recommendation
Road Transport	Complete full modelling of the transport network within the QLDC region, focussing on the number of trips performed between key locations and the type of vehicles used for these trips. This will enable the correct technological and behavioural interventions to be identified for each area.
Aviation	Engage with Air NZ (and other flight operators in the region) and Queenstown Airport regarding their projections for future carbon intensity of flights, with a view to identifying key actions QLDC can encourage/undertake to minimise carbon per trip.
Agriculture	Liaise with key stakeholders in the region to perform trials in ways of reducing carbon emissions through the agriculture sector. This may involve reviewing current literature and programmes and modifying them for the unique QLDC region.
Electricity	Engage with Aurora to ensure that the electricity infrastructure is in place to aid decarbonisation. Pricing levers, such as export rates, and peak charges should be reviewed to ensure maximum energy is available, while minimising capital investment.
LPG	Engage with LPG suppliers to confirm total LPG consumption within the district. Further, engage with Contact/Rockgas regarding the LPG distribution network within the region to discuss ways to decarbonise the network, such as supplying biomethane into the network.

Wastewater	Confirm detailed emissions factors of various wastewater treatment options and assess measures to provide further reductions. Consideration needs to be given to N_2O emissions as these make up the bulk of carbon equivalent emissions.
Landfill	Investigate alternative means of carbon reduction within the landfill environment and determine their feasibility within the QLDC context. The key item regarding this is a pyrolysis plant to reduce emissions from waste, while providing fuel that be used elsewhere in the QLDC region.
QLDC	Complete a full and verified carbon inventory for QLDC. This will confirm emissions from all directly and indirectly controlled activities performed by the council.

References

Castalia. (2020). *Modelling hydrogen pathways for MBIE - model results.* Retrieved from https://www.mbie.govt.nz/dmsdocument/11513-modelling-hydrogen-pathways-for-mbie-model-results

Concept. (2019). *Hydrogen in New Zealand Report 2 - Analysis.* Retrieved from http://www.concept.co.nz/uploads/2/5/5/4/25542442/h2_report2_analysis_v4.pdf

Davies, P. (2017). *Cost-benefit analysis of a Container Deposit Scheme.* Retrieved from http://www.wasteminz.org.nz/wp-content/uploads/2017/12/Container-Deposit-CBA-Report-Final.pdf

Leading the Charge. (2019). *ALSCO leads the way*. Retrieved from https://www.leadingthecharge.org.nz/alsco_leads_the_way

MBIE. (2012). *Electricity insights.* Retrieved from https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-modelling/new-zealands-energy-outlook/new-zealands-energy-outlook-electricity-insight/

MBIE. (2020a). *Electricity cost and price monitoring.* Retrieved from https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/energy-prices/electricity-cost-and-price-monitoring/#:~:text=An%20electricity%20retailer%20may%20charge,(2125%2F8000)x100.

MBIE. (2020b). *Electricity statistics.* Retrieved from https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/electricity-statistics/

McKinsey. (2019). *Global Energy Perspective.* Retrieved from https://www.mckinsey.com/industries/oil-and-gas/our-insights/global-energy-perspective-2019#

MfE. (2020). *Marginal abatement cost curve analysis for New Zealand.* Retrieved from https://www.mfe.govt.nz/sites/default/files/media/Climate%20Change/marginal-abatement-cost-curves-analysis_0.pdf

Moultak, M. L. (2017). *Transitioning to zero-emission heavy-duty freight vehicles.* Retrieved from https://theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

My Solar Quotes. (2020a, September 1). *How much does a solar power system cost*. Retrieved from My Solar Quotes: https://www.mysolarquotes.co.nz/about-solar-power/residential/how-much-does-a-solar-power-system-cost/

My Solar Quotes. (2020b, September 1). *Solar Power Buy Back Rates NZ*. Retrieved from My Solar Quotes: https://www.mysolarquotes.co.nz/about-solar-power/residential/solar-power-buy-back-rates-nz/

NREL. (2019). *Annual Technology Baseline.* Retrieved from https://atb.nrel.gov/electricity/2020/data.php

Prod Comm. (2018). *Low emissions economy*. Retrieved from https://www.productivity.govt.nz/assets/Documents/4e01d69a83/Productivity-Commission_Low-emissions-economy_Final-Report.pdf

Scion. (2018). *New Zealand biofuels roadmap.* Retrieved from https://www.scionresearch.com/science/bioenergy/nz-biofuels-roadmap

SLR. (2019). *Organic waste mass balance modelling.*

Transport & Environment. (2017). *Roadmap to climate-friendly land freight and buses in Europe.* Retrieved from https://www.transportenvironment.org/sites/te/files/publications/Full_%20Roadmap%20freight%20buses%20Europe_2050_FINAL%20VERSION_corrected%20%282%29.pdf

Appendix A: Emissions factor assumptions

Table 22 Emissions factors used for energy

Source of emission	Unit	Value	Source
Diesel	$kgCO_2$/litre	2.69	MfE, 2019
Biodiesel	$kgCO_2$/litre	0.000125	MfE, 2019
Petrol	$kgCO_2$/litre	2.45	MfE, 2019
Electricity	$kgCO_2$/kWh	2019-2021: 0.0977 2022-2035: curved reduction from 0.0977 to 0.056 2036-2050: 0.056	MfE, 2019 MBIE Global Low Carbon forecast
LPG	$kgCO_2$/litre	3.02	MfE, 2019

Table 23 Emissions factors used for road transport

Source of emission	Unit	Value	Source
Petrol bus	$kgCO_2$/km	0.784	MfE, 2019
Petrol motorcycle	$kgCO_2$/km	0.121	MfE, 2019
Petrol light commercial vehicle	$kgCO_2$/km	0.262	MfE, 2019
Petrol light passenger vehicle	$kgCO_2$/km	0.268	MfE, 2019
Diesel bus	$kgCO_2$/km	0.784	MfE, 2019
Diesel heavy truck	$kgCO_2$/km	0.455	MfE, 2019
Diesel light commercial vehicle	$kgCO_2$/km	0.296	MfE, 2019
Diesel light passenger vehicle	$kgCO_2$/km	0.270	MfE, 2019
Battery electric vehicle - default	$kgCO_2$/km	0.025	MfE, 2019
Battery electric vehicle – 7-10t	$kgCO_2$/km	0.061	MfE, 2019

Table 24 Emissions factors used for agriculture

Source of emission	Unit	Value	Source
Dairy	tCO_2/animal	2.724	MfE, 2019
Beef	tCO_2/animal	1.841	MfE, 2019
Sheep	tCO_2/animal	0.375	MfE, 2019
Deer	tCO_2/animal	0.695	MfE, 2019

Table 25 Emissions factors used for landfill

Source of emission	Unit	Value without LFGC	Value with LFGC	Source
Paper	tCO_2/t	3.000	0.620	MfE, 2019
Organic	tCO_2/t	1.315	0.272	MfE, 2019
Textiles	tCO_2/t	1.800	0.372	MfE, 2019
Sanitary paper	tCO_2/t	2.400	0.992	MfE, 2019
Timber	tCO_2/t	3.230	0.667	MfE, 2019

Table 26 Emissions factors used for wastewater and septic tanks

Source of emission	Unit	Value	Source
MLE Plant	tCO_2/m^3	0.000151	Tonkin & Taylor, 2020
SBR Plant	tCO_2/m^3	0.000227	Tonkin & Taylor, 2020
Pond	tCO_2/m^3	0.00057	Tonkin & Taylor, 2020
Septic Tank	tCO_2/person	0.202	Tonkin & Taylor, 2020

Appendix B: Technical assumptions

Table 27 Technical assumptions

Description	Unit	Value	Source
Diesel energy density	kWh/litre	10.58	DETA
Petrol energy density	kWh/litre	9.70	DETA
Diesel vehicle efficiency, incl. drive train	%	35%	DETA
Electricity to hydrogen efficiency conversion	%	52%	Concept (2019)
Fuel cell efficiency, incl. electric drive train	%	51%	Based on Concept (2019)
Electricity to hydrogen to motive power efficiency	%	26.5%	Calculated based on conversions above
Hot water heat pump COP	COP	2.0	DETA
Split heat pump COP	COP	3.0	DETA
LPG combustion efficiency	%	85%	DETA

Appendix C: Climate Action Plan mapping

Table 28 Mapping the carbon reduction options from the modelling to the CAP outcomes

Subsector	Opportunity	CAP	
Road Transport	Public Transport & Ride Sharing	2	Transport
Road Transport	Convert from Petrol Vehicles to BEV	2	Transport
Road Transport	Convert from Diesel Light Vehicles to BEV	2	Transport
Road Transport	Heavy Vehicle Driver Training & Telemetrics	2	Transport
Road Transport	Heavy Vehicle Efficiency	2	Transport
Road Transport	Trucking Collaboration	2	Transport
Road Transport	Heavy Vehicles to BEV	2	Transport
Road Transport	Heavy Vehicles to Biodiesel	2	Transport
Road Transport	Heavy Vehicles to Hydrogen	2	Transport
Aviation	Aircraft Efficiency	2	Transport
Aviation	Biofuel for Aircraft	2	Transport
Aviation	Electric Aircraft	2	Transport
Aviation	Electric Vehicles for Airport	2	Transport
Aviation	Biodiesel Vehicles for Airport	2	Transport
Aviation	Hydrogen Vehicles for Airport	2	Transport
Agriculture	Agricultural Emissions Mitigation Programme	5	Economy
Stationary Electricity	Reduce Hot Water Demand - Small Users	3	Bldgs / infra
Stationary Electricity	Hot Water Heat Pumps - Small Users	3	Bldgs / infra
Stationary Electricity	Heat Pumps for Space Heating - Small Users	3	Bldgs / infra
Stationary Electricity	Insulation & Glazing Upgrades - Existing Small Users	3	Bldgs / infra
Stationary Electricity	Energy Efficient Housing - New Builds	3	Bldgs / infra
Stationary Electricity	Solar PV for Small Users	3	Bldgs / infra
Stationary Electricity	Building Energy Efficiency - Medium Users	3	Bldgs / infra
Stationary Electricity	Solar PV for Medium Users	3	Bldgs / infra
Stationary Electricity	Energy Efficiency - Large Users	3	Bldgs / infra
LPG	Phase Out Residential LPG Cooktops and Ovens	3	Bldgs / infra
LPG	Reduce Residential Hot Water Demand	3	Bldgs / infra
LPG	Residential Hot Water Heat Pumps	3	Bldgs / infra
LPG	Residential Heat Pumps for Space Heating	3	Bldgs / infra
LPG	Phase Out Commercial LPG Cooktops and Ovens	3	Bldgs / infra
LPG	Reduce Commercial Hot Water Demand	3	Bldgs / infra
LPG	Commercial Hot Water Heat Pumps	3	Bldgs / infra
LPG	Commercial Heat Pumps for Space Heating	3	Bldgs / infra
Wastewater	Wakatipu WWTP Pond Decommissioning	3	Bldgs / infra
Wastewater	Send WWTP Biosolids to Landfill with Gas Capture	3	Bldgs / infra
Wastewater	Convert Hawea Ponds to Mechanical WWTP	3	Bldgs / infra
Wastewater	Convert Septic Tanks to Mechanical WWTPs	3	Bldgs / infra
Landfill	Waste Reduction	4	Communities
Landfill	Divert Food and Green Waste from Landfill	4	Communities
Landfill	Divert Timber from Landfill	4	Communities
Landfill	Landfill Gas Capture & Flaring	4	Communities
Landfill	Pyrolysis Plant	4	Communities
QLDC Direct Control	Convert from Fossil Fuel Vehicles to BEV	1	Leadership
QLDC Direct Control	Increase Electrical Efficiency - Buildings and Equipment	1	Leadership
QLDC Direct Control	Convert Alpine Aqualand Water Heating from LPG to Heat Pumps	1	Leadership
QLDC Direct Control	Solar PV	1	Leadership

Appendix D: Assumptions for estimating transport MACs

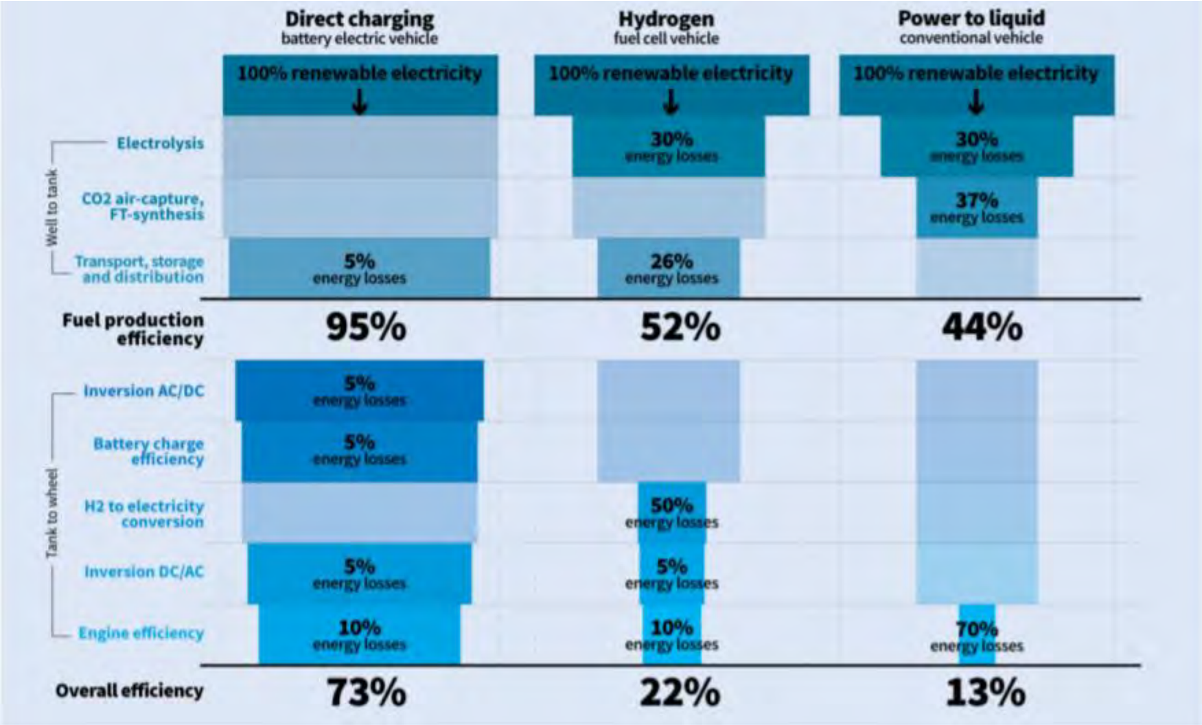
Table 29 Assumptions used for estimating transport MACs

Parameter	Value	Source / method
Diesel retail price, incl. ETS cost, excl. GST	$1.25/litre today$1.44 by 2030 and $2.08 by 2050	It is the sum of retail diesel price excluding taxes and the ETS component estimated based on a diesel emissions factor of 2.69 kgCO2e/litre. The 2020 diesel retail price excl. taxes is $0.95/litre, and is the sum of the 2020 average diesel importer cost and retail importer margin as reported by MBIE in its weekly fuel price monitoring.[31] The diesel retail price excl. taxes increases by 1.1% p.a., which is the real CAGR estimated for importer costs over 2004-2019.
Wholesale electricity price	$0.108/kWh, $0.119/kWh in 2036 and $0.126/kWh in 2050.	Current price is the average NZ wholesale price over Jan 2018-Aug 2020. Our price forecast over the long-term reflects an average estimate that accounts for a 22% probability of a dry year (this usually occurs every 4.5 years). Based on our LCOE estimates, we determine that, on average, the lowest cost generation mix required meat peak adequacy and security of supply (dry-year problem) from 2036 is a 22% partially loaded wind and 78% geothermal, The wholesale price estimates include the carbon cost component associated with geothermal generation. Future price increase reflects increasing carbon prices.
Commercial electricity price for BEV trucks, incl network charges (base)	$0.12/kWh today, , $0.116/kWh in 2030, 0.119/kWh	Off-peak commercial electricity prices are used to estimate electricity cost for BEV trucks charging at base. The wholesale price component for off-peak cost is the average wholesale electricity price above multiplied by a factor of 0.8. This factor reflects the average ratio of off-peak/average wholesale prices based on 2015-2019 EMI data.[32]
Commercial electricity price for	$0.172/kWh, real CAGR of -0.4%,	Daytime commercial electricity prices are used to estimate electricity cost for BEV trucks recharging at

[31] https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/weekly-fuel-price-monitoring/
[32] https://www.emi.ea.govt.nz/

Parameter	Value	Source / method
BEV trucks, incl network charges (away from base)	$0.164/kWh in 2030, 0.169/kWh	stations during daytime due to longer travel distances than trucks charging at base. The wholesale price component for off-peak cost is the average wholesale electricity price above multiplied by a factor of 1.13. This factor reflects the average ratio of morning peak/average wholesale prices based on 2015-2019 EMI data
Price of B5 biodiesel	6c/litre premium	Based on previous Sapere work
Price of B20 biodiesel	24c/litre premium	Based on B5 costs and accounting for additional ETS cost savings
Carbon price	$32/tCO2e in 2020, $55/tCO2e in 2030, and $175/tCO2e in 2050	Future prices based on (Prod Comm, 2018)
BEV truck capex (base)	$294,613 today, dropping to $181,936 in 2050	Today - 143% of diesel truck cost, as per (Concept, 2019). Cost decline estimates based on previous Sapere work
BEV truck maintenance cost	1.2% capex	Based on ALSCO case study (Leading the Charge, 2019)
Diesel truck maintenance cost	4.3% capex	Based on ALSCO case study (Leading the Charge, 2019)
Hydrogen truck maintenance	3.3 % capex	Based on relative assessment of BEV, hydrogen and diesel trucks as per (Concept, 2019)
Hydrogen truck capex	$500,000 today and $206,023 by 2045	Cost declines based on previous Sapere work

Figure 29 Energy efficiency of different technologies



Source: (Transport & Environment, 2017)

Appendix E: Assumptions for estimating pyrolysis plant MAC

Table 30 Assumptions used for estimating pyrolysis plant MAC

Parameter	Value	Source
LPG price	\$10/GJ to 2030, then increases to \$25/GJ in 2050	Value reflect increasing carbon prices. Post-2035 values are based on MBIE Electricity Insights - assumptions in their global low-carbon scenario (MBIE, 2012). The value before 2035 are interpolated
Electricity price	\$0.099/kWh now, decreasing by 0.3% p.a. to 2036, then increasing by 0.4% p.a. to 2050	Sapere previous work
% of waste feedstock for each output stream	Biochar – 33% Natural gas – 32% Bio-fuel – 35%	George Hooper previous work and international case studies

Appendix F: About Us

About Sapere

Sapere Research Group is one of the largest expert consulting firms in Australasia, and a leader in the provision of independent economic, forensic accounting and public policy services. We provide independent expert testimony, strategic advisory services, data analytics and other advice to Australasia's private sector corporate clients, major law firms, government agencies, and regulatory bodies.

'Sapere' comes from Latin (to be wise) and the phrase 'sapere aude' (dare to be wise). The phrase is associated with German philosopher Immanuel Kant, who promoted the use of reason as a tool of thought; an approach that underpins all Sapere's practice groups.

We build and maintain effective relationships as demonstrated by the volume of repeat work. Many of our experts have held leadership and senior management positions and are experienced in navigating complex relationships in government, industry, and academic settings.

We adopt a collaborative approach to our work and routinely partner with specialist firms in other fields, such as social research, IT design and architecture, and survey design. This enables us to deliver a comprehensive product and to ensure value for money.

About DETA

DETA Consulting (DETA) is a New Zealand owned and managed consultancy specialising in identifying, developing, and delivering efficiency projects. Our expertise in energy efficiency is second to none across Australasia and has led to our strong growth to a team of 20 staff across three offices in New Zealand, one in Australia, and work across the Asia Pacific region.

We work to improve our clients' business by helping identify, scope and deliver optimization projects. We always analyse the impacts of our solutions on the client as a whole, considering practicality, health and safety, business and environmental concerns. We ensure our analysis is "real" and that clients can make informed decisions.

Our customers are broad and far reaching and include large industrial processors in the dairy, meat, wood and food production areas, commercial and governmental agencies, healthcare providers, and small SME businesses. We are at the forefront of technology in our industries – we have rolled out several 'first in country' projects in the refrigeration and energy generation space and are working closely with several of our customers to deliver significant market leading automation projects. Our recent project at Hanmer Springs thermal resort, completed in 2018, won several innovation awards for its application of new technology.

About Maidstone

Maidstone Associates is a private consulting firm led by George Hooper offering expert advisory and consulting services to clients within the technology and resources sectors, with a primary focus on industry strategy and operational support, technology commercialisation, and technical due diligence. This includes a strong interface role between the university and research sectors of NZ and industry research investments. A core competency of the firm is in front-end conceptual engineering. Assignments have included evaluations of emerging technologies, specific project investigations and feasibility assessments of commercial resource development proposals, plus the evaluation of new business opportunities in the renewable energy sector. In this capacity, the company plays a key role in scoping and identifying project opportunities, and in the formulation of deployment pathways.

In respect of this assignment specific projects include expert contributions to a range of industry studies assessing future energy supply options, biomass gasification studies, appointment as Technical Advisor to the New Zealand CCS Partnership, stage gate risk analysis for new technology investments across a range of biofuel and non-conventional energy options, plus expert review of the carbon default emissions factors for gas mining and processing.

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