



**SUBMISSION OF
LPG ASSOCIATION OF NEW ZEALAND**

**TO
HE POU A RANGI
CLIMATE CHANGE COMMISSION
DRAFT ADVICE**

28 MARCH 21

EXECUTIVE SUMMARY

The LPG industry can achieve the emissions reductions that the Draft Advice proposes by migrating to renewable LPG. In this submission we outline a pathway and we propose regulation to provide assurance.

Our alternative depends on replacing the proposal to ban new connections to LPG with a requirement to use renewable LPG.

Renewable LPG is identical to existing LPG. It can be used by existing customers with no change to appliances or industry infrastructure.

Over 180,000 businesses and residential customers use LPG in applications such as space heating, especially in agriculture and horticulture, in manufacturing processes, and for cooking and water heating in homes and businesses.

The Draft Advice emissions budget is achievable using renewable LPG

First generation renewable LPG technology is commercially available today.

Renewable LPG depends on sustaining a vibrant LPG industry. It may not be viable if new connections are banned.

The LPG Association commissioned an external review from leading consultants, Worley. It looked at renewable LPG technologies and feedstocks. The review demonstrates that our proposed alternative is credible. The Draft Advice emissions budget is achievable using renewable LPG.

The LPG Association of New Zealand supports the Commission's recommended pathway for emissions reductions. However, at 'Necessary Action 9C' the Draft Advice recommends: *"Setting a date by when no new natural gas connections are permitted, and where feasible, all new or replacement heating systems installed are electric or bioenergy. This should be no later than 2025 and earlier if possible."* (Page 118).

We ask the Commission to replace its proposed ban on new connections with a new recommendation: Achieve the emissions budget by requiring the introduction of renewable LPG.

In our alternative, renewable LPG would be introduced from 2025.

**The Draft Advice
emissions budget
is achievable using
renewable LPG**

The Gas Industry Company would regulate to ensure emissions fall below the forecast 'no new connections' emissions profile.

RENEWABLE LPG SHOULD BE PREFERRED TO A BAN ON NEW CONNECTIONS

The proposed ban on new connections is not supported by the Commission's own reasoning or guiding principles—in particular, Principle 3: *"The decisions taken now should open up a wide range of future options and keep options open for as long as possible."*

An emissions target incentivises market participants to develop renewable LPG and transition to the new energy source.

Existing heating and cooking appliances and LPG infrastructure (such as pipelines, tanks, cylinders, and trucks) are ready for renewable LPG today. Transitioning to renewable LPG allows continued, undisrupted use of equipment.

A ban on new LPG connections may have unintended consequences, such as customers and market players exiting the industry, which would negatively affect confidence and the economics of renewable LPG.

The existing user cases for LPG can be replicated with renewable LPG. A ban overrides consumer preference and choice, and risks losing public support for decarbonisation.

The proposed alternative achieves an equally ambitious emissions pathway while providing opportunities for economic upside and greater technology options.

Our proposed alternative is practical and supported by research. It relies on technology that is available to reduce emissions today and will continue to be developed over coming years.

LPG

About 180,000 customer installations use around 185,000 tonnes of LPG each year.

LPG is an energy-rich fuel source with a higher calorific value than other commonly used fuels, including, coal, natural gas, diesel, petrol, fuel oils, and biomass-derived alcohols. This means that an LPG flame burns hotter. LPG is high efficiency. It is ideal for space and water heating, especially in commercial applications.

Even where alternatives are possible, customers choose LPG for uses such as continuous hot water in a large household; cooking and catering where high, instant heat control is required; or fuelling remote, energy-intensive businesses where the primary alternative would be diesel or coal generators.

LPG ASSOCIATION

LPG has lower carbon content per unit of energy than most other fossil fuels, and almost no particulates that damage air quality.

LPG is versatile and portable. It can be transported safely, which makes it a cost-effective energy source that is available in remote areas.

A review by consultants Worley (attached) states:

LPG is primarily used where the high burn temperature or mobility value is prized and providing this service with electricity is very expensive and often impractical. Substitution with biomass pellets and biofuels is possible, but will likely be limited by availability of supply, cost of transition, and concerns around poorer burn properties. The hurdles associated with indirect substitution suggest that the alternative of retaining the existing LPG infrastructure and sourcing substantial volumes of renewable LPG could be the most effective decarbonisation route.

RENEWABLE LPG

BioLPG is propane and butane produced from biological sources only. Renewable LPG is bioLPG and any LPG produced using renewable processes. Dimethyl-ether (DME) has similar chemical properties to propane and can be blended with LPG. Renewable DME produced from animal waste has a large negative carbon intensity. When blended with conventional LPG, renewable DME can reduce the net emissions of the mix to a level approaching zero.

Renewable LPG is already used internationally. Production of renewable LPG worldwide reached 450,000 tonnes in 2020.

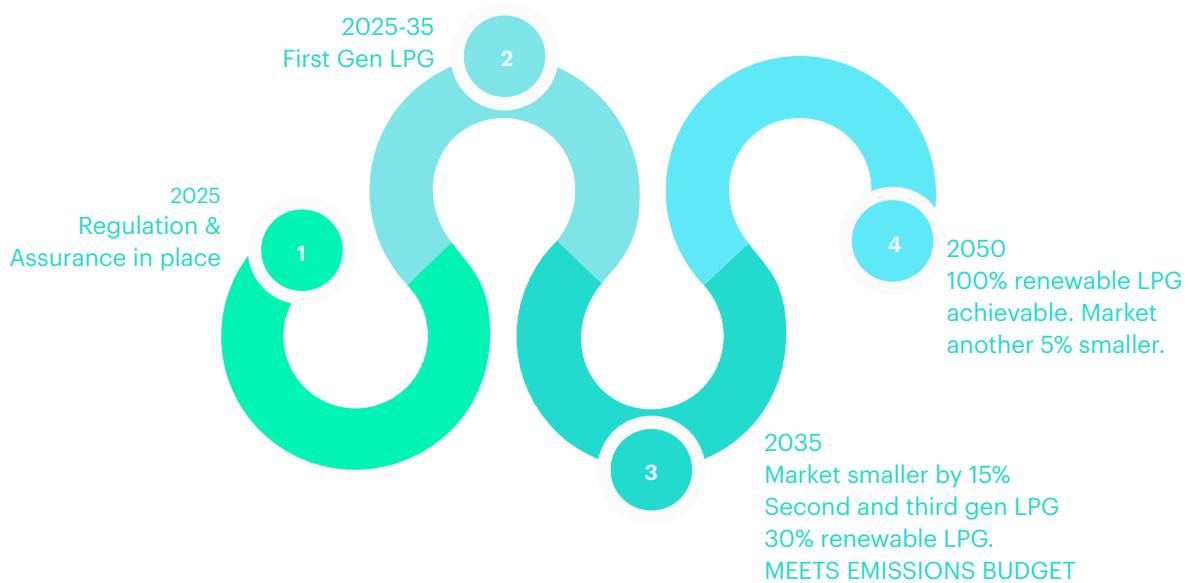
The most credible pathways to renewable LPG based on New Zealand feedstock availability and scalability of technology, are:

1st Generation	Fatty lipids ¹ to renewable LPG	3kt p.a.
2nd Generation	Mixed wastes to rDME and renewable LPG	9 kt p.a.
	Biogas to renewable DME	30kt p.a.
	Biogas to renewable LPG	40kt p.a.
3rd Generation	Softwood to biofuels	20kt p.a.

Worley calculated the likely size of the market in 2035 to be 15% less than the 2020 market of 185kt p.a., increasing to 20% less by 2050, due to improvements in energy efficiency and customer substitution to other energy sources.

¹ Examples of fatty lipids are tallow from meat waste, bio-crude and algae.

PATHWAY to 2050



Worley found 100% renewable LPG is achievable but introduces greater risk. The 70% target achieves the emissions budget modelled in the Draft Advice.

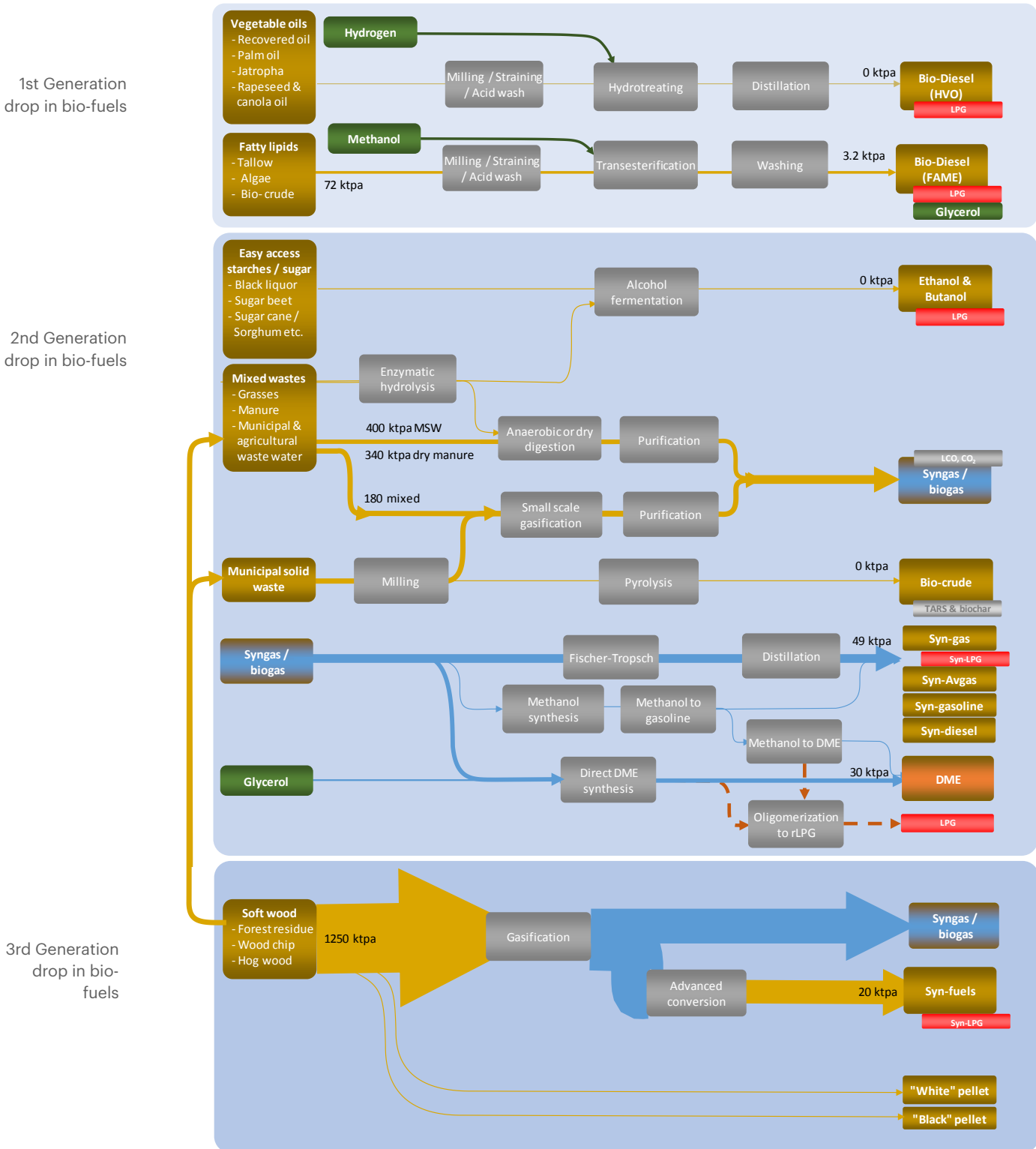
Modelling by Worley demonstrates that the emissions budget proposed in the Draft Advice can be achieved by replacing 70% of all LPG sourced with renewable LPG.

REGULATION, CERTIFICATION AND ASSURANCE

While the pathway to 100% renewable LPG is achievable it will require strong co-operation from industry and government to develop the technologies and market conditions to achieve it.

Gas Industry Company is already working on regulatory issues of emerging gases. It is equipped to be the regulatory authority for a transition to renewable gas. In our proposal, Gas Industry Company would use its co-regulatory model (working with industry) to ensure emissions from LPG fall below the forecast 'no new connections' emissions profile. This model is the lowest cost, and least disruptive method to transition the conventional industry.

70% Renewable LPG Scenario



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PART ONE

INTRODUCTION

We're working in good faith ...

The LPG industry is grateful for the opportunity to make this submission and for the Commission's invitation to engage with its advice about options to transition to a net carbon zero economy. The LPG sector has committed to the emissions budgets. Our submission is a genuine effort to manage the transition in the most effective way, with the least disruption, introducing opportunities for energy diversity and growth of the New Zealand economy.

We're already on it...

The LPG industry is already working to adopt existing renewable LPG technology from overseas into New Zealand.

Up to today, the major obstacle has been that, like other alternative fuels, there is a cost to adoption. Accelerated development and use of renewable LPG to meet emissions budgets is likely to cost more than conventional LPG, but it is preferable than exiting gas altogether, both economically and for practical convenience.

We're up for the challenge.

This submission puts forward a credible plan to make the transition to renewable LPG. The New Zealand LPG industry is not working alone on the transition, with Europe and the United Kingdom investing significantly in strategies to transition to renewable LPG. We have invested in a study by Worley to verify our plan and review the availability of feedstocks to create renewable LPG.

We are confident in our evidence and our case. We invite the Commission to engage with us on the emissions target for renewable LPG rather than a new connections ban.

GENERAL COMMENTS ON THE DRAFT ADVICE

1. Existing infrastructure is suitable for renewable LPG.

The Draft Advice approaches LPG in the same framework as natural gas. Although renewable pipeline gas may have advantages similar to those of renewable LPG, the user case for LPG is different.

The consultation document proposes to ban new connections to natural gas and LPG on the basis that, *“Assets and investments with long lifetimes will need to be transformed, and planning for and developing new low emissions infrastructure will take time.”* [Principle 1, Page 30].

However, existing LPG appliances and infrastructure (such as pipelines, tanks, cylinders and trucks) are suitable for renewable LPG.

If the ban on new connections led investment away from gas infrastructure, as the Draft Advice projects, then the uptake of renewables would be inhibited.

Consumers would either move away from gas altogether, or be less likely to switch to low carbon alternatives due to scarcity and price. Instead consumers would be likely to continue to use conventional LPG until the end of the life of existing appliances. Industry would be incentivised to supply that demand, instead of transitioning to renewable LPG.

Renewable LPG is chemically identical and suitable for existing equipment.

2. Diversity of policy instruments and multiple pathways to emissions reductions.

Replacing conventional LPG with renewable LPG begins to directly decarbonise the energy source from the date of introduction, and can eventually reach complete decarbonisation.

A ban on new LPG connections might not directly help to decarbonise—for example if it led to increased use of thermal electricity generation. Since conventional LPG would remain the best alternative for some uses, consumer pressure to keep emissions in the system would continue.

Introducing renewable LPG sustains a diversity of policy instruments and policy optionality, and thereby improves the potential resilience of the transition and the energy system.

Optimising the policy mix requires care to ensure instruments do not conflict. In particular, care is needed in the interaction with the Emissions Trading System to reduce emissions rather than just redistributing them across the economy.

If the proposal to ban new connections to LPG is implemented then the ETS may simply shuffle avoided emissions to another sector.

3. Maintain a vibrant industry.

Although renewable LPG technology is here today, new technologies are becoming available and are likely to be in use in the 2030s as LPG transitions to the emissions budget outlined in the Draft Advice. The relevant technologies are wider than the LPG industry. Renewable jet fuel and diesels are examples of LPG-adjacent fuels. The recovery and sale of LPG helps to make a transition of those fuels more viable.

Development will require the LPG industry to maintain investment and scale to sustain its commercial viability.

The risk from banning new LPG connections is that, at some point, the industry will lose the scale required to incentivise the transition to renewable LPG. The people, skills, knowledge and investment currently in conventional LPG are needed to transition the LPG industry into renewable energy.

By way of example, the loss of critical mass from the LPG-powered vehicle industry led to the loss of critical skills, to the point that the industry could not service even reduced demand.

The technology and opportunity to transition LPG to renewables is here today. It is far less likely to be available in the future if the existing industry has become sub-scale.

RENEWABLE LPG AND THE PATHWAY TO DECARBONISING

Renewable LPG and its pathway to decarbonising are studied in detail in the Worley report in Part Three.

Renewable LPG is chemically identical to conventional LPG so it can be used as a “drop in” fuel. That is, it can be used within existing distribution systems (bottles and pipelines) and appliances.

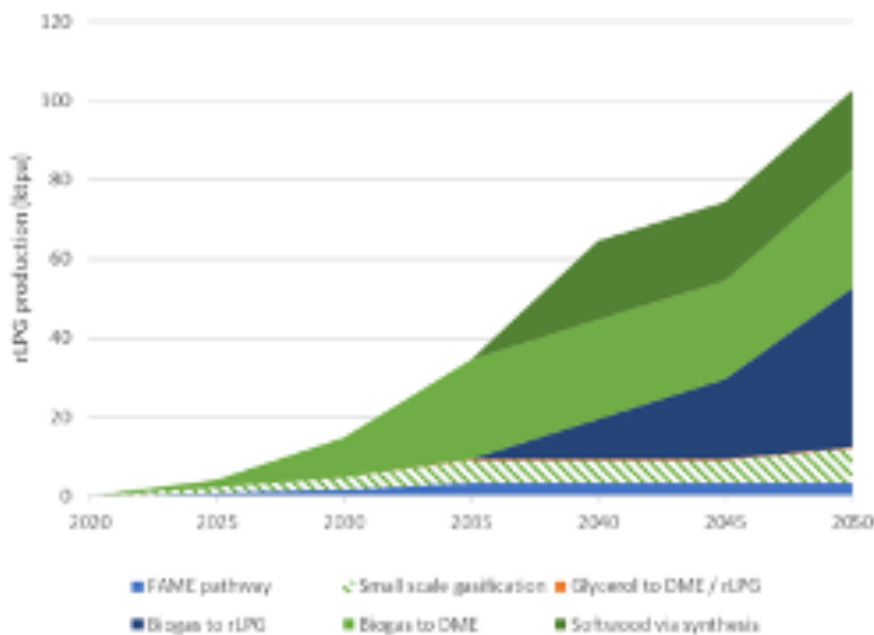
Worley investigated numerous pathways to renewable LPG and identified the most credible pathways for New Zealand based on feedstock availability and scalability of technology at commercial economics.

The most credible pathways to renewable LPG based on New Zealand feedstock availability and scalability of technology, are:

Generation	Technology	Output p.a. 000 tonnes
First	Fatty lipids (tallow from meat waste, bio-crude and algae) to renewable LPG	3
Second	Mixed wastes to renewable DME and renewable LPG	9
	Biogas to renewable DME	30
	Biogas to renewable LPG	40
Third	Softwood to biofuels	20

Worley calculated the likely size of the market in 2035 to be 15% less than the 2020 market of 185kt p.a., and 20% less by 2050, due to improvements in energy efficiency and customer substitution to other energy sources.

Modelling by Worley demonstrates that the 2050 emissions budget proposed in the Draft Advice can be achieved by replacing 70% of all LPG sourced with renewable LPG.



Renewable LPG buildup in the 70% renewable LPG scenario (Worley, p41).

As part of its investigation, Worley's also modelled the pathway to replacing 100% of LPG with renewable LPG. They found 100% renewable LPG is achievable but

introduces more risk than 70% renewable LPG. The 70% target achieves the emissions budget modelled in the draft advice.

Biofuel production trends witnessed in Europe and North American provide promise that the commercial pathways identified by Worley can be operating prior to 2035. Since renewable LPG is a natural co-product from these pathways, it has been possible to demonstrate that substitution of more than 30% of the current LPG market with renewable LPG by 2035 is realistic.

After 2035, increased production of renewable LPG will require commercial use of softwood and softwood residues.

Renewable LPG co-existing with conventional LPG

Worley's analysis examines a range of options for introducing renewable LPG.

At introduction, renewable DME would likely be blended with conventional LPG. The result is that the DME reduces the carbon intensity of conventional LPG.

This submission avoids going into detail about the best mechanism for achieving a steady introduction of renewable LPG. Options are set out in Worley's report.

The exact pathways are uncertain and the process will not be easy. However, the industry is confident it can achieve the outcome through collaboration between government and industry.

Existing industry arrangements and regulatory tools are well-suited to develop arrangements.

ABOUT LPG

New Zealand's LPG demand runs at 185,000 tonnes a year.

There are about 180,000 customer installations. LPG is used in residential homes and businesses all over New Zealand. In addition, 9kg cylinders are used for LPG cooktops, outdoor heating, catering, camping, caravans, barbecues and boating.²

LPG is an energy-rich fuel source with a higher calorific value per unit than other commonly used fuels, including electricity, coal, natural gas, diesel, petrol, fuel oils, and biomass-derived alcohols. This means that an LPG flame burns hotter.

² A small number of households use portable LPG heaters for home heating. About 7500 tonnes of LPG was sold in 9kg cylinders in four winter months (May-August) of 2020, down from 26,000 in 2006. Of the 2020 usage, about 3,500 tonnes, or 2% of the LPG market, is estimated to have been portable cabinet heaters. LPG Association does not support using portable LPG cabinet heaters for home heating. No part of this submission implies that LPG would continue to be used in domestic portable heaters.

LPG ASSOCIATION

It has lower carbon content per unit of energy than most other fossil fuels and almost no particulates that damage air quality.

LPG is versatile and portable and is able to be transported safely across the country, which makes it a cost-effective energy source, that is available in even the remotest areas.

LPG is high efficiency, so it is ideal for cooking and for space and water heating. Even where alternatives are possible, customers choose LPG for uses such as continuous hot water in a large household; cooking and catering where high, instant heat control is required; or fuelling remote or energy intensive businesses, where sufficient electricity would only be available from diesel-powered generators.

WHO USES LPG?



CASE STUDIES IN THIS SECTION ARE ALL REAL NEW ZEALANDERS. NAMES HAVE BEEN CHANGED.

At 3.8.2 *Buildings* the Draft Advice states it is already feasible to transition away from heating homes with gas.

Heat pumps already offer a lower cost way to heat homes than natural gas. For hot water, where feasible, electric resistive hot water cylinders offer an alternative to natural gas systems with comparable costs. Heat pumps will offer a lower cost option to heat most new commercial and public buildings. For existing buildings, renovations offer an opportunity to replace fossil fuel heating systems, such as gas central heating, with lower emissions alternatives such as heat pumps or biomass.

Ray and Ashleigh have a remote holiday home in Taupo. There is no electricity supply to the bay, where about 20 baches are located. All of them use LPG for cooking, water heating, refrigeration (and, in one case, lighting). A PV and battery solution would be far more expensive and would not likely be able to meet demand in winter.

The success of the transition depends on recognising the strengths of existing fuels. Only then can alternatives meet the needs consumers identify for themselves. Consumers use LPG because its particular qualities are suitable for their needs. If existing alternatives were 'feasible', offered 'a lower cost option' and 'an opportunity' then consumers would already be switching.

It is possible to favour decarbonisation, while also recognising the strengths of existing fuels. In order to propose an alternative, and a ban on new connections, it is important to understand the use case.



Steve runs a 5 star restaurant in Wellington. Gas is used for the hob, frier and grills. Electric induction replacements are available (except for the grillers), but the cost is high and the building would require a complete rewire to cater for the larger load. The business could not sustain this cost.

The Worley analysis in Part Three of this submission notes:

LPG is primarily used where the high burn temperature or mobility value is prized and providing this service with electricity is very expensive. Substitution with biomass pellets and biofuels is possible, but the cost of fuel and transition are likely to be substantially greater than retaining existing infrastructure and fuelling with renewable LPG.

Mark and Lisa's home is in Mount Eden, Auckland, on a back section up a driveway. It is heated with a gas-ducted heating system and gas continuous flow hot water powered by LPG. When they installed these appliances, they investigated electric options but the electrical load could not be sustained by the electricity supply from the street. A quote for a new supply cable was \$30,000.



Trish and Tim developed an apartment complex in Queenstown. Gas water heating and gas fireplaces were chosen for the reasonable cost, ambience and, for water heating, space saving. These installations could not be electrified without great cost as the plumbing infrastructure and space is not available within the buildings.



Caitlyn operates a vineyard and winery in Central Otago. To start the ferment of the later harvest Pinot Noir, the vats require heating. This is achieved by running warm water over the outside of the vats from a continuous flow LPG water heater. This very effectively transfers the heat and can be run continuously for a period of several days. The water heater has an input of 45kW. There is no practical electric solution to meet this requirement and the electricity supply could also not meet this load without significant upgrade.

A chocolate factory uses LPG water heater to warm vats of chocolate by immersion in water vats. Fast heating and the precise temperature control cannot be delivered by electric solutions.



Commercial hot water in hotels and apartments is commonly heated with LPG boilers because of the small foot-print and the availability of high density energy. Electric alternatives require substantial water storage, which in many cases will not be possible due to space and structural engineering constraints.

DISTRIBUTED ENERGY LOADS

The Draft Advice recognises that a constraint exists in electricity generation and transmission. Considerable investment will be required to build a renewable electricity network capable of supplying demand as carbon exits the energy system. Increased demand for electricity will be particularly pronounced as natural gas users transition.

Renewable LPG can help to reduce pressure on the electricity system.

Instead of conventional connections transitioning to electricity, the LPG market would transition to renewable LPG. Sunk capital costs would not need to be

written off. The requirement for new capital to distribute electricity would be reduced—all without increasing emissions compared to the Commission’s pathway.

Introducing renewable LPG not only decarbonises LPG, but avoids creating even further stress on a stretched electricity system at a time when considerable new capacity issues are likely to emerge as other sectors decarbonise.

The cost of bringing electricity to remote properties is prohibitive in many cases. PV and battery systems may be appropriate for high-end power requirements such as televisions, computers and lighting. Higher heating loads are much more cost effectively delivered through LPG so that the electrical power system can be an affordable size.

LPG AND CHANGES TO THE BUILDING CODE

The Draft Advice discussion of Building Code makes it clear that changes to the Code are likely. We expect that limits will be imposed on carbon emissions in proportion to floor area. As our user cases show, the elimination of LPG for many building designs would impose considerable costs. The amended standard requiring more energy efficient buildings will be more achievable if the fuel source de-carbonises. Renewable

Many apartments and townhouses have been designed over the last 20 years to use the small footprint of continuous flow gas hot water systems. These are generally installed externally and no allocation is made inside for the provision of a water cylinder.

LPG providing continuous hot water is likely to be more preferable for many home owners and commercial businesses than attempting to make space for an electric water heater. This change would make a transition of the Building Code more feasible, minimise the negative impacts on consumers and enable LPG users to continue to enjoy the advantages of LPG as a fuel.

PART TWO

ALTERNATIVE PROPOSAL

We recommend that the Commission revises policy recommendation 'Necessary Action 9(c.)' in the Draft Advice and replaces it with the following recommendation:

NECESSARY ACTION

- **Require the introduction of renewable LPG from 2025.**
- **Require the proportion of renewable LPG, as a percentage of total LPG supplied, to be sufficient to at least equal the reduction in emissions that would result if no new connections were permitted. This will mean at least 20% of the LPG market will be renewable by 2035 and at least 70% by 2050.**
- **Direct the Gas Industry Company to regulate renewable LPG, operate a certification scheme, monitor security of supply, and report publicly on the emissions profile.**

Worley estimates that this pathway meets the same Draft Advice emissions budget.

REGULATION, CERTIFICATION AND ASSURANCE

In our alternative, the certification methodology and emissions produced would be confirmed by the regulator in the lead up to 2025.

LPG Association has approached Gas Industry Company to ascertain that a 2025 deadline to introduce a regulation framework and identify targets is achievable and realistic. Work on setting up regulation could begin in the current financial year.

Gas Industry Company is identified in the Gas Act as the industry body that co-regulates gases in New Zealand, working with the industry to develop regulations that are recommended to the Minister of Energy for approval.

Gas Industry Company is already working on regulatory issues of emerging gases. It is equipped to be the regulatory authority for renewable gas and for the transition.

In our proposal, the Government Policy Statement would require Gas Industry Company to regulate LPG to ensure emissions fall below the forecast 'no new connections' emissions profile.

This model is the least cost, and least disruptive, method to transition the conventional industry.

Regulated introduction of renewables alongside conventional gas exists in other jurisdictions

Comparable regulation of the renewable content of fuel has existed in the United Kingdom since 2018.

The statutory instrument, the Renewable Transport Fuels and Greenhouse Gas Emissions Regulations 2018, can be reviewed here:

<https://www.legislation.gov.uk/uksi/2018/374/contents/made>

Those regulations impose a 'development fuels' obligation on suppliers, in which specified proportions of fuels must include low emissions content at levels that escalate each year to 2032.

New Zealand regulation of gas is less prescriptive, which makes for a lighter-weight, more flexible and efficient industry model. This model currently facilitates issues such as the specification and certification of gases entering distribution networks.

Therefore, regulations as prescriptive and detailed as the UK model are not required. Instead, the optimal pathway, and rules about blending, and substitution, would be developed in close consultation with the industry prior to 2025.

Government would retain control over the dates by which certain emissions reductions targets will need to be achieved.

EMISSIONS FROM ALTERNATIVE PROPOSAL

In its study, Worley reports:

We find that decarbonisation of LPG contribution to the heating sector can be achieved through 70% renewable LPG substitution.

In response to the Climate Change Commission's challenge to fully decarbonise the heating sector, the LPG Association has suggested a phased decarbonisation approach, aligned to the Commission's pathway analysis. The Worley study analyses the feedstock available to produce renewable LPG in that phased way. It anticipates

that, 'a healthy renewable LPG production industry will progressively evolve', although it will not match the decline in conventional LPG production.

Worley uses conservative interpretations of technology development and feedstock utilisation that 'is a realistic projection which can yield greater resilience and economic value than a ban on new connections.'

Of the scenario where LPG is 70% renewable, Worley comments:

The emissions reduction identified for this scenario was ~434 kt CO₂e and therefore exceeds the GHG emissions reduction target set by the CCC for the heating sector.

In summary:

The energy density and transportability of LPG/renewable LPG and cost-effective production make it an ideal energy carrier for the future.

The capacity to realistically achieve 70+% renewable LPG substitution with emissions reductions comparable or in excess of the CCC targets suggest that sustaining the current LPG delivery infrastructure and distribution mechanisms is likely to provide considerable benefit to New Zealand.

PART THREE - WORLEY STUDY

The Worley study, *Pathway to 70 / 100% renewable LPG*, is appended to this document.

PART FOUR

RESPONSE TO CONSULTATION QUESTIONS:

We comment only on those consultation questions, and subsections within questions, where our comment adds to the advice.

Consultation question 1

Principles to guide our advice

Do you support the principles we have used to guide our analysis? Is there anything we should change, and why?

Principle 1: Align with the 2050 targets. Aotearoa must adopt actions that set it on a path to meet the 2030 and 2050 emissions reduction targets, sustain those targets and set Aotearoa up for net negative emissions later, and contribute to the global effort to limit warming to 1.5°C. Meeting these targets requires a long-term view of investments and infrastructure developments. Assets and investments with long lifetimes will need to be transformed, and planning for and developing new low emissions infrastructure will take time. For these reasons, actions taken in the next five years will need to set Aotearoa up to deliver the deeper reductions required in subsequent emissions budgets and to meet and sustain the 2050 targets.

- We support the alignment with the 2050 targets.
- Current infrastructure assets can be adapted to carry renewable LPG.

Principle 3: Create options. There is much uncertainty in embarking on this decades-long transition. Uncertainty is not a reason for delay. There is value in creating options for meeting the targets and having the ability to adjust course as the transition proceeds. The decisions taken now should open up a wide range of future options and keep options open for as long as possible. This needs to be balanced with the need to take advantage of key windows of opportunity, where making significant investments in key technologies could ultimately make the transition to low emissions cheaper and faster.

- We support 'creating options for meeting the targets and having the ability to adjust course as the transition proceeds.' Introducing renewable LPG today maximises optionality.
- We believe an emissions target and mandate to introduce renewable LPG is a more effective policy approach. A ban on new connections would more likely produce an unfavourable environment to support transition to renewable LPG.

Principle 4: Avoid unnecessary cost. The actions Aotearoa takes to meet emissions budgets and targets should avoid unnecessary costs. This means using measures with lower costs and planning ahead so that technologies, assets and infrastructure can be replaced with low emissions choices on as natural a

cycle as possible. This will help to avoid scrapping assets before the end of their useful lives or being left with stranded assets

- We support avoiding unnecessary cost.
- Existing gas infrastructure can be utilised for renewable LPG today, as outlined in our submission. As renewable LPG is often a by-product of other chemical processes, it would increase the value and viability of interconnected energy sources.

Principle 6: Increase resilience to climate impacts. The actions Aotearoa takes to reduce emissions should avoid increasing the country's overall exposure to climate risks such as drought, flooding, forest fires and storms. Where possible, actions should increase the country's resilience to the impacts of climate change that are already being experienced and that will increase in the future.

- We support this Principle.
- Renewable LPG is a synthesised product created from a number of sources, such as oils, soft woods, and lipids. This provides resilience in the development of renewable LPG and also reduces over-dependence on electricity, especially when much of that electricity is generated from weather-related sources. Therefore, displacing as much energy use as possible to renewable LPG reduces stress on electricity and improves overall resilience.

Principle 7: Leverage co-benefits. The actions Aotearoa takes to meet emissions budgets and targets should consider the wider benefits, including benefits to health, broader wellbeing and the environment. Co-benefits can provide further reason to take particular actions where the initial emissions reductions may be modest or appear relatively costly.

- Renewable LPG is very low impact. There are no particulate emissions. It is a healthy choice for energy.

Consultation question 2

Emissions budget levels

Do you support budget recommendation 1? Is there anything we should change, and why?

- Yes, we believe that LPG can contribute to meeting this target. However, we recommend the policy advice should change to adoption of renewable LPG, supported by a regulated emissions target as proposed.

Consultation question 8

Central and local government working in partnership

Do you support enabling recommendation 4? Is there anything we should change, and why?

While we have no view on the substantive recommendation, we note that the Building Code proposals require heavy intervention by local authorities in connecting new buildings and renovations. We see other agencies as potentially better placed to wield regulatory tools.

For example, instead of further encumbering local authorities, the gas industry's self-regulatory model is proven. Applied to introduce renewable LPG it would be more likely to have an impact on national carbon emissions than local government inspections of renovations and new builds.

Consultation questions 10 & 11

Locking in net zero

Do you support our approach to focus on decarbonising sources of long-lived gas emissions where possible? Is there anything we should change?

Do you support our approach to focus on growing new native forests to create a long-lived source of carbon removals? Is there anything we should change, and why?

We support decarbonising sources of long-lived gas emissions wherever this is feasible.

Renewable LPG can contribute by displacing emissions from LPG. The study by Worley in our accompanying submission shows that 100% renewable LPG by 2050 is feasible. The Commission's emissions budget for LPG can be met with 70% renewable LPG.

However, it requires introduction of renewable LPG to be an alternative to banning new connections. A ban on new connections will inhibit uptake of renewable LPG, which would make the task of decarbonising significantly harder.

Consultation questions 12

Our path to meeting the budgets

Do you support the overall path that we have proposed to meet the first three budgets? Is there anything we should change, and why?

Low and medium temperature heat in industry and buildings could be decarbonised by 2050 through a switch away from coal, diesel and gas to electricity and biomass. Our analysis indicates that these costs could range up to \$250 per tonne CO₂e reduced but would be less than this where heat pumps or biomass can be used.

- See the costings by Worley in our accompanying submission.
- The Draft Advice is non-specific about LPG, appearing to conflate it with natural gas for some purposes, but not all.
- The Commission's emissions budget for LPG can be met with 70% renewable LPG.

Non-road transport: Electrification of rail and Biofuel blending

We do not have a response to this specific proposal but we note that if blending with conventional fuels is suitable for one sector, it is logically suitable for another. In our submission, renewable LPG blended with conventional in steadily greater proportions allows the emissions budget to be achieved. This alternative is supported by analysis from Worley.

Renewable LPG is a by-product of the bio-fuel process, and adds value to the bio-fuel creation process, which in turn increases the economic viability of bio-fuel.

[Buildings: No new gas heating systems installed after 2025 Improve thermal efficiency](#)
[Start phase out of gas in buildings](#)

See our accompanying submission.

We identify numerous user cases where phasing out gas is not practical or cost effective.

Examples include remote locations and buildings designed without a footprint for electric water heating.

Renewable LPG can help to meet user cases without the emissions downside of conventional LPG. LPG is often preferred by businesses that require industrial heating. A customer using renewable LPG for authentic gas fireplaces is likely to also use the product for cooking and hot water heating.

The LPG industry does not support the use of portable gas heating in homes, and has long been active in advocating for the removal of portable gas heaters.

[Industrial process heat: Replace coal with biomass and electricity](#) [Replace gas with biomass and electricity](#)

Renewable LPG should be included among the replacements selected, alongside biomass and electricity.

Our accompanying submission explains how this can be achieved.

3.8.2 Buildings

It is already feasible to transition away from heating homes with coal and natural gas. Heat pumps already offer a lower cost way to heat homes than natural gas. For hot water, where feasible, electric resistive hot water cylinders offer an alternative to natural gas systems with comparable costs. Heat pumps will offer a lower cost option to heat most new commercial and public buildings. For existing buildings, renovations offer an opportunity to replace fossil fuel heating systems, such as gas central heating, with lower emissions alternatives such as heat pumps or biomass.

This statement is not supported by reasoning in the Draft Advice. No modelling supports the statement.

LPG Association supports decarbonisation of fossil fuel heating systems. Renewable LPG is equivalent to bio-mass recommended in the Draft Advice. Our modelling shows renewable LPG is a viable alternative. It is chemically identical, and supports the existing use cases.

The success of the transition depends on recognising the strengths of existing fuels. Only then can alternatives meet the needs consumers identify for themselves.

Consumers use LPG because its particular qualities are suitable for their needs. If existing alternatives were 'feasible', offered 'a lower cost option' or 'an opportunity' then consumers would already be switching. See the real life user cases outlined from Page 14 of our accompanying submission under the Heading 'Who Uses LPG?'

It is possible to favour decarbonisation, while replicating the performance and adaptability of conventional fuels.

It is true that feasible alternative technologies exist, so the comparison should fairly recognise the costs and practicalities of alternatives as well as the decarbonisation benefits. In order to propose an alternative, and a ban on new connections, it is important to understand the use case.

The Worley analysis in Part Three of this submission notes:

LPG is primarily used where the high burn temperature or mobility value is prized and providing this service with electricity is very expensive. Substitution with biomass pellets and biofuels is possible, but the cost of fuel and transition are likely to be substantially greater than retaining existing infrastructure and fuelling with renewable LPG.

Fossil fuel heating systems will typically last for 20 years or longer. Our path looks to avoid new heating systems having to be scrapped before the end of their useful lives. This means that our path assumes all new space heating or hot water systems installed after 2025 in new buildings are either electric or biomass. For existing buildings, the phase out begins in 2030 (Figure 3.12). No further natural gas connections to the grid, or bottled LPG connections occur after 2025. This would allow time for a steady transition, to be on track for a complete transition away from using natural gas in buildings by 2050.

- We do not support this proposal.
- Replacement with renewable LPG achieves the same emissions reductions without the disruption. Consumers would not notice a difference because the renewable product is chemically identical.
- Our accompanying submission discusses this point in detail, and presents robust analysis of the merits of renewable LPG as an alternative to a ban.
- Renewable LPG is equivalent to bio-mass. Because renewable LPG is a by-product of bio-fuel processes, it increases the economic viability of those alternatives as well.

In our path, fuel switching to biomass also occurs in some other energy-intensive industries such as pulp and paper production.

Overall, our path takes advantage of the country's currently under-used biomass resource, moving towards a more circular economy. Achieving this uptake will require the development of supply chains for gathering and processing biomass along with the establishment of local markets.

- The scope of this recommendation should be widened to include uptake of renewable LPG. Renewable LPG does not require the establishment of new markets.
- Softwoods are a pathway to renewable LPG.
- If policy selection is careful, renewable gases will flow to their highest economic value. This may be energy intensive industries identified.
- However, the introduction of renewable LPG into existing conventional LPG networks is required to achieve maximum optionality.
- If new LPG connections are banned, renewable LPG might not be able to scale. Industrial use to replace fossil fuels, as envisaged in this section, would be unlikely to occur.

5.3.1 Electricity bills

Our analysis suggests that overall household electricity bills for heating, cooking and lighting are unlikely to increase as a result of our proposed emissions budgets. However, exactly how they could change is highly uncertain.

- We are sceptical of this claim. Our markets are mature and well understood by our businesses. Markets would already be supplied with renewable products if there were no impact on prices.
- For many uses, electrification is not economically feasible as a replacement for LPG. For example, rewiring and connecting remote locations, and redesigning buildings that do not have space for water storage, would all impose significant costs.
- Building new transmission and distribution capacity to replace LPG (and gas) with electricity will be capital intensive, and consumers ultimately will foot the bill. Re-use of existing assets to distribute renewable LPG is clearly more economic.
- The Draft Advice could helpfully provide further options if models changed with alternative assumptions and showed significant increases in household energy bills were likely.
- Models could engage specifically with the feasibility of introducing renewable LPG.

5.3.2

The transition away from natural gas may mean that, over time, many households would benefit from replacing gas appliances. This could happen as households naturally need to replace appliances and heating systems, reducing the cost to households.

As this advice appears to conflate LPG connections, we submit that the proposal (and the costs to consumers) would not be required if the option instead was to introduce renewable LPG.

Removing LPG would impose considerable cost on consumers who change in many cases. These costs can be mostly avoided, and emissions reductions achieved on the same pathway, by introducing renewable LPG.

Also 5.3.2

Portable gas heaters are still used by some households in Aotearoa. They are used proportionately more in the North Island, particularly in Gisborne and Northland. These heaters tend to be used by lower income households due to the low upfront cost and the ease of budgeting for heating bills. However, they contribute to mouldy homes and cause health problems. Although the number of these heaters is decreasing, replacing them with more efficient low emissions options will take continued government support.

Portable LPG heaters are not supported by the LPG Association and we support removal of them from household heating. LPG Association has long advocated the removal of portable LPG heaters.

5.5.3

However, there are a number of small businesses that currently rely on natural gas. For example, restaurants, cafes and bars often use natural gas for cooking. These businesses will need to move away from natural gas to lower emissions solutions. Our path described in chapter 3 assumes that businesses would replace natural gas appliances at the end of their natural lifetime. Avoiding replacing these appliances early avoids significant additional cost.

The best option for many businesses that currently rely on LPG is likely to be continued use of cylinder-supplied energy. This could be managed by requiring LPG suppliers to introduce renewable LPG.

Consultation question 14

Transport

Do you support the package of recommendations and actions for the transport sector? Is there anything we should change, and why?

Necessary action 4

Increase the use of low carbon fuels for trains, ships, heavy trucks and planes

We recommend that, in the first budget period the Government take the following steps to support the use of low carbon fuels for heavy vehicles such as trucks, planes, ships, and off-road vehicles to meet emissions budgets:

a. Set a target and introduce policies so that at least 140 million litres of low carbon liquid fuels are sold in Aotearoa by 31 December 2035.

b. Introduce low carbon fuel standards or mandates to increase demand for low carbon fuels, with specific consideration given to aviation.

c. Introduce incentives to establish low emissions fuel plants, such as biofuel sustainable aviation fuel, and make those fuels more competitive with traditional fossil fuels.

d. Place further emphasis on decarbonising the rail system, and establish an investment strategy and clear targets to increase the share of rail and coastal shipping.

Although we have no view on this recommendation as applied to transport, we note that renewable LPG is a viable by-product of renewable jet fuel and diesel. The recovery and sale of LPG from the process helps to make a transition of those transport fuels more viable.

Requiring the introduction of renewable LPG fits the same policy framework as 'introducing low carbon fuel mandates', and increases the viability of the proposed transport options, whereas banning new LPG connections achieves the opposite result.

Incentives could be a policy tool to encourage a broad range of pathways to renewable LPG and other low carbon energy sources.

Consultation question 15

Heat, industry and power sectors

Do you support the package of recommendations and actions for the heat, industry and power sectors? Is there anything we should change, and why?

There will be some nationally significant forks in the road as the energy system decarbonises, where choices will need to be made. For example, whether Aotearoa should keep its gas pipeline infrastructure long term as an option for low emissions gases, or whether a low emissions steel industry is critical for security of supply for the country's construction industry. Also, whether the skills of those who work in the oil and gas sector should be actively retained in Aotearoa for new low emissions industries. The country's current energy system is extensive, with a dedicated infrastructure and workforce behind it spread throughout the regions and the transition away from fossil fuels will need to be carefully managed in partnership with industry and communities (see time-critical necessary action 1 in chapter 5).

P 112 (emphasis added)

We support keeping infrastructure as an option for low emissions gases.

Existing LPG appliances and infrastructure (such as pipelines, tanks, cylinders and trucks) are suitable for renewable LPG.

If the ban on new connections led investment away from gas markets, then the uptake of renewables would be inhibited. Consumers would be less likely to switch to low carbon alternatives, and instead continue to use conventional LPG until the end of the life of existing appliances. Industry would be incentivised to supply that demand, instead of transitioning to renewable LPG.

Unnecessary capital costs would be incurred across the economy as customers transitioned to alternative energy, without achieving emissions gains.

Scale up provision of low emissions energy sources

Producing low emission fuels is important in meeting the 2050 target. Government support will be needed to increase the amount of clean energy Aotearoa can produce during the first emissions budget. This will ensure the emissions reductions required in later emissions budgets can be met.

Some activities, such as industrial processes that use high temperature heat, will be hard to electrify. Aotearoa will need a range of energy sources to support decarbonisation. Diverse energy sources will also be needed to maintain energy security.

Bioenergy and hydrogen both hold promise, but Aotearoa needs to understand how best to make use of their potential. Our analysis indicates that these fuels have significant potential for reducing emissions in transport, process heat and industrial processes. However, more work is needed to support establishing supply chains and infrastructure and making them more cost competitive.

To establish a bioeconomy, greater government coherence and coordination is needed. The Government needs to provide direction on the priority uses of bioenergy, to signal the optimal scale of a system, help overcome barriers, and to provide investment and procurement support.

P 115

We strongly support this Advice.

First generation renewable LPG is ready for introduction to the LPG market today, and analysis shows 100% renewable LPG is achievable before 2050 as second and third generation products enter they market.

LPG ASSOCIATION NZ

Pathway to 70 / 100% renewable LPG



26 March 2021

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Synopsis

This study explores the appropriate journey for decarbonisation of the New Zealand LPG sector, and demonstrates that maintaining existing LPG distribution assets and progressively displacing conventional LPG with renewable LPG can support growth of a biofuels industry whilst supporting jobs, fuel security and energy supply diversity.

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Pathway to 70 / 100% renewable LPG

Rev	Description	Originator	Reviewer	Worley Approver	Revision Date	Customer Approver	Approval Date
A	Initial draft	D. Stewart	R. de Vos		16 March 2021		
B	Draft update	D. Stewart	G. Hooper		19 March 2021		
C	Client comment	D. Stewart	G. Hooper	R. de Vos	24 March 2021		
0	Issued for use	D. Stewart	G. Hooper	R. de Vos	26 March 2021	A. de Geest	

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Executive summary

This study explores the opportunities for decarbonisation of the New Zealand LPG sector, and demonstrates that maintaining existing LPG distribution assets and progressively displacing conventional LPG with renewable LPG can support growth of a biofuels industry whilst supporting jobs, fuel security and energy supply diversity.

Liquefied Petroleum Gas (LPG) is a flexible, high density fuel that provides a range of commercial and residential heating services. This fuel is a by-product of domestic natural gas and light condensate production and is valued because it can be readily transported / stored and has much cleaner burn properties than solids and other liquid fuels. The most familiar form of this fuel are the 9 kg and 45 kg “LPG bottles” used in commercial kitchens, in homes for heating and cooking, and classic kiwi BBQs.

The journey to reduce the greenhouse gas footprint of New Zealand will naturally challenge the value of LPG services relative to the emissions that the combustion of conventional LPG (cLPG) yields. It is thus appropriate to consider alternative low carbon mechanisms for delivering LPG services. Electrification is unlikely to be a favoured substitution approach since LPG is primarily used where the high burn temperature or mobility value is prized and providing this service with electricity is very expensive and often impractical. Substitution with biomass pellets and biofuels is possible, but will likely be limited by availability of supply, cost of transition, and concerns around poorer burn properties. The hurdles associated with indirect substitution suggest that the alternative of retaining the existing LPG infrastructure and sourcing substantial volumes of renewable LPG (rLPG) could be the most effective decarbonisation route.

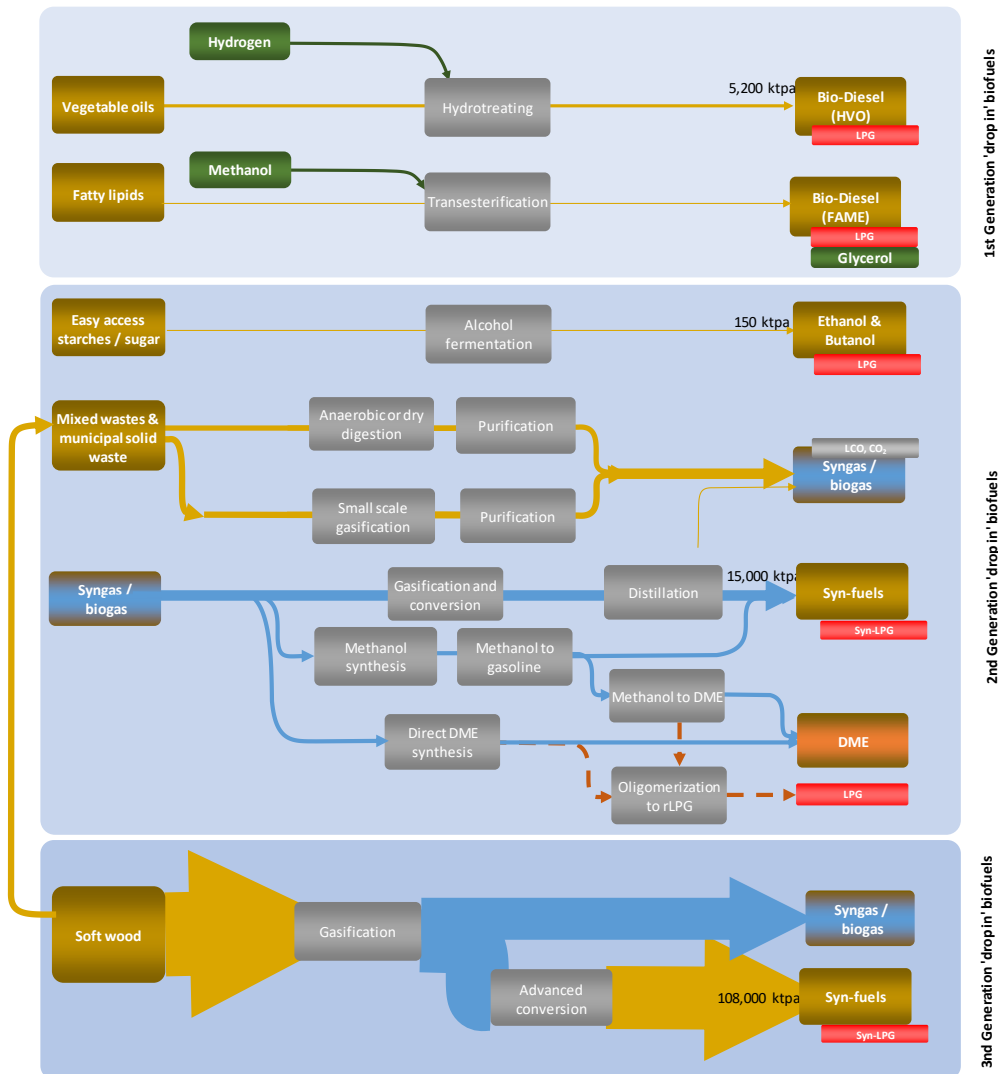
Renewable LPG is chemically identical to conventional LPG so it can be used as a “drop in” fuel i.e. it can be used within existing distribution systems (bottles and pipelines) and appliances. There are a number of different supply routes for rLPG which will be explored in this study, all of which have a much lower greenhouse gas footprint (some are strongly negative) than the cLPG counterpart. The ultimate source of energy for all the rLPG pathways is basically biomass derived or established waste streams, and the relative availability and cost of different sources of biomass will ultimately dictate the preferred routes to rLPG.

A huge range of rLPG production pathways have been distilled into three (3) generations of biofuel technology.

In this analysis we have distilled a huge range of biofuel / rLPG production pathways into four (4) groupings that represent comparable feedstocks and levels of technical / commercial maturity. These groups are characterised in Figure 1 and listed below:

1. 1st generation "drop-in" rLPG
2. 2nd generation "drop-in" rLPG
3. 3rd generation "drop-in" rLPG
4. "Blended" components

Figure 1 – Simplified Sankey diagram forecast of world LPG production in 2050



Renewable LPG (rLPG) is a natural co-product of first-generation biofuel (i.e. HVO/HEFA and FAME) pathways and is likely to be the source of the first tranche of rLPG. The production capacity from this pathway is limited by the availability of low-cost vegetable oils and animal fats that are needed for these pathways.

The biofuel production trends witnessed in Europe and North American provide promise that New Zealand will have a second generation of biofuel pathways based on recovery and utilisation of municipal and agricultural sector waste streams, successfully operating prior to 2035. For this tranche of technologies, dry digestion and gasification pathways will yield biogas precursors that can be oligomerised to yield either renewable dimethyl ether (rDME) or rLPG, both of which can be substituted into the LPG pool.

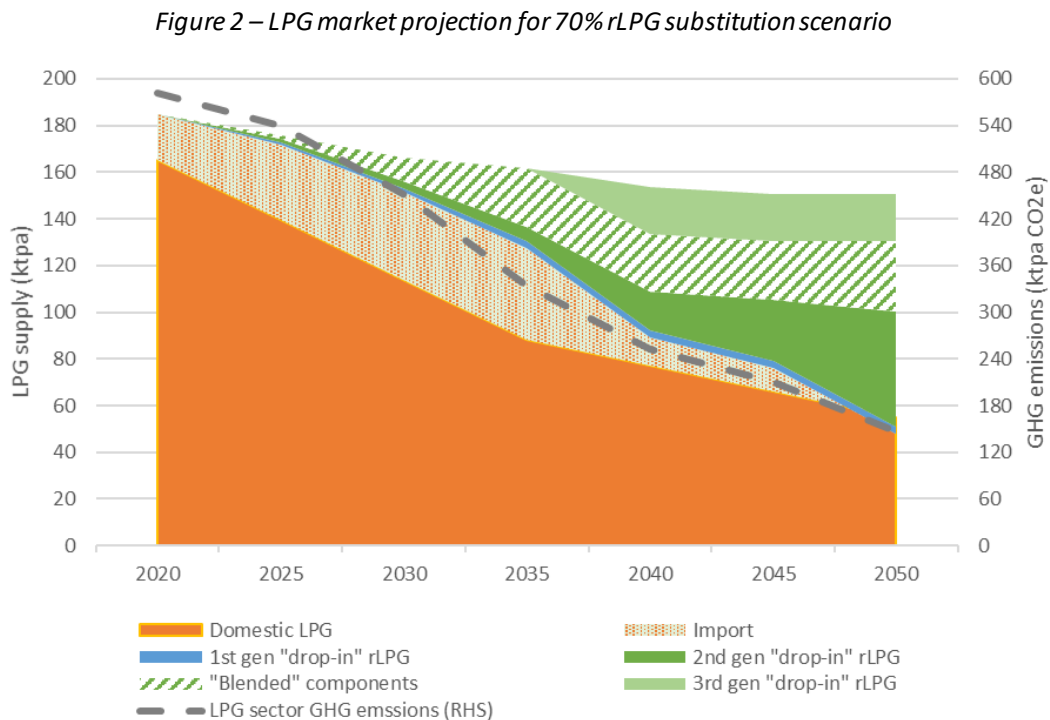
The exploitation of soft wood cellulosic to yield biofuels has been heavily researched yet is still considered to be a 3rd generation technology due to competitive use of feedstock and scale that is required to achieve a commercial outcome. New Zealand has comparative feedstock advantages that could drive the commercialisation of this pathway prior to 2050.

We find that decarbonisation of LPG contribution to heating sector can be achieved through 70% rLPG substitution.

In response to the Climate Change Commissions challenge to fully decarbonise the heating sector, the LPGA has suggested a phased decarbonisation approach, aligned to the Commission’s pathway analysis. This phased approach undertakes:

- Enabling actions prior to 2025;
- Leveraging 1st and 2nd generation biofuel / rLPG technologies, as well as substitution with “blended” components to achieve 30 ktpa LPG substitution between 2025 and 2035, and
- Leveraging 3rd generation biofuel / rLPG technologies to achieve 70% rLPG substitution prior to 2050.

The overall outcome is summarised in Figure 2 below. The Sankey diagram for this scenario can be found in Appendix C.



In this projection of the LPG sector, it is anticipated that New Zealand’s natural gas industry will continue to evolve and deliver conventional LPG up to and beyond 2050. To balance the decline in cLPG production, a healthy rLPG production industry will progressively evolve, with the following developments expected:

- Reinstatement of ZBioD at full capacity – yielding 1.6 ktpa rLPG before 2035;
- A further HVO or FAME plant adding a further 1.6 ktpa rLPG before 2035;
- Two mixed waste gasification to rLPG developments – yielding 6 ktpa rLPG before 2035;
- A further mixed waste gasification to rLPG developments – yielding 3 ktpa rLPG before 2050;
- Multiple wastewater / manure to rDME facilities yielding 25 ktpa LPG equivalent (as rDME) before 2035;
- Direct biogas to rLPG capability yielding 40 ktpa before 2050;
- One softwood to biofuels plants to add 20 ktpa rLPG capacity prior to 2050.

It is anticipated that rLPG production will not be able to match the decline in cLPG production, hence a proportion of the demand will be met through import of LPG / rLPG. Prior to 2035 it is assumed that majority of imports will be cLPG, but after 2035 rLPG will be imported.

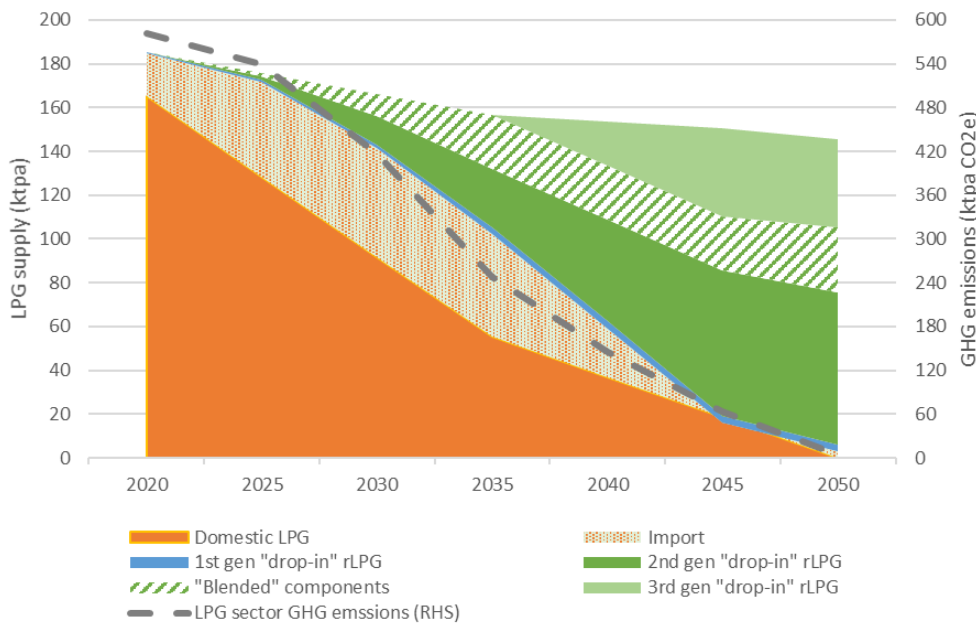
This production scenario is founded on conservative interpretations of technology development and feedstock utilisation. We believe that this is a realistic projection which can yield greater resilience and economic value than a ban on new connections.

The emissions reduction identified for this scenario was ~434 ktCO₂e and therefore exceeds the GHG emissions reduction target set by the CCC for the heating sector.

A more aspirational, 100% rLPG substitution scenario was characterised to reveal key challenges.

Some energy market analysts suggest that New Zealand’s natural gas production sector will collapse prior to 2050, with commensurate demise of cLPG production. We characterised a hypothetical LPG sector response to this outcome based on the same phased approach that was used for the 70% substitution scenario, but with acceleration of key production elements. The overall outcome is summarised in Figure 3 below.

Figure 3 – LPG market projection for 100% rLPG substitution scenario



In this projection of the LPG sector, it is anticipated that New Zealand’s natural gas industry will be sustained until 2035, but rapidly decline thereafter. To balance the decline in cLPG production, an rLPG production industry must aggressively evolve to fill the shortfall. The following developments above what would already be required by the 70% rLPG scenario are:

- An additional 20 ktpa rLPG via biogas conversion;
- A second softwood to biofuel plant yielding an additional 20 ktpa of rLPG.

The primary uncertainties associated with the 100% rLPG substitution scenario are tabled in Section 7.2, and mostly relate to:

- Inconsistency between demise of the natural gas sector, and benefits of biogas as a biomass energy delivery vector;
- rLPG market signals and prospective LPG price that is required to accelerate development.

The 100% rLPG pathway is technically plausible but faces numerous commercial challenges which will require considered messaging regarding the sustained operation of the natural gas / biogas industry.

rLPG provides a promising forward path.

This report has undertaken a holistic interpretation of the relationship between the decline of cLPG production and potential to substitute with renewable LPG. New Zealand certainly has the feedstock resources to take advantages of the technical advancements that are occurring in this area. The report identifies that rLPG (and blend components e.g. rDME) can be both co-products and targeted products of a burgeoning biofuels industry.

The energy density and transportability of LPG / rLPG and cost-effective production make it an ideal energy carrier for the future. The capacity to realistically achieve 70+% rLPG substitution with emissions reductions comparable or in excess of the CCC targets suggest that sustaining the current LPG delivery infrastructure and distribution mechanisms is likely to provide considerable benefit to New Zealand.

In order to sustain the promise of a rLPG supported economic growth requires continued engagement of the LPG industry with industry players who are prepared to support investment in biofuels (including biogas and rLPG) production facilities, and research groups that are enabling the advancement of new / novel production pathways.

1. Context

Conventional Liquified Petroleum Gas (termed cLPG in this report) is a flexible, high density fuel that provides niche energy services within New Zealand’s energy ecosystem. This fuel currently accounts for ~185 ktpa (~9 PJ/a) of energy demand. The combustion of cLPG like all fossil fuels contributes to climate change through the release of greenhouse gases. The combustion of LPG in New Zealand is considered to contribute nearly 560 ktCO_{2eq}/year.

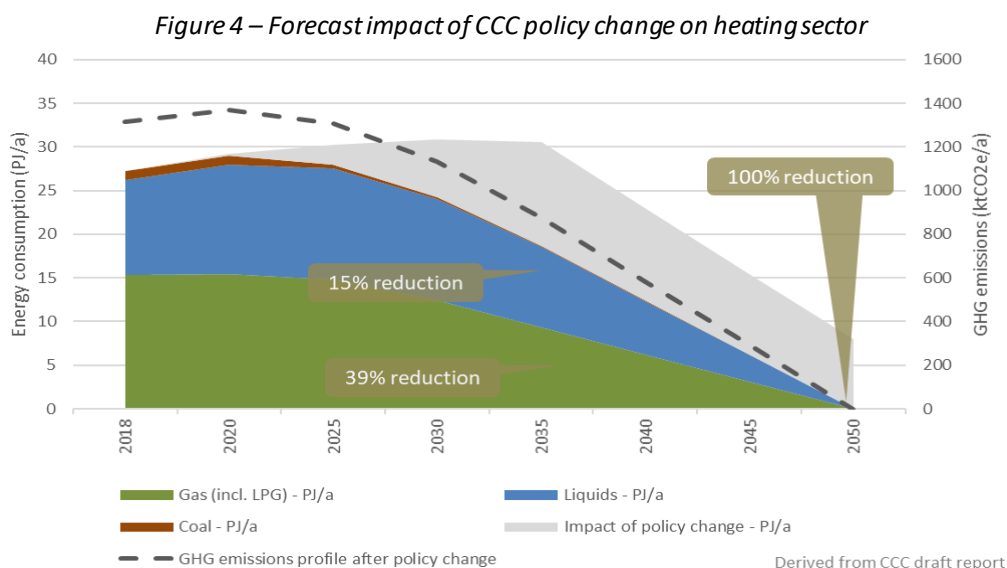
1.1 Accelerated decarbonisation policy

In late 2019, the New Zealand Climate Change Commission (CCC), formed as part of the Climate Change Response (Zero Carbon) Amendment Act 2019, was tasked with defining a pathway towards decarbonisation of the NZ economy by 2050. In their “Advice to Government” (31 Jan 2021 Draft) the CCC targeted the phase out of fossil fuel based heating systems in existing buildings prior to 2030. The implications for the current LPG industry were captured under necessary action 9c, namely:

“Setting a date by when no new natural gas connections are permitted, and where feasible, all new or replacement heating systems installed are [to be] electric or bioenergy [based]. This should be no later than 2025 and earlier if possible”.

The interpretation of this advice from the CCC is that there will be no new LPG or gas connections or new builds after 2025, followed by an active phase out of existing LPG and gas infrastructure post 2030. Based on the assumption that LPG and gas infrastructure has a lifespan of 20 years, it is inferred that there will be no LPG or gas consumption in buildings post 2050. In the view of the Commission, the phase out of LPG (& natural gas) should not add costs beyond normal asset lifecycle costs. Although these lifespans are suggested for residential infrastructure only, and not the distribution networks which are longer.

The energy consumption trend and greenhouse gas advantage of the proposed actions from the Commission is summarised below. The Climate Change Commission seeks to fully decarbonise the ~320 tCO_{2eq} attributed to current LPG use in the heating sector. It should be noted the LPG is considered to be part of the “liquids” stream.



The overall decarbonisation strategy nominated by the CCC, which is comparable to other international jurisdictions who are now setting strong decarbonisation strategies, involves high levels of electrification complimented by biofuel & hydrogen developments. The biofuels aspirations for New Zealand are captured under necessary action 4a, namely:

“Set a target and introduce polices so that at least 140 million litres [per year] of low carbon liquid fuels are sold in Aotearoa by 31 December 2035”.

This level of biofuel production represents less than 2% of current liquid fuel demand, but the concomitant quantity of C3/C4 by-products would yield nearly 3% of the current LPG demand.

Conventional LPG has an emission density (on HHV basis) of 62 ktCO_{2eq}/PJ¹, which is lower in contrast to diesel (70 ktCO_{2eq}/PJ), coal (90-106 ktCO_{2eq}/PJ depending on grade), and ethanol (~68 ktCO_{2eq}/PJ depending on feedstock)². Fugitive emissions of LPG do not contribute to global warming i.e. Global Warming Potential is 0³.

1.2 International LPG production trends

Renewable LPG production worldwide is predominantly a co-product of HVO/HEFA manufacture of sustainable aviation fuel. The World LPG Association⁴ estimates current renewable LPG production to be 460 ktpa⁵.

The demand for biofuels is immense however increasing production from the HVO/HEFA pathway is limited by the availability of low-cost vegetable oils. In Europe and North America, alternative (2nd generation) biofuel pathways are already emerging and there is high expectation that a third generation of biofuel pathways will emerge circa 2030 - 2040.

Key observations regarding the state of the world biofuel production include:

- The “easy access sugar fermentation” pathway is emerging now with several alcohol-to-jet/LPG facilities under construction / slated for development in the near term;
- Biogas production from mixed wastes is a mature market in Europe and parts of North America;
- Recovery of residue biomass and municipal waste for syngas and synthetic liquids are, after years of struggling to commercialise, finally gaining some traction;
- Technologies for upgrading biogas to rDME and BioLPG are reaching commercial maturity now
- Small refineries are looking to reconfigure operations to support either HVO processing or catalytic cracking of bio-oils and bio-pyrolysis oils;
- The carbon footprint of rLPG is significantly lower than cLPG, often lower than biodiesel and bioethanol and their fossil counterparts. Sometimes the emissions intensity of rLPG is lower than wood pellets, depending on the feedstock (wood residue or whole trees) and the method used to dry pellets.

¹ www.mfe.govt.nz/sites/default/files/media/Climate%20Change/voluntary-ghg-reporting-summary-tables-emissions-factors-2015.pdf

² www.epa.gov/sites/production/files/2015-07/documents/emission-factors_2014.pdf

³ <https://cip-glob-cdn.azureedge.net/-/media/sites/greatbritain/pdfs/atlanticconsultingscientificreviewcarbonfootprint2009.pdf>

⁴ www.wlpga.org

⁵ “BioLPG - The Renewable Future”, Atlantic Consulting, 2020 V2

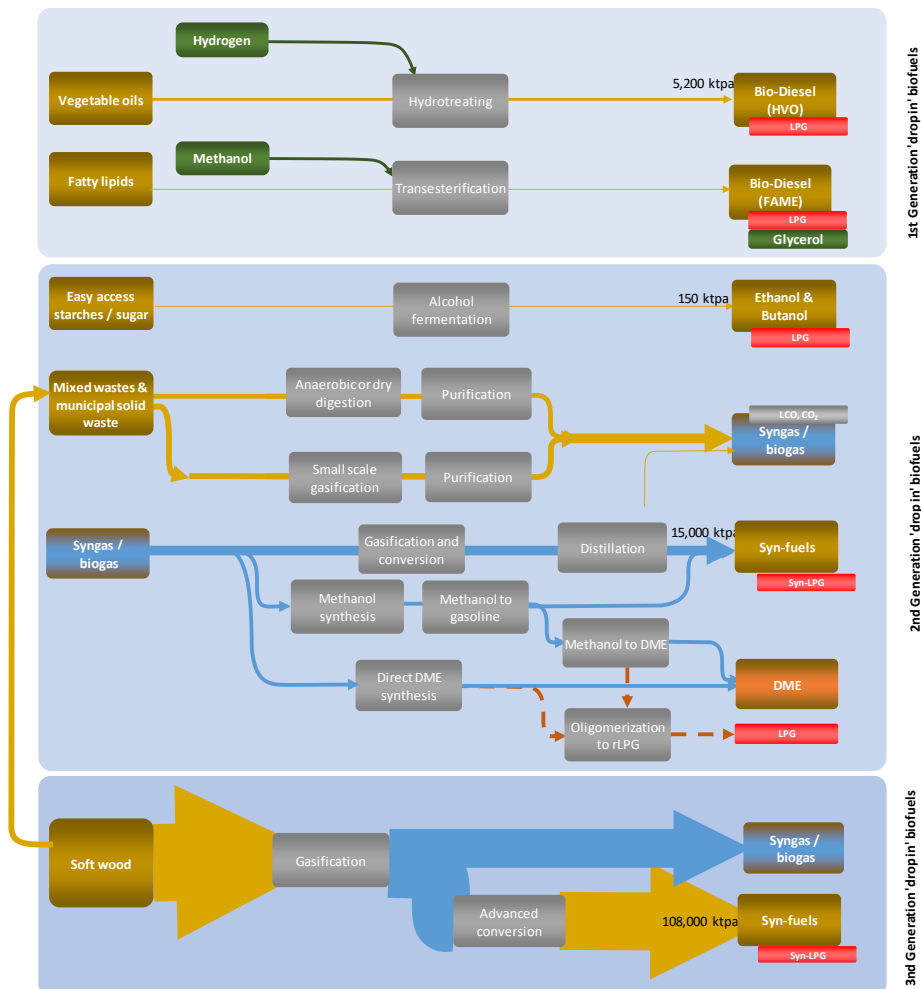
Whilst public sentiment for rLPG is strong, regulatory policy is weak with as yet no specific mandates at jurisdictional level; limited guidelines for benchmarking different supply routes / application, and regulatory gaps. In Europe these issues are being addressed and it is likely that these omissions will be rectified in the near to medium-term.

The World LPG Association production forecast for rLPG is summarised in tabular and simplified Sankey diagram formats below.

Table 1 - Forecast world LPG production profiles (ktpa)

Pathway	Technology wave	2020	2030	2050
Hydrotreated vegetable oils	Current	450	3,300	5,200
Easy access sugar fermentation	Emergent now	15	150	150
Mixed waste digestion + gasification	2 nd gen	0	15,000	15,000
Cellulosic / Softwood synfuels	3 rd gen	0	94,000	108,000
TOTAL		465	112,450	128,350

Figure 5 – Simplified Sankey diagram forecast of world LPG production in 2050



1.3 Decarbonising pathway

The LPGA have suggested a three (3) step pathway for decarbonising the LPG industry which follows the same time steps at the Climate Change Commission’s phasing – see Figure 6 below.

Figure 6 – Suggested LPG decarbonisation transition roadmap



The phased approach provides clear business targets and a framework for measuring progress.

The first step involves accessing easy wins in rLPG production, through facilitating reinstatement, modification and expansion of existing biofuel production assets which co-yield rLPG.

The second step introduces and incentivises well established global pathways that exploit existing waste and residue streams to yield rLPG and rDME. This phase leverages 1st and 2nd generation biofuel / rLPG technologies, as well as substitution with “blended” components.

The final step seeks to totally replace or offset cLPG by 2050. It is expected that this will leverage a significant New Zealand softwood to biofuels industry. This phase leverages 3rd generation biofuel / rLPG technologies.

1.4 Acceptance of dimethyl ether (DME) in New Zealand

It is widely understood that dimethyl ether (DME) is a competitive LPG substitute up to a 20% v/v blend limit.

DME is a methanol derivative, which is produced globally both for use as a fuel servicing automotive heating and small-scale power generation markets. World production of DME today stands at approximately 9,000 ktpa (5,600 ktpa LPG equivalent)⁶. China has actively pursued the production and use of methanol and DME as an automotive fuel, because it enables the utilisation of marginal / poor coal assets to contribute to economic resilience. The USA has advanced small scale developments of DME as a mechanism of contributing to the pool of liquid heating fuels.

As an automotive fuel, blends of up to 30% DME / 70% LPG, can be used to fuel diesel engines. Further, 100% DME can be consumed in a diesel engine with only modest modifications, and it is interesting to note that numerous manufacturers of heavy vehicles are building vehicles with DME as the preferred fuel. DME has a cetane rating between 55 – 60, which yields stable combustion characteristics and significant advantages from a clean air perspective.

As a heating fuel, DME is a flammable, thermally stable liquid like LPG and can be handled like LPG with similar safety guidelines and codes as cLPG. For domestic heating and similar services, the use of up to 20% DME / 80% LPG is acceptable with minimal (if any) modifications.

⁶ <https://aboutdme.org/FAQ#:~:text=World%20production%20of%20DME%20today,or%20through%20natural%20gas%20reforming.>

The use of 100% DME is common for small-scale power generation markets, since the supporting diesel gensets are easily modified to support this fuel.

New Zealand fuel specifications address ethanol and methanol blends with petrol, biodiesel and fatty acid methyl esters. LPG use in vehicles are addressed but with little comment on the associated specification. DME is neither an ester nor an alcohol and thus DME is not specifically allowed for. It could potential be treated as an LPG component but would limit opportunities. Ideally, this omission should be addressed to improve regulatory certainty.

1.5 Emissions intensity evaluation

The emissions intensity nominations for key biofuel production pathways assessed in this report have been assumed modest emission reductions from waste to biogas pathways in line with similar applications globally – generally IEA references. The emissions intensity for each pathway will be highly dependent upon which feedstocks are recovered, the point of ownership transition and value of offsets attributed to diversion of waste streams.

1.6 Acronym list

The following acronyms are used in this report.

Table 2 – List of acronyms

Acronym	Short descriptor	Long descriptor
Biogas	Biological methane	Methane produced not from fossil fuels
C3	Propane	Constituent of LPG
C4	Butane	Constituent of LPG
CCC	Climate change commission	An independent advisory body on climate change
cLPG	Liquified petroleum gases	Conventional / fossil LPG
CO ₂	Carbon dioxide	Greenhouse gas
DME	Dimethyl ether	Simple chemical - used as feedstock for production of other compounds
FAME	Fatty acid methyl esters	Category of feedstock used to produce biofuels
FT	Fischer - Tropsch	Process to convert gas mixtures into liquid hydrocarbon using a chemical catalyst
Gasification		Process to produce gas by heating (not burning) a substance
GHG	Greenhouse gas	Gas which contributes to heating of the atmosphere.
HHV	Higher heating value	Energy released upon combustion of a product
HVO	Hydrogenated vegetable oil	Feedstock for many existing biofuels products
LPGA	LPG association	NZ association representing LPG producers and users
Pyrolysis		Process to decompose a substance, usually organic, via heating
rLPG	Renewable LPG	LPG made via renewable / low GHG emission process
synLPG	Synthetic LPG	LPG made via synthetic gas processes

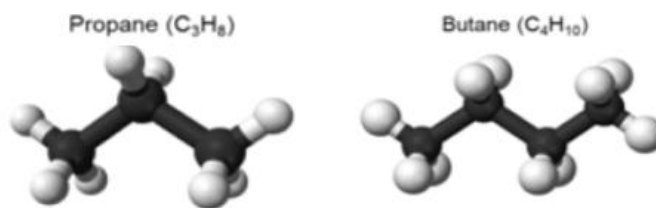
2. Fossil LPG and substitutes

Liquefied petroleum gas (LPG) describes hydrocarbon mixtures in which the main components are propane (C₃), butane (nC₄), isobutane (iC₄), propene and butenes. Most commonly this term is applied to mixtures of propane and butane- see Figure 7. In the New Zealand market, the propane to butane ratios are typically 55:45, with minimal olefin volume. The vast majority (>99%) is used in the heating sector, with <1% used as autogas.

Conventional (or fossil) LPG is a by-product of domestic natural gas and light condensate production and is valued because it can be readily transported / stored and has much cleaner burn properties than solids and liquid fuels.

The most familiar form of this fuel is “LPG bottles” used in commercial kitchens and home BBQs. For simplicity, and to minimise risk of confusion, in this report we term conventional LPG as cLPG.

Figure 7 – Chemical structure of key LPG components⁷

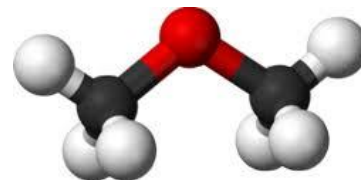


In New Zealand the ratio of C₃/C₄ varies depending on source and production ratios, although variation year to year can be >15%, the average higher heating value remains ~49 MJ/kg and emissions density is 62 ktCO_{2eq}/PJ.

Although renewable LPG (termed rLPG in this report) is not a conventional / internationally recognised naming convention, we have chosen to use this term to cover a broad range of low carbon LPG production pathways where naming conventions have not yet firmed. Some examples of the products that are potentially covered under this term include:

- BioLPG – LPG component that have been sourced from ‘biological’ material;
- SynLPG - LPG components that have been sourced from a gasification pathway (which generally has biomass as feedstock);
- eLPG – LPG components that have been sourced from combination of green hydrogen and carbon neutral carbon dioxide (e.g. direct air capture);
- Dimethyl-ether (DME) – A product of methanol dehydration which has chemical properties that allow blending up to 30% v/v in LPG without significant change in LPG blend properties – see Figure 8.

Figure 8 - Chemical structure of DME (CH₃OCH₃)



⁷ Source: Thompson, Robertson and Johnson, 2011

When we consider the nature of the energy service (or “duty”) that cLPG provides, there are a number of energy carriers / fuel categories that provide the highly valued cLPG service. We consider three classes of energy carriers / fuels, namely:

1. “Drop-in” fuels – As the name implies these fuels can be added to existing LPG infrastructure at any concentration or physical condition, for example bioLPG and synLPG.
2. “Blend-in” components - These fuels can be added to existing LPG infrastructure within confined blend concentrations or physical conditions, for example rDME and butylene.
3. Indirect substitutes - These fuels can replace existing LPG services but will require new delivery infrastructure / end-use appliances in order to provide an equivalent service. Electrification and use of wood pellets are examples of indirect substitutes.

The technical, commercial and GHG abatement potential for rLPG as a drop in fuel and blend-in components are considered in the following chapters.

2.1 LPG market niche

LPG is primarily used where the high burn temperature or mobility value is prized and where providing this service with electricity is very expensive. The most familiar form of this fuel is “LPG bottles”, which are used in commercial kitchens, homes for cooking and heating, and BBQs.

The reticulation of LPG via a pipeline network in Christchurch, Dunedin, Queenstown and Wanaka represents the value of LPG in communities where high-grade, clean heat is desired and natural gas is not readily available. This infrastructure provides highly reliable (and diversified) energy services to these communities.

In this Section we describe some of the most common uses of LPG and provide some context to illustrate why indirect substitution of this fuel is challenging.

2.1.1 Commercial and home kitchens

The high flame temperature and quick heating associated with LPG burners make it a preferred fuel for high stress commercial kitchen environments and domestic households nationwide.

Electric induction cooking can work as quickly as LPG / gas burners, but the electrical infrastructure required to support large electric induction unit is considerably more expensive than an LPG / natural gas based commercial kitchen. Further certain styles of cooking are not feasible with electricity based cooking e.g. wok-based cooking. Electric cooking is not resilient in the same way that LPG is, if the power goes off for any reason then food cannot be cooked. As LPG is stored in bottles / or a network, it has higher availability during adverse weather conditions.

Figure 9 - Commercial kitchen



Biogas is an acceptable substitute for most cooking applications. However, this substitution approach is only viable where a natural gas reticulation network exists – this covers a majority of population centres in the North Island, but none in the South Island.

Biomass pellets are a potential substitute; however, this substitution approach is not without significant conversion costs. The burners would be much less responsive than the LPG service and the poorer combustion characteristics of biomass pellets with low air recirculation raises GHG and indoor air quality concerns due to particulates released.

2.1.2 Space heating

Figure 10 - Cosy gas fire



Buildings with poor thermal efficiency rapidly lose the low-grade heat provided by electrical heat pump systems. Also, heat pumps don't provide the instant heating that a point source of heating like a fireplace does. Finally, heat pumps are not as resilient as LPG burners since any loss of electricity results in a loss of heating.

Biomass pellets are the most suitable substitute. They require a specific biomass pellet installation so are not without cost, however they produce heat in a similar manner to LPG / gas fires. Biomass is similarly resilient to LPG, as it is storable at the home, and is independent of external utilities. Recent air quality concerns in Christchurch has seen an increase in LPG fires to replace wood burners.

Biogas is a suitable substitute for LPG, but only in areas where natural gas reticulation systems exist.

2.1.3 Hot water heating

Up to 50% of the energy requirements of domestic homes relate to the heating of hot water. LPG and natural gas both provide instantaneous water heating services. These systems tend to be very efficient and cost effective because there are no losses associated with standing water cylinders.

Solar thermal and heat pump driven hot water systems can provide water heating services with comparable cost and lower greenhouse gas emissions. If time of use management tools are applied to the heat pump based systems, these can also provide grid balancing services.

Biomass fired water heating systems are viable, but are limited by sourcing limitations, higher labour / intervention and burn quality concerns.

2.1.4 Barbeques / portable cooking

Figure 11 - Classic NZ BBQ



Everyone loves a BBQ/ portable cooking – be it in the backyard, on a camping trip, in a caravan/ motor home, or on a boat. For all of these situations, the most practical fuel is LPG.

The implication of the CCC proposal is that by reducing demand for LPG, the costs associated with these BBQs / portable cooking appliances will likely rise.

Electrification is not a realistic replacement for LPG BBQs or portable cooking appliances. It is not practical to transport batteries of size

such that they can replace the energy from an LPG bottle.

Biomass pellets are a potential substitute, do often have lower energy density and burner devices are less compact, hence are inherently less portable.

2.1.5 Industrial heating

Some industrial heating demands require high temperature heating that cannot be easily substituted via electrification or biomass based solutions.

A preliminary review of industrial LPG uses in New Zealand did not identify any services where the LPG service could not be indirectly substituted – subject to the challenges identified by other LPG end-uses above.

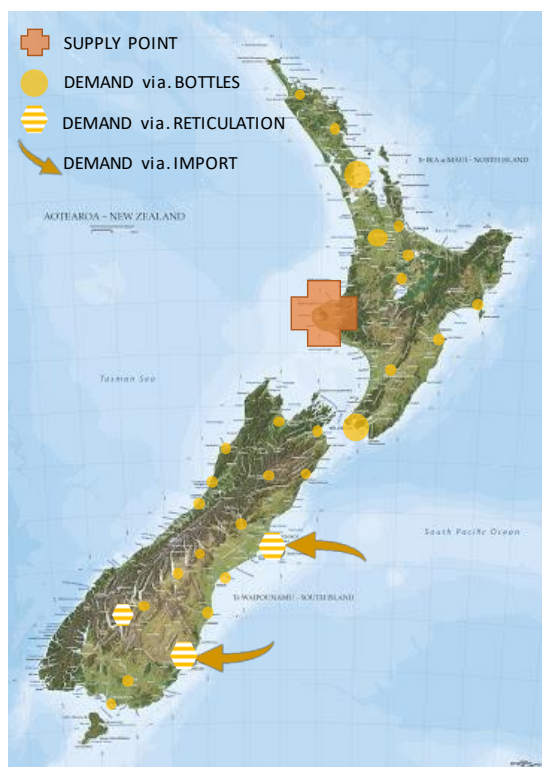
2.1.6 Autogas

Autogas currently makes up a very small portion of New Zealand LPG demand, however it has historically made up a significant portion of vehicles in the national fleet. The resilience provided by locally produced LPG and CNG during the 1970s oil crisis helped New Zealand continue to survive economically. At its peak gaseous fuels contributed as much as 11% of New Zealand’s petrol demand, predominantly for light vehicles. We assume that autogas will be phased out entirely in the next few years.

2.2 LPG market size trend

The New Zealand LPG market size has progressively grown in step with the growth on the domestic natural gas and light condensate industry. The source of domestic LPG is the Taranaki region, with South Island demand being met by shipping from the North Island or imports – see Figure 12.

Figure 12 – Illustrative demand-supply profile



The current market is characterised by:

Table 3 – Current LPG market parameters (based on 2020)

Parameter	Demand	GHG emissions
Annual domestic production	165 ktpa	
Domestic demand	95 ktpa North Island; 90 ktpa South Island (35 ktpa is reticulated) 185 ktpa total (20 ktpa is imported) 9.4 PJ/a	560 ktCO ₂ e/y
Indicative number of customer installations	178,000 excluding BBQs, camping and mobile	
Indicative industrial volume	56 ktpa	170 ktCO ₂ e/y
Indicative commercial volume	38 ktpa;	115 ktCO ₂ e/y
Indicative residential volume	70 ktpa	210 ktCO ₂ e/y
Indicative portable volume	21 ktpa	65 ktCO ₂ e/y

The drive to decarbonise is likely to substitute some LPG services to electricity, biogas or biomass pellets. LPG demand shrinkage is forecast to be as much as 50%⁸ in Europe but is expected to be less significant in New Zealand due to more limited natural gas substitution potential, forecast population growth (Europe assumes flat population growth), and a much smaller portion of LPG demand from the autogas market to be offset by electrification.

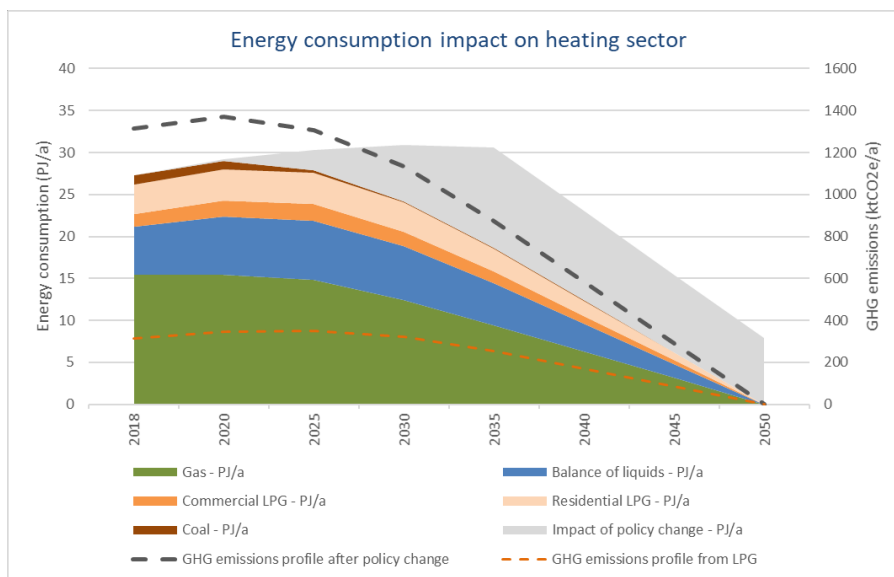
For this study we assume a 15% market shrinkage to 2035, with a further reduction to 20% by 2050, giving a demand forecast of 157 ktpa in 2035 and 148 ktpa by 2050.

We note that the CCC plan for natural gas energy end-use demand in 2035 is 52 PJ/a, which is 38.5% of the current end-use demand of 135 PJ/a (i.e. 180 PJ/a production – 45 PJ/a non-energy uses). If it was assumed that the future LPG yield from natural gas production is comparable to current yields, the domestic production of cLPG in 2035 is expected to be 63.5 ktpa (i.e. 38.5% of 165 ktpa) in 2035 and 40 ktpa in 2050. In reality, very little LPG is sourced from Pohokura, which is the dominant gas source and most like facility to reduce production, hence domestic cLPG production is likely to remain proportionately higher than this. We forecast domestic cLPG production of 90 ktpa in 2035 and 55 ktpa in 2050.

2.3 GHG emission reduction target

In Section 3.8.2 of the CCC Advice to Government (31 Jan 2021 Draft), it is recommended that “no further ... bottled LPG connections occur after 2025”. Based on the supporting energy demand profiles associated with the Commission’s “our policy” setting, we have interpreted the break-out of commercial LPG and residential LPG end-use energy and greenhouse footprint trends implied by the “our policy” framework – see Figure 13, which is derived from CCC and MBIE data⁹. The Climate Change Commission seeks to fully decarbonise the ~320 tCO_{2e}q attributed to current LPG use in the heating sector.

Figure 13 - Forecast impact of CCC policy change on heating sector



⁸ “BIOLPG A renewable pathway towards 2050”- Liquid Gas Europe

⁹ <https://www.mbie.govt.nz/building-and-energy/energy-and-natural-resources/energy-statistics-and-modelling/energy-statistics/oil-statistics/>

2.4 Potential role of rDME

An important use of rDME is as a blend stock for LPG. At blending levels below 20 vol %, the existing LPG blending facilities, local distribution infrastructure and end-use equipment can be used with minimal (if any) modifications.

DME / rDME is a flammable, thermally stable liquid like LPG and can be handled like LPG with similar safety guidelines and codes as LPG. Tables 4 & 5 below set out key physical properties of DME compared with specific conventional fuels. DME / rDME has a higher mass density than LPG but lower energy density, hence it takes ~1.6 kg of DME / rDME to provide the equivalent heating service (LHV) as a kilogram of LPG. The classic 9 kg bottle would weigh 1.4 kg more and carry 97% of the energy that a 100% cLPG bottle would.

In Section 6.1.2 we suggest that the GHG emissions intensity of rDME would likely be around 10 - 12 ktCO_{2eq}/PJ, hence a 20% DME/80% cLPG blend, has a ~3% lower heating capacity but has ~17% lower GHG intensity.

Table 4 - Key physical properties of DME and specific hydrocarbon fuels

Property	Propane	Methanol	DME	Diesel oil	Methane
Boiling Point (°C)	-42	64.6	-25.1	180-360	-161.5
Vapor Pressure @ 20 °C, bar	8.4	-	5.1	-	-
Liquid Density @ 20 °C, gm/cm ³	0.509	0.79	0.67	0.84	-
Sp. Gravity of gas (vs. Air)	1.52	-	1.69	-	0.55
Flammability Limits in Air, vol.%	2.1-0.4	5.5-36	3.4-17	0.6-7.5	5-15
Wobbe Index, kJ/m ³	69,560 ^a	-	46,198	-	48,530
Cetane Number	5	5	55-60	40-55	0
Calorific value, LHV, Kcal/kg	11,100	4800	6900	10,200	12,000
Calorific value, LHV, Kcal/nm ³	21,800	-	14,200	-	8600

^a Typical LPG.

Table 5 - DME /LPG blend properties

Parameter	Unit	DME	LPG	20 vol% DME / 80 vol% LPG
Mass density	kg/m ³	667	540	565.4
Heating value (LHV)	MJ/kg	28.8	46	42.6
Mass per bottle unit vol.	kg/m ³	567	432	459
Energy per bottle unit vol.	GJ/m ³	16.3	19.9	19.2

3. First generation “drop in” rLPG

Renewable LPG produced as a by-product of first generation biofuel production is considered to be a “drop in” replacement for conventional LPG. The fuel could be integrated directly into the current supply and distribution pathways and would not require any change of end-use appliances.

The two (2) production pathways considered in this chapter are:

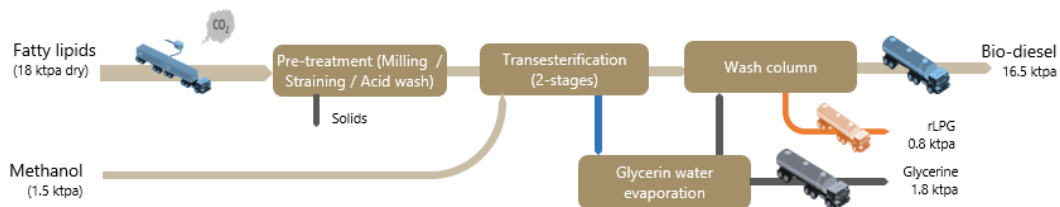
1. Transesterification of fatty lipids (FAME) pathway;
2. Hydrotreated vegetable oil pathway.

3.1 Transesterification of fatty lipids (FAME) pathway

The conversion of fatty lipids to biodiesel (FAME) pathway involves a comparatively simple transesterification process. The cost effectiveness of this 1st generation biofuel technology is constrained primarily by the cost and access to feedstock. The biodiesel yielded by this route is generally of high quality but requires care with management due to potential fuel instability and cold-temperature performance.

The primary feed for the pathway is fatty lipids, with glycerol being a key co-product. The typical minimum commercial scale is 50 tpd (~18 ktpa on a dry mass basis) with overview flow scheme summarised below. Fatty lipids are comprised of animal fats and vegetable oils

Figure 14 - Transesterification of fatty lipids summary flow schematic (50 tpd plant)



LPG production from FAME facilities will vary depending on both process conditions and the feedstock mix, but 5 -10% of the product slate is regularly identified.

ZBIOD plant

Z Energy built a fatty lipid to bio-diesel plant in Wiri, Auckland in 2016 for a nominal \$26 million investment. The facility has a bio-diesel capacity of 20 million L/y (16 ktpa or 0.76 PJ/y) using tallow as feedstock. This is 0.5% of New Zealand’s current diesel demand.

The plant feed rate is ~50 ton/day.

Based on an expected 5% side yield, the potential renewable LPG yield is 0.8 ktpa.

Z state that double production is easily achievable for the plant given feedstock availability.



3.1.1 Potential scale

The biomass feedstock associated with this pathway is fatty lipids. The volume of fatty lipid feedstock in New Zealand is very limited, as summarised below:

- Non-edible tallow - Tallow is a triglyceride fat produced as an abattoir by-product at plants throughout New Zealand. The NZ Bioenergy Association estimates that there is some 150 ktpa of tallow produced in New Zealand, with some 120 to 130 ktpa exported - principally for use in animal foods and chemicals manufacture¹⁰.
- Recovered waste cooking oil - The Bioenergy association estimates that 5-7 ktpa cooking oil is available.

These two resources together can be used for the manufacture of around of approximately 120 ktpa of fatty acid methyl esters (biodiesel) and some 12 ktpa of glycerol.

3.1.2 Timing and decarbonisation value

New Zealand experience with FAME biodiesel manufacture is quite variable; due in part to a lack of consistency over the years in government policy regarding industry support. Whilst there has been a number of small-scale facilities producing biodiesel from waste cooking oil, the industry in NZ remains at a nascent state. Z Energy has built a 20 million L/y plant in Wiri Auckland utilising tallow as feedstock, but that plant is currently mothballed. Subject to ongoing tallow supply and plant performance challenges, but there is potential for that plant to be re-established and expanded to ~40 million L/y, subject to confirmation of feedstock supply¹¹.

By 2025 it would be expected that the Wiri plant would have been restarted and by 2030 another plant of similar scale would have been built.

The FAME pathway is in principle commercial now, and benefits from first mover advantage. Consequently, consistent with international trends, it is expected that this technology will advance in the near term (i.e. next decade), rather than later term.

The carbon footprint reduction associated with the FAME process is expected to be at least 60% less than conventional LPG. The majority of this footprint is associated with feedstock production and transport.

3.2 Hydrotreated vegetable oil pathway

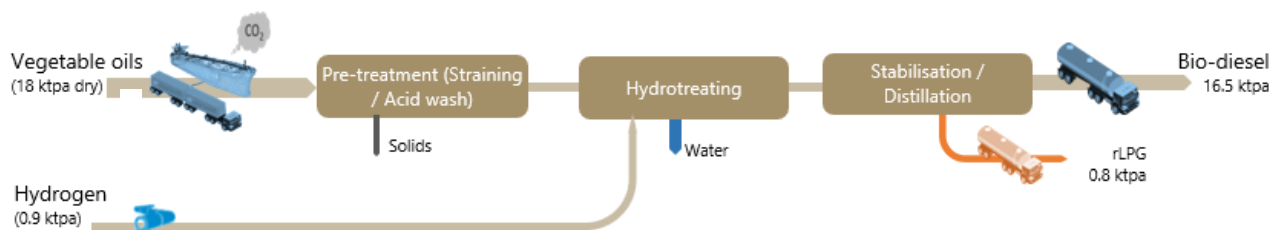
The conversion of vegetable oils to biodiesel (HVO) pathway involves a comparatively simple but capital intensive hydrotreating. This 1st generation biofuels technology is the preferred commercial pathway worldwide. This technology yields high-quality bio-based diesel fuels without compromising fuel logistics, engines, exhaust aftertreatment devices, or exhaust emissions^[4]. In particular it avoids the instability and cold-temperature performance concerns that can be associated with FAME-derived products.

The primary feed for the pathway is vegetable oil with a secondary feed of hydrogen. The typical minimum commercial scale is 50 tpd (~18 ktpa on a dry mass basis) with the overview flow scheme as summarised below.

¹⁰ https://www.liquidbiofuels.org.nz/documents/resource/WLB01_LiquidBiofuels-biodiesel-bioethanol-sources-details.pdf

¹¹ <https://z.co.nz/assets/Biodiesel/Z-biodiesel-plant.pdf>

Figure 15 - Vegetable oil hydrotreating summary flow schematic (50 tpd plant)



Chemically hydrotreated vegetable oils (HVOs) are mixtures of paraffinic hydrocarbons. The cold properties of HVO can be adjusted to meet the local requirements by adjusting the severity of the process or by additional catalytic processing. LPG production from HVO facilities will vary depending on both process conditions and the feedstock mix, but 5 -10% of the product slate is regularly identified.

Regionally the largest operation of this type is at the Neste's Singapore refinery – 3 million ton per year. The operation started operation in 2010 and produces exclusively renewable products based on its NEXTBL process¹². At the end of 2018, Neste made an investment decision of €1.4 billion to expand¹³ capacity to 4.5 million ton per year in 2023.

3.2.1 Potential scale

The biomass feedstock associated with this pathway are vegetable oils. The volume of vegetable oil feedstock in New Zealand is very limited, as summarised below:

- Waste oil – The Bioenergy association estimates that nearly 5 - 7 ktpa waste cooking oil is available out of an approximated national total of 30 ktpa.^{14 15} Much of what exists is already allocated to existing industries such as cement and asphalt manufacture, greenhouse heating, dust suppression. Distribution and availability broadly follows population centres, a government scheme to recover and reuse waste oil (i.e. ROSE) has been in place since 2011¹⁶.
- Rapeseed industry – New Zealand currently produces around 15 ktpa of rapeseed in the South Island, the majority of which is sold as edible oil¹⁷. Diverting this oil from export to biofuel production will require a long-term diesel pump price close to \$2 per litre to be a financially sustainable.
- Additional oil seed cropping to support biofuel industry growth is highly unlikely.

Hydrogen is a secondary feed to this process. It is assumed that green hydrogen production can be achieved relatively easily anywhere in New Zealand. Costs are still uncertain, but it is likely that cost will be high in the near term unless capital and energy input costs are supported by Government.

As noted, the hydrogenation process is capital intensive and benefits from scale. It is unlikely that New Zealand can domestically source enough vegetable oil feedstocks to justify a development of this nature.

¹² <https://www.neste.com/about-neste/innovation/nexbt1-technology>

¹³ <https://www.neste.com/releases-and-news/neste-hosts-foundation-stone-ceremony-singapore-expansion>

¹⁴ <https://www.wasteminz.org.nz/wp-content/uploads/Greg-Slaughter.pdf>

¹⁵ https://www.liquidbiofuels.org.nz/documents/resource/WLB01_Liquid Biofuels-biodiesel-bioethanol-sources-details.pdf

¹⁶ <https://www.beehive.govt.nz/release/used-oil-recycling-programme-extended>

¹⁷ <https://www.stuff.co.nz/business/farming/99097913/former-biodiesel-plant-now-makes-culinary-oil>

If Refining NZ were to undertake a reconfiguration in operation structure, it is possible that HVO bio-diesel production was possible using imported feedstock or bio-oil.

3.2.2 Timing and decarbonisation value

The movement towards decarbonisation, rise of electric vehicles and commercial pressures are impacting smaller refineries worldwide. It is therefore consistent with international trends to assume that a refinery reconfiguration would occur in the near term (i.e. next decade if economics allow), rather than in the later term. Should RefiningNZ decide to move to a simple import terminal operation as has been suggested, then it is unlikely that any refining capacity will remain in this country over the longer term.

Johnson in a paper published in 2017¹⁸ shows that HVO biopropane's footprint varies considerably, by feedstock and production scenario but essentially the product qualifies for government support under the biofuel mandates enacted by EU member states. He reports an HVO footprint from imported feedstock of around 40 ktCO₂/PJ (i.e. 35% reduction in emissions intensity).

The majority of this footprint is in the harvest and transport of the feedstock, which will likely be in a different jurisdiction, hence the NZ GHG footprint could be an order or magnitude lower than cLPG.

¹⁸ E Johnson, A carbon footprint of HVO biopropane, *Biofuels, Bioprod. Bioref.* Wiley Online Library (wileyonlinelibrary.com); DOI: 10.1002/bbb.1796; 11:887–896 (2017)

4. 2nd generation “drop in” rLPG pathways

The second generation of biofuel production is expected to use a variety of conversion pathways to capture smaller volumes of “mixed” feedstocks to yield “drop in” replacements for conventional LPG. The fuel could be integrated directly into the current supply and distribution pathways and would not require any change of end-use appliances.

The production pathways that we considered in this chapter are:

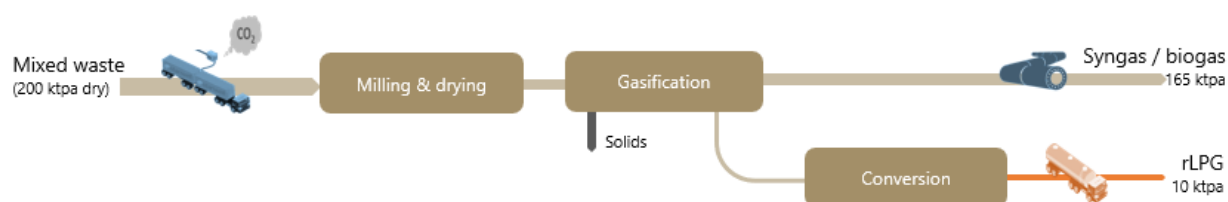
1. Small scale gasification and conversion;
2. Lignocellulosic fermentation;
3. Syngas fermentation;
4. Sugar fermentation.

4.1 Small scale gasification and conversion

The technology and processes for converting municipal solid waste (MSW) into low-carbon transportation fuels via thermochemical process routes is well understood with a number of developments world-wide aimed at commercial demonstration. These plants provide another pathway that might have application in the more population dense areas¹⁹. The common route of all small scale thermochemical pathways is gasification (or ionisation) to syngas, which is then further converted to yield either: methane, methanol, liquids via MTG process, or liquids via Fischer-Tropsch process.

The typical minimum commercial scale for MSW gasification plants is ~200 ktpa (dry), but the minimum commercial scale for the subsequent syngas upgrading system is trending towards 10 ktpa (dry). An overview flow scheme is summarised below.

Figure 16 – Small scale gasification and conversion pathway flow schematic (200 ktpa feed / 10 ktpa rLPG plant)



Below are brief descriptions of three projects that represent potential viable routes, once fully proven.

4.1.1 Fulcrum Bioenergy

Fulcrum Bioenergy Sierra BioFuels Plant located in Storey County, Nevada, approximately 20 miles east of Reno. Once completed, Sierra is expected to process approximately 175 ktpa of MSW feedstock annually, creating 11 million gallons per year of renewable synthetic crude oil, or “syncrude,” that will be processed by Marathon Petroleum into transportation fuel²⁰.

¹⁹ Eric Johnson, *Process Technologies and Projects for BioLPG*, *Energies* 2019, 12, 250; doi:10.3390/en12020250

²⁰ <https://fulcrum-bioenergy.com/technology/our-feedstock/>

4.1.2 Advanced Biofuel Solutions

Advanced Biofuel Solutions has secured funding of £10 million to restart construction of a waste-to-gas facility in Swindon. The facility uses a multi-stage conversion process to convert MSW into bio-substitute natural gas (Bio-SNG). The facility is intended to convert 8 ktpa of waste into 22 GWh of pipeline gas each year^{21,22}. The Advanced Biofuel Solutions process²¹ involves: Gasification; syngas clean-up; water shift to methane; CO₂ recovery; and natural gas grid injection.

4.1.3 Red Rock biofuel

The Red Rock biofuel technology platform converts waste woody biomass into low-carbon, renewable jet (SAF – sustainable aviation fuel) and diesel fuels²³. The Red Rock process involves: Gasification; syngas clean-up; Fischer-Tropsch refining and hydro-processing. The Lake view project proposed to convert approximately 166,000 dry tons of waste woody biomass into 16.1 million gallons/year of low-carbon, ASTM-approved renewable jet and diesel fuels. rLPG production is estimated at approximately 8% of the final product slate²⁴.

4.1.4 Potential scale

The primary feedstock associated with this pathway is municipal solid waste stream. The volume of this feedstock in New Zealand is moderate:

- Municipal solid waste (MSW) – In the order of 3,300 ktpa across the country, which follows population density. This accounts for Class 1 landfills which are those which accept all waste from all sources including food waste. It is estimated that these landfills account for approximately 30% of total NZ net waste landfilled²⁵. This MSW will produce around 5 PJ of landfill gas, or it can be processed to produce biogas providing in the order of 7 PJ of biogas.
 - Refuse derived fuel (RDF) is a product recovered from separation of high energy materials from recycled waste streams. After mild processing, this stream often has a consistent energy / moisture profile and is easily transported as a solid fuel.
- Food scraps – A portion of MSW is food waste. Across NZ this food waste is estimated in the order of 330 ktpa. The yield of biogas from food scraps can be up to 5× that of blended MSW.

Other feedstocks that can feed this pathway are crop residues, wastewater, and manure:

- Straw / stover – are the crop remnants left in the field after harvesting. It is treated as a residue of the arable crop from which it was grown and is often burned prior to replanting. It is estimated that around 950 ktpa of straw / stover is present across New Zealand²⁶.

²¹ <https://www.letsrecycle.com/news/latest-news/waste-to-gas-plant-revived-after-administration/>

²² Advanced Biofuels, : <https://absl.tech/about-us>

²³ <https://www.redrockbio.com/technology/>

²⁴ Arno de Klerk, Fischer-Tropsch Refining, Thesis, Department of Chemical Engineering, University of Pretoria, February 2008

²⁵ “Waste Levy Extension Estimates of extending and raising levy” NZIER report to Ministry for the Environment November 2019

²⁶ [130614 Cover page + blank.pdf \(far.org.nz\)](#)

- Crop waste – the crops which are simply not recovered after harvesting and wasted. They are estimated at around 500 ktpa²⁷.
- Municipal wastewater estimated at 470 million m³/year – with 18 larger wastewater treatments plants (supplied by over 35,000 people) making up 80% of this volume²⁸.
- Dairy wastewater estimated at 60 million m³/year.²⁹
- Abattoir wastewater estimated at 20 million m³/year.³⁰
- Easily accessible and recoverable agriculture manure is estimated at 600 ktpa.³¹

If 1 PJ/y of biogas was converted to rLPG (refer to Section 6.4), then rLPG yields from this pathway would be ~18.5 ktpa.

4.1.5 Timing and decarbonisation value

Biofuel production trends associated with small scale gasification and conversion witnessed in Europe and North American provide promise that New Zealand will have several commercial pathways licensed and deployed prior to 2035. Population growth and continued technology evolution will likely yield continued upscaling of biogas to rLPG towards 2050.

The GHG footprint of biogas derived from MSW and RDF depend on the current disposal path and waste collection efficiency (i.e. fuel consumed by waste management trucks). If the waste is currently managed to yield landfill gas, then the GHG footprint of resulting rLPG from biogas will reflect the impact of ~10 - 20% conversion efficiency and will likely be 30 - 40 ktCO_{2eq}/PJ.

If the waste is currently not being managed (i.e. biodegrades to methane), then the GHG footprint of resulting rLPG from biogas will reflect the recovery and diversion of methane and will yield a negative GHG intensity between -100 and -80 ktCO_{2eq}/PJ.

4.2 Lignocellulosic fermentation

Lignocellulosic fermentation is a multi-step process where lignocellulosic biomass is pre-treated and then hydrolysed in order to convert the carbohydrate polymers, cellulose and hemicellulose, to monomeric sugars, which are fermented to produce ethanol. Scion and others have undertaken considerable work in this area to interpret New Zealand's potential for using this pathway.^{32,33}

²⁷ NZ Biomass Resource Atlas, Vol. 1 | Use Wood Fuel - a Bioenergy Association site

²⁸ https://www.lei.co.nz/images/custom/lrc-2016-cass_lowe-160205-.pdf

²⁹ B. Cox 'TNGB14 – sources of biogas feedstock'

³⁰ B. Cox 'TNGB14 – sources of biogas feedstock'

³¹ B. Cox 'TNGB14 – sources of biogas feedstock'

³² Scott-Kerr C et al, Bioethanol – status report on bioethanol production from wood and other lignocellulosic feedstocks” on line from: <https://www.osti.gov/etdeweb/servlets/purl/21390241>

³³ Scott-Kerr C et al, Bioethanol – status report on bioethanol production from wood and other lignocellulosic feedstocks” on line from: <https://www.osti.gov/etdeweb/servlets/purl/21390241>

It has been predicted that lignocellulosic fermentation will eventually replace first generation fermentation technologies for bioethanol production³⁴, however the unmanageable nature of lignin (which typically makes up 10% – 25% of volume and 25 – 35% of energy) fermentation remains.

To allow fermentation of the carbohydrate fraction of this resource, lignin must be separated from cellulose and hemicellulose polymers via a complex and costly pre-treatment process so that these polymers may be broken down into fermentable sugars by enzymatic hydrolysis. Methods used for pre-treatment include physical treatments such as milling and irradiation as well as chemical treatments such as the use of oxidising agents and strong acids.

4.2.1 Potential scale

The biomass feedstock associated with this pathway are easily accessible cellulose, such as straw or crop wastes. Softwoods are unlikely to be a commercial option in any future supply scenario, except for speciality chemicals or bioplastics.

- Straw / stover – are the crop remnants left in the field after harvesting. It is treated as a residue of the arable crop from which it was grown and is often burned prior to replanting. It is estimated that around 950 ktpa of straw / stover is present across New Zealand³⁵.
- Crop waste – the crops which are simply not recovered after harvesting and wasted. They are estimated at around 500 ktpa³⁶.

These two resources together could be used for the manufacture of around of approximately 100 ktpa of rLPG.

4.2.2 Timing and decarbonisation value

Whilst New Zealand has relevant experience in fermentation, it is deemed an unlikely route for rLPG production because of the lack of feedstock and the more easily deployed and commercial alternative route to biogas via dry digestion of crop waste. However, there are commercial plants already in operation globally whose design can easily be licensed, should an economic opportunity arise.

4.3 Syngas fermentation

Syngas fermentation also offers an alternative route to methanol from biomass, but it is largely at a developmental stage.³⁷ A potential advantage over traditional thermochemical conversion routes is that the derived biofuels include; hydrogen, ethanol, butanol, acetic acid and butyric acid. Worldwide there is significant ongoing research and development with the literature suggesting some five demonstration or semi-commercial plants either operating or planned.

Known commercial syngas fermentation plants include Indian River (INEO) and Lighthouse in Pennsylvania (Coskata). LanzaTech (formerly Range Fuels) has operated a waste gas fermentation demonstration plant at

³⁴ Gnansounou, E.; Dauriat, A. Techno-economic analysis of lignocellulosic ethanol: A review. *Bioresour. Technol.* 2010, 101, 4980–4991.

³⁵ [130614 Cover page + blank.pdf \(far.org.nz\)](#)

³⁶ [NZ Biomass Resource Atlas, Vol. 1 | Use Wood Fuel - a Bioenergy Association site](#)

³⁷ Daniell J., *et al* Commercial Biomass Syngas Fermentation, *Energies* 2012, 5, 5372-5417 ; doi :10.3390/en5125372

Bluescope Steel in New Zealand and is reported to have developed two additional demonstration plants in partnership with Baosteel and Capital Steel in China. The current status of these plants is unknown. In recent news the US biofuels company, Aemetis, was reported as proposing a woody biomass gasification plant in India to produce ethanol via Lanzatech's microbial fermentation technology. To date, no investment decision has been made.

Meanwhile Lanzatech continues moving forward on scale-up of sustainable aviation fuels in US and Japan³⁸. Commercialization of this process has been years in the making, but essentially remains unproven.

4.4 Sugar fermentation

Fermentation of sugars to ethanol is a first generation biotechnology, but sustained enterprise in the waste to alcohol pathway has led to the development of 2nd generation biotechnology that yields liquids such as isobutene and butanols. Many of the resulting products can be blended with conventional LPG and potentially contribute to the decarbonisation of the heating sector.

An interesting recent development by the French company, Global Bioenergies, converts sucrose into isobutene using genetically engineered microorganisms³⁹. The process has been operating at demonstration plant level, capable of producing 0.15 ktpa of final product, with a commercial-scale facility in France expected to be commissioned in 2022. This project is currently at the planning stage and is reported to produce up to 50 ktpa of isobutene. We understand that consideration is also been given to entering the LPG market, by demonstrating the feasibility of blending isobutene into domestic bottled gas (LPG) as well as its compatibility with the logistics chain and domestic appliances⁴⁰.

4.4.1 Potential scale

The volume of "easy access sugars" that are available for this pathway are very low in New Zealand:

- Sugar beet – nominal amounts produced for stock feed. Assume nil available
- Sugar cane & sorghum – nominal amounts produced for niche edible products. Assume nil available.

We consider that the commercial development of sugar crops for fuel is highly unlikely for New Zealand

4.4.2 Timing and decarbonisation value

The GHG footprint of biofuels derived from sugar fermentation are generally low and likely between 10 – 15 ktCO_{2eq}/PJ.

³⁸ <https://www.greencarcongress.com/2019/11/201091121-lanzatech.html>

³⁹ <https://www.global-bioenergies.com/group/isobutene-process/?lang=en>

⁴⁰ LPG Association NZ, personal communication.

5. 3rd generation “drop in” rLPG pathways

New Zealand’s most abundant biomass resource is softwood and woody residues. These resources are readily available with secure and reliable supply chains, which would enable biofuel facilities to benefit from economies of scale. The majority of softwood resources are destined for export markets and hence command a premium price. Woody residue and comparatively stranded softwood supplies are available and may contribute to biofuel production and decarbonisation.

The selection of preferred processing pathways for this feedstock is generally not feedstock dependent, rather about conversion process efficiency and the technology risk management.

The production pathways that we considered in this chapter are:

1. Softwood to biofuels via conventional synthesis;
2. Softwood to biofuels via advanced synthesis;
3. Softwood to biofuels via pyrolysis.

5.1 Softwood to biofuels via conventional synthesis

Two pathways involving gasification (to syngas) followed by conversion to partially oxygenated liquid hydrocarbon products are well proven and established, namely:

- a. Fischer-Tropsch (FT) production of syn-biofuels and mixed alcohols;
- b. Methanol to gasoline (MTG) pathway.

Both technologies entail high capital costs for gasification and conversion units, and benefit from economies of scale, hence commercial units are expected to have a minimum of 500 ktpa (dry basis) capacity. The capital cost estimates for a first-of-its-kind commercial plant of this scale are forecast to be in the region of USD \$600-900 million⁴¹.

In previous work undertaken by Worley for Arena in Australia⁴² a conceptual process configuration for a commercial softwood to biofuel plant based of the MTG pathway with feed capacity of 700 ktpa (2,000 tpd dry basis; 50% moisture content) was developed. The methanol (intermediate product) yield was 320 ktpa (913.4 tpd) at approximately 96% purity⁴³. If the downstream plant targeted gasoline via the MTG route⁴⁴, the yield per metric tonne of dry biomass was 230 L of gasoline and 39 L of LPG, hence, the LPG (i.e. co-product) yield is ~15 ktpa. At a feed price of NZD 75.94/dry metric tonne, the gate prices for gasoline and LPG were NZD 0.71/L and NZD 0.54/L respectively. Alternatively, if the downstream plant targeted conversion to DME, then rDME yield is ~218 ktpa.

⁴¹ 2000 Summary of Task 39 report: “The potential and challenges of drop-in biofuels” ISBN: 978-1-910154-09-0 (electronic version) July 2014

⁴² WorleyParsons, Australian Liquid Fuels Technology Assessment, BREE (Bureau of Resources and Energy Economics), Canberra, September 2014

⁴³ A grade suitable for subsequent use; either directly as transport fuel blend or indirectly as feed stock to a downstream MTG or DME conversion plant.

⁴⁴ Steven D. Phillips, et al Gasoline from Woody Biomass via Thermochemical Gasification, Methanol Synthesis, and Methanol-to-Gasoline Technologies: A Technoeconomic Analysis. ACS dx.doi.org/10.1021/ie2010675 | Ind. Eng. Chem. Res. 2011, 50, 11734–11745

The gasification technology presumed for the above study was based on the Battelle Columbus laboratory low pressure indirectly-heated circulating fluidised bed technology. However, we acknowledge that recent advances in gasification technology may offer improved yields and thermal efficiency over those utilised in this study. We note in particular that at small scale a variety of other gasifier types are being promoted.

5.2 Softwood to biofuels via advanced synthesis

In Section 4.1 of this report we highlight a sample of technologies that are able to cost effectively convert municipal solid wastes and softwoods to target liquid fuels. The improving efficiency and selectivity of these pathways brings forward the prospect of being able to realise large scale biofuel synthesis using readily available biomass.

The advances in gasification and conversion technology are likely to bring the minimum scale for commercial units towards 200 ktpa (dry basis) capacity.

New Zealand is well placed to be an early adopter of advanced synthesis options due to access to secure and reliable woody biomass supply chains, which may be augmented with MSW (or refuse-derived-fuel) supplies.

5.2.1 Potential scale

Feedstocks associated with this pathway are derived from New Zealand's existing forestry industry. The volume available is significant, and dense within certain regions⁴⁵. The central North Island accounts for approximately 35% of the total NZ forestry area.

- Forest residue – roots, trimmings, waste not associated with saw or pulp logs, termed hog and chip quality, is estimated in the order of 1,680 ktpa (dry weight).
- Pulp logs – logs for use in the pulp and paper industry, currently allocated or exported, but if were repurposed provide approximately 3,360 ktpa (dry weight).
- Saw logs – used for timber both locally and internationally. Total cut for saw logs is approximately 13,000 ktpa (dry weight).

The advances in gasification and conversion technology are likely to bring the minimum scale for commercial units towards 200 ktpa (dry basis) capacity. Adopting a Fischer-Tropsch (FT) style conversion process will likely yield 1-3% rLPG of feed basis, hence 2 ktpa rLPG as a side product per plant of this size is entirely realisable. It is equally possible to target rLPG production and yield >20 ktpa rLPG per plant of this size.

5.2.2 Timing and decarbonisation value

Considering the technology and scale risks of this production pathway, it is unlikely to be an early mover, rather it is forecast that the first plants of this type will emerge near 2040.

The majority of the GHG footprint associated with this pathway is associated with the harvest and transport of the feedstock and intensified by conversion efficiency. The GHG footprint is anticipated to be between 15 – 25 ktCO_{2eq}/PJ.

⁴⁵ <https://www.mpi.govt.nz/dmsdocument/14221-Wood-Availability-Forecasts-New-Zealand-2014-2050>

5.3 Softwood to biofuels pathway via pyrolysis

Thermochemical processing conditions for lignocellulosic feedstocks can be optimised to influence the ratio of the three main products, namely: bio-oil, synthesis gas and char, depending on the end-use application envisaged.

Bio Pacific Partners in their recent report to MPI and other government agencies⁴⁶ on the use of commercial forest biomass to move New Zealand towards a carbon-zero future, suggest that the manufacture of biocrude is an option for New Zealand's oil and gas industry to utilise its existing assets and distribution networks in ways which lower the carbon intensity of the fuel industry. Whilst the report is correct in observing that the processing of biocrude may well allow companies that operate refineries to generate carbon credits under a low carbon fuel standard, the reality is that at the scale required to maintain refinery operations via biomass pyrolysis in New Zealand will require feedstock quantities that are simply not possible.

Pyrolysis technology is limited by scale and also the need to find markets for the char by-product. There are commercially mature routes to substitute diesel from the pyrolysis of waste tyres and recovered waste plastics, but these routes typically use batch distillation (similar to waste oil recovery) of the produced pyrolysis oil under reduced pressure and do not entail any form of hydrotreating - this is not the case for a biomass feed, due to the material having low hydrogen and high oxygen contents. The process breaks the pyrolysis oil into usable fractions with minimal additional cracking or production of undesirable deposits or aromatics.

We note also that a major study was undertaken in 2008 by Norske Skog (Stump-to-Pump) and their technology partners Licella (Catalytic Hydrothermal Reaction (CAT-HTR)) to examine the feasibility of converting up to 1,600 ktpa (oven dried) wood residues to biocrude. They estimated the potential to produce up to 4 million barrels/year, or 10% of NZ crude requirements. This process centres on using supercritical water to break down carbon-oxygen linkages of the biomass structure to liquefy it into a form of bio-oil (also termed biocrude).

The severe process conditions required by this process have led to sustained challenges such as corrosion (or use of expensive alloys), and high wear on process components. The resultant high investment cost and also the high oxygen content of the derived bio-oil becomes a considerable hurdle to commercial deployment. Nevertheless, a few pilot / demonstration processes do exist, and this route may well evolve based on lower-oxygen, carbonaceous materials. The proposed demonstration project in New Zealand did not proceed.

5.3.1 Potential scale

The pyrolysis of woody biomass for biocrude is not envisaged to contribute strongly to biofuel or rLPG production in New Zealand.

⁴⁶ BioPacific partners Wood Fibre Futures, report to NZ Forestry Advisory Group, 2020

6. “Blend in” component production

6.1 DME pathway

DME is a methanol derivative, with rapidly growing global production rates. DME is being produced for use as a fuel (in both the transportation and heating sectors), small-scale electric power generation, and specialty chemicals market. A number of DME plants are in different stages of development around the world with the majority of world supply either natural gas or coal based. However, DME from biomass, based on syngas production from biomass (including MSW and black liquor)⁴⁷, is both technically feasible and an emergent commercial play.

We assess rDME as being near-commercial in its capacity to meet renewable fuel standards as well as having an available mature distribution and fuels infrastructure. Whilst the conventional routes via methanol as an intermediary are technically mature, there are limitations associated with scale and cost. Several companies, including Haldor Topsoe, Japan JFE Holdings Company, and Korea Gas Corporation, have developed direct DME synthesis technologies which are at early-stage commercialisation⁴⁸. The direct DME synthesis process, offers a significantly improved conversion per pass of syngas to DME and thus potentially improved economics.

6.1.1 Potential scale

The scale is potentially only limited by the availability of biogas.

6.1.2 Timing and decarbonisation value

A study by the European Commission Directorate Joint Research Centre, showed that Well-to-Wheels CO₂ emissions from the use of rDME in the diesel vehicle fleet to be less than 5% of petroleum diesel and about 20% lower than synthetic diesel via BTL Fischer-Tropsch.

A wheel-to-wheel comparison for the production of rDME by Tomatisa, showed that the recycling of waste CO₂ as a gasifying agent significantly reduced total GHG emissions when compared to diesel (0.46 and 1.62 kg CO₂-eq/km for rDME and diesel respectively) whilst also offering a lower impact on human health, and ecosystem (55 and 68% lower compared to pure diesel respectively). These numbers compare with studies in Thailand based on the conversion of rice straw to rDME⁴⁹.

On the basis that biogas is derived from a managed waste stream (i.e. carbon neutral source) we estimate that the GHG emissions intensity of rDME would likely be between 20 - 30 ktCO₂eq/PJ. However, in applications where the bioga / rDME is derived from an unmanaged waste stream (e.g. animal waste), the resultant product will have a largely negative carbon emissions value, this is true for rLPG also - see Section 4.1.5⁵⁰. We interpret that the resultant mixture of rDME and cLPG will have a significantly reduced carbon

⁴⁷ T.H. Fleisch et al. / Journal of Natural Gas Science and Engineering 9 (2012) 94e107

⁴⁸ Marco Tomatisa, A life cycle analysis (LCA)-based case study in China, Fuel 254 (2019) 115627

⁴⁹ T. Silalertruksa et al., Life cycle GHG analysis of rice straw bio-DME production and application in Thailand, Applied Energy 112 (2013) 560–567

⁵⁰ <https://www.sciencedirect.com/science/article/pii/S0959652620350137>

emissions profile than cLPG on its own, at the requisite 80/20 blend of cLPG/rDME the net emissions trend towards zero.

There are significant advantages for rDME from a clean air perspective. Due to the high oxygen content of DME and the lack of direct carbon-carbon bonds, soot-free combustion is possible using DME allowing increased exhaust gas recirculation to help reduce NOx emissions. In engine tests, emissions from DME combustion have been shown to be lower than those from diesel combustion under almost all engines operating condition. CO emissions however are slightly greater⁵¹.

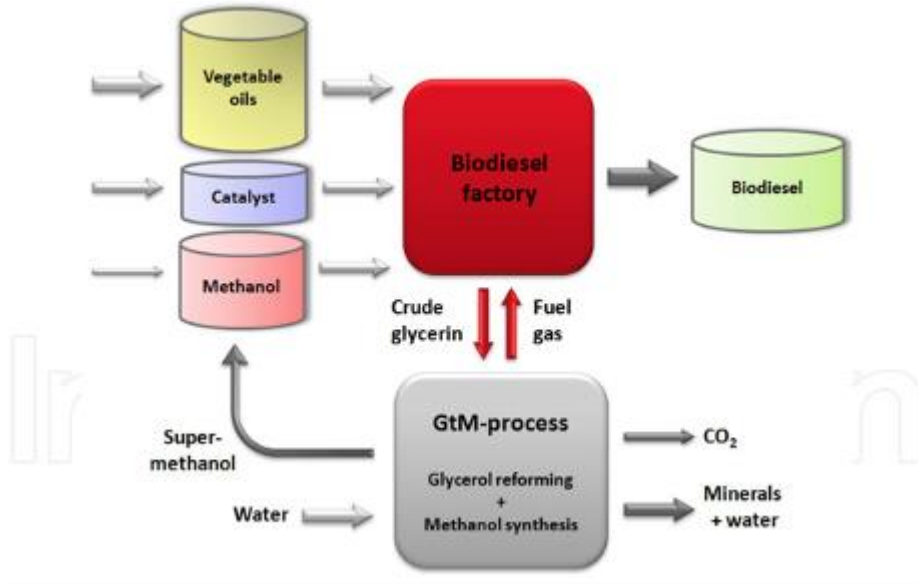
Given the lack of regulatory oversight specifically on DME handling and use within New Zealand, it would be prudent that this should be addressed to improve regulatory certainty and is something the Commission may wish to consider in its final recommendations.

6.2 Glycerol to DME / rLPG

Surplus glycerol from FAME biodiesel processing can be used to produce methanol via the (GtM) process⁵². This methanol can then be upgraded to DME or potentially rLPG.

This process is an integration of two separate processes, the reforming in supercritical water (RSCW) of glycerol to syngas, followed by the conversion of this syngas into methanol.

Figure 17 - Gas to Methanol BFD



In Europe this technology is at an early-stage of commercialisation with Bio-MCN being operated in the Netherlands. The company also produces bio-methanol from biogas sourced from waste digestion plants⁵³.

⁵¹ Su Han Park a, Chang Sik Lee, Applicability of dimethyl ether (DME) in a compression ignition engine as an alternative fuel, Energy Conversion and Management 86 (2014) 848–863

⁵² Joost G. van Bennekom; <http://dx.doi.org/10.5772/53691>

⁵³ <https://www.oci.nl/operations/biomcn/>

6.2.1 Potential scale

Roughly 100 kg of glycerol is produced for every ton of biodiesel produced via the FAME biofuel pathway. As identified in Section 3.1.1, the potential 120 ktpa FAME biofuel capacity of New Zealand could yield ~12 ktpa of glycerol. After being converted to methanol, then DME and then rLPG the yield would be 0.2 ktpa.

6.2.2 Timing and decarbonisation value

In Section 3.1.2, it is forecast that FAME biodiesel will likely be advanced in the near term (i.e. next decade), and there is no reason why glycerol to DME / rLPG development would not occur in this same timeframe.

6.3 Biogas feedstock

Global biogas / biomethane production is estimated at 1,500 PJ⁵⁴. The vast majority of production lies in European and North American markets, with some countries such as Denmark and Sweden boasting more than 10% shares of biogas / biomethane in total gas sales.

The primary source of this biogas is anaerobic digestion. Digestion technology has become increasingly popular in the last 25 years as it reduces environmental issues (e.g. wastewater loading and odours) facing primary producers.

The primary feedstocks for the anaerobic digestion pathway are: Agriculture wastewater (e.g. Dairy and piggery effluent); Crop residues; Municipal wastewater; Landfill gas and organic (e.g. food waste) municipal waste.

The rising interest in biomethane means that the number of operating plants worldwide is increasing rapidly. Around 60% of plants currently online and in development inject biomethane into the gas distribution network, with a further 20% providing vehicle fuel⁵⁵.

Fair Oaks Farms in northwest Indiana, has developed a biogas system for their 11,000 head cow herd to produce compressed natural gas (CNG). They convert dairy effluent to biogas for use directly as CNG fuel or conversion to DME via methanol. The CNG is used to operate 42 milk trucks taking carrying some 300,000 gallons per day of milk from the farms to the processing facility. Anaerobic digestion at Fair Oaks Farms generates about 865 MMBtu of renewable natural gas per day, displacing more than 1.5 million gallons of diesel fuel per year. Interestingly, in this case study the upgraded biogas is transported via pipeline to the fuelling station in Fair Oaks, where it is further compressed and dispensed as rCNG⁵⁶.

In Section 6.4 we describe how this biogas / biomethane can be converted to DME and rLPG.

6.3.1 Dry digestion

Dry digestion is seen as a highly desirable pathway for New Zealand's use of municipal waste and dry matter derived from energy cropping. Dry digestion involves anaerobic digestion at temperatures of between 50 - 58°C in either batch or continuous flow systems. The system is capable of processing a range

⁵⁴ http://www.worldbioenergy.org/uploads/181017%20WBA%20GBS%202018_Summary_hq.pdf

⁵⁵ IEA *Outlook for biogas and Prospects for organic growth*, World Energy Outlook Special Report, Biomethane, IEA 2020

⁵⁶ Tomich *et al*, Cow Power: A Case Study of Renewable Compressed Natural Gas as a Transportation Fuel, Argonne

of mixed waste streams with solids contents of up to 50%. It is also ideally suited for the digestion of energy crops such as maize, lucerne and other crops without further processing (apart from size reduction) or water addition.

Typical process properties for a dry digestion plant are given in the table below⁵⁷.

Table 6 – Dry digestion (Dranco process) key features

Property	Value
Wet or dry process, solids content (%)	Dry, TS = 20 to 50 %
Number of Stages	single stage
Hydraulic Retention Time (HRT)	13 to 30 days
Type of Reactor	vertical, input stream by the top
Biogas production (Nm ³ .t ⁻¹ MSW)	100 to 120
Use of biogas produced by the plant (%)	-
Mixing the residue inside the reactor system	Recirculation of the solid mass in anaerobic digestion.
Temperature	Thermophilic

Reference: adapted from Angelidaki, Ellegaard & Ahring (2003), Deublein & Steinhauser (2010).

6.3.2 Potential scale

Anaerobic digestion has progressed quietly in New Zealand but has never received significant focus. New Zealand has a few dozen examples of anaerobic digestion of agriculture wastewater and a few examples of anaerobic digestion of municipal wastewater (e.g. Mangere Wastewater treatment plant, Auckland).

Wastewater resources within New Zealand are scattered between North and South Islands, with municipal wastewater centred about population centres. Agricultural wastewater and manure follow areas of high agricultural intensity, Waikato and central North Island, and Canterbury basin.

- Municipal wastewater estimated at 470 million m³/year – with 18 larger wastewater treatments plants (supplied by over 35,000 people) making up 80% of this volume⁵⁸.
- Dairy wastewater estimated at 60 million m³/year⁵⁹.
- Abattoir wastewater estimated at 20 million m³/year⁶⁰.
- Easily accessible and recoverable agriculture manure is estimated at 600 kt pa⁶¹.

6.3.3 Timing and decarbonisation value

Anaerobic digestion is already technically and commercially mature, with rates of development dependent on the demand and pricing of biogas.

Of more importance, however, is the recent announcement from Ecogas Limited, who have announced a food waste & organics to biogas and biofertilizer facility at Reporoa, Central North Island which will be

⁵⁷ de Lima H Q, *Anaerobic digestion AD of municipal solid waste in Santo Andre-SP – Review*, conference paper <https://www.researchgate.net/publication/291334691>,

⁵⁸ https://www.lei.co.nz/images/custom/lrc-2016-cass_lowe-160205-.pdf

⁵⁹ B. Cox 'TNGB14 – sources of biogas feedstock'

⁶⁰ B. Cox 'TNGB14 – sources of biogas feedstock'

⁶¹ B. Cox 'TNGB14 – sources of biogas feedstock'

capable of processing up to 75ktpa of feedstock. This \$30m+ facility will be the largest private biogas facility in the country⁶².

If the waste is currently not being managed (i.e. biodegrades to methane), then the GHG footprint of resulting rLPG from biogas will reflect recovery of methane and will yield a negative GHG intensity between -160 and -100 ktCO_{2eq}/PJ.

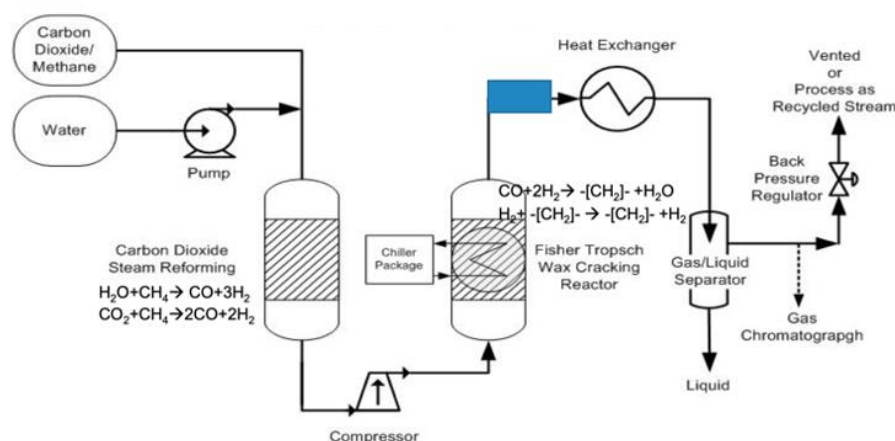
6.4 Biogas to rLPG pathway

There are a number of emerging technologies that take biogas through to useful fuels, including DME and rLPG. Two examples are provided below.

6.4.1 Cool GTL approach

The US-based Gas Technology Institute (GTI) has developed a process called Cool GTL¹⁷ that can convert digester biogas to higher hydrocarbons, including propane and butane^{63,64}. The process reforms the carbon dioxide and methane in the biogas into a syngas mixture that is fed to a Fischer-Tropsch reactor. FT reactors typically produce waxes that must be hydrotreated into liquid fuels, but the GTI technology integrates a wax cracking / isomerisation into the FT reaction step. Discussion with the Institute⁶⁵ indicates that Cool GTL is currently aimed at jet fuel but say that the process could just as readily make propane or butane.

Figure 18 - Cool GTL schematic



The Institute is also testing variants of their biogas technology to allow direct biomass conversion via their licensed IH² (Integrated Hydro-pyrolysis and Hydro-conversion) pyrolysis technology⁶⁶ or their in-house U-Gas fluidized bed gasifier. They report that the addition of the IH²® technology for conversion of biomass increases biogenic liquid yields by 40%. Liquid yields of 89 US gallons per dry tonne are claimed. LPG would be a by-product commodity.

⁶² Ecogas, personal communication, 2020. Also see <https://www.ecogas.co.nz>

⁶³ <https://www.gti.energy/wp-content/uploads/2019/10/04-tcbiomass2019-Presentation-Terry-Marker.pdf>

⁶⁴ <https://www.gti.energy/cool-gtl-a-low-cost-system-for-converting-co2-rich-natural-gas-to-fungible-liquids/>

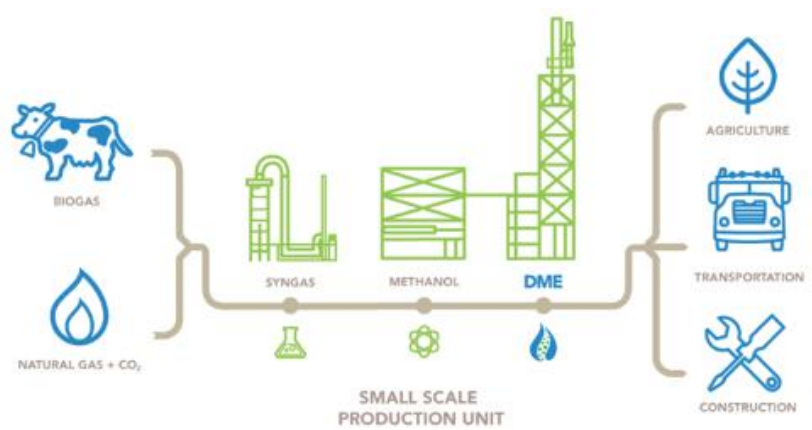
⁶⁵ E Johnson, personal communication

⁶⁶ <https://www.shell.com/business-customers/catalysts-technologies/licensed-technologies/benefits-of-biofuels/ih2-technology/hydrolysis.html>

6.4.2 Oberon – Modular conversion system

Oberon Fuels in California⁶⁷ utilise various feedstocks - such as biogas (animal and food waste, wastewater treatment, landfills), natural gas, and stranded gas to convert methane to DME.

Figure 19 - Oberon Fuels - Biogas to DME schematic



The company’s modular designed plants are intended to be deployed to remote to industrial operations in order to monetize waste CO₂ streams or alternatively biogas (up to 50% CO₂). Example waste streams include pulp mill wastes and dairy farm effluent. The company has a deal with Suburban Propane (one of the largest US LPG companies) to supply DME for blending with propane for autogas. Suburban have taken up a 39% shareholding in Oberon. Standard plants are sized to produce 2.7 – 9 ktpa of DME (from 15,000 to 25,000 cows), which is 1.7 - 5.6 ktpa rLPG equivalent.

⁶⁷ <https://oberonfuels.com/technology/oberon-process/>

7. Decarbonisation scenario assessment

In this section we assess two scenarios for decarbonisation of New Zealand’s LPG industry, namely:

1. 70% rLPG substitution - to decarbonise the LPG portion of the heating sector;
2. 100% rLPG substitution - to decarbonise the entire LPG industry.

7.1 70% renewable LPG substitution scenario

For the 70% rLPG substitution scenario, it is anticipated that New Zealand’s natural gas industry will continue to evolve and deliver conventional LPG up to and beyond 2050. To balance the decline in cLPG production, a healthy rLPG production industry will progressively evolve.

Based on our interpretation of the status of biofuel technology paths and current availability of feedstocks (refer to Sections 3 through 6) we characterised what we believe to be a conservative and realistic string of biofuel developments with rLPG yields. It was clear that the build-up of rLPG production capacity would not be able to match the decline in cLPG production, hence we assume that a proportion of the demand will be met through import of LPG / rLPG. Prior to 2035 it is assumed that majority of imports will be cLPG, but after 2035 rLPG will be imported.

We observed that this scenario resulted in 70% substitution of the 2050 demand and achieved an emission reduction trend comparable to that outlined in the Climate Change Commissions “our policy” approach for the heating sector. We note that our emissions intensity analysis / outcome is not rigorous and is highly dependent upon which feedstocks are recovered for biofuel production and point of ownership transition for these feedstocks – refer to Section 1.5.

The rLPG market build-up is summarised in Table 7 and visualised in Figure 20. Further detail is available in Table 9 / Appendix A.

Table 7 - 70% rLPG scenario plant scale

Plant by 2035	Plant by 2050
2 @ 100 tpd FAME biodiesel plants ≈ 3.2 ktpa rLPG	
2 @ Mixed waste gasification to rLPG plants ≈ 6 ktpa rLPG	3 @ Mixed waste gasification to rLPG ≈ 9 ktpa rLPG
2 @ Wastewater / manure to rDME facility ≈ 25 ktpa rLPG equivalent (40 ktpa rDME) ⁶⁸	3 @ Wastewater / manure to rDME facility ≈ 30 ktpa rLPG equivalent (48 ktpa rDME)
	Biogas to rLPG capability ≈ 40 ktpa rLPG
	1 @ Softwood to biofuels plant ≈ 20 ktpa rLPG

⁶⁸ Capacity limited to avoid exceeding DMR / LPG blend limit.

Figure 20 – Target rLPG build-up – 70% rLPG substitution scenario

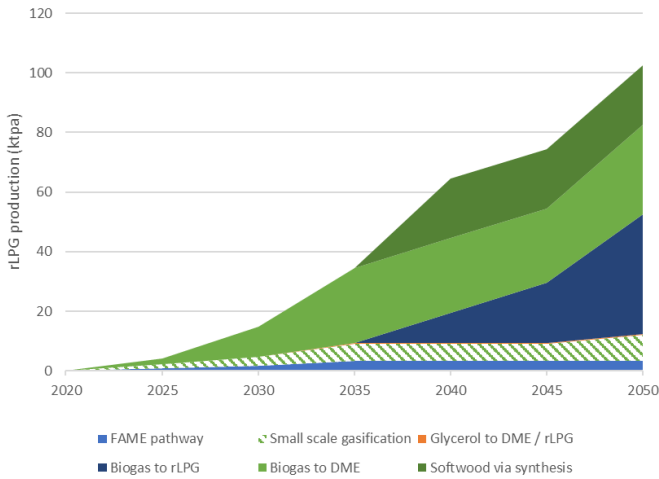
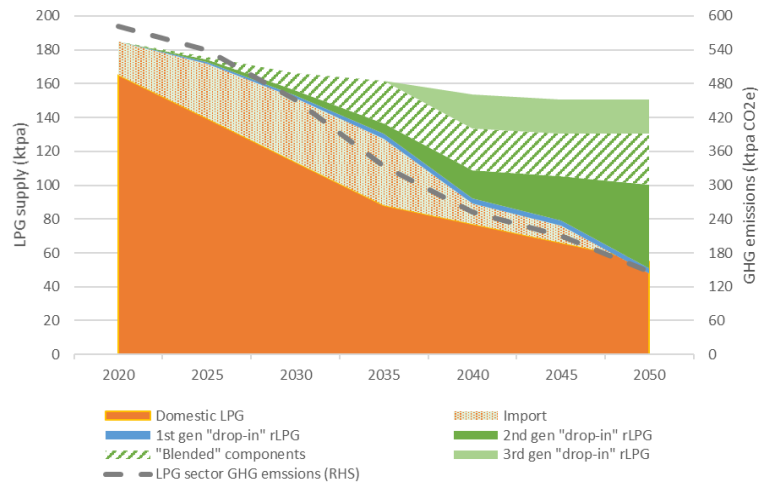


Figure 21 - NZ LPG market plan – 70% rLPG substitution scenario



The ~3 ktpa rLPG target from 1st generation biofuels represents around 40% of the domestically available feedstock – we believe that this is achievable and could be complemented by imported feedstock.

The ~70 ktpa rLPG equivalent target from 2nd generation biofuel technology represents less than 10% of available feedstock. There are likely to be two contributors to this target, namely:

Three mixed wastes (i.e. Cellulosics, forestry residues or MSW) to rLPG plants (2 in North Island and 1 in South Island), or a single rLPG targeted plant. This pathway targets less than 10% of available feedstock and is likely to yield zero or negative GHG emission profile due to the value of offsets attributed to diversion of waste streams.

Multiple small wastewater or manure to rDME plants, yielding up to 30 ktpa of rLPG equivalent. This pathway targets nearly 40% of available feedstock and is likely to yield zero or negative GHG emission profile due to the value of offsets attributed to diversion of waste streams. Our confidence in adoption of this pathway is based on:

- i) Value add to stranded resources;
- ii) Globally proven technology and cost effectiveness;
- iii) GHG abatement value.

On the basis that biogas production from waste will be used to complement natural gas production, the direct conversion of biogas to rLPG provides a capacity flexible (i.e. opportunity based) mechanism for upgrading biogas to the much more readily transported / higher density rLPG fuel. We forecast that a development of this nature will occur post 2035, but earlier than 2050 and will on average produce ~40 ktpa by 2050.

The target of ~20 ktpa rLPG from 3rd generation biofuels is based on the development of a single large softwood to biofuels plant, from which rLPG would be a side stream rather than the main product. New Zealand's dense softwood reserves and demonstrated supply chains has generated interest in this pathway for several decades. We believe that facilities of this nature will be possible by 2050.

The resulting LPG market plan for the 70% rLPG substitution scenario is summarised in *Figure 21*.

7.2 100% renewable LPG substitution scenario

The more ambitious 100% rLPG substitution scenario is premised on a rapid decline / collapse of the natural gas industry prior to 2050 with commensurate demise of cLPG production. We characterised a hypothetical LPG sector response to this outcome based the same phased approach that was used for the 70% substitution scenario, but with acceleration of key production elements. The two areas of acceleration are:

1. 20 ktpa rLPG additional production from biogas conversion;
2. An additional softwood to biofuels plant (with 20 ktpa rLPG yield).

The proposed market build-up to meet the 100% rLPG target is shown in Table 8 and visualised in Figure 22. Further detail can be found in Table 8 / Appendix B. The resulting LPG market plan is summarised in Figure 23.

Table 8 - 100% rLPG scenario plant scale

Plant by 2035	Plant by 2050
FAME biodiesel plants ≈ 3.2 ktpa rLPG	
Mixed waste gasification to rLPG plants ≈ 6 ktpa rLPG	Mixed waste gasification to rLPG ≈ 9 ktpa rLPG
Biogas to rDME facility ≈ 25 ktpa rLPG equivalent	Biogas to rDME facility to 30 ktpa rLPG equivalent
Biogas to rLPG ≈ 20 ktpa rLPG	Biogas to rLPG ≈ 60 ktpa rLPG
	2 @ Softwood to biofuels plant ≈ 40 ktpa rLPG

Figure 22 – Target rLPG build-up – 100% rLPG substitution scenario

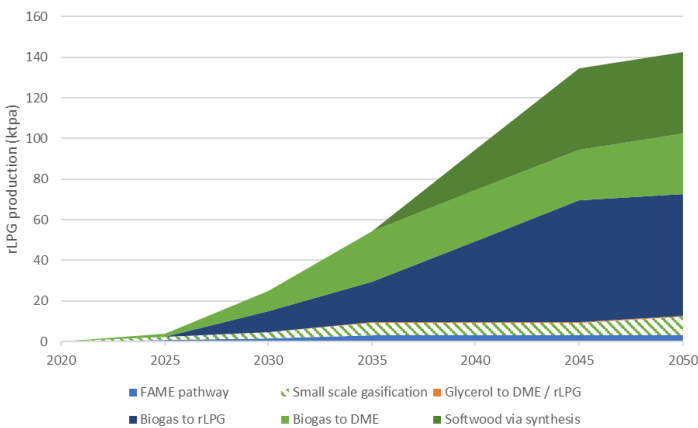
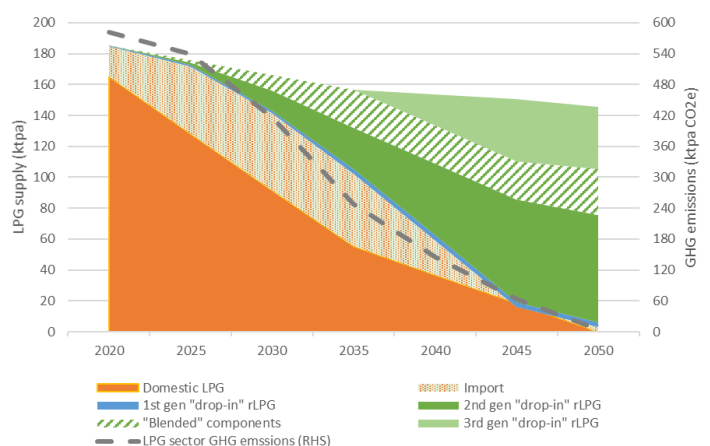


Figure 23 - NZLPG market plan – 100% rLPG substitution scenario



The primary uncertainties related to this scenario are:

- A rapid decline / collapse of the natural gas network could substantially increase the demand for LPG / rLPG, hence targeted demand is highly uncertain;

- If the rLPG industry is given strong demand signals, but finds itself competing with cLPG production there will be heavy negative economic impacts that will suppress rLPG industry growth;
- If the natural gas network volume declines significantly, then support of natural gas reticulation infrastructure and demand for biogas could be challenged. This would directly impact on the biogas to rLPG pathway that is slated to deliver ~60 ktpa;
- Competition for softwoods from pellets and biofuel industries;
- The successful commercialisation of softwood to biofuels technology has been aspirational for at least two decades. Delivering 40 ktpa from this pathway is certainly possible but will likely have rLPG cost impacts that are beyond what the current industry can sustain, and likely to be beyond the value provided by cost on carbon.

7.3 Interpretation of scenario analysis

Globally the LPG industry is actively pursuing opportunities to increase renewable LPG production so as to meet growing demand for this product⁶⁹. New Zealand has a comparatively dense biomass production base and hence is an ideal location for advancing rLPG technologies. Overseas developments demonstrate that biogas and DME production (i.e. 2nd generation) pathways are already commercial in many sectors and promise to be so in New Zealand shortly.

This report has identified a number of immediate opportunities that will allow a significant measure of substitution of conventional LPG supplies by rLPG and also blended rDME. These opportunities have been classified into four groups based on feedstock source and technology maturity.

In our 70% rLPG substitution scenario we adopted a conservative interpretation of technology development and feedstock utilisation to yield a realistic and achievable decarbonisation pathway that matched the decline in cLPG production. We believe that this scenario would yield greater resilience and economic value than a ban on new connections, and result in a similar GHG emissions reduction.

The more ambitious 100% rLPG substitution scenario is premised on a rapid decline / collapse of the natural gas industry prior to 2050 with commensurate demise of cLPG production. We characterised a hypothetical LPG sector response to this outcome based the same phased approach that was used for the 70% substitution scenario, but with acceleration of the biogas to rLPG and softwood to rLPG pathways.

The primary uncertainties associated with the 100% rLPG substitution scenario are tabled in Section 7.2, and mostly relate to:

- Inconsistency between demise of the natural gas sector, and benefits of biogas as a biomass energy delivery vector;
- rLPG market signals and prospective LPG price that is required to accelerate development.

In view of the above comments, we consider that achieving 70% rLPG substitution is realistic and achievable, whereas achieving 100% rLPG substitution will require considered messaging regarding the sustained operation of the natural gas / biogas industry. The 100% rLPG pathway is technically plausible but faces numerous commercial challenges.

⁶⁹ WLPGA, LPG Industry Narrative - LPG and Renewable LPG, 23rd November 2020

Appendix A. 70% rLPG Scenario

Table 9 - 70% renewable LPG production build-up

Pathway	Feedstock	Potential feedstock volume	Potential energy	Potential rLPG or equivalent yield	Proposed plants by 2035	Proposed plants by 2050	GHG Emissions Intensity (ktCO ₂ eq/PJ) (Note 1)
Domestic rLPG	NG co-product	160 ktpa					61.8
Imported LPG / rLPG							61.8 to 6.2
1 st gen "drop-in" rLPG	Fatty acids	150 ktpa tallow	~6 PJ	~7 ktpa rLPG	2 @ 36 ktpa tallow feed 3.2 ktpa rLPG yield	2 @ 36 ktpa tallow feed 3.2 ktpa rLPG yield	25
2 nd gen "drop-in" rLPG	Cellulosics	500 ktpa crop waste 950 ktpa straw & stover	~6 PJ of biogas	106 ktpa rLPG	2 @ 60 ktpa mixed feed 6 ktpa rLPG yield	3 @ 60 ktpa mixed feed 9 ktpa rLPG yield	6
	MSW / food waste	3,300 ktpa of MSW 330 ktpa food waste	~11 PJ of biogas	~207 ktpa rLPG		2 @ 200 ktpa MSW 40 ktpa rLPG	0 (Note 2)
	Wastewater / manure	550 million m ³ pa of wastewater 600 ktpa manure.					
3 rd gen "drop-in" rLPG	Softwood Cellulosics	1,700 ktpa Residue & roots 3,400 ktpa Pulp logs 12,600 ktpa Total	~320 PJ	~260 ktpa rLPG (as a by-product yield)	Nil	1 @ 1,250 ktpa dry feed 20 ktpa rLPG yield (7.5% of total)	20
"Blended" components	Biogas from 2 nd gen				Manure from 200,000 cows (~340 ktpa dry manure) 25 ktpa rLPG equivalent – with a high % rDME	Expansion to 30 ktpa rLPG equivalent – with a high % rDME	-30 (Note 3)

Note 1 – Emissions intensity analysis is not rigorous, see Section 1.5 for further detail.

Note 2 – Intensity for rLPG from MSW based which can be diverted away from atmospheric degradation, assume overall GHG emissions intensity is neutral. See Section 4.1.5 for detail.

Note 3 – Intensity for rDME based on manure from which a portion would otherwise degrade to methane, a modest negative GHG emissions intensity assumed. See Section 6.3.3 for detail.



Appendix B. **100% rLPG Scenario**

Table 10 - 100% renewable LPG production build-up

Pathway	Feedstock	Potential feedstock volume	Potential energy	Potential rLPG or equivalent yield	Proposed plant by 2035	Proposed plant by 2050	GHG Emissions intensity (ktCO ₂ eq/PJ) (Note 1)
Domestic rLPG	NG co-product	160 ktpa					61.8
Imported rLPG / rLPG							61.8 to 6.2
1 st gen "drop-in" rLPG	Fatty acids	150 ktpa tallow	~6 PJ	~7 ktpa rLPG	2 @ 36 ktpa tallow feed 3.2 ktpa rLPG yield	2 @ 36 ktpa tallow feed 3.2 ktpa rLPG yield	25
2 nd gen "drop-in" rLPG	Cellulosics	500 ktpa crop waste 950 ktpa straw & stover	~6 PJ of biogas	~106 ktpa rLPG	2 @ 140 ktpa mixed feed 6 ktpa rLPG	6 @ 140 ktpa mixed feed 9 ktpa rLPG (60% of potential)	6
	MSW / food waste	3,300 ktpa of MSW 330 ktpa food waste	~11 PJ of biogas	~207 ktpa rLPG		2 @ 200 ktpa MSW 60 ktpa rLPG	0 (Note 2)
	Wastewater / manure	550 million m ³ pa of wastewater 600 ktpa manure.					
3 rd gen "drop-in" rLPG	Softwood Cellulosics	1,700 ktpa Residue & roots 3,400 ktpa Pulp logs 12,600 ktpa Annual tree total	~320 PJ	~260 ktpa rLPG (as a by-product yield)	Nil	2 @ 1,250 ktpa dry feed 40 ktpa rLPG yield (15% of total)	20
"Blended" components	Biogas from 2 nd gen				Manure from 200,000 cows (~340 ktpa dry manure) 25 ktpa rLPG equivalent – with a high % rDME	Expansion to 30 ktpa rLPG equivalent – with a high % rDME	-30 (Note 3)

Note 1 – Emissions intensity analysis is not rigorous, see Section 1.5 for further detail.

Note 2 – Intensity for rLPG from MSW based which can be diverted away from atmospheric degradation, assume overall GHG emissions intensity is neutral. See Section 4.1.5 for detail.

Note 3 – Intensity for rDME based on manure from which a portion would otherwise degrade to methane, a modest negative GHG emissions intensity assumed. See Section 6.3.3 for detail.



Appendix C. Sankey diagram of 70% rLPG scenario in 2050

