

LPG ASSOCIATION NZ

# Exploring short term renewable LPG/DME production for NZ



22 December 2021

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**Synopsis**

*This study extends the findings of the "Pathway to 70/100% rLPG renewable LPG" report by more deeply exploring second generation pathway for the production of renewable LPG / DME at NZ scale.*

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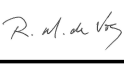
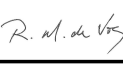

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0	Issued for Use	 D. Stewart	 R. de Vos	 R. de Vos	22 December 2021	 A. de Geest	

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## Executive summary

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### *Where we started*

In March 2021 the NZ LPG Association commissioned Worley to undertake a study on the decarbonisation of the NZ LPG sector, that report was the “Pathway to 70/100% renewable LPG”. The picture was bright, with early indications showing that achieving significant decarbonisation of the NZ LPG sector was credible and within reach.

The 70/100% Pathway report found that the 2nd generation production pathway was considered to have more opportunity (in terms of volume) than current 1st generation technology and lower risk than future 3rd generation technology for New Zealand.

It was also considered that although there maybe risks with supporting a 2nd generation technology, that it is the only mechanism for direct decarbonisation of the LPG sector.

The NZ LPG Association sees value in demonstrating smaller scale 2nd generation pathways at a pilot or early commercial scale. Accordingly, the intention of this study was to more deeply explore the status of these 2nd generation pathway.

### *What we did next*

*In this study we explore the status of key 2<sup>nd</sup> generation pathways for the production of renewable LPG / DME at NZ scale, that were identified in the “Pathway to 70/100% renewable LPG” report.*

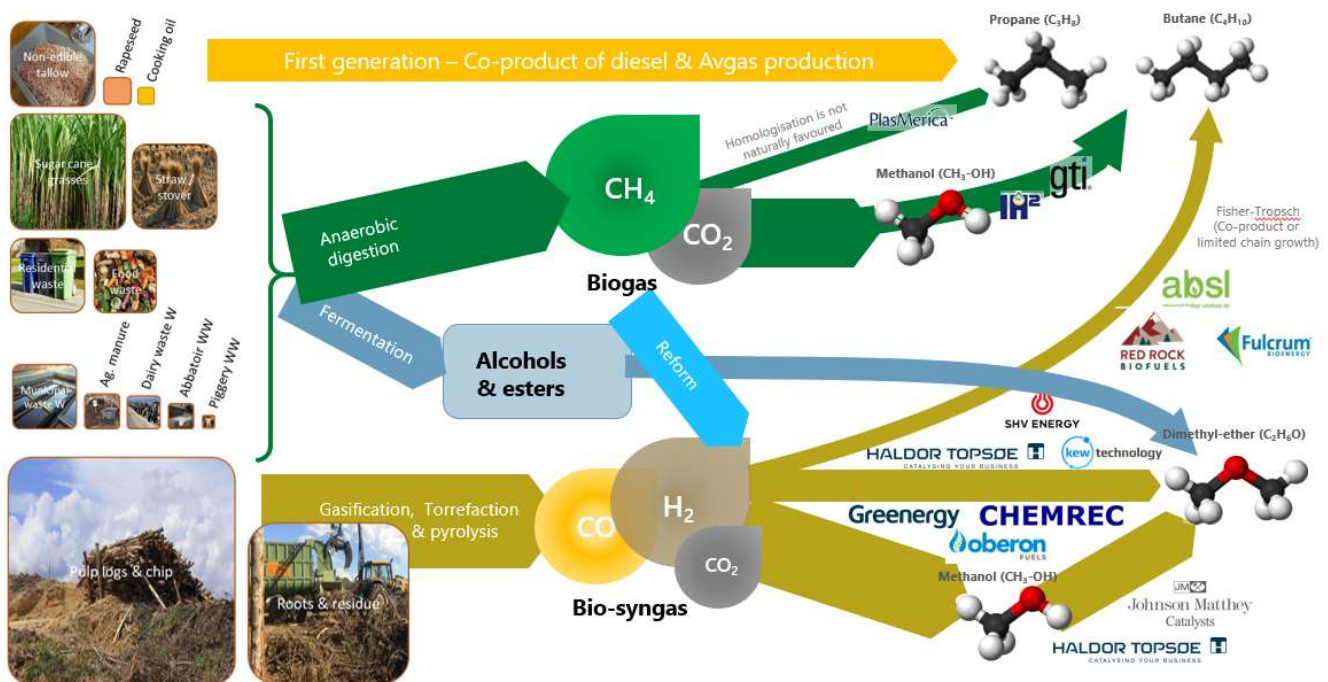
In support of this study, we engaged with 15 different rLPG / rDME technology development players, regarding 100 kg/d biogas conversion plants. Many developers are targeting plants that are 50 times larger, and none have achieved a commercial offering. All of these vendors promote the prospect of a commercially viable pathway emerging, but technology development is still slow and there only a few / partially operating demonstrating plants.

### *What we found*

*In the “Pathway to 70/100% renewable LPG” report, we noted that at small scale, it was likely that conversion to rDME would likely be more achievable initially, since the limited chain extension and dehydration steps in LPG conversion route are more challenging.*

We found that the active players in the syngas to renewable LPG (rLPG) space are: GTI, IH<sup>2</sup> and PlasMerica. The active players in the syngas to rDME space are: SHV, Haldor Topsoe, Casale, and Oberon.

The pathway to rDME is relatively mature, however the methanol intermediate is a valued commodity, whilst DME still has regulatory hurdles. The conversion of syngas to alcohols technology appears to be slowly advancing as a preferred pathway for monetisation of stranded syngas.



*The most significant entrepreneurial effort going into the advancement of the syngas to rLPG pathway is by the Gas Technology Institute (GTI) with backing from BioLPG LLC.*

GTI leverage concepts from their Cool GTL process for their Cool LPG process. This thermo-catalytic process converts biogas to LPG via a novel methanol mediated catalytic reaction. The process was demonstrated at lab scale in 2020 and has recently had an injection of funding to advance the technology to pilot (~40 kg/d) scale.

The Shell IH<sup>2</sup> (integrated hydro-pyrolysis and hydro-conversion) process is expected to provide commercial yields of liquid fuels at flow rates as low as 33 ktpa MSW feed. This process typically yields gasoline with a significant LPG co-product (e.g., up to 50% LPG product is proposed, however the priority of IH<sup>2</sup> is to produce gasoline).

PlasMerica uses a non-thermal ionisation technology to yield LPG from methane. The technology shows promise but is developing slowly.

*There is emerging interest in the syngas to rDME pathway because it can yield a low-carbon liquid fuel via a mature technical pathway.*

SHV are considered as the largest player in the rDME space, based on a recent partnerships with Kew Technology to develop rDME from MSW. The partnership is looking to build a 50 ktpa plant in the UK, with expansion into Europe and America. SHV also have a significant presence in the production of rLPG as a by-product from HVO based bio-diesel production.

Oberon are an emerging player based out of California, who are demonstrating rDME production from dairy manure biogas. They recently began operating their pilot plant which produces rDME via the indirect methanol to DME pathway.



Haldor Topsoe are a well-respected technology developer and licensor of biomass to methanol and DME technologies. They are not currently actively developing novel approaches to rDME.

Casale are a similar technology developer and licensor to Haldor Topsoe, with minimal levels of recent research into new rDME pathways.

Production of DME is not itself a novel pathway, and it has been used as an intermediate product in methanol to fuel plants for many years. The novel aspect is pairing the DME synthesis with a renewable feedstock to produce rDME.

*Second generation biogas to rLPG / rDME conversion technologies target relatively accessible (& lower cost) bio-syngas or biogas derived from anaerobic digestion. In New Zealand, the scale of these resources is expected to range from 100 and 1,000 kg/d.*

Key NZ sources of accessible bio-syngas and biogas are characterised below:

- MSW gasification (i.e., bio-syngas) – The scale of NZ urban populations imply the available Municipal Solid Waste streams of interest would range from 30 to 100 tpd (dry basis). Use of IH<sup>2</sup> technology for this scale of supply could yield up to 5 ktpa rLPG by-product. Although the use of bio-syngas is not ideal for the GTI Cool LPG, it could yield up to 1.5 ktpa rLPG. Use of SHV / Kew Technology is currently targeting a much larger scale of development.
- Wood pellet torrefaction (i.e., bio-syngas) – The potential scale of this application could rival MSW gasification.
- Wastewater treatment (i.e., biogas) – An urban centre with population in excess of 35,000 people could produce more than 700 kg/d of biogas with a yield of >80 tpa using the GTI Cool LPG process.
- Abattoir wastewater digestion (i.e., biogas) – These facilities could produce more than 1000 kg/d of biogas with a yield of >160 tpa LPG using the GTI Cool LPG process.
- Aggregation of biogas from dairy farm collectives could produce more than 800 kg/d of biogas with a yield of >150 tpa LPG using the GTI Cool LPG process.
- Taranaki biogas network (i.e., bio-syngas & biogas) – combining of hog wood and MSW gasification with other sources of biogas from the Taranaki region could yield >100,000 kg/d (i.e 100 tpd) of biogas.

There are two distinct scales of opportunity for New Zealand. The larger scale (>30 tpd) bio-syngas based applications can support greater downstream plant complexity e.g., upgrading to gasoline or sustainable aviation fuel. The smaller scale (<1000 kg/d biogas per site) applications will have less competition for the resource and requires much simpler / lower cost processing technology to be commercially attractive.

*High level / indicative techno-economic assessment of IH<sup>2</sup> for larger scale and Cool LPG process for smaller scale suggests that both conversion technologies should be considered in the rLPG / rDME roadmap.*

These two processes are the most mature we found for the production of rLPG, and both are early in their stages of a producing a commercial offering. Both vendors have a strong history of commercialising novel technologies.

*DME is a significantly more mature technology pathway, with several rDME plants emerging globally, it is easier to envisage a biogas to rDME plant in New Zealand in the short term.*

The current New Zealand regulatory framework for the use of rDME presents some challenges, but nothing that any new fuel wouldn't also be tasked with. LPG associations around the world are making the testing and certification a priority and New Zealand is well positioned to leverage off their work.

### ***What we need to progress***

*The next steps for the New Zealand LPG decarbonisation pathway:*

- Clarification of the rDME blending position
- Clarification on the use of alcohol intermediaries (e.g., ethanol or methanol)
- Incorporation of biogases into the New Zealand regulatory and legislative environment
- Confirmation of biogas feedstock resources and production processes
- Continued engagement with GTI and PlasMerica on their rLPG processes
- Ongoing market investigation on emerging rLPG production pathways
- Ongoing partnerships with local and global entities to ensure alignment of decarbonisation goals

*Sound analysis, partnerships and persistence remain the keys to making a breakthrough for New Zealand.*



## 1. Context

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In the “Pathway to 70/100% renewable LPG” report, we forecast technology advances in two key 2<sup>nd</sup> generation pathways that would support ~30 ktpa rLPG equivalent production by 2035. Considering that the current scale of LPG production is ~170 ktpa, this would represent a significant contribution to the market. The 2<sup>nd</sup> generation pathway was considered to have more opportunity (in terms of volume) than 1<sup>st</sup> generation technology and lower risk than 3<sup>rd</sup> generation technology for New Zealand.

Although there maybe risks with supporting a 2<sup>nd</sup> generation technology, this is the only mechanism for direct decarbonisation of the LPG sector. The NZ LPG Association sees value in demonstrating smaller scale 2<sup>nd</sup> generation pathways at a pilot or early commercial scale. In this study we sought to more deeply explore the status of these 2<sup>nd</sup> generation pathways.

### 1.1 Governmental decarbonisation advice status

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 document “Ināia tonu nei: a low emissions future for Aotearoa” (31 May 2021) the CCC softened their draft recommendation on the timeline for a moratorium on fossil gas connections, instead leaving it to the NZ Government to decide what the specifics of the decarbonisation path the use of fossil gases must take. Their “Recommendation 20 - Decarbonise the energy system and ensure the electricity sector is ready to meet future needs” includes a raft of points, of particular interest is point 8:

Determining how to eliminate fossil gas use in residential, commercial and public buildings.

Actions should include:

- Setting a date to end the expansion of pipeline connections in order to safeguard consumers from the costs of locking in new fossil gas infrastructure.
- Evaluating the role of low-emission gases as an alternative use of pipeline infrastructure.
- Determining how to transition existing fossil gas users towards low-emissions alternatives.

This stance is less prescriptive than the previous recommendation from the CCC draft advice document which set a date for a connection ban in 2025. Similar to their draft advice, there is no specific differentiation between natural gas (fossil gas in their advice documents) and LPG within the recommendation, however they interpret fossil gas and LPG connections as similar per Section 7.3 – point 51.

The CCC also recommend the development of a low-carbon fuels market as a function of “Recommendation 19 – Create options to decarbonise heavy transport and freight by 2050”. This Recommendation is targeted at difficult to electrify sectors and doesn’t differentiate traditional liquid fuels (such as petrol and diesel) from LPG. The report does however provide a strong signal for the development of renewable or low carbon gases such as renewable LPG.

As of July 2021, the NZ government have closed the consultation period relating to “Increasing the use of sustainable biofuels in Aotearoa New Zealand”<sup>1</sup>. The interpreted intention, based on discussion points from the Government, is that the development of a biofuels mandate is on the horizon, and it is anticipated that such mandates will be announced in the next 6 months.

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 in Section 7.2.4 - Increasing use of low carbon liquid fuels:

“The demonstration path assumes the use of low carbon fuels increases to 5 petajoules per year by 2030 and 9.5 petajoules per year by 2035. This is equivalent to around 270 million litres of fuel or roughly 5% of total liquid fuel demand in 2035. For simplicity, we have modelled this as an equal share across all fuel types (petrol, diesel, jet fuel and marine fuel oil).”.

## **1.2 Prospective bio-fuel / biogas mandate**

New Zealand is scaling to implement a bio-fuels mandate to assist with our decarbonisation journey, however at time of writing nothing had been released which outlined the shape that such a mandate would take. It is unknown whether the mandate would cover all fossil based liquid and gaseous fuels, or only liquid transport fuels. GasNZ are advocating for a gaseous fuels mandate.

There is also the impact that such a mandate would make on the existing fuel standards, regulations, and legislation. Work to revise the existing operating environment to accommodate mandated bio-fuels should not be considered as a trivial task, and there should be clear signals to industry as soon as practical to allow the most positive reaction.

New Zealand does not currently have an agreed mechanism for calculating the relative carbon intensity of renewable fuels produced from different feedstocks via different processes. This carbon intensity calculation would need to be developed to support the decarbonising efforts of the LPG industry and the country as a whole. Variation in carbon intensity measurement approaches internationally has led to certain processes and products being treated as carbon neutral or carbon negative in one location, being treated differently in others.

The status of blending LPG with lower carbon products, such as rDME is discussed further in Section 1.5.

## **1.3 LPG market size trend**

In 2020, the NZ LPG market was characterised by 165 ktpa domestic production and 20 ktpa import. This fuel is considered to contribute 560 ktCO<sub>2</sub>e GHG emissions. A full characterisation is provided in the “Pathway to 70/100% renewable LPG” report.

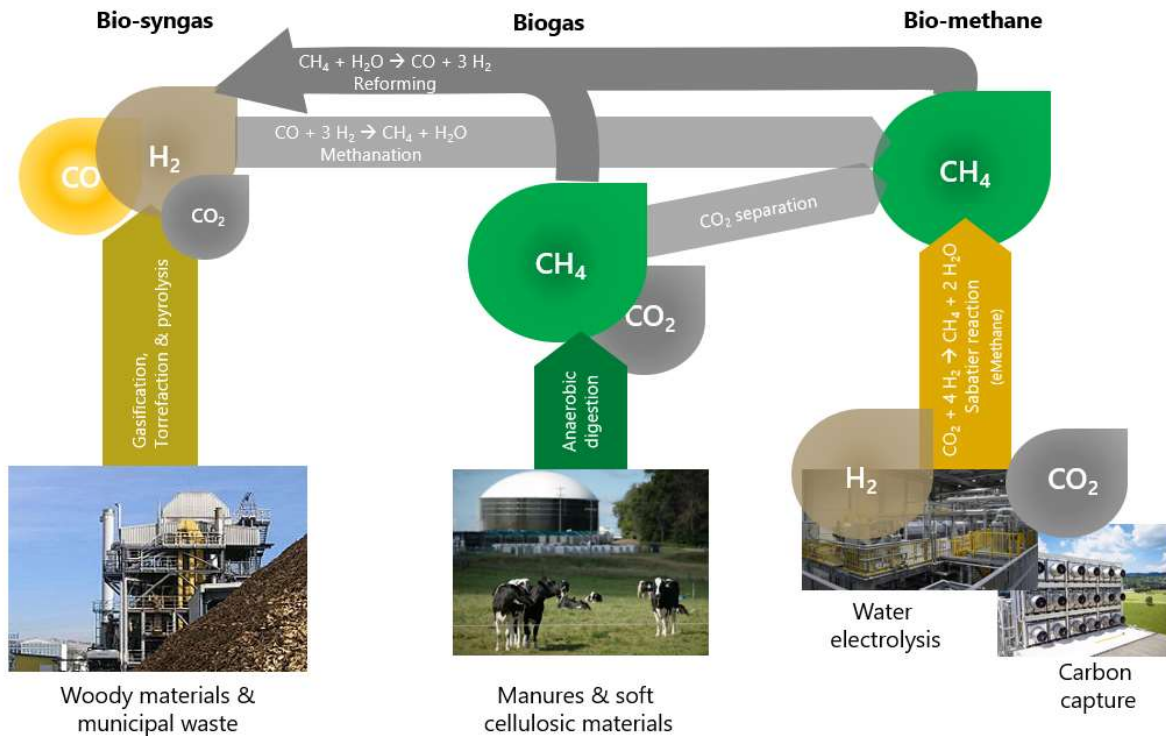
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<sup>1</sup> <https://www.mbie.govt.nz/have-your-say/increasing-the-use-of-sustainable-biofuels-in-aotearoa-new-zealand/>

## 1.4 Gaseous intermediates (Bio-syngas, biogas and bio-methane)

A common element of all biomass to liquid fuel conversion, is the preparation of a gaseous intermediate. Three different gas intermediates are typically recognised, as summarised below.

Figure 1 – Summary of gaseous intermediates



Bio-syngas is generally derived from the thermo-chemical breakdown of biomass without oxygen. The gaseous elements that result from gasification include: carbon dioxide, carbon monoxide, and hydrogen (i.e.,  $\text{C} + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{CO}$ ,  $\text{C} + \text{CO}_2 \rightarrow 2 \text{CO}$  and  $\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2$ ). Using the methanation process, it is possible to then yield methane (i.e.  $4 \text{CO} + 2 \text{H}_2\text{O} \rightarrow \text{CH}_4 + 3 \text{CO}_2$ ). Syngas, bio or otherwise, is the intermediate of many chemical production processes, and is used in a majority of the gas to liquids pathways globally.

Biogas is generally derived from the biological reduction of biomass via anaerobic digestion. The gaseous elements that result from digestion include carbon dioxide and hydrogen. The separation of carbon dioxide from this stream yields bio-methane. Global biogas production is estimated at 1,500 PJ<sup>2</sup>. The vast majority of this production lies in European and North American markets, with some countries such as Denmark and Sweden boasting more than 10% shares of biogas in total gas sales.

Biogas and bio-methane can be used directly as heating fuel, or they can be reformed to produce bio-syngas and passed to another process for upgrading.

Renewable natural gas (called eMethane in some international applications) can be created via the reaction of low-carbon hydrogen and carbon dioxide. This process is based on the Sabatier reaction. Increasing global interest in renewable natural gas as a method of decarbonising has led to a substantial increase in

<sup>2</sup> [http://www.worldbioenergy.org/uploads/181017%20WBA%20GBS%202018\\_Summary\\_hq.pdf](http://www.worldbioenergy.org/uploads/181017%20WBA%20GBS%202018_Summary_hq.pdf)

the number of operating plants worldwide. Around 60% of plants intend to inject renewable natural gas into the gas distribution network, with the balance of plants providing vehicle fuel<sup>3</sup>.

There is no chemical difference between bio-methane produced from upgraded bio-gas and eMethane produced by the Sabatier reaction, it is simply a matter of nomenclature.

### **1.5 Dimethyl ether / LPG blending**

Dimethyl ether (DME) is a methanol derivative, which can be used directly as a liquid fuel or blended with LPG as an LPG substitute. China has actively pursued the production and use of methanol and DME as an automotive fuel. The USA has advanced small scale developments of DME as a mechanism of contributing to the pool of liquid fuels, both transport and heating.

The verification of physical and chemical properties of different DME blends in LPG (with up to 20% v/v DME) has been carried out in Indonesia and Japan. Indonesia and Japan have also undertaken combustion testing of DME / LPG blends using an LPG cooktop. This testing can provide the basis for discussion on a pathway for introducing an DME / LPG blending certification regime. The use of DME / LPG blends in other LPG appliances is still immature. Physical and chemical characteristics of rDME and LPG blends are described in Section 2.4 of the "Pathway to 70/100% renewable LPG" report.

As with many other countries, the New Zealand fuel regulations currently do not allow the use of DME / rDME as a fuel or as a blend stock. However, this is due to it being relatively immature as a fuel rather than any specific exclusion. The LPG associations around the world are working together to investigate what is required for certification of gas appliances to run on rDME / LPG blends.

Liquid Gas Europe and Liquid Gas UK have stated their intention to transition to fully renewable LPG by 2050, using both bio-LPG and rDME. Both these associations have commenced discussions on how to realise the potential of rDME / LPG blends in gas appliances and have identified that establishing a testing / certification regime is a priority.

Once a sound basis of blending has been established and the requisite testing completed, New Zealand specific regulations would need to be created, or existing regulations revised, to accommodate the blending of rDME with LPG.

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<sup>3</sup> IEA Outlook for biogas and Prospects for organic growth, World Energy Outlook Special Report, Biomethane, IEA 2020

## 1.6 Acronym list

The following acronyms are used in this report.

*Table 1 – 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
CAPEX		Capital Expenditure
CCC	Climate change commission	An independent advisory body on climate change
cLPG	Liquified petroleum gases	Conventional / fossil LPG
CO <sub>2</sub>	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
F-T	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.
GTI	Gas Technology Institute	Research institute located in the United States
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
MTPD		Metric Ton Per Day – unit of production
OPEX		Operational Expenditure
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

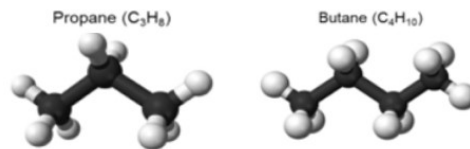
## 2. Fossil LPG and substitutes

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 2. 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.

LPG is used in homes and commercial / industrial businesses, for space and water heating, for food preparation and process heat. As well as being a fuel for the ubiquitous BBQ. For simplicity, and to minimise risk of confusion, in this report we term conventional LPG as cLPG.

Figure 2 – Chemical structure of key LPG components<sup>4</sup>

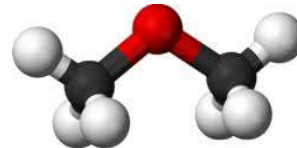


In New Zealand the ratio of C3/C4 varies depending on source and production ratios, although variation year to year can be >15% and imported LPG is 100% propane. The average higher heating value remains ~49 MJ/kg and emissions intensity is 62 ktCO<sub>2eq</sub>/PJ.

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);
- Renewable Dimethyl-ether (rDME) – A product of methanol dehydration which has chemical properties that allow blending up to 20% v/v in LPG without significant change in LPG blend properties. For more details of DME / LPG blending, refer to Section 1.4.

Figure 3 - Chemical structure of DME (CH<sub>3</sub>OCH<sub>3</sub>)



<sup>4</sup> Source: Thompson, Robertson, and Johnson, 2011

### 3. New Zealand scale

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#### 3.1 Biogas sourcing

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 production of biogas within New Zealand is currently solely focused on use as an energy offset fuel, with all biogas produced either used directly as a heating medium or within biogas engines to produce electricity to offset energy import.

Of interest, 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 capable of processing up to 75 ktpa of feedstock. This facility will be the largest private biogas facility in the country<sup>5</sup>. The expected biogas production from the Ecogas facility is around 24,000 Sm<sup>3</sup>/d or 180,000 GJ per annum<sup>6</sup>. The digestate will be sold as fertilizer.

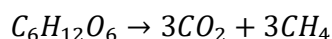
##### 3.1.1 Anaerobic digestion

Anaerobic digestion (AD) is the process by which micro-organisms break down biodegradable matter in the absence of oxygen. During the process, biodegradable waste materials (with the exception of those containing lignin) are degraded and biogas is produced, composed mainly of methane (CH<sub>4</sub>) and carbon dioxide (CO<sub>2</sub>).

The process can be divided into four steps:

1. Hydrolysis - Carbohydrates, fats and proteins are broken down to sugars, fatty acids and amino acids,
2. Acidogenesis - Creation of carbonic acids and alcohols plus hydrogen, acetic acid and carbon dioxide from the sugars, fatty acids and amino acids),
3. Acetogenesis - Creation of hydrogen, acetic acid and carbon dioxide; and
4. Methanogenesis - Methane and carbon dioxide as the final compounds.

The general equation for the process can be written using a glucose molecule as an example:



Farm dairy effluent is a good feed for AD as it contains all the essential elements required by the microorganisms. In addition, it has a good buffering capacity which is an advantage in optimising the

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<sup>5</sup> Ecogas, personal communication, 2020. Also see <https://www.ecogas.co.nz>

<sup>6</sup> Private email correspondence with Alzbeta Bouskova – General Manager Ecogas



process. However, the carbon to nitrogen ratio (C:N) for dairy effluent is around 9:1, whereas the optimum ratio (around 15:1 to 45:1) would require the addition of extra carbon.

Co-digestion of dairy manure with other substrates, such as straw or food waste, increases the yield of biogas by optimising the C:N ratio.

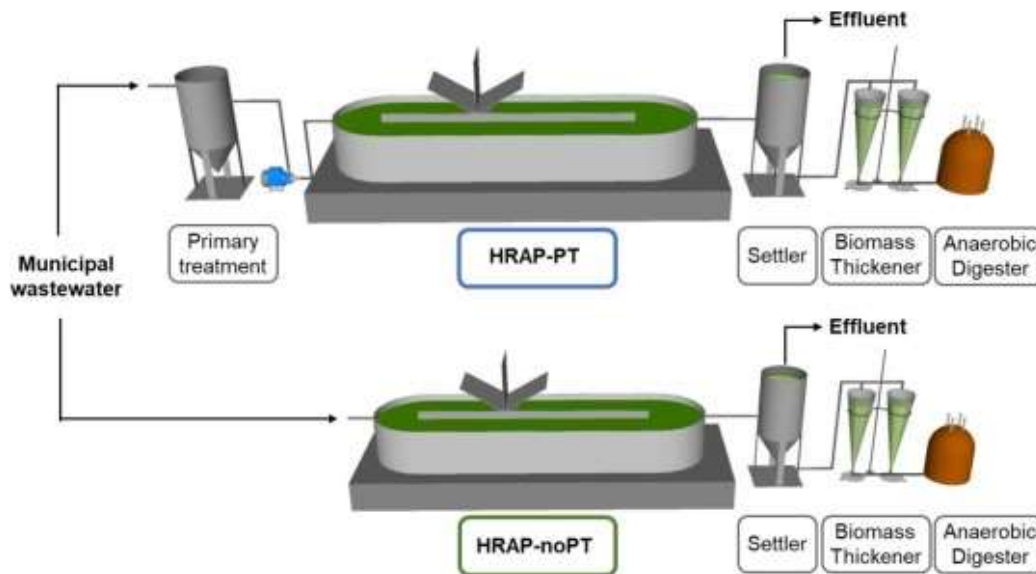
The digestion of dairy manure alone produces a biogas containing 55% to 70% of methane and 30% to 40% CO<sub>2</sub>, with the make up being nitrogen, hydrogen, or hydrogen sulphides. Before the biogas can be used, generally the hydrogen sulphide must be removed. Biogas production from dairy manure varies across references, but generally from 1 ton of manure approximately 40-60 Sm<sup>3</sup> of biogas can be achieved. The addition of other substrates can increase this yield.<sup>7</sup>

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

### 3.1.2 High rate algal ponds

When treating agricultural wastewater with anaerobic digestion it is possible to increase biogas yield and improve wastewater treatment by adding high rate algal ponds to the digestate stream. The effect of the high rate algal pond (HRAP) is to capture CO<sub>2</sub> from the atmosphere in algal form. This improves the carbon content (i.e., higher C:N ratio) of the mixed anaerobic digester feed stream.

Figure 4 – Two applications of HRAP to wastewater treatment system



### 3.1.3 Dry digestion

Dry digestion is seen as a highly desirable pathway for New Zealand’s use of municipal waste and dry matter derived from crops. 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 of mixed waste streams with solids contents of up to 50%. It is also ideally suited for the digestion of energy crops

<sup>7</sup> [https://www.worldbiogasassociation.org/wp-content/uploads/2019/09/WBA-globalreport-56ppa4\\_digital-Sept-2019.pdf](https://www.worldbiogasassociation.org/wp-content/uploads/2019/09/WBA-globalreport-56ppa4_digital-Sept-2019.pdf)

such as maize, lucerne and other crops without further processing (apart from size reduction) or water addition.

Typical process properties for a MSW dry digestion plant are given in the table below<sup>8</sup>.

Table 2 – 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 <sup>3</sup> .t <sup>-1</sup> 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).

### 3.1.4 NZ scale considerations

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). In this section, we consider the high-level opportunities and site scales for biogas generation in New Zealand.

Table 3 – NZ scale biogas generation opportunities

Biomass resource <sup>9</sup>	Predominant existing treatments	Potential for alternative treatment	Potential scale per site
Municipal wastewater - 470 million m <sup>3</sup> /year.	Aerated pond	Transition to AD with HRAP leads to lower costs, improved effluent quality, less power consumption and higher treatment quality.	Around 15 urban centres with population >35,000 could be converted. More than 700 kg/d of biogas per centre.
Abattoir wastewater – 20 million m <sup>3</sup> /year	Aerated pond	Transition to AD with HRAP leads to lower costs, improved effluent quality, less power consumption and higher treatment quality.	8 significant scale abattoirs exist. More than 1,000 kg/d of biogas per centre.

<sup>8</sup> de Lima H Q, *Anaerobic digestion AD of municipal solid waste in Santo Andre-SP – Review*, conference paper <https://www.researchgate.net/publication/291334691>,

<sup>9</sup> [https://www.lei.co.nz/images/custom/lrc-2016-cass\\_lowe-160205-.pdf](https://www.lei.co.nz/images/custom/lrc-2016-cass_lowe-160205-.pdf)

Agricultural (especially dairy) wastewater – estimated at 60 million m <sup>3</sup> /year	Digestion lagoons	Covering lagoons (or converting to AD systems) and converting to HRAP enables methane capture.	Dairy farm collectives with >5000 cows or smaller farms with higher collection rates could produce more than 800 kg/d. Aggregation of more than 5 farmers to a collective, is considered to be challenging, hence total number of opportunities at this scale is expected to be ~300.
Food waste (Ecogas)	Anaerobic digestion	Wet and dry digestion.	75 ktpa (205 tpd) food waste to produce 24,000 Sm <sup>3</sup> /d of biogas (16,000 kg/d methane)

### Case study – Biogas from dairy wastewater



In New Zealand, dairy cows are generally pasture feed, and are milked in “dairy sheds” twice daily. The manure collected at dairy sheds is approximately 8.5% of the total manure loading. Utilisation of feed lots or covered housing of cows would increase time on hard standing and improve manure recovery, however this practice is counter to the “clean, green” image and may have social license implications. In some locations internationally, recovery of manure can approach 40 – 50% on farms which house the animals rather than paddock grazing. Manure collection from the paddock would improve overall yield, although requires a significant manual handling aspect.



In order to utilise dairy waste for use as a feedstock, multiple farms would need to be aggregated to produce a sizeable feedstock. Given the average farm size of 440 cows, we consider that aggregation of 5,000 cows at current yield, or 2,000 cows through an approach targeting an improved manure recovery, could produce ~1,200 Sm<sup>3</sup>/d of (800 kg/d methane).

### 3.2 Bio-syngas sourcing

The production of bio-syngas from various feedstocks is well understood, with multiple technology suppliers globally. The common means of producing bio-syngas from a biomass is to directly gasify the biomass or convert the biomass to biogas then reform that gas

There are numerous gasification technologies. Generally, the best-in-class performance for biomass gasification is given by a fluidized bed gasifier as these are available in a large range of capacities and are commercially proven. Oxygen for large scale gasifiers is sourced via an Air Separation Unit (ASU).

It is possible to produce syngas using other types of gasifiers which use steam or air instead of pure oxygen to provide the reactant oxygen. In practice these gasifiers tend to produce a lower quality of syngas and are not as efficient at converting biomass.

#### 3.2.1 NZ scale considerations

In this section, we consider the high-level opportunities and site scales for bio-syngas generation in New Zealand.

Table 4 – NZ scale bio-syngas generation opportunities

Biomass resource	Predominant existing treatments	Potential for alternative treatment	Potential scale per site
Municipal solid waste	Landfill (with some gas recovery)	Mass burn provides cheap heat generation. Gasification (with methanation or downstream conversion) is more expensive but yields more versatile / higher value products.	Around 12 urban centres with population >30,000 could be converted. More than 500 kg/d of biogas per centre are estimated.
Wood pellet	None - Emerging market	Torrefaction enables production of more stable / higher value wood pellets (i.e., black pellets) as well as producing bio-syngas product.	5 -10 significant torrefaction facilities can be envisaged. More than 1,000 kg/d of bio-syngas per centre are estimated.

### 3.3 Bio-methane sourcing

Bio-methane can be used to directly substitute natural gas, so is therefore an attractive proposition for carbon emission reduction within wider natural gas network or industries. It is included for completeness in this report.

Bio-methane can be produced from biogas via traditional gas treatment processing to remove pollutants and excess carbon dioxide, so the sourcing is simply biogas plus an upgrading step.

Bio-methane / eMethane can also be produced through the Sabatier process which reacts carbon dioxide and hydrogen across a catalyst to produce methane and water, conceivably a large renewable power resource could be utilised to manufacture bio-methane / eMethane from carbon sequestered from the air and hydrogen produced from an electrolyser. Both of which only require power and/or water as a feedstock. For the purposes of this report, we do not consider that bio-methane sourced via the Sabatier process for the purposes of producing LPG to be a cost effective approach to renewable LPG.

### 3.4 Reforming

Irrespective of the nature and source of the methane or the selected downstream route the feed gas generally needs conversion to syngas in a syngas generation step.

Generally, all the different reforming unit permutations rely on one or a combination of the following units:

- Steam Methane Reformer (SMR)
- AutoThermal Reformer (ATR)
- Gas Heated Reformer (GHR)
- Heat Exchange Reformer
- Pre-Reformer
- Compact / Bayonet reformer
- Electric reformer

Typically, for smaller capacity syngas generation (capacity of less than 500 MTPD of plant feed) the use of an SMR only option is favourable. This design decision is driven by the commonly accepted optimum trade-off between CAPEX vs. process plant efficiency. SMRs provide a higher efficiency design than a cheaper heat exchange or compact reformer unit would be able to achieve. The high cost of an additional ASU unit negates the efficiency benefits of either ATR or combined reformer unit (either SMR+ATR or GHR+ATR) and these designs are not practical at the small scales required.

However, two issues are worth taking into consideration with regards to the use of SMR only for syngas generation for LPG/DME production:

- Process performance of SMR based plants
- Different SMR designs available from the technology providers

The first issue, which applies to all SMR processes, is the suitability of SMR produced syngas and the methane slip through the SMR reaction tubes. SMR syngas is typically hydrogen rich and suitable for the requirements of liquid fuel production processes, such as Fisher-Tropsch (F-T) chemistry and methanol/DME synthesis reactions.

In reality, F-T and methanol/DME synthesis all benefit from a slight hydrogen excess, so the actual hydrogen to carbon oxides range depend on the choice of process, catalyst and reactor design.

The second issue is related to the required capacity. From a technology basis there are minimal restrictions on the selection of the various SMR designs. However, the selected design may be influenced by the practices and requirements of the downstream technology licensors, and their suitability in their selected plant design for the required capacity.

Investigation of electric reformers is also underway by several parties, such as Haldor Topsoe<sup>10</sup> and the Gas Technology Institute<sup>11</sup>. The use of an electrical sourcing method for bio-syngas would improve the overall system conversion of feedstock, as no gas would be required for fuel and could improve the overall carbon efficiency of the process, assuming a green electricity supply. However, no such commercial offerings of electric reformers are available, but are expected to appear within 5 years.

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<sup>10</sup> <https://www.greencarcongress.com/2019/05/20190524-e-smr.html>

<sup>11</sup> <https://www.energy.gov/sites/default/files/2021-04/beto-34-peer-review-2021-sdi-marker.pdf>

## 4. 2<sup>nd</sup> 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.

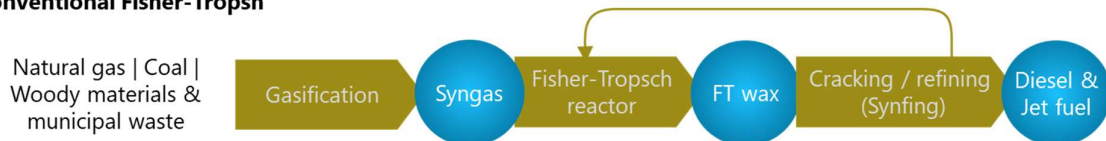
The production pathways that we considered in this chapter are:

1. Short chain Fisher-Tropsch (F-T)
2. Alternative thermochemical conversion
3. Non-thermal plasma
4. Biological conversion.

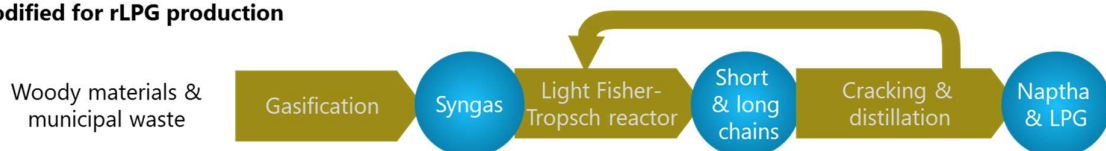
### 4.1 Short chain Fisher-Tropsch

The technology and processes for converting municipal solid waste (MSW) into low-carbon transportation fuels via the Fischer-Tropsch process is well understood with a number of developments world-wide aimed at commercial demonstration. The technology for converting biomass to F-T waxes is a burgeoning application, with the likes of Fulcrum and Redrock Biofuels operating commercial scale plants targeting jet and diesel fuels<sup>12</sup>. The Fischer-Tropsch process polymerises syngas molecules to build long chain hydrocarbon molecules which are then cracked to predominantly yield diesel and jet fuel. The concepts involved in modifying this process to enable short chain hydrocarbon production (i.e., LPG liquids) is summarised below.

#### Conventional Fisher-Tropsch



#### Modified for rLPG production



Fischer-Tropsch technology was developed to yield higher order liquid fuels from large scale resources. Modifying this technology to achieve LPG yield at small scale has significant challenges, such as:

- There has been minimal research into optimising the catalyst to produce the short chain length that is required for LPG.
- Producing LPG range short chain lengths will considerably increase the amount of methanation and CO<sub>2</sub> per pass (i.e., side reactions), which then consume energy and require recycle.

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



- The recycle of methane and CO<sub>2</sub> reduces conversion efficiency and increases equipment sizes i.e., more CAPEX and OPEX per tonne of product.
- It may take more than a decade to modify the process to suit LPG yield.
- F-T is high temperature exothermic process and there is the need for heat integration and ideally steam raising to cool the process. This level of plant complexity is difficult to deploy cost effectively at small scale.
- The market value of diesel and jet fuel is much greater than LPG, hence can offset costs more readily.

For the reasons above, it is unlikely that small to medium scale F-T to produce rLPG will occur in the medium term. It is more likely that any rLPG which is produced via F-T is done as part of a larger biorefinery type project which produces a large slate of renewable liquid products for which LPG is a co-product rather than a primary product – refer to 3<sup>rd</sup> generation technologies in the “Pathway to 70/100% renewable LPG” report.

Emerging technologies in this space, that we reviewed were of interest in a New Zealand context are summarised below. Brief descriptions of technologies that were reviewed, but not appropriate for the NZ context are provided in Appendix B.

#### **4.1.1 Cool GTL by GTI**

The Cool GTL process developed by GTI is a mature technology that converts biogas to higher hydrocarbons<sup>13</sup>. The process reforms the carbon dioxide and methane in the biogas into a syngas mixture that is fed to a Fisher-Tropsch reactor. GTI promote Cool GTL with the incorporation of an electric reformer (that they are developing) which improves overall feedstock efficiency. Discussion with GTI suggest they are nearing commercial demonstration of an electric reformer at the 1 ton of biogas/day scale.

F-T 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 which reduces the need for significant recycle and additional equipment.

In and of itself, the Cool GTL is not relevant to LPG, however their smaller target scale and the use of an electric reformer are notable for the intended New Zealand application.

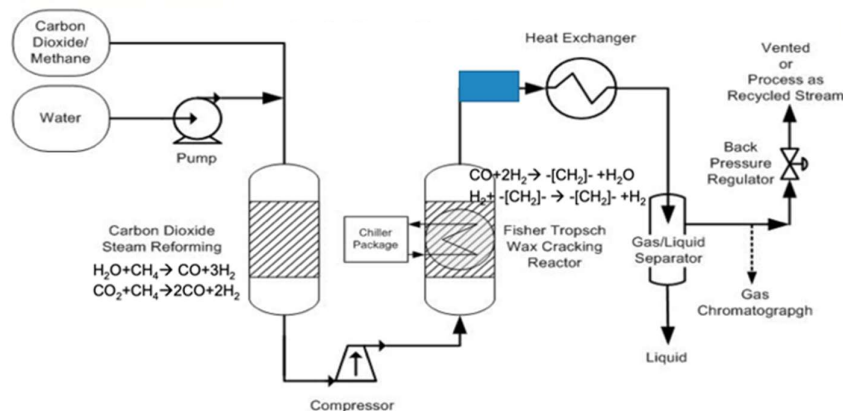
GTI have leveraged their Cool GTL pathway to begin development of a technology to produce LPG - see Cool LPG process discussion below.

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<sup>13</sup> <https://www.gti.energy/cool-gtl-a-low-cost-system-for-converting-co2-rich-natural-gas-to-fungible-liquids/>



Figure 5 - Cool GTL schematic



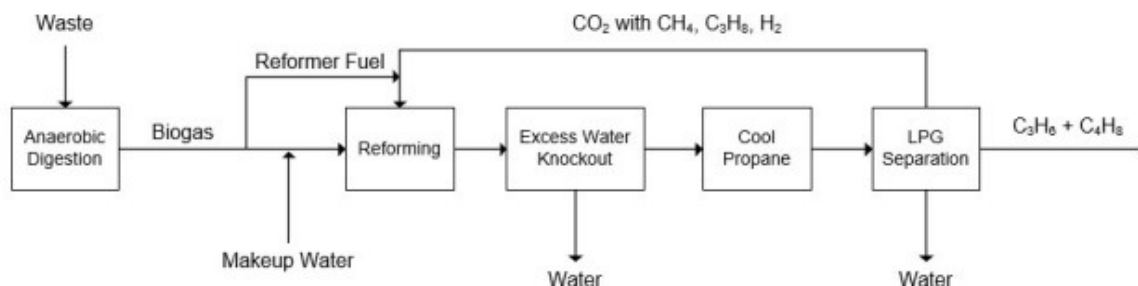
## 4.2 Alternative thermochemical conversion

There are a few emerging technologies that take biogas through to liquid fuels, LPG included. Examples are provided below.

### 4.2.1 Cool LPG by GTI

As mentioned above, GTI has developed a process called Cool LPG that converts biogas to propane and butane, without the requirement to strip the CO<sub>2</sub> out of the biogas<sup>14</sup>. The process, per Figure 6, reforms the biogas feed to syngas, prior to undertaking a novel methanol mediated synthesis reaction which produces propane and butane. We see value in this pathway as they utilise the CO<sub>2</sub> associated with biogas directly.

Figure 6 - Simplified process diagram of AD + Cool Propane process for converting waste (MSW,



The approach is similar to an integrated methanol synthesis + MTO route but produces a mixture of mostly propane and butane for fuel rather than separated olefins for use as a chemical feedstock. Because it is one of the only routes specifically targeting propane and butane, this is a promising technology for LPG production within the context of this Report.

Worley have opened discussion with GTI and their partner BioLPG, LLC and have an NDA in place to further assess this technology development. We consider this technology as a highly promising pathway to renewable LPG, their intended scale and biogas feedstock are of particular relevance to the New Zealand target application.

<sup>14</sup> GTI Project 22730 Production of BioLPG in Africa: Final Report

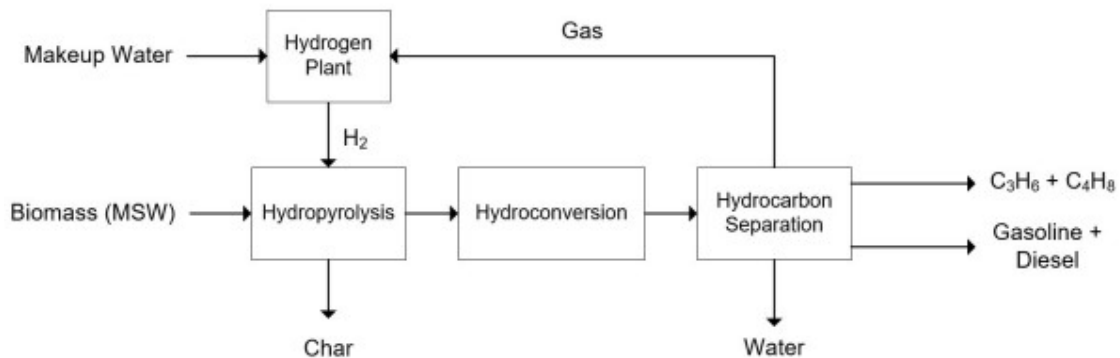
As part of their report “GTI Project 22730 Production of BioLPG in Africa: Final Report”, GTI completed high level economic analysis which proposes a levelized cost of LPG at between 551 and 432 USD/ton for 5 to 25 ktpa plants respectively. These economics were based on an assumed zero cost of a municipal solid waste feedstock which is anaerobically digested to produce the requisite biogas feedstock. GTI estimate the plant cost at 23 and 86 million USD for the same 5 and 25 ktpa plants respectively.

#### 4.2.2 Shell IH<sup>2</sup>

Originally developed by GTI and now licensed to Shell, the IH<sup>2</sup> process convert biomass via an integrated Hydro-pyrolysis and Hydro-conversion process to Gasoline / Diesel as well as LPG. The IH<sup>2</sup> process uses a hydrogen fed catalytic pyrolysis reactor to produce hydrocarbon via a pyrolysis oil intermediate, it then upgrades those hydrocarbons to meet the required specification via traditional refinery hydrotreating processes.<sup>15</sup>

IH<sup>2</sup> is of particular interest as it produces LPG as a direct product without additional upgrading. GTI report that the IH<sup>2</sup> technology for conversion of biomass produces biogenic liquid yields of around 40% by mass of waste feed. Gasoline is the intended target product, however when tuned for LPG production, product splits approaching 50/50 LPG and gasoline are suggested. Water and electricity is required to produce the hydrogen for the hydro-pyrolysis step. Electricity could be sourced from renewable electricity to improve the overall emissions profile. A 5 tonne per day demonstration plant in India is currently nearing operation, with plans to scale the process up to 2,000 tonne per day commercial plants.<sup>16</sup>

Figure 7 - Simplified process diagram for IH<sup>2</sup> MSW to gasoline and LPG process



In the same report that the Cool LPG economics were produced, GTI presented similar values for the IH<sup>2</sup> process, a levelized cost of LPG with a similar zero cost municipal solid waste feedstock is stated as 1,418 to 500 USD per ton for a 5 and 25 ktpa (LPG) plant respectively. The installed plant cost was estimated at 72 and 188 million USD for the same 5 and 25 ktpa plants respectively. Note that the plants themselves would also produce a significant volume of gasoline.

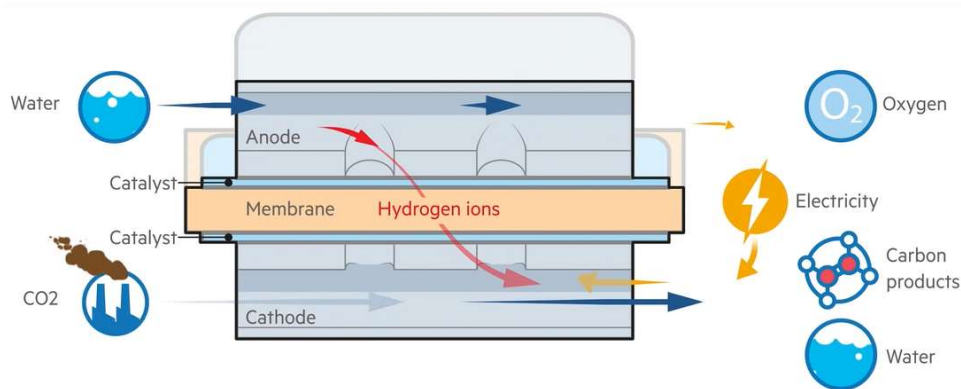
<sup>15</sup> GTI. Refinery Upgrading of Hydro-pyrolysis Oil from Biomass; Des Plaines, IL, 2015

<sup>16</sup> GTI Project 22730 Production of BioLPG in Africa: Final Report

#### 4.2.3 Twelve

A novel process of converting CO<sub>2</sub> and water directly to CO has been developed by the start-up Twelve. Their process is similar to a hydrogen electrolyser except CO is produced along with hydrogen from a feed of CO<sub>2</sub> and water. This method of producing CO and hydrogen directly is effectively creating syngas from air and water, rather than some other carbon source. A yield of 1 ton of CO from 1.6 ton of CO<sub>2</sub> are claimed by Twelve. They are currently at lab scale, however they have received significant funding.<sup>17</sup>

Figure 8 - Twelve process



#### 4.2.4 General commentary

There are numerous processes in the development stage, whilst there is a strong possibility one or more of these technologies will be reliable, efficient and economically viable, this is for the future. Process development and commercialisation is difficult and time-consuming. Every stage of the process has to be optimised and have a design specification developed. Each catalyst transformation needs catalyst development to ensure that the catalyst has the required performance life and that it can be manufactured at large scale whilst keeping the costs at required levels. These steps are time consuming and typically take years. It is possible to short-cut these process development steps although this will introduce risks, which the development process is aimed at reducing.

Notably, several examples of direct LPG synthesis from syngas have been observed or posited in the university space, however no significant commercial progress has been demonstrated.

Of the routes in development one of the more interesting routes is a syngas to ethanol to LPG route. The challenge to overcome is the economics of converting a liquid fuel (ethanol) to a liquid fuel (LPG). The value of fuel is linked to calorific value and the conversion of ethanol to LPG means removing the oxygen as water, so a significant proportion of the feed is lost.

### 4.3 Non-thermal plasma pathways

#### 4.3.1 Methane to LPG direct

Direct methane coupling is considered to be a major goal for future natural gas use. It has been the focus of intensive research over the past decades. The ability to go from CH<sub>4</sub> to C<sub>2</sub>+ and thus add significant value in

<sup>17</sup> <https://channels.ft.com/en/ft-energy-source/how-to-build-an-artificial-tree/>

a single step is highly desirable. However, this has not been commercially achieved. Technological problems include low yield, harsh reaction conditions and coke generation.

The notable exception to this is non-thermal plasma conversion technology. This has a strong foundation of lab-scale data for technologies such as dielectric barrier discharge (DBD) and there are several start-ups (notably - Alkcon, PlasMerica) with processes that can directly couple CH<sub>4</sub> to propane and butane (as well as other C<sub>2</sub>-C<sub>4</sub> products). A technological issue with plasma technologies such as DBD is that of scaling up, due to the limitations in physical distance between the electrodes. Process scaling is therefore expected to be modular with linear cost, and therefore increasingly uncompetitive with non-linear scale efficiencies as the scale increases. The largest module currently targeted by Alkcon is 32 tonnes per week (i.e. 1.6 ktpa) of propane output which equates to a methane feedstock of approximately 8,200 m<sup>3</sup>/d (or 13,600 m<sup>3</sup>/d biogas at 60% methane content)<sup>18</sup>.

While non-thermal plasma technology still requires an additional level of investment to demonstrate it beyond the lab scale, it may be an attractive long-term solution for decentralised conversion of biogas to LPG, at scales that are not economic for small scale syngas-mediated routes. The intended containerised form factor is also attractive to a New Zealand application, where renewable electricity is plentiful and the feedstocks relatively distributed.

#### **4.3.2 Technology status**

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

##### **4.3.2.1 PlasMerica**

PlasMerica are intending to utilise a plasma process to upgrade otherwise non-economic pockets of short chain gaseous hydrocarbons to longer chain liquid hydrocarbons. The primary target being oilfield associated gas which is otherwise flared on site, however they envisage a modular or containerised type process plant which could be mobilised to any location and supplied with any gas feedstock.

The process is a single step, non-catalytic upgrading process, the chain length of the products generally depend on the nature of the feed, however methane through to propane is the early target. They state that saturated hydrocarbons are formed preferentially, so there is no benzene or aromatic by-product. A potentially useful by-product however is non trivial volumes of hydrogen, due to the nature of the process where hydrogen is removed from the methane molecule and not required in the formation of propane or butane in the product.

They state their process as technical readiness level 5/6, with field trials intended for Q3 2022. They are targeting a 250,000 scfd (~7,000 Sm<sup>3</sup>/d) plant producing around 3,500 kg/d (i.e. 1.3 ktpa) of propane. As of Q3 2021, they had not investigated feeding biogas directly, so had no advice on the impact of the significant CO<sub>2</sub> quantity within biogas, however they are continuing investigation. The plasma process is generally known to consume significant quantities of electricity, and PlasMerica did not share their efficiency with Worley, however this requirement must not be understated<sup>19</sup>.

Their targeted scale is at a level which would be suitable for the utilisation of a smaller bio resource cluster.

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<sup>18</sup> <https://www.alkcon.com/mp32k-gas-processor/>

<sup>19</sup> Personal discussion with Plasmerica 17/09/2021 – D. Manning, J. Pellizzon.

We anticipate that they might be ready to start a commercial plant within the next 5 years.

#### **4.3.2.2 Alkcon**

Alkcon are purportedly also targeting a similar containerised plasma process for upgrading methane to propane, however at this stage they appear to have made no public progress since circa 2015. For the purposes of this report, we consider them defunct.

### **4.4 Biological pathways**

#### **4.4.1 Sugar fermentation**

The most widely used biological pathway is the production of ethanol from both sugars, starches, and woody biomass. This is a commercially proven route and it used extensively to produce millions of litres of ethanol for use in gasoline blending across the world.

Other promising routes are the transformation bioethanol and to LPG. Similar to what is outlined in Section 4.2.4 this is a difficult process as the catalyst and process is complicated, value added by converting a liquid fuel to a liquid fuel is minimal and process economics are unfavourable relative to other routes. Bioethanol to DME is similar to bioethanol to LPG with the same challenges.

New Zealand currently lacks any significant available feedstock for this pathway. We consider that the commercial development of sugar crops for fuel is highly unlikely for New Zealand. However other ethanol production pathways may be used to produce that as a feedstock for some other process.

#### **4.4.2 Syngas and lignocellulosic fermentation**

Syngas and lignocellulosic fermentations are niche pathways which were addressed in the "Pathway to 70/100% renewable LPG" report and are not sufficiently prospective to justify further comment in this report.

## 5. 2<sup>nd</sup> generation “blend component” rDME pathways

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)<sup>20</sup>, is both technically feasible and an emergent commercial prospect.

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. The use of rDME as blend stock is facing hurdles globally, with many interested parties.

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 commercialisation<sup>21</sup>. The direct DME synthesis process offers a significantly improved conversion per pass of syngas to DME and thus potentially improved economics.

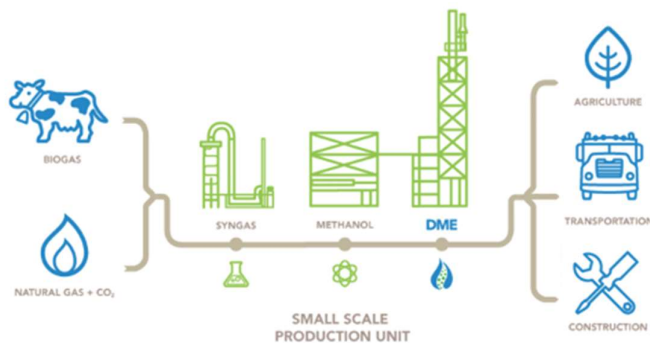
### 5.1.1 Technology status

Below are brief descriptions of projects that represent potential viable routes, once fully proven or re-established.

#### 5.1.1.1 Oberon

Oberon is converting waste methanol into rDME at its upgraded facility in Brawley, California. The methanol is an intermediate product which can be converted to rDME, it is the first time this feedstock has been used to make rDME at commercial scale. They are targeting a more conventional gas to liquids process via feedstocks of biogas from dairy waste, food wastes, agricultural waste, or even excess electricity and CO<sub>2</sub>, all of which result in ultra-low carbon to carbon negative rDME.<sup>22</sup>

Figure 9 - Oberon Fuels - Biogas to DME schematic



<sup>20</sup> T.H. Fleisch et al. / Journal of Natural Gas Science and Engineering 9 (2012) 94e107

<sup>21</sup> Marco Tomatisa, A life cycle analysis (LCA)-based case study in China, Fuel 254 (2019) 115627

<sup>22</sup> <https://oberonfuels.com/technology/oberon-process/>

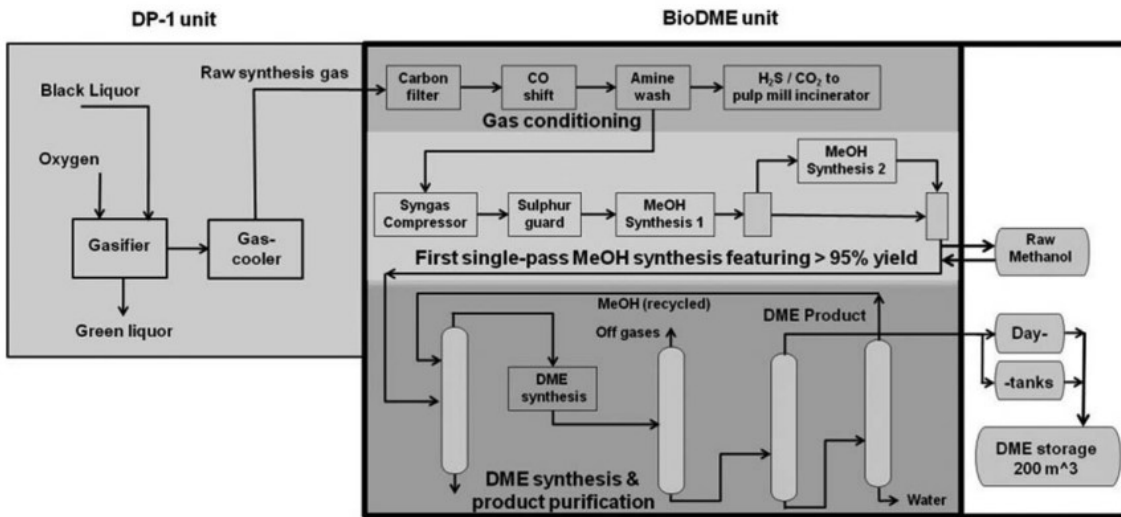
The company's modular designed plants are intended to be deployed to remote industrial operations in order to monetize waste CO<sub>2</sub> streams or alternatively biogas (up to 50% CO<sub>2</sub>). Example waste streams include pulp mill wastes and dairy farm effluent. The company has a deal with Suburban Propane (one of the largest US LPG companies) to supply rDME for blending with propane for autogas. Suburban have taken up a 39% shareholding in Oberon. Standard plants are sized to produce 2.7 – 15 ktpa of rDME (from 15,000 to 40,000 cows), which is 1.7 - 9 ktpa rLPG equivalent.

### 5.1.1.2 Chemrec / Lulea University of Technology

A plant which processed black liquor, a by-product of the pulp and paper industry, through to DME was manufactured by Chemrec and then passed on to Lulea University of Technology. The process was to first gasify the black liquor to syngas, convert to methanol, and then synthesise DME. The backend of the process is similar to indirect DME production, the plant itself was novel in that it produced bioDME (rDME) from the black liquor by-product. The plant ran for several years without significant issue.<sup>23</sup>

The methanol and DME synthesis process for the Chemrec plant are Haldor Topsoe licensed technologies.

Figure 10 - Block diagram of DP-1 BL gasification unit and BioDME syngas conversion unit



### 5.1.1.3 SHV / KEW

SHV Energy and KEW Technology, a pioneering UK sustainable energy solutions company, have formed a joint venture (Circular Fuels) to develop rDME production plants. This strategic collaboration will demonstrate the viability of converting renewable and recycled carbon feedstock into renewable liquid gas.

KEW's proprietary "advanced thermal conversion" technology will be used to produce renewable DME by processing a wide range of waste, bio-based and residue feedstocks with high efficiency. SHV Energy, KEW and SHV Energy subsidiary Calor Gas have been working closely together for over a year on a FEED (Front-End Engineering Design) study for the first-of-a-kind plant which will be located in the UK. The plant will have a production capacity of 50 ktpa of rDME from municipal solid waste.

<sup>23</sup> Landalv et al. - 2014 - Two years experience of the BioDME project - A complete wood to wheel concept



Subsequent plants will be located across Europe and North America. The parties anticipate the development of up to 6 production plants within the next 5 years, targeting a total production capacity of 300 kilotons of rDME per year by 2027.

#### **5.1.1.4 Haldor Topsoe**

Haldor Topsoe represent a mature technology developer and licensor, who, at the time of writing do not appear to be actively pursuing novel rDME pathways. They could easily pair their DME synthesis technology with some renewably sourced biogas feed in order to produce rDME, similar to the Chemrec black liquor plant. This commentary is also relevant to other similarly mature technology suppliers.

#### **5.1.1.5 JFE Holdings**

Japan's JFE Holdings demonstrated at a commercial scale direct DME from natural gas, however the plant has since been shut down and no further plants have been developed on the same technology. It is assumed that the economics were unattractive hence the lack of progress, however shifting global trends may make the direct DME production a credible pathway.

#### **5.1.1.6 Korea Gas**

KOGAS (Korea Gas) proposed the construction of a 300 ktpa DME synthesis plant in circa 2011<sup>24</sup>, they proposed a 'one step' process which we consider as a direct DME process. The feedstock would have been natural gas, and the technology was considered sound enough to justify a plant of such scale. As of 2017 the plant was still in the planning stage, and as of the writing of this Report, it is unknown whether it has progressed.<sup>25</sup>

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<sup>24</sup> <https://www.businesswire.com/news/home/20110209005232/en/Korea-Gas-to-Build-a-300000-Tons-Per-Year-Dimethyl-Ether-DME-Plant>

<sup>25</sup> <https://store.globaldata.com/report/gd-130167--kogas-jubail-dimethyl-ether-plant-saudi-arabia/>

## 6. Conclusions

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In the short term (<2 years), the regulatory position on the use of biofuels and the use of rDME as a blend must be clarified. Global interest in both DME and rDME as an LPG blend suggests that there will be significant effort will be put into overcoming the blending hurdles. This will be a challenge, but it is something that any new fuel, renewable or otherwise, would need to overcome prior to entering the market and New Zealand is in a good position to leverage from global developments.

The technology for the production of rLPG is immature, with only a few technology vendors with promising pathways. Post technology readiness, the advancement of the rLPG pathway requires access to sizable volumes of low-cost renewable feedstocks and ensuring the that the end product has higher value return that competing use for this feedstock. The processes for producing rLPG are promising but are a few years away from commercial reality. A continued engagement with GTI and PlasMerica on their rLPG production processes, as well as a broad market observation for any new emerging players is highly prudent.

The technology for the production of DME or rDME is relatively mature, with many technology vendors available to provide a process license for DME. The advancement of the rDME pathway as an LPG blend stock (rather than a direct fuel) requires the development of smaller scale projects which can gain access to low cost renewable feedstock and cap production at less that ~20% of the regional LPG demand. It is noted that there may be competition for the rDME and intermediary products (e.g., methanol) by other sectors.

Increasing interest in biogas production will mean that there will be competition for the requisite feedstocks, this will likely be more prevalent in the North Island where a natural gas network exists, and biogas could be upgraded and injected as a means of decarbonising natural gas. However, in the South Island, there is no natural gas infrastructure and many LPG users. Capturing some of the stranded biogas potential of the South Island to produce distributable fuel, has natural attraction for rLPG / rDME capacity development.

The global trends in recent years towards 'green' fuel production, suggests that 3<sup>rd</sup> generation technologies (e.g., softwood to fuel) are likely to be realised prior to 2030. This pathway to LPG production is considered in the "Pathway to 70/100% renewable LPG" report and is still on the horizon.

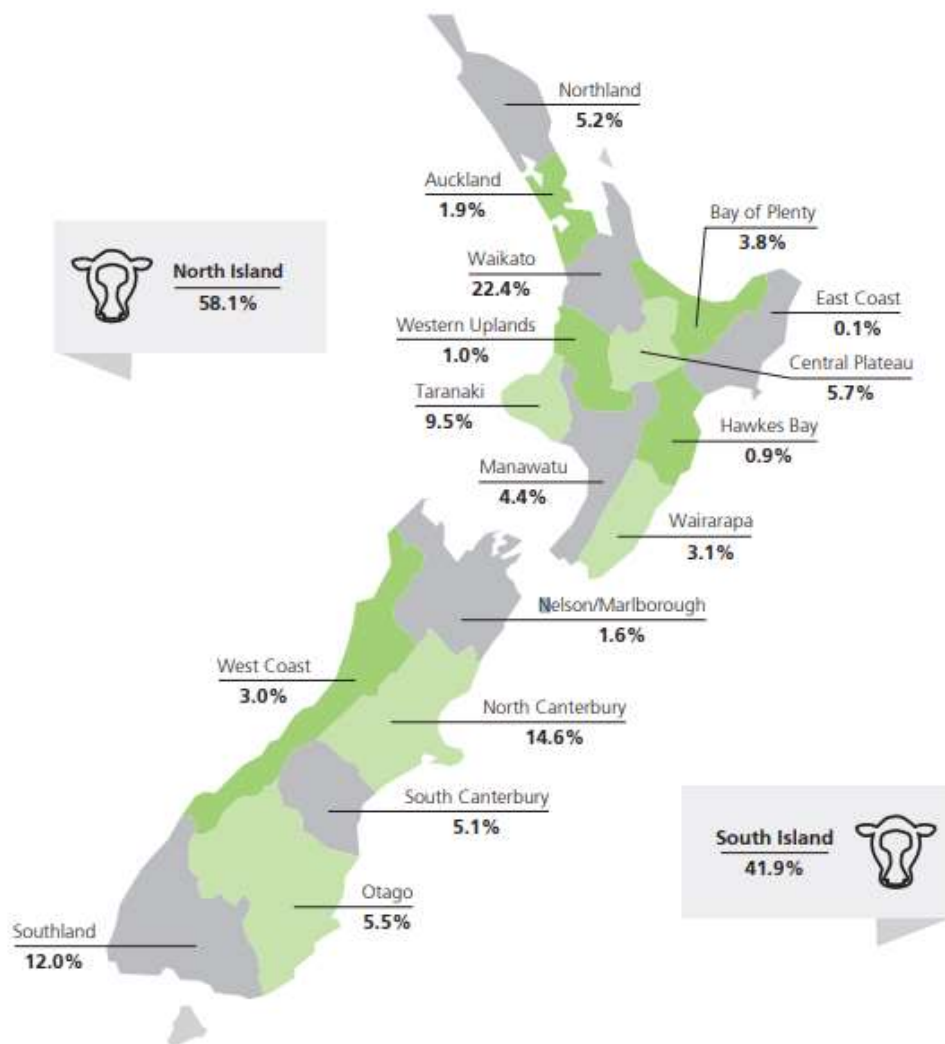
Recognising that North Canterbury distributes to a large number of LPG users and has access to a large volume of biomass resources (dairy, food waste, residues, MSW, etc), this area could be a target for the development of a biogas / bio-syngas cluster, which could then be commercialised as: rLPG, rDME, or an alcohol intermediary.

## Appendix A – Dairy farm case study

Recovery of manure and wastewater from dairy sheds in New Zealand presents an interesting opportunity for biogas generation, largely due to the widespread nature of dairy cattle. With approximately 5 million head of dairy cow generating around 5,500 ktpa of manure.

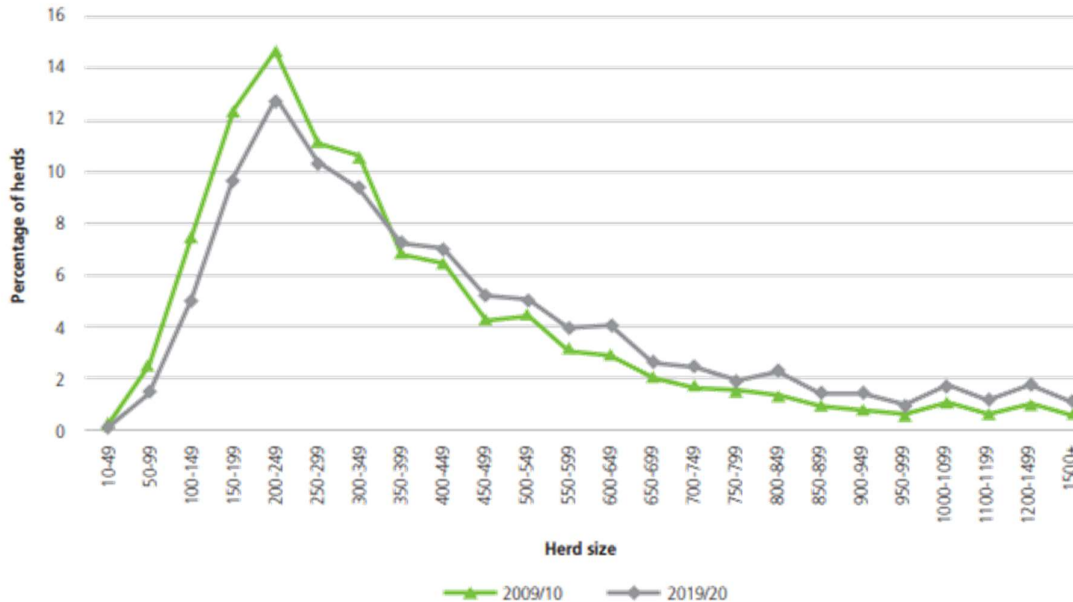
As illustrated in Figures 11,12, & 13, the national average herd size is 440 cows, with more than 600 farms having more than 1000 head. The majority of herds (71.4%) are in the North Island, however only 58% of dairy cows are in the North Island.<sup>26</sup>

Figure 11 - Regional distribution of dairy cows in 2019/20



<sup>26</sup> New Zealand Dairy Statistics 2019-20 – Livestock Improvement Corporation / Dairy NZ

Figure 12 - Herd size distribution for 2019/20 compared with 2009/10



Generally, recovery of manure from dairy farms is poor, as New Zealand widely utilises paddock grazing and shed based milking, the opportunity for recovery is only the time in which cows are in the shed. Widely regarded as one hour milkings twice daily, therefore only 8.5% of manure is available for easy recovery. Utilisation of feed lots or covered housing of cows would increase time on hard standing and improve manure recovery, however this practice is counter to the “clean, green” image and may have social license implications. In some locations internationally, recovery of manure can approach 40 – 50% on farms which house the animals rather than paddock grazing.

In order to utilise dairy waste for use as a feedstock, multiple farms would need to be aggregated to produce a sizeable feedstock. Given the average farm size of 440 cows, we consider that aggregation of 5000 cows or 2000 cows with higher manure recovery (~25%), could produce ~1,200 Sm<sup>3</sup>/d of (800 kg/d methane).

Figure 13 - Herd analysis by region in 2019/20

Farming region	Total herds	Percentage of herds	Total cows	Percentage of cows	Total effective hectares	Percentage of effective hectares	Average herd size	Average effective hectares	Average cows per hectare
Northland	793	7.1	258,292	5.2	113,445	6.6	326	143	2.28
Auckland	338	3.0	95,806	1.9	39,178	2.3	283	116	2.45
Waikato	3,184	28.5	1,104,097	22.4	377,739	21.8	347	119	2.92
Bay of Plenty	524	4.7	185,461	3.8	65,851	3.8	354	126	2.82
Central Plateau	482	4.3	280,462	5.7	103,556	6.0	582	215	2.71
Western Uplands	87	0.8	46,958	1.0	18,046	1.0	540	207	2.60
East Coast	9	0.1	6,022	0.1	2,155	0.1	669	239	2.79
Hawkes Bay	69	0.6	45,516	0.9	15,940	0.9	660	231	2.86
Taranaki	1,568	14.0	467,761	9.5	168,154	9.7	298	107	2.78
Manawatu	522	4.7	214,293	4.4	81,392	4.7	411	156	2.63
Wairarapa	403	3.6	152,420	3.1	57,032	3.3	378	142	2.67
<b>North Island</b>	<b>7,979</b>	<b>71.4</b>	<b>2,857,088</b>	<b>58.1</b>	<b>1,042,489</b>	<b>60.2</b>	<b>358</b>	<b>131</b>	<b>2.74</b>
Nelson/Marlborough	209	1.9	79,963	1.6	28,543	1.6	383	137	2.80
West Coast	363	3.2	150,040	3.0	68,725	4.0	413	189	2.18
North Canterbury	883	7.9	719,289	14.6	206,790	12.0	815	234	3.48
South Canterbury	318	2.8	252,197	5.1	73,668	4.3	793	232	3.42
Otago	445	4.0	271,347	5.5	92,042	5.3	610	207	2.95
Southland	982	8.8	591,623	12.0	218,117	12.6	602	222	2.71
<b>South Island</b>	<b>3,200</b>	<b>28.6</b>	<b>2,064,459</b>	<b>41.9</b>	<b>687,886</b>	<b>39.8</b>	<b>645</b>	<b>215</b>	<b>3.00</b>
<b>New Zealand</b>	<b>11,179</b>		<b>4,921,548</b>		<b>1,730,375</b>		<b>440</b>	<b>155</b>	<b>2.84</b>

## Appendix B – Other interesting technologies

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This section briefly covers a few of the burgeoning waste to fuel projects that were considered but ultimately were not relevant to this report. Fulcrum and Red Rock both produce fuels via F-T and provide useful general comments on scale but do not produce LPG and are not easily adapted.

### 6.1 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 fuel<sup>27</sup>. LPG is sometimes a side draw of traditional refinery processes, however it is usually consumed internal to the refinery as a fuel gas and without strong economic incentives it is difficult to see that changing as the fuel gas demand within the refinery would still need to be met if the LPG was removed as product.

### 6.2 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-synthetic natural gas (Bio-SNG). The facility is intended to convert 8 ktpa of waste into 22 GWh of pipeline gas each year<sup>28,29</sup>. The Advanced Biofuel Solutions process involves: Gasification; syngas clean-up; water shift to methane; CO<sub>2</sub> recovery; and natural gas grid injection.

### 6.3 Red Rock biofuel

The Red Rock biofuel technology platform converts waste woody biomass into low-carbon, renewable jet (SAF – sustainable aviation fuel) and diesel fuels<sup>30</sup>. 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 slate<sup>31</sup>. The same concerns around rLPG extraction as product applies to Red Rock biofuel as it did to Fulcrum.

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<sup>27</sup> <https://fulcrum-bioenergy.com/technology/our-feedstock/>

<sup>28</sup> <https://www.letsrecycle.com/news/latest-news/waste-to-gas-plant-revived-after-administration/>

<sup>29</sup> Advanced Biofuels, : <https://absi.tech/about-us>

<sup>30</sup> <https://www.redrockbio.com/technology/>

<sup>31</sup> Arno de Klerk , Fischer-Tropsch Refining, Thesis, Department of Chemical Engineering, University of Pretoria, February 2008