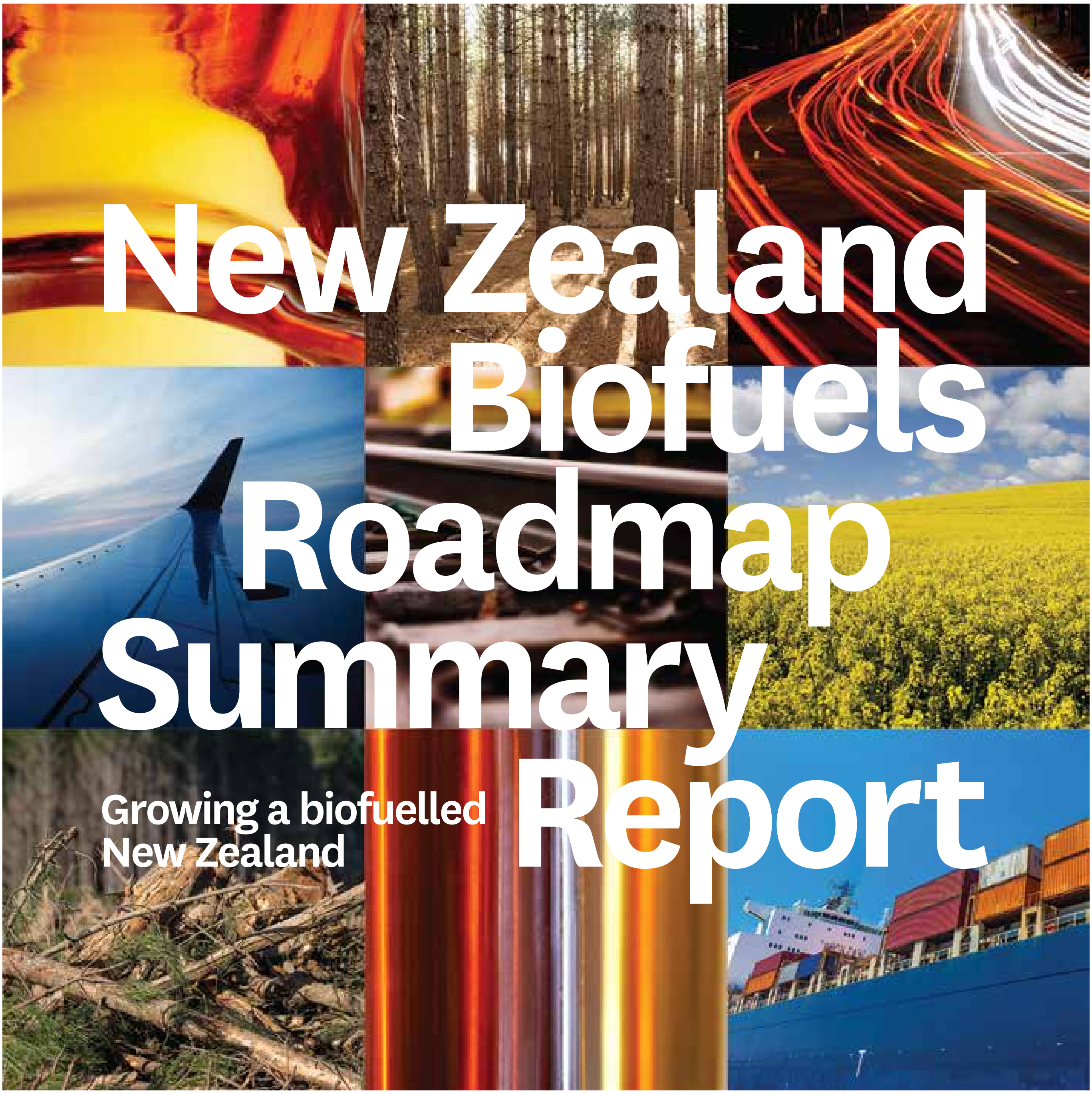

New Zealand Biofuels Roadmap Summary Report

Growing a biofuelled New Zealand

scion

NZBiofuelsRoadmap


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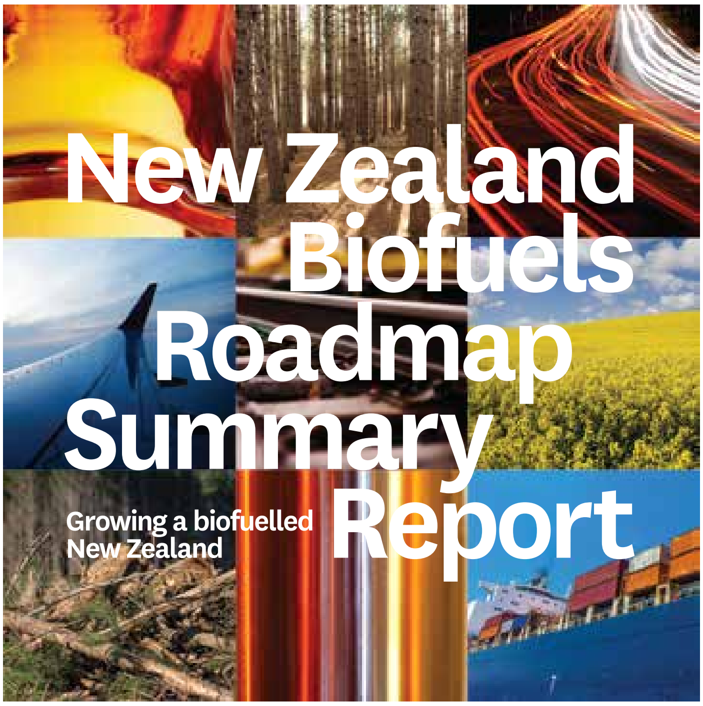

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- Ministry of Business, Innovation and Employment
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- NZ Post - Tukurau Aotearoa
- Oji Fibre Solutions
- Pure Advantage
- Sustainable Business Network
- Wood Processors and Manufacturers Association of New Zealand
- Z Energy

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Some or all of the contents of this document were produced based on the Energy Technologies Institute's Bioenergy Value Chain Model (BVCM).

The BVCM mathematical formulation was extended by Drs Nouri Samsatli (Samsatli Solutions) and Sheila Samsatli (Department of Chemical Engineering, University of Bath).

Contents

Foreword

To date, liquid biofuels have made a very minor contribution to transportation fuels in New Zealand, despite their extensive deployment in other parts of the world and fossil oil being responsible for 23% of our country's GHG emissions. Internationally, deployment has been largely driven by three key strategic drivers: climate change, energy security/independence and rural economic development. Currently all three drivers are very pertinent to New Zealand.

Consistent with one of Scion's four core purpose outcomes, "to increase renewable energy production and energy security by growing New Zealand's ability to produce sustainable bioenergy and liquid biofuel products," we have led a study to investigate what liquid biofuel options are best suited to New Zealand. This work builds on Scion's 2007-2009 Bioenergy Options for New Zealand study*, which evaluated the potential contribution of bioenergy to New Zealand's energy future by comparing technologies, biomass resource and regions and potential solutions and their implications in some depth. Scion (and international groups) also have extensive subsequent work on bioenergy, bioproducts and forestry.

Specifically, in this Roadmap we wanted to understand what a large-scale biofuels industry could look like here, for example:
- What currently available crops could we grow and where could we grow them?
- What currently available technologies to convert crops to liquid fuels could we use?
- Which liquid fuels should we be targeting as a priority?
- What are the key considerations and implications in developing such an industry?

Throughout this work our guiding principle has been to identify options for the 'good of New Zealand' rather than benefiting specific sectors.

We conducted an extensive modelling analysis using publically available data which has also been technically evaluated by industry. This included feedstock growth rates and conversion technology efficiencies and costs and has looked at the lowest cost feedstock and conversion options and their potential greenhouse gas emission reduction in future New Zealand supply chains. This quantitative scenario optimisation modelling was conducted using the UK Energy Technologies Institute's Bioenergy Value Chain Model after modification to make it suitable for New Zealand use. This model had previously been successfully used to assess and understand the prominent role bioenergy is playing in meeting the UK's greenhouse gas emission reduction targets, informing policy and legislation development on UK renewable energy.

We have also sought input from a host of different stakeholders including government departments and agencies, energy companies, forestry companies, pulp and paper companies, research organisations, Māori and others, for which I am extremely grateful. Through this engagement we gained an insight into diverse views on biofuels, highlighting stakeholder drivers and barriers to biofuels implementation in New Zealand.

We believe this study is a great starting point for an open and fact-based discussion around the New Zealand biofuels opportunities. We recognise that the information reported here is not an exhaustive study of all elements of a new biofuels industry and can envisage brownfields as well as greenfield options being considered. Clearly too, a large scale biofuels industry such as is considered here would have very significant impacts on the whole New Zealand economy and intended and unintended consequences would need to be fully evaluated. It is vitally important to fully understand, vigorously debate and eventually reach a national consensus on the future role biofuel deployment should play in decarbonising New Zealand and how best to go about achieving the desired outcomes before committing to any large scale implementation.

We hope this study will inform and catalyse such a debate.

This two year study has been supported by Scion's Strategic Science Investment Fund from the Ministry of Business, Innovation and Employment.

Dr Julian Elder
Chief Executive, Scion

* www.scionresearch.com/bioenergyoptions

Summary

New Zealand, if it has the will, can grow its way to a biofuelled transport future.

This country has the capability and capacity to sustainably grow plant materials to process into low greenhouse gas biofuels, and power heavy vehicles, aircraft and ships. These biofuels would substitute for fossil transport fuels now proven to contribute to global warming.

Crown Research Institute Scion has undertaken the New Zealand Biofuels Roadmap study and produced a technical report that outlines how biofuels could become a viable economic and environmentally optimal option for New Zealand. This study was based on extensive stakeholder conversations and feedback within the transport biofuels processing to distribution supply chain, and intensive computer modelling and scenario examination.

New Zealand Biofuels Roadmap: Growing a biofuelled New Zealand is a less technical report outlining the key messages, conclusions and suggested next steps from the study.

This report outlines the thinking that has gone into the Scion study, considerations around technologies and investment requirements, and the practical requirements of establishing an entirely new way to sustainably provide a large proportion of the country's liquid transport fuels.

Various possible biofuel substitution rates for fossil fuels were fed into a bioenergy model, along with different constraints, and the model was asked to outline the least-cost crop material options, locations, biofuel processing technologies and investment requirements to achieve a pre-determined level of biofuel output.

Three key messages revealed by the study and this Summary report are:

1. We can do this. Credible large-scale biofuel production and use routes exist for New Zealand, based on sustainably-produced feedstocks.
2. The opportunity has major national and regional implications, but biofuels could make a substantial contribution to meeting New Zealand's greenhouse gas (GHG) commitments and provide transport fuel independence.
3. National, strategic and corporate leadership is required to build a biofuel consensus and impetus to develop long-term planning and implementation to put all the components in place.

The modelling and discussions show that the development of a biofuels industry alone will not solve New Zealand's need to lower its greenhouse gas emissions. Biofuels are only part of the solution.

Increasing use of EVs (electric vehicles), particularly for private transportation, will strongly reduce demand for petrol in particular. But other, more difficult to decarbonise transportation such as trucks, ships and aircraft will still require liquid fuels. The domestic low-carbon production of diesel, marine fuel and aviation fuel as biofuels will be in the interest of the New Zealand economy, environment and international relations as the best long-term strategy.

The market alone will not bring about a biofuelled future for New Zealand. The level of forward-thinking, commitment and investment required means it is difficult for significant biofuel production to come into being without strong leadership to initiate and implement major components in a strategic national plan.

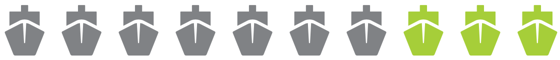
However, large-scale biofuel production and integration into the New Zealand economy cannot and would not happen spontaneously or on its own. Coordinated development and deployment around a shared biofuels strategy will need astute leadership. Both

cities and regions will have to be involved as important parts of this picture, in a plan bought into by all.

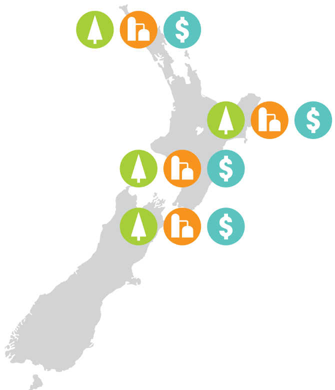
Wise government (with a small 'g') will be vital.

What would happen if 30% of the liquid fuels we use were made from plants grown on non-arable land by 2050?

We would reduce greenhouse gas emissions by 5 million tonnes per year, which is equivalent to taking half the cars in the country off the road.



We would be more energy independent cutting our oil imports by 30%.



Regional economies would grow as we plant feedstocks to turn into fuels at nearby processing plants.

Our goods and services would continue to have access to international markets.

With a forest the size of the Taranaki region, and processing as many logs onshore as we currently export, we could make 2.3 billion litres of liquid fuels annually. This is more than enough to meet all the South Island's needs for a year.

How the New Zealand Biofuels Roadmap study came about and what it means

Biomaterials and forest research institute, Scion took the initiative to consult with stakeholders in the potential liquid transport biofuel value chain and build a shared view around possible scenarios if the country wants to pursue a biofuel, low greenhouse gas future.

The Rotorua-based Crown Research Institute employed and adapted a bioenergy model previously used in the United Kingdom for New Zealand conditions. It asked the model to optimise the land use, crop requirements, processing and distribution requirements under different possible scenarios and constraints to show what would be required at a national and regional level to achieve certain levels of biofuel substitution for fossil-fuel derived transport fuels.

This modelling serves two very important functions:

- An underpinning logic and rationale for the conclusions and recommendations provided by this report.
- A means to further explore (if required) the consequences and requirements if New Zealand adopts a biofuel strategy and implementation.

Scion developed this robust and reusable tool on behalf of New Zealand to show how biofuels might be integrated into the nation’s transport fuel mix.

This summary report is a less-complicated version of the *New Zealand Biofuels Roadmap Technical Report* (technical report), which has a greater amount of explanation around the intensive modelling carried out to inform these conclusions. The technical report also acknowledges the sources of information used in the study. It is available at www.scionresearch.com/nzbiofuelsroadmap

New Zealand Inc, assuming it understands the ‘why’ of biofuels, now has a roadmap and pathway to comprehensively debate the how, who, where, what and when of feedstocks and processing - and the means to achieve different levels of greenhouse gas mitigation and transport fuel independence.

Findings from the New Zealand Biofuels Roadmap study

1. Credible large-scale biofuel production and use pathways exist for New Zealand. The country can, realistically, bring a biofuelled economy and environment into existence and general adoption.

2. Biofuels could be a large to very large longer term answer to meeting New Zealand's greenhouse gas reduction commitments. This is particularly so for sectors such as aviation, shipping and long-haul road freight, which are difficult to decarbonise through other means.

3. The biofuels opportunity is large-scale.
   - There are multiple ways to address issues raised.
   - Any solution must consider the whole value chain and its impact on other value chains.
   - Timing is important, especially at high fossil fuel substitution levels. This is particularly so if significant biomass quantities are to come from new forests - given the length of time required to grow such trees.
   - Decisions made now have a major long-term impact.

4. Biofuel production can provide strong regional economic development and employment growth.
   - Prominent biomass growing areas predicted by the model are Northland, East Coast and the central North Island. Biofuel conversion plants would generally be located close to where the feedstocks are grown.

5. Drop-in fuels (hydrocarbons functionally equivalent to fossil fuels) from non-food feedstocks, particularly forestry grown on non-arable land, look to be the most attractive longer-term opportunity for New Zealand.

6. Technologies for producing drop-in biofuels from non-food feedstocks are less developed than other technologies. But it is an area of intense global research and rapid development, so viable technologies are expected within the required timeframes. From that perspective, what is being advocated is not too technically risky.
   - Pyrolysis followed by upgrading appears to be particularly attractive for producing drop-in petrol, diesel, and marine fuels; but multiple options targeting all fuel types are being developed.

7. Government policy support will be required in the short to medium term to enable large-scale biofuel production to occur. Market forces alone will not be sufficient to initiate large-scale production.
   - Currently, fossil fuel and carbon prices are too low and the technical risks still high.
   - Stable long-term policies will be critical for required investment to occur.
   - Biofuel production costs will fall as technologies and the new value chain mature.

Next steps

Leadership is required now to build a national consensus on the future role biofuel deployment should play in decarbonising New Zealand. Key decisions are needed on:

1. Which fuel families and which specific biofuels we should be targeting.
2. Acceptable land and feedstocks for biofuel production.
3. The level of biofuel substitution required, and in what timeframe.
4. The best uses of biomass.

Once this national consensus is in place, an implementation plan must be developed. Critical to this will be:

1. National leadership to coordinate implementation.
2. National buy-in to the trade-offs required and 'biofuels done right'.
3. Alignment of different stakeholders, taking ownership for delivering each part of the value chain.
4. Strongly leveraging international learnings and experience.

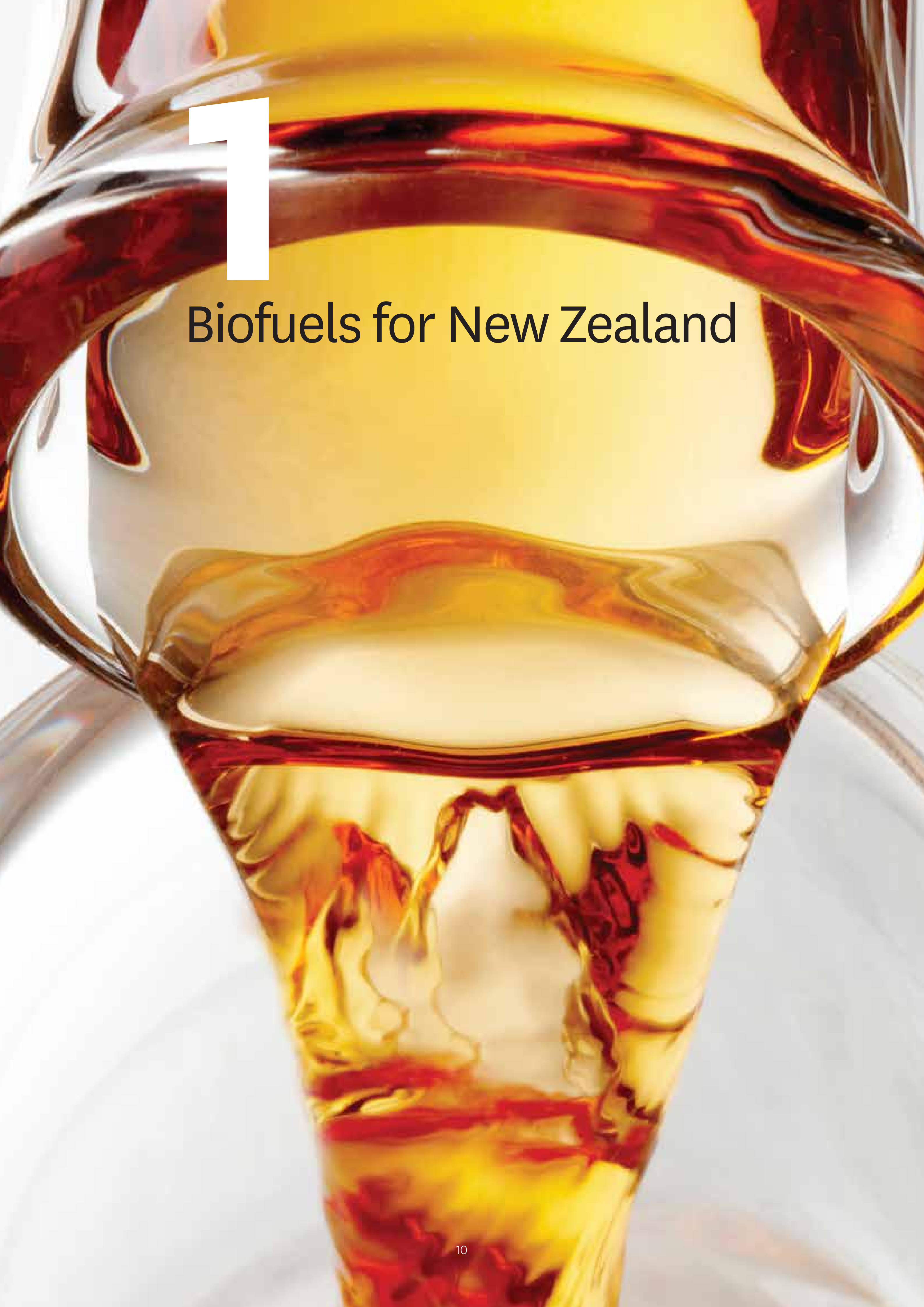
New Zealand needs to continue to explore short term niche opportunities to produce biofuels to start building momentum, provide early wins, create a positive perception of biofuels and develop New Zealand's regulatory environment.

If conventional forests are identified as the best feedstock option, planting needs to start soon to provide the large and sustainable supply of feedstock needed for future biofuels.

Further work is required to de-risk future options for rapid and large-scale biofuel implementation particularly to:

1. Increase our knowledge on the growth and suitability of energy crops such as miscanthus and willow in New Zealand
2. Develop new forestry options grown specifically for energy applications, and
3. Better understand the suitability of different conversion technologies to New Zealand feedstocks and fuel needs.

1 Biofuels for New Zealand



Why should New Zealand head towards a biofuelled future?

1. Being part of a global movement to lower greenhouse gas emissions

Liquid fuels drive the world and New Zealand economy.

However, transport fuels derived from fossil crude oil bring ancient, underground plant-stored carbon to the surface, which when burned in engines enters the atmosphere as carbon dioxide (CO_2). The concentration of CO_2 and other greenhouse gases (GHG) has sharply risen in the past 140 years (contributed to by burning fossil fuels, including coal) and is driving global warming.

Increases in the earth's temperature are affecting weather patterns, causing more extreme droughts, storms, floods and a rise in sea levels.

One way to reduce GHG emissions from liquid fuels is to produce them from sustainable renewable biological sources such as agricultural or forest crops. CO_2 captured from the atmosphere during these crops' growth, then burnt in an engine is considered to be low-carbon, reducing the contribution to global warming.

New Zealand consumed 8.6 billion litres of liquid fuels in 2015, equivalent to 5 litres a day for every one of the country's 4.6 million inhabitants. This combustion of fossil fuels represented about 23% of New Zealand's domestic GHG emissions in 2015, so reducing this use would have a major impact on an overall lowering of carbon emissions.

The production and use of biofuels is one way for New Zealand to carry out its part in reducing GHG emissions.

2. International commitments

As part of the Paris Agreement, New Zealand has committed to reduce GHG emissions by 30% over 2005 levels by 2030. New Zealand has since ratified the agreement on 4 October 2017.

These legally binding documents pledge New Zealand to mitigate its production and/or absorption of GHG in order to meet this country's stated part of global GHG reduction.

The country has both a legal and moral obligation to meet these commitments.

3. International market pressure

It is increasingly likely that, as sustainability becomes a given in world trade, market pressure will dictate that New Zealand exporters of goods and services (e.g. tourism) will be required to show a greatly reduced GHG footprint and move to low-carbon transport fuels.

Unless this country has clearly demonstrated low GHG transport fuel production it faces the risk of non-tariff barriers to entry in many markets.

4. Regional development

The regions recommended for greatest feedstock growth will receive a significant boost from being core parts of the biofuel infrastructure, particularly around jobs and economic advantage.

As a sustainable commercial enterprise, regions will have another secure economic base on which to also build other original businesses.

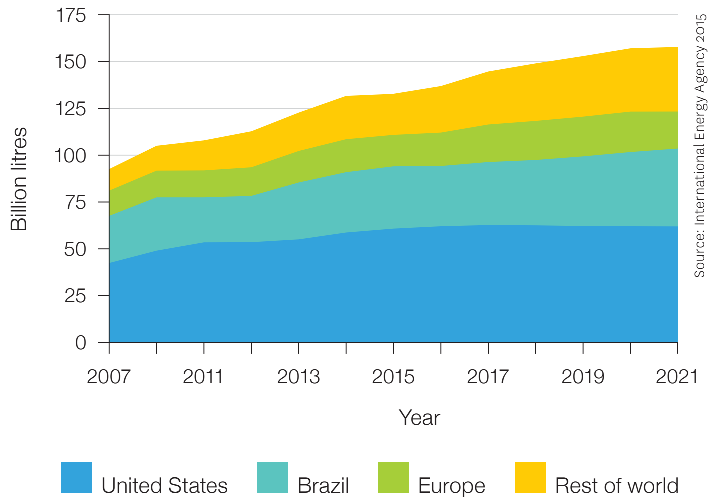
5. Energy independence

Growing a biofuelled future will generate independence from oil imports, totalling almost $5 billion in 2015.

The development of national (and hence international) competence in wood-based biofuel production will also be of economic importance.

What the rest of the world is doing in biofuel production

World liquid biofuel production, mostly for on-road use, has increased steadily over recent years and now accounts for about 4% of fuel for transport in 2015.



Global biofuel production.

The main liquid biofuels produced are bioethanol (74% of global production), biodiesel (22%) and renewable diesel (4%).

Bioethanol

- Normally, bioethanol is part of a petrol blend, though 100% bioethanol can be used in modified engines. Most is made by fermenting edible carbohydrates such as starch (from corn or wheat), or sugar (from sugarcane). Such bioethanol is generally referred to as conventional or first generation ethanol.

Biodiesel

- Produced by reacting vegetable oils or animal fats with methanol to produce a fatty acid methyl ester. Can be blended with fossil diesel, typically up to 7% for use in existing compression engines.

Renewable diesel

- Produced by reacting fats and waste oils with hydrogen.

- The first drop-in fuel because it is chemically very similar to fossil fuel diesel.
- However, there are limitations regarding the high cost and limited supply of the initial non-edible or waste fats or oils; and questions whether fuel should be produced from potential food crops such as canola.

Renewable jet fuel

- Made from fats and waste oils in the same way as renewable diesel.

Major global research is developing new biofuel routes from non-food feedstocks. This is focused mainly on using cellulose-based biomass such as agricultural and forest residues, forest and non-food energy crops, as well as municipal solid wastes and algae.

These feedstocks do not compete with food crops and can be grown on steeper or poorer quality land. They provide far greater opportunities for larger-scale biofuel production compared to edible carbohydrates or oils.

The first commercial cellulosic ethanol plants, converting lignocellulosic feedstocks such as corn stover and sugarcane bagasse into ethanol, have started to produce commercial quantities of bioethanol.

Drop-in biofuels, or hydrocarbon biofuels that can be blended with or completely replace current fossil fuels, are a second major focus of biofuel technology development.

They can be used in current vehicles without engine modifications, and utilise existing fuel infrastructure and distribution systems.

However, the routes to manufacture of these new drop-in fuels are often more complex - and most have yet to be commercially proven.

Current biofuel production in New Zealand

Liquid biofuel use makes up less than 0.1% of total liquid fuel sales in New Zealand. Bioethanol is produced by Fonterra’s Anchor Ethanol plant from whey, a by-product of cheese (2.9 million litres in 2015). This is blended with petrol and sold at retail outlets, particularly by Gull.

Biodiesel production was 0.6 million litres in 2015. Z Energy will soon start producing 20 million litres a year of biodiesel from tallow.

A number of New Zealand companies are or have been exploring the potential to produce biofuels. Some examples follow.

- Z Energy and Norske Skog with funding support from the Ministry for Primary Industries, completed the Stump to Pump project to evaluate the commercial feasibility of producing biofuels from forest residues.
- Air New Zealand, partnering with Virgin Australia, put out a request for information for bio-jet fuel supply.
- KiwiRail issued a request for proposals for supply of bio-marine fuel for their Interislander ferries.

What the Biofuels Roadmap study set out to provide

Biofuels will only be a part of New Zealand's future low-carbon economy, and will complement other options as the country transitions to a more sustainable society.

That said, the idea and small scale prototypes for biofuel production in New Zealand have often been proposed over the past 25 years.

These desktop and actual projects have shown that theoretically biofuels could be produced in this country.

However, there needs to be a much more robust base on which to decide or develop larger-scale initiatives.

It is only by having a clear picture of the implications of growing, processing and using biomass to produce biofuels over the longer term, particularly out to say 2050, that informed debate can be initiated.

That is, because large quantities of biomass crops, on considerable areas of land, allied with considerable investment in manufacturing plants, and linked into fuel distribution systems is required, New Zealand will need to have a purposeful mindset if and when it goes down a biofuels pathway.

In other words, what would need to be planted when and where, how capital investment would be made in biomass growing and processing, and the biofuel types required needs to be well understood before decisions are made to proceed.

The New Zealand Biofuels Roadmap study was internally commissioned by Scion to provide a much clearer picture of what is required in the timescales necessary for successful implementation of a biofuels liquid transport fuels economy and environment. It is a means to provide objective information to enable businesses, government and communities to make choices or understand the benefits, trade-offs and the role biofuels could have in future New Zealand.

The study does not provide a single 'best' pathway of how biofuels should be implemented in New Zealand, but, rather, it gives the impacts, implications, and consequences of answering multiple 'what-if' questions.

The only way to provide future clarity and to understand the implications of different deployment choices was to use a model capable of calculating what would happen depending on what pathways were chosen.

Such modelling is complex, especially as it is being asked to paint a picture of the outcomes over a 35-year period from 2015 to 2050.

But, without the testable, verifiable and repeatable calculations possible with such a model, any conclusions of the Biofuels Roadmap study would be much more speculative.

By basing the study on empirical evidence, and using informed decisions to constrain the model itself, the technical report and this summary report provide the basis for a well-thought-through and comprehensive base on which New Zealand Inc. can begin and commit to a biofuelled transport future.

The New Zealand Biofuels Roadmap study's scope

The study focuses on:
- production of liquid biofuels from sustainable feedstocks,
- large scale deployment and use, and
- narrowing down a broad range of options to find the best solutions for New Zealand

Out of scope for this study were:
- Novel and gaseous fuels that would require new or modified engines.
- Niche applications which could provide one-off opportunities in specific locations. While it is recognised that these opportunities are very important for New Zealand, a separate more detailed and focussed study would be required.
- Predictions around New Zealand's future fuel demand. Available public information was used.

Constraints, costs, assumptions and technical understandings built into the study

A more thorough explanation is provided in the *New Zealand Biofuels Roadmap Technical Report*.

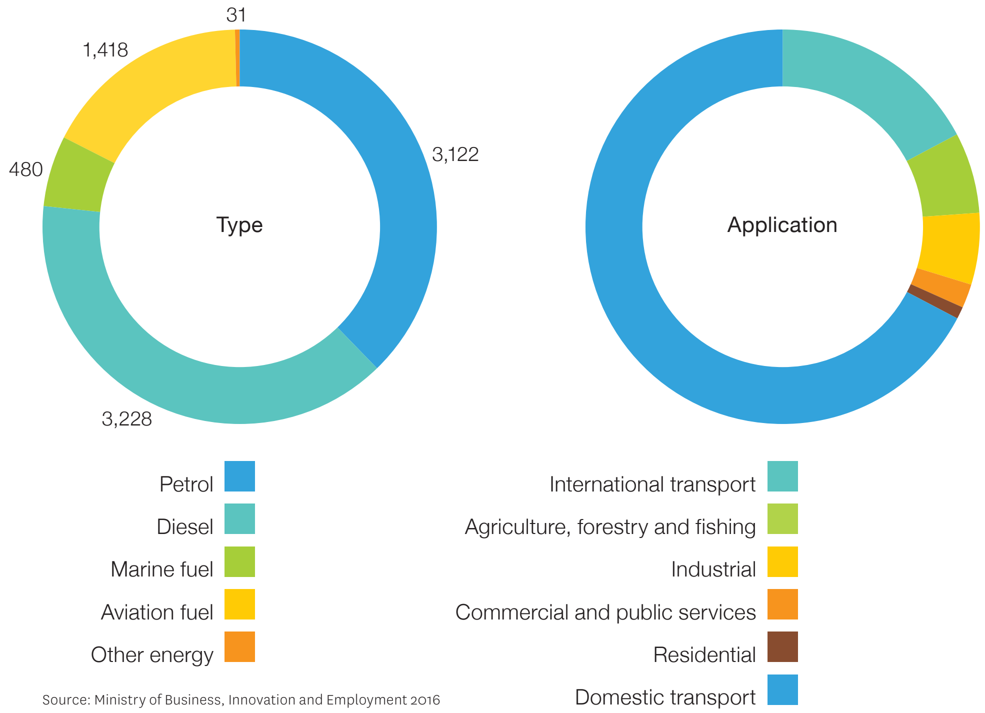
For the purposes of this summary report, some of the main considerations applied as inputs are outlined in the following.

Current liquid fuel use in New Zealand

New Zealand imports about 98% of its liquid fossil fuel from overseas as a mix of crude oil and refined fuels. These were worth about NZ$5 billion in 2015, or almost 10% of total imports.

The vast majority of liquid fuel use is as petrol, diesel, marine fuel and aviation fuel.

Liquid fuel usage by type and application is seen in the following diagram.



Source: Ministry of Business, Innovation and Employment 2016

Liquid fuel use in New Zealand in 2015, by fuel type (million litres) and application.

Fuel uses

New Zealand's total fleet was about 4.0 million vehicles in 2016. For comparison, there were 2,662 electric vehicles in 2016.

New Zealand's liquid transport fuel use		
Fuel type	Application	Impact
Petrol	98% for transportation, mainly in light vehicles	Passenger travel
Diesel	• 70% domestic transport • 30% off-road (agriculture, forestry, fishing, construction, etc.)	• Commercial land transport • Strongly linked to economic performance
Aviation fuel	• Domestic - 0.3 billion litres • International - 1.1 billion litres	• Aircraft carry 14% of exports and 22% of imports by value • Nearly all tourists arrive by air • Regional travel
Marine fuel	• Domestic - 0.2 billion litres • International - 0.3 billion litres	Moves 99.5% of New Zealand's international trade by weight

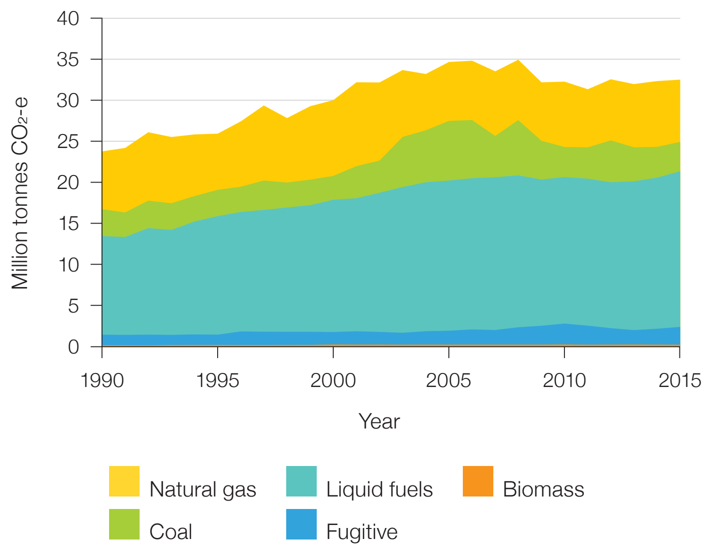
The nation's light vehicle fleet is old by international standards, and with no domestic vehicle manufacturing or assembly industries and many of our imports being used vehicles, it would be difficult and slow to deploy a biofuel that could only be used in new cars.

Greenhouse gas emissions from current fuel use

New Zealand's net GHG emissions (gross emissions less CO_2 taken out of the atmosphere by trees) grew by 64% between 1990 and 2015. This totalled 56.4 million tonnes CO_2-e in 2015.

Energy was responsible for 40.5% of New Zealand's gross emissions in 2015, the second largest contributor after agriculture.

Within the energy sector, liquid fuels account for 58% of emissions. The growth in GHG emissions from liquid fossil fuel use (in particular) from 1990 - 2015 is shown in the following diagram. Road transport emissions in New Zealand have increased 78% since 1990.



New Zealand energy sector emissions by fuel type.

Source: Ministry of Business, Innovation and Employment 2017

Emissions Trading Scheme

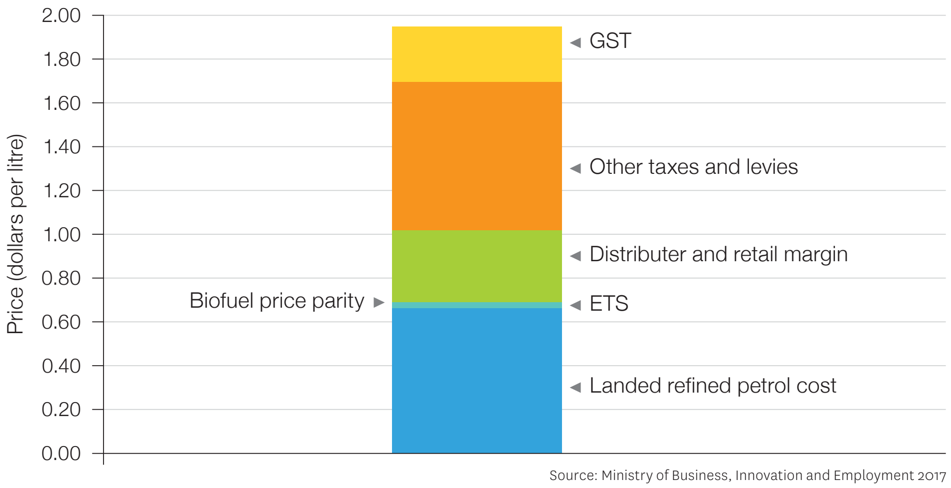
The New Zealand's Emissions Trading Scheme (ETS) is the key tool for reducing emissions, including carbon emissions from fossil-fuel use. Putting a price on emissions creates financial incentive for businesses and consumers to invest in technologies and practices to reduce emissions.

The ETS also provides a financial benefit to forest growers for the CO_2 their trees remove from the atmosphere. The ETS creates a market-driven price for emissions units by placing compliance obligations on emitters, allowing emitters and ETS forestry participants to trade emission units.

In practice, however, the ETS has had little effect on transport fuel use to date owing to historically low prices for emissions units.

Fuel costs

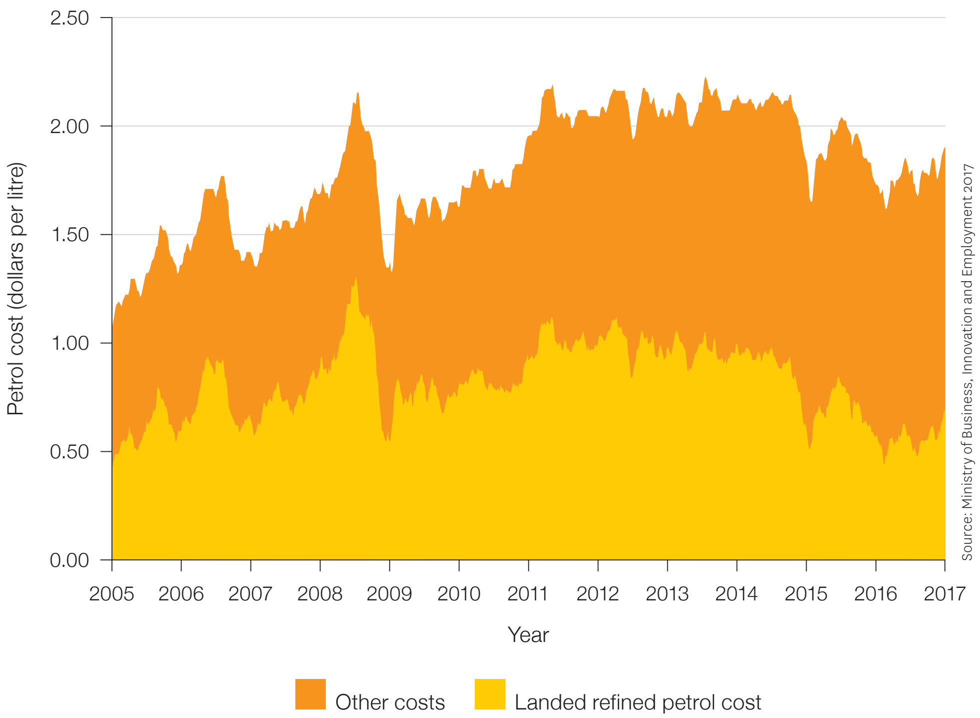
Fossil fuel costs. Currently, taxes and levies make up almost half the final retail cost of petrol, meaning that the cost of importing the fossil fuels is only part of the actual pump price. Represented graphically, the components of the retail price of petrol are as follows.



Retail petrol price breakdown (week beginning 17 Feb 2017).

Fossil fuels are a volatile commodity and consumers are very sensitive to the fuel cost, either directly at the pump, or indirectly via goods and services they purchase.

While most of the fuels used in New Zealand are produced from imported crude oil processed at Refining NZ in Whangarei, almost one quarter is imported as a refined product. The cost of this landed refined fuel provides a good indication of the New Zealand cost of fossil fuel. Major variables influencing the final fuel cost include the cost of crude oil and the US/NZ dollar exchange rate.



Variation in the retail price of petrol and landed refined petrol cost since 2005.

Biofuel costs. Biofuels are currently more costly to produce than fossil fuels; one of the major barriers to their greater deployment. In addition, a significant upfront capital investment is required to begin biofuel production. Consequently most overseas biofuel implementation programmes involve government subsidies or mandated levels of biofuel incorporation - meaning the retail prices of biofuels are equivalent to those of fossil fuels and allowing biofuel production to begin in earnest.

Biofuel value chain

A future biofuel value chain requires different interlocking components. These include:

- growing a crop to produce a biomass feedstock, either as the main product or as a waste product,
- harvesting and transport of the feedstock to a biofuel production site,
- conversion into biofuel, and
- distribution of the biofuel to the point of demand to be used to power the final vehicle, ship or plane.

No such value chains of any significant scale exist in New Zealand.

For biofuels to be adopted, every step in the value chain needs to be profitable - especially since participants at different stages have options. There are different possible land use choices, growers can determine where best to sell their products, and a fuel distributor can use imported rather than domestically-produced biofuels.

Choosing from all the possible options to identify the best future biofuel value chains for New Zealand is extremely complex. The existence of dozens of potential feedstocks, numerous transport and conversion options, multiple fuel types (differing in demand, ease of manufacture, price) and diverse options for obtaining or growing the feedstock, create a risk of seizing upon sub-optimal solutions that are not in the country's long-term best interest.

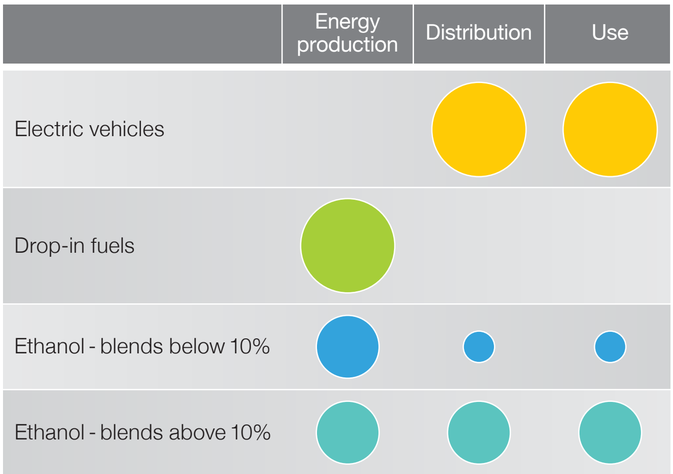
There is not 'one biofuel story' for New Zealand, but many different scenarios - each with its own advantages, disadvantages, costs, market challenges and opportunities.

Alternatives to liquid fossil fuels

There are a number of options in addition to biofuels as possible renewable replacements for fossil fuels. These include electric vehicles, hydrogen for fuel cell-powered vehicles and gaseous biofuels. Each has its own advantages and barriers to implementation.

A mix of options will be the best way to decarbonise New Zealand's energy system. It includes more efficient vehicles, greater use of public transport and switching freight to more efficient models such as from trucks to rail or ship.

Such alternatives also need to be considered not only in terms of their production, but also in how they are distributed to where they are needed, and the vehicles in which they are used. Within such value chains, the barriers to implementation vary depending on the option.



Location and significance of barriers to implementation of different alternatives to fossil fuels. Larger dots represent bigger barriers.

Battery electric vehicles (EVs)

- Main barriers are the need for both completely new vehicles and a new charging infrastructure.
- However, largely renewable electricity is already produced and distributed at a large scale in New Zealand.

Drop-in biofuels

- A challenge to produce large volumes of biofuel at a competitive cost (i.e. the focus of this study).
- But once produced, biofuels can be blended into the existing fossil fuels and used in existing vehicles and distribution.
- Challenges in the availability of sustainable feedstocks, and the high risks in investing in production facilities (when the technologies are not mature and costs are high).

Ethanol

- While in use overseas, and able to be used in blends of up to 10% in most existing petrol engines, the barriers to implementation are mostly in producing the fuel at scale.
- Blends above 10% require significant upgrades to distribution infrastructure, and modified vehicles.

The best way to decarbonise the New Zealand transport sector will be application specific. EVs could replace a significant portion of New Zealand's light vehicle fleet (passenger vehicles and light commercial vehicles). But it is much more difficult to see electricity replacing liquid fossil fuels in international aviation and shipping, at least out to 2050.

This study focuses on the production of liquid biofuels.

Biomethanol is not considered because of its toxicity, and gaseous biofuels such as biomethane or bio-dimethyl ether are excluded because they would require a new distribution network and vehicle modifications. Likewise hydrogen, a promising longer term option, has also been excluded from further consideration.

What are acceptable feedstocks?

If large-scale production and consumption of biofuels is to take place in New Zealand, production in particular, will need to be 'sustainable'.

What constitutes ‘sustainable biofuels’ in the New Zealand context, and how this might evolve with time is still not clear.

But, in all cases, the feedstock choices are critical.

Using feedstocks from New Zealand’s conservation lands or native forests, or planting of crops on our conservation lands is highly unlikely to be acceptable, and is excluded from consideration in this study.

Global first-generation biofuel deployment initially used existing agricultural commodity food crops such as sugarcane and corn; encouraged by government mandate in many countries. But international food shortages, tensions around best land use and food security issues has seen the use of food crops for fuel production vigorously debated.

The conversion of rainforest to palm oil production, and consequent emissions of carbon and loss of biodiversity has also caused an outcry. Imports of feedstocks are excluded as an option in this study.

It is likely that New Zealand would follow overseas trends and be unwilling to allow arable land to be used for growing biofuel feedstocks.

Biofuel implementation barriers

For large-scale biofuels to be deployed, some major barriers will need to be overcome. These barriers are more fully discussed in the technical report, but include:

The challenge of implementation

- Scale, complexity and timeframes are daunting, no broad societal/political consensus exists on biofuels’ role within New Zealand.

Financial

- Biofuels are currently more costly to produce than fossil fuels, and upfront investment costs are high.

Technical

- There is technical risk, particularly around biofuel conversion technologies that have yet to be commercially proven.

Timing

- Biofuel introduction will require all parts of the value chain to act in a coordinated way, and at a large scale.

Social/environmental

- For biofuels to have a significant role in reducing the New Zealand energy sector’s environmental footprint, the public must buy into the benefits of addressing climate change, the role of biofuels in addressing these and the impacts/tradeoffs that will be required.

These, and other challenges, have been overcome in different ways in other parts of the world. New Zealand could leverage this international knowledge and experience with a fit-for-purpose biofuel deployment.

Necessary first steps are to identify:

1. Which of the huge number of feedstock, feedstock transport, conversion processes and biofuel options being used or considered for implementation overseas are best suited for New Zealand?
2. What are the actual issues, barriers and risks going to be for biofuel implementation

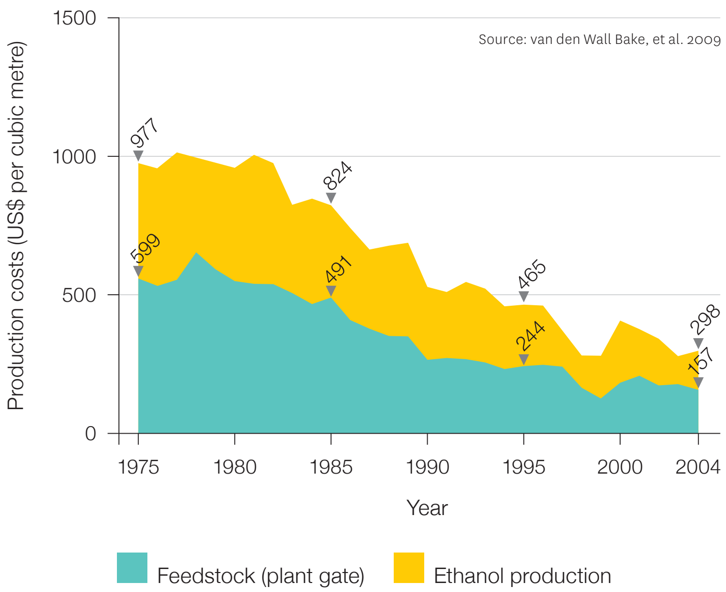
in New Zealand under a range of possible futures - as a precursor to working out ways to address them?

The purpose of the study was to use quantitative modelling of various biofuel deployment scenarios to address these questions.

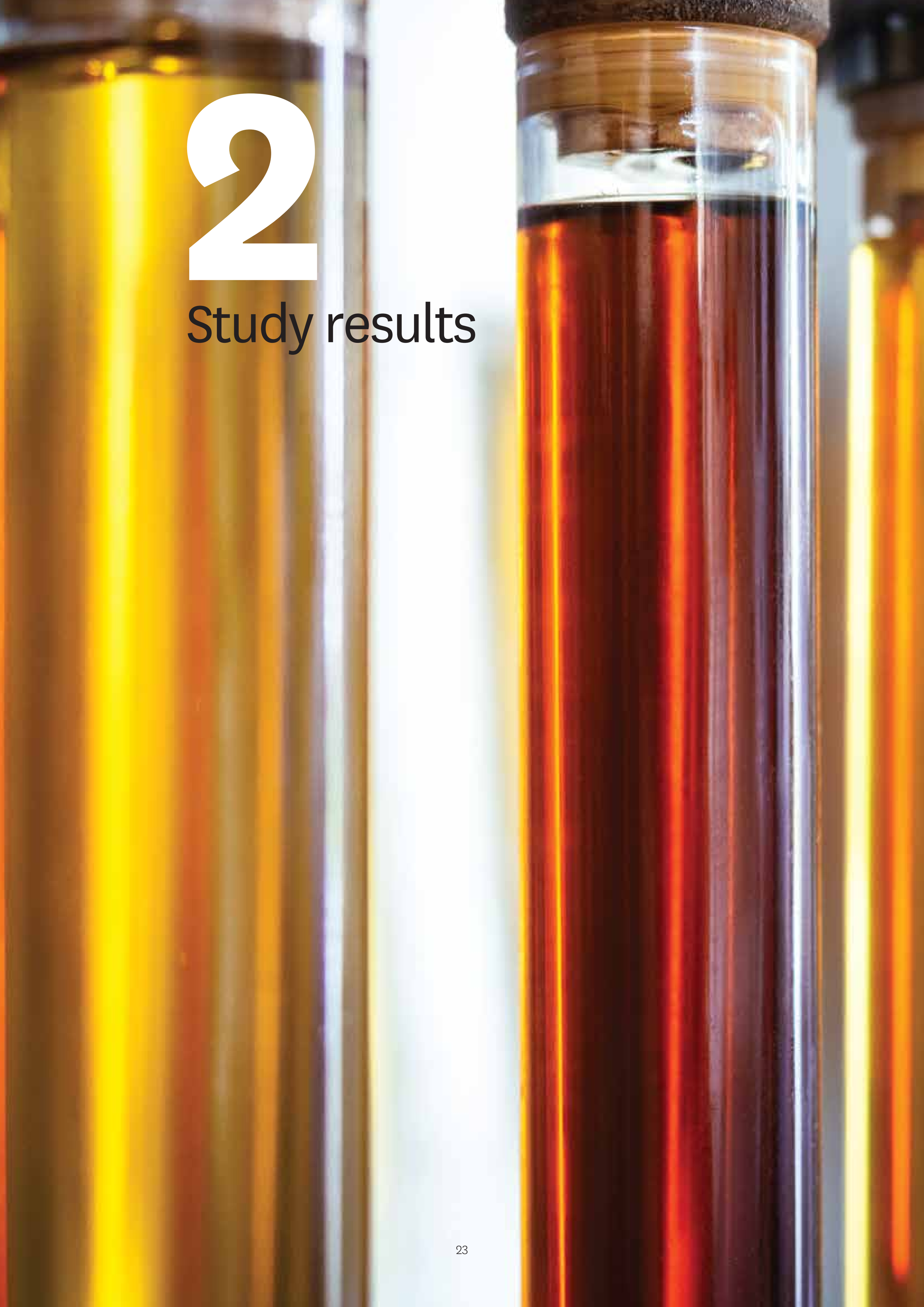
Biofuel costs and technical risk will reduce with time

A biofuel technology, when at commercial scale, will see both capital and operating costs drop substantially over time, as the technologies are optimised and commercial experience increases. Such 'technology learning' is normal for new technologies and new feedstocks and should improve biofuel competitiveness relative to fossil fuels over time.

These falls in price are illustrated below in Brazil from 1975 to 2004, where the conversion cost and delivered feedstock costs for producing bioethanol from sugarcane fell by 66% and 72%, respectively.



Decrease in production costs of Brazilian ethanol as the technology matures.



2 Study results

How the New Zealand Biofuels Roadmap study was carried out

Quantitative modelling and mathematical optimisation techniques were used to 'look at the future' and create scenarios of what this might look like.

Using specific questions, the model estimated the impacts and implications of specific 'futures'. The model answered questions such as by how much would GHG emissions be reduced, which feedstocks could be used and where could they be grown, or what technology is the most cost effective.

A parallel qualitative component of the study was undertaken to understand in detail the issues, implications and potential barriers facing biofuel implementation in New Zealand. As many countries, including Brazil, Sweden and the United States, are further down the path to implementing biofuels, global experience with biofuel deployment provided valuable lessons and perspectives.

Stakeholders were extensively involved in the entire process, including participating in interviews, workshops and shaping the scenarios.

The results, conclusions and next steps presented in the technical report and this summary report are extracted from the combined efforts of both the quantitative and qualitative components of the project.

A brief description of the Bioenergy Value Chain Model

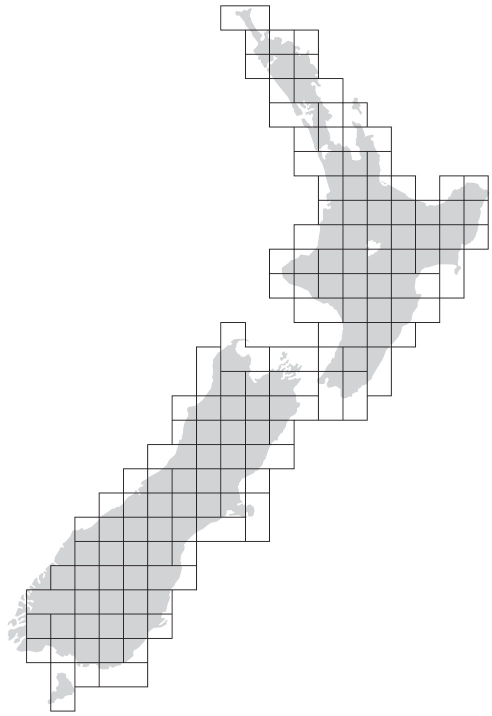
A much more thoroughly explained background to the modelling parameters and inputs is available in the technical report, which also contains all the references and sources of data.

An optimisation model is well-suited to a study of the biofuels value chain in New Zealand, and for this study, Scion chose an existing comprehensive modelling framework, rather than create its own model from scratch. The Bioenergy Value Chain Model (BVCM) was selected to investigate feasible options over space and time.

The BVCM was developed by the Energy Technologies Institute (ETI) in the United Kingdom and successfully used to assess and understand the prominent role of bioenergy in meeting the United Kingdom's GHG emission reduction targets.

Scion licenced the BVCM and modified it to make it suitable for New Zealand requirements and populated it with New Zealand-specific data.

The New Zealand version of the BVCM divides the country into 50 x 50 kilometre cells, with a planning horizon of seven 5-year periods from 2016 to 2050.



2016-2020	2021-2025	2026-2030	2031-2035	2036-2040	2041-2045	2046-2050

Cells and time horizons used in the BVCM to represent New Zealand spatially.

Once a specific ‘future’ or scenario is defined, the model chooses from among the many potential biofuel pathways, identifying the lowest cost solution across the whole value chain and timeframe modelled. It then provides the technical, economic and environmental impacts associated with the end-to-end elements of a particular course of action.

The model includes a broad range of potential crops, feedstocks, transport modes, conversion technologies and final biofuels that might be relevant to a biofuelled New Zealand.

Inputs to the modelling include:

Land class. Within each cell, the productive land is classified into five land classes depending on its potential productivity. The conservation estate, urban land, water bodies and other non-productive land are excluded. A cell-specific land opportunity cost is used to reflect the value of land under current competing land use.

Crop production. A range of crops can be grown as feedstocks for biofuel production. These include canola, conventional forests, dedicated energy forests, corn, and energy crops such as miscanthus or willow. A crop can only be grown on appropriate quality land, for example, canola cannot be grown on steep land because it needs harvesting machinery. The yields and growth rate of each crop is estimated depending on the cell and land class to account for productivity and climate variations across New Zealand.

Existing forests. Logs of different grades and residues can be purchased from existing plantation forests at current prices. The model assumes that these forests are replanted.

Point source feedstocks. Feedstocks available at specific locations are also included in the model. These include municipal wood waste from current landfills and chips from current sawmills.

Conversion technologies. More than 20 conversion technologies are included to convert the different biomass feedstocks to final fuels. For each technology, the model contains data on fuel production yields, additional resource requirements (e.g. electricity or chemicals), capital and operating costs, and co-products produced. The model can also choose from among different plant sizes. Conversion plant costs and process information were obtained from commercial experience or reputable scientific/industry sources for immature processes.

Feedstock/intermediate transportation. The model calculates the costs of moving the biomass feedstocks and intermediates (e.g. wood pellets from forest residues) by road, train or ship. The model includes existing ports, rail and road networks, as well as costs for loading and transporting the different feedstocks and intermediates.

Final biofuels. A range of final biofuels can be produced. These are classified into fuel types according to their use as substitutes for fossil petrol, diesel, marine or aviation fuels. The amount of biofuel that needs to be produced is one of the main input parameters for the model.

A list of the feedstocks and technologies considered in the model can be found in the appendix and a more detailed discussion in the technical report.

Model assumptions

Key model assumptions are:

- national level model, optimising across the whole value chain and planning horizon,
- fuel distribution not modelled,
- constant input costs and co-product prices based on current (2016) values,
- the interaction between supply and demand and its impact on costs/prices is not considered,
- all conversion technologies will be commercially proven and costs of immature process will reduce over time,
- non-feedstock inputs are available in unlimited quantities at the same cost throughout the country and there is no limit on the amounts of co-products that can be sold,
- single 7% discount rate for all parts of the value chain, and
- imports or exports of biofuels are not allowed.

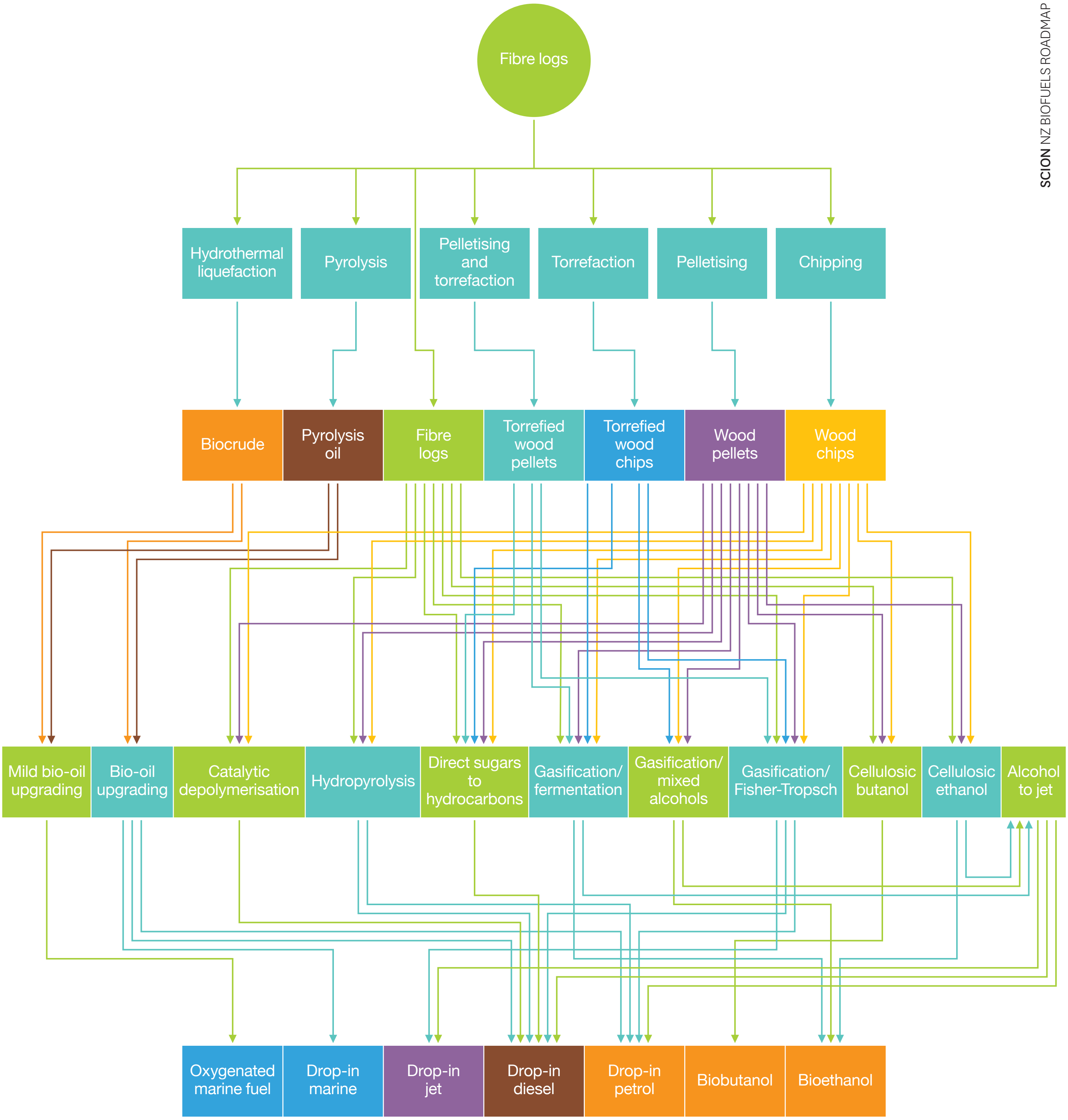
Many other assumptions are also built into our modelling. These are available in the technical report.

The complex links between feedstocks, conversion technologies and final fuels

The BVCM model must mix, match and analyse many moving parts - whether the start point is a raw material, or a final fuel.

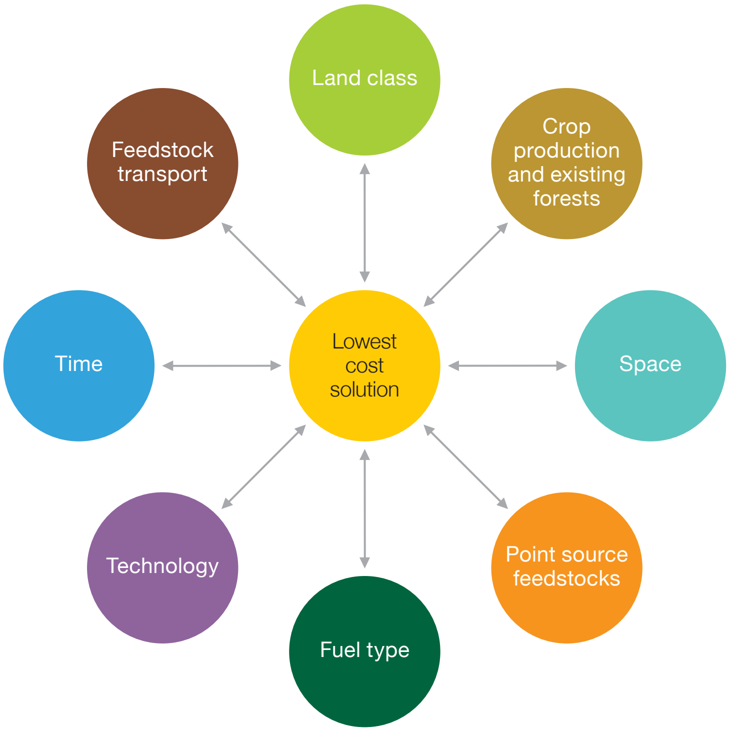
These ‘What If?’ scenarios demonstrate the complexity of the modelling.

Each pathway is restricted to realistic connections, and different feedstocks have completely different pathways. For example, canola oil can be used to produce biodiesel but not as feedstock for gasification. Even with these restrictions, the potential feedstock-to-biofuel pathways are almost uncountable. For just one product, fibre logs from forest plantations, the potential pathways are shown in the following diagram.



Potential pathways for fibre logs from plantation forests.

The model balances all this information to provide the lowest cost solution possible when considering the entire value chain.



The model finds the lowest cost solution by balancing multiple considerations.

Future fuel demand

The types and quantities of liquid fuels required in the future is vital when considering options for large-scale biofuel production.

Drivers of this demand include:

- population growth,
- economic growth, in and outside New Zealand,
- on-going efficiency gains in vehicles and engines,
- long-term trends in liquid fuels future price and availability, and their alternatives,
- uptake of electric powertrain vehicles,
- disruptive developments such as hydrogen-fuelled vehicles, or breakthrough battery technologies,
- government policies and decision-making,
- changes to the modes of transport - e.g. greater use of public transport, shifting of freight from trucks to rail and ships, acceptance of autonomous vehicles,
- future social/demographic changes such as urbanisation, digital connectivity and changing attitudes to climate change - which might alter society's attitudes towards travel, and
- global developments including supply chain disruptions due to wars, climate change and socio-political uncertainty

Predicting future fuel demand is complex and beyond this study's scope.

However, the BusinessNZ Energy Council's recent BEC2050 study provided credible and reliable future demand projections and these are used in Scion's modelling.

The BEC2050's high and low use scenarios provided credible boundary fuel demand projections, and are described in the technical report.

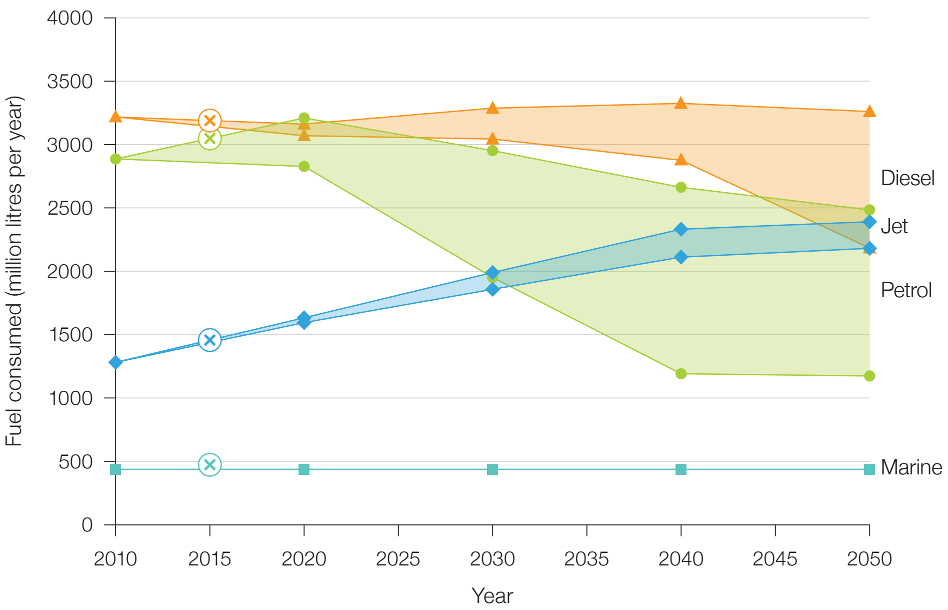
Because the BEC2050 study did not include off-road applications for diesel, nor marine fuel use, these figures were kept at constant 2015 values.

Total 2050 fuel demand is projected to remain almost the same as actual 2015 demand in the high liquid fuel use scenario, and decrease by approximately 30% in the lower use scenario. However, in both cases the mix of fuels required changes significantly.

Jet demand is projected to rise under both scenarios, diesel is either relatively constant or decreases.

Petrol demand decreases under both scenarios, but more under the low use scenario due to reduced private vehicle travel and greater penetration of EVs into the light vehicle fleet (66% of the light vehicle fleet is EVs in 2050).

Even in the low use scenario, almost 6 billion litres of liquid fuels will be required in New Zealand in 2050.

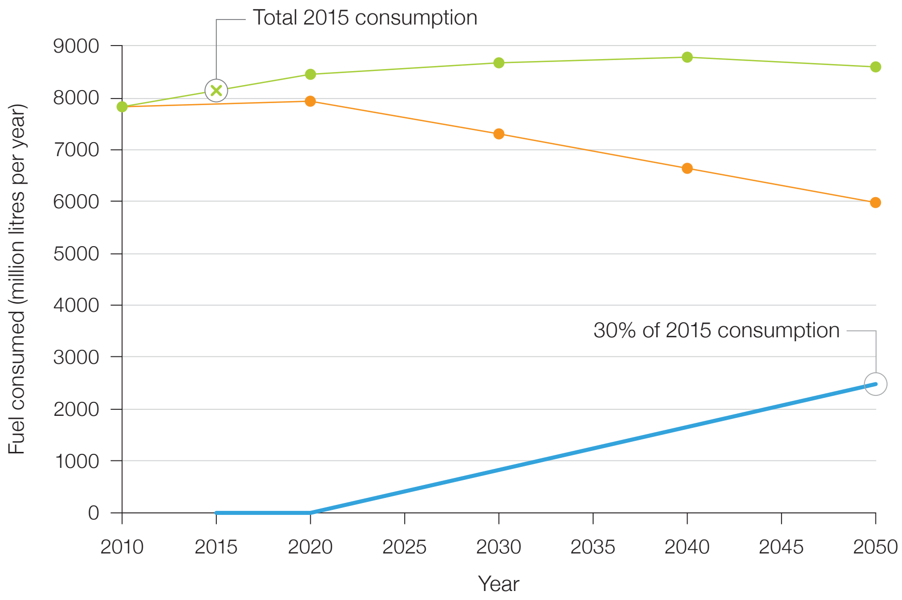


Future fuel demand projections for liquid fuels in the high and low use scenarios based on BEC2050 modelling. Actual 2015 fuel consumption volumes (crosses) are used as reference in later scenarios.

Results of modelling – 30% substitution

The modelling began with a scenario where the minimum level of biofuel production was set to climb linearly from 0% in 2020 to 30% of 2015 fuel demand in 2050.

While not necessarily a realistic scenario, the model was run to see what it chose to do and the issues revealed when biofuels are implemented at a relatively high level - with as few restrictions as possible.



30% biofuel substitution scenario relative to the total liquid fuel demand projections made under high and low fuel demand projections.

The model was 'asked' to determine the lowest cost way to achieve this target, leaving the model free to:

- choose which biofuels to produce, and
- allow all feedstocks and all conversion technologies to be used.

Two different land class use options were modelled.

- Scenario 1 (All land classes) – where feedstocks can be produced on all land classes, i.e. with as few restrictions as possible.
- Scenario 2 (No arable land) – where all other variables are held the same as Scenario 1, except that feedstocks are only able to be grown on land unsuitable for arable crops. This restricts possible feedstocks to forestry and wastes because neither food crops nor energy crops like miscanthus or willow could now be grown.

The second scenario was chosen to understand what would happen under a situation where New Zealand decides that not only is using food crops for biofuel production ethically unacceptable; using land capable of growing food is also unacceptable.

Feedstocks and fuels

In Scenario 1, the main biofuels produced are biodiesel from canola and a mix of drop-in petrol and diesel through pyrolysis/upgrading of lignocellulosic feedstocks, mainly miscanthus, willow, fibre logs and forest residues.

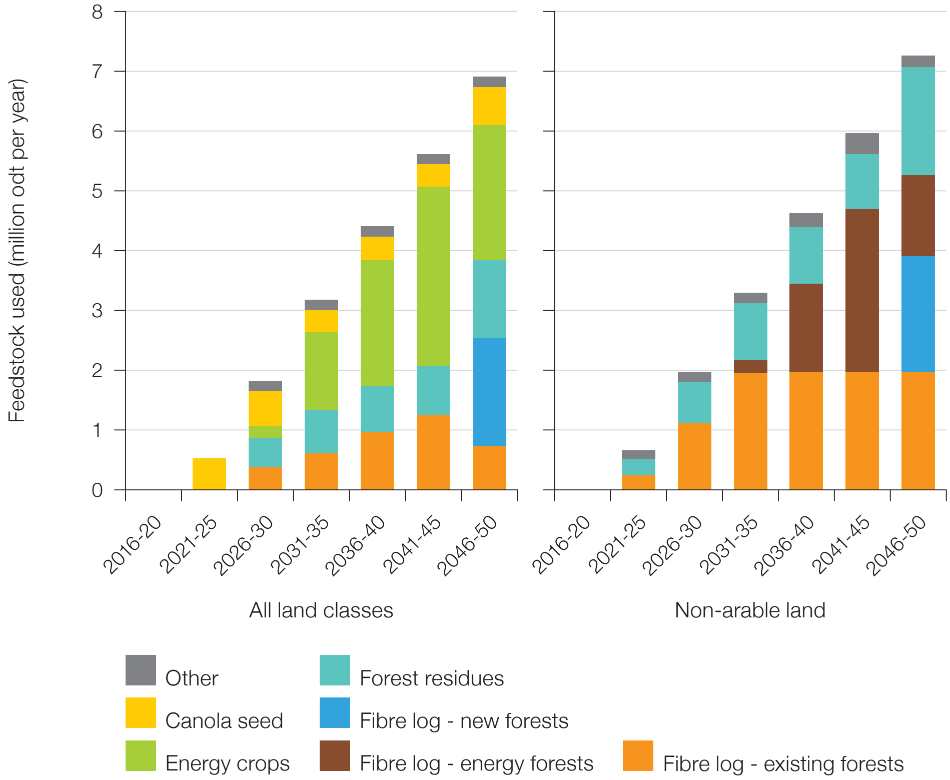
To repeat, of all possible options the model selects a comparatively simple mix of biodiesel from canola and a mix of drop-in petrol and diesel by pyrolysis/upgrading of lignocellulosic feedstocks.

In Scenario 2, where arable land cannot be used, then neither canola nor mechanically-harvested energy crops can be used. In this case:

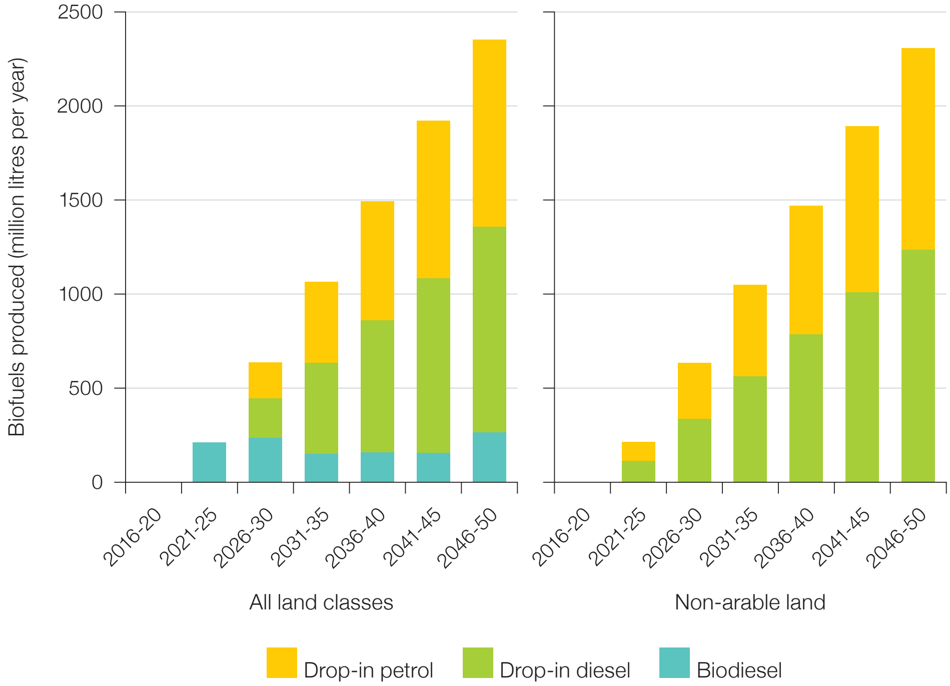
- biodiesel production is replaced by more drop-in petrol and drop-in diesel,
- energy crops are replaced by larger volumes of fibre logs from existing and new conventional forests, energy forests and forest residues, and
- new conventional forests take 30 years to mature, so fibre logs from these forests are only available after 2045, and fibre logs from energy forests are only available after 2030, 15 years after planting.

The model chooses these options because they are the lowest overall cost.

Across time the biofuel production and feedstocks were as follows.



Feedstocks used as a function of time in the two 30% substitution scenarios, Scenarios 1 & 2 (odt - oven dried tonnes).

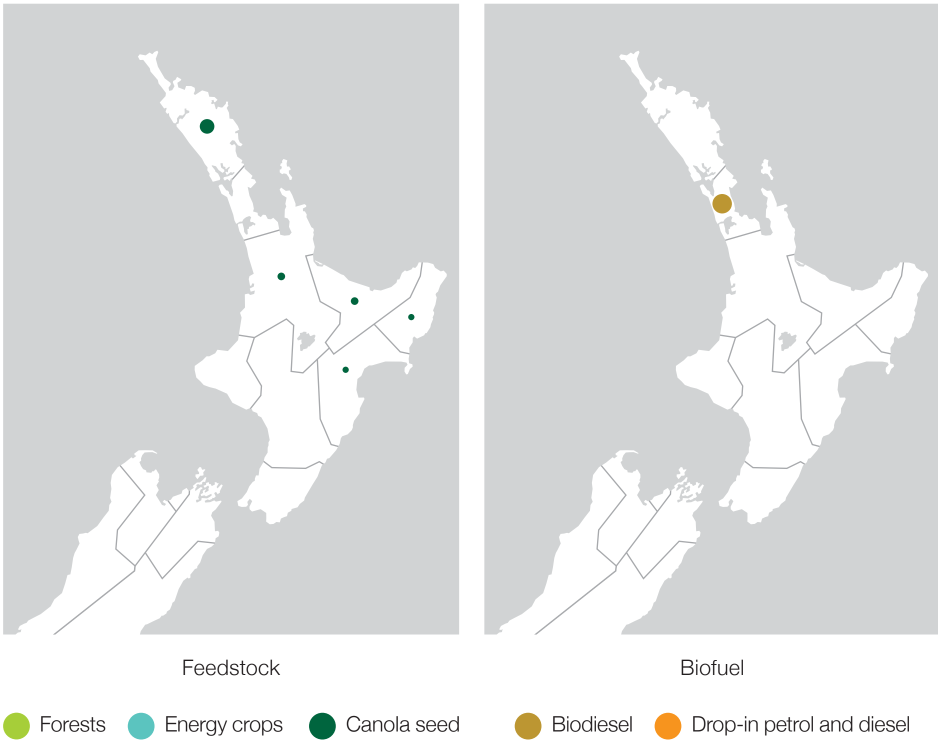


Biofuel production as a function of time in the two 30% substitution scenarios, Scenarios 1 & 2.

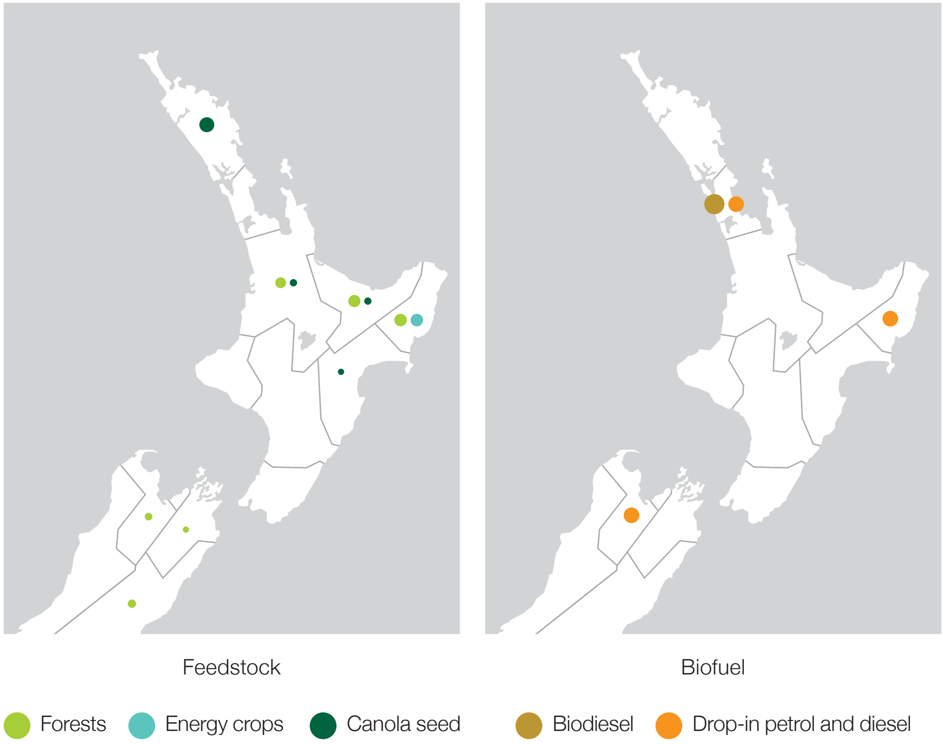
Where are feedstocks and fuels produced?

The following maps show where and when the feedstocks are produced and where the biofuel production plants are located as a function of time for Scenario 1.

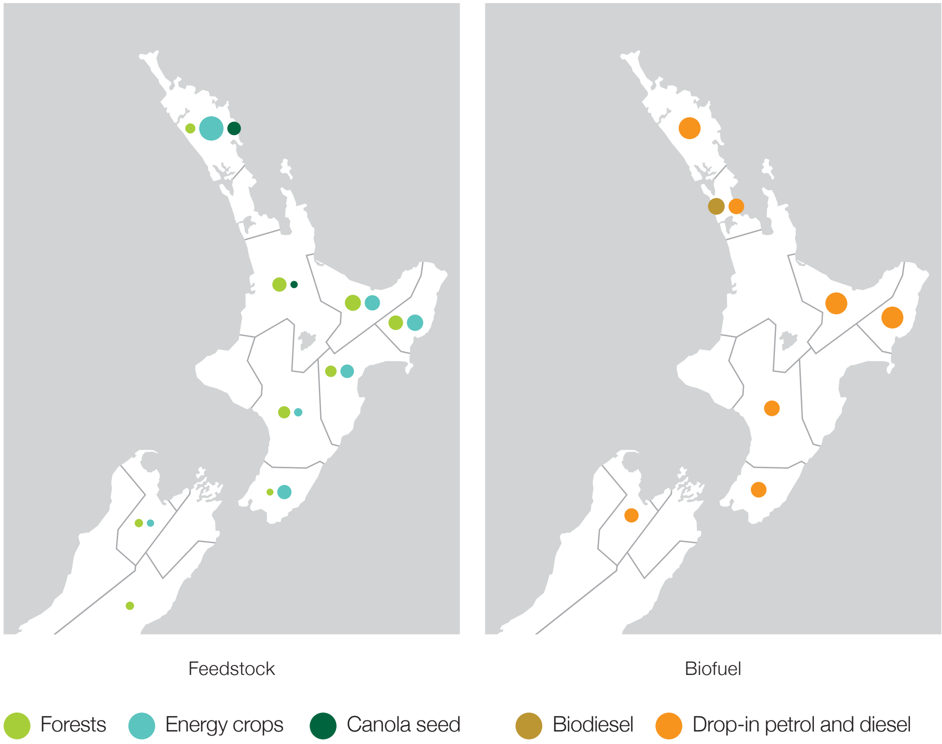
- In the 2021-25 period only biodiesel is produced in a single plant near Auckland using canola grown across the country, particularly in Northland.
- Then, in subsequent periods, increasing volumes of fibre logs and forest residues from existing forests, particularly in the central North Island are consumed. In addition, increasing volumes of willow and miscanthus are used. These energy crops are grown principally in Northland, East Coast and in the central North Island.
- In the last period, new conventional forests planted in the first period primarily in the East Coast region mature and become important feedstocks.



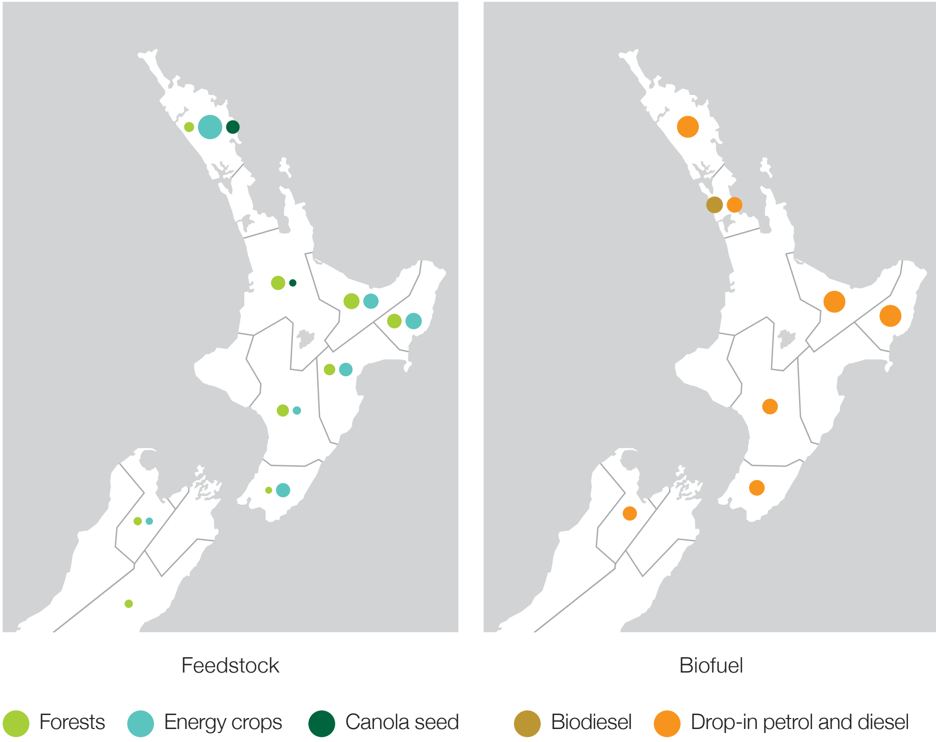
Maps showing feedstock consumed and biofuels produced for Scenario 1 (30% substitution, all land classes) in the 2021-25 period. The area of the dots in this and the following maps is proportional to the amount of feedstock consumed or final biofuel produced.



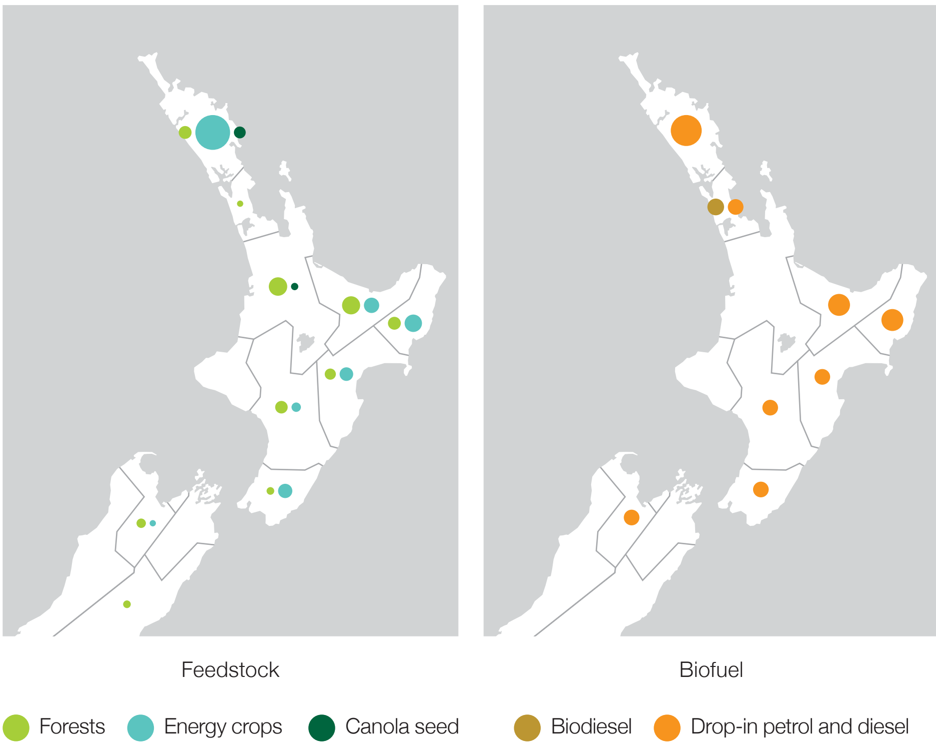
Maps showing feedstock consumed and biofuels produced for Scenario 1 (30% substitution, all land classes) in the 2026-30 period.



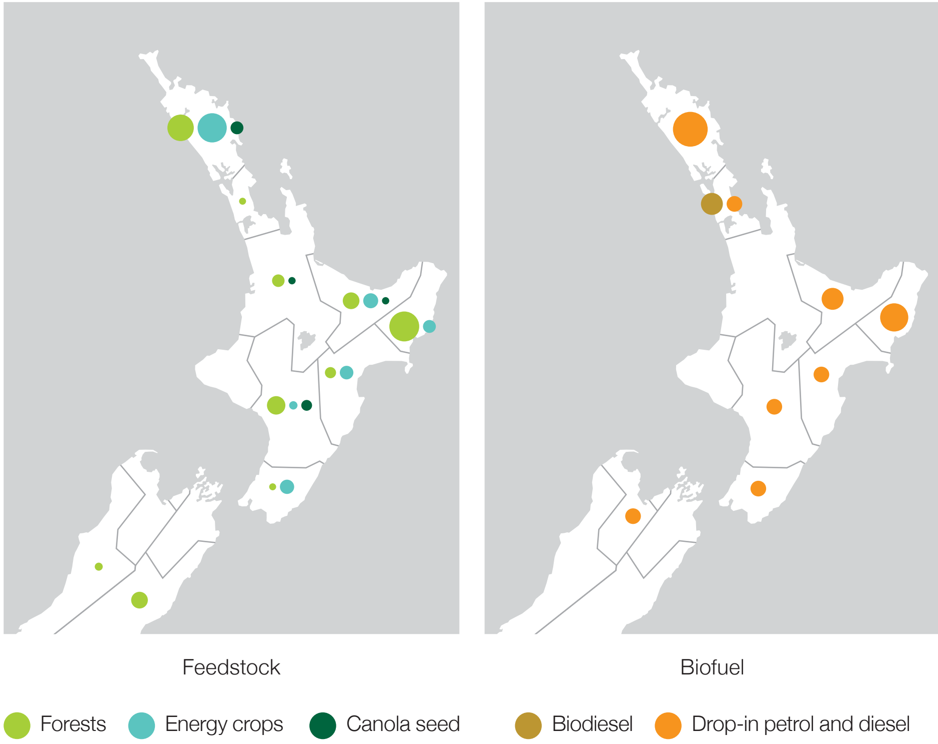
Maps showing feedstock consumed and biofuels produced for Scenario 1 (30% substitution, all land classes) in the 2031-35 period.



Maps showing feedstock consumed and biofuels produced for Scenario 1 (30% substitution, all land classes) in the 2036-40 period.



Maps showing feedstock consumed and biofuels produced for Scenario 1 (30% substitution, all land classes) in the 2041-45 period.



Maps showing feedstock consumed and biofuels produced for Scenario 1 (30% substitution, all land classes) in the 2046-50 period.

The model choses to grow crops predominantly in areas such as Northland, East Coast/ Gisborne and the central North Island because these regions have lower land cost (dollars per hectare) and higher crop yields (tonnes per hectare). Crop yields are governed by climatic conditions, explaining why the model chooses to plant on lower priced land in the northern half of the North Island, rather than on lower priced land in the South Island.

Crops are generally planted on the lowest possible land class (i.e. on steep land rather than highly productive flat land) due to its lower cost.

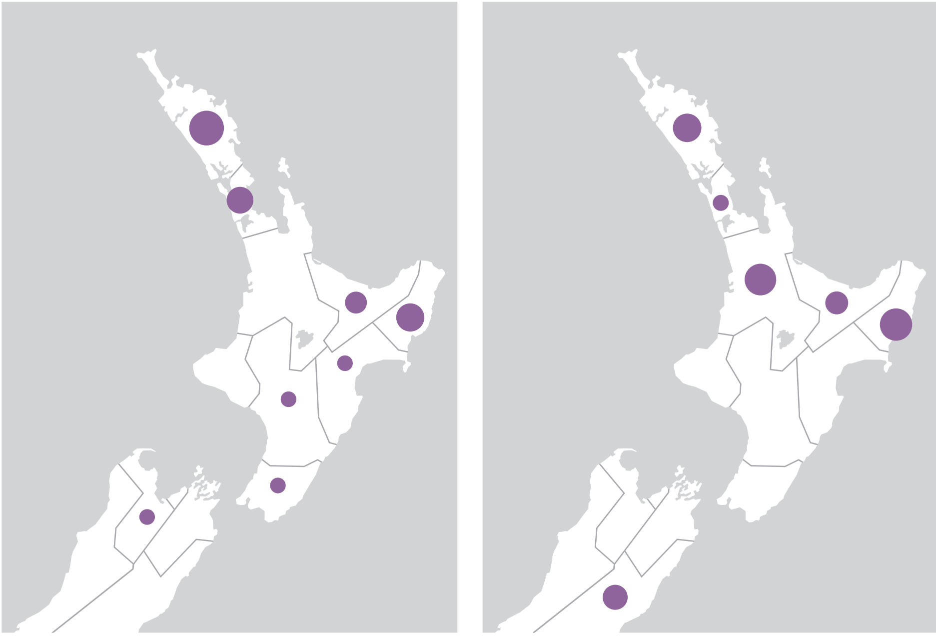
The model tends to minimise biomass transport costs by locating conversion plants close to feedstock production. This is often in less-developed parts of the country.

Regional development opportunities

These scenarios represent major regional development opportunities. For example, for the Gisborne/East Coast region, Scenario 2 would result in an additional 75,220 hectares of new forest plantings, or approximately a 50% increase in the existing area of plantation forests. In addition, it would require construction of four new pyrolysis plants and four new bio-oil upgrading plants, requiring around $936 million in capital expenditure and creating over 1,000 new direct, indirect and induced jobs.

The land use choices made determine where the feedstocks are grown, as well as where the fuels are produced, so have a major effect on where regional development will occur.

The following maps illustrate how the land class choices made in Scenarios 1 and 2 influence where regional development occurs.



Locations of biofuel production during 2046-2050 in Scenarios 1 and 2 in the 2046-50 period. Bubble size is proportional to the volumes produced.

Infrastructure and services

Questions could be raised over whether current services and infrastructure such as roading and population would support major new processing plants in regions such as the East Coast.

In particular, pyrolysis oil upgrading requires natural gas to generate the hydrogen required for processing. Such natural gas is currently only available where there is a gas grid - which excludes the South Island, East Coast beyond Gisborne, Wairarapa and parts of Northland.

However, there are multiple possible ways to address such issues, including:

- restricting the location(s) where conversion plants can be built to areas close to the gas pipeline,
- extending services and upgrading infrastructure to these locations - something New Zealand has done in the past, and
- choosing conversion technologies that do not require natural gas, or producing hydrogen on-site from biomass via gasification.

Fuel distribution

Biofuel must also be moved to where it is needed. Biofuels produced in the central North Island and East Coast would need to be distributed to areas where the demand is, such as Auckland.

Existing fossil fuel marketers already have a substantial distribution infrastructure, so it would make sense to use this.

Trucks, coastal shipping and rail could cleverly be used to move biofuels from places of production to cities of consumption.

The cost of shipping the final biofuel is much less than the cost of shipping an equivalent volume of the original biomass.

Conversion plant size

The cost of processing feedstocks into biofuels drops as the size of the conversion plant increases due to economies of scale. The cost of transporting the required volumes of biomass to the conversion plant rise as it becomes necessary to draw on biomass further away to meet demand.

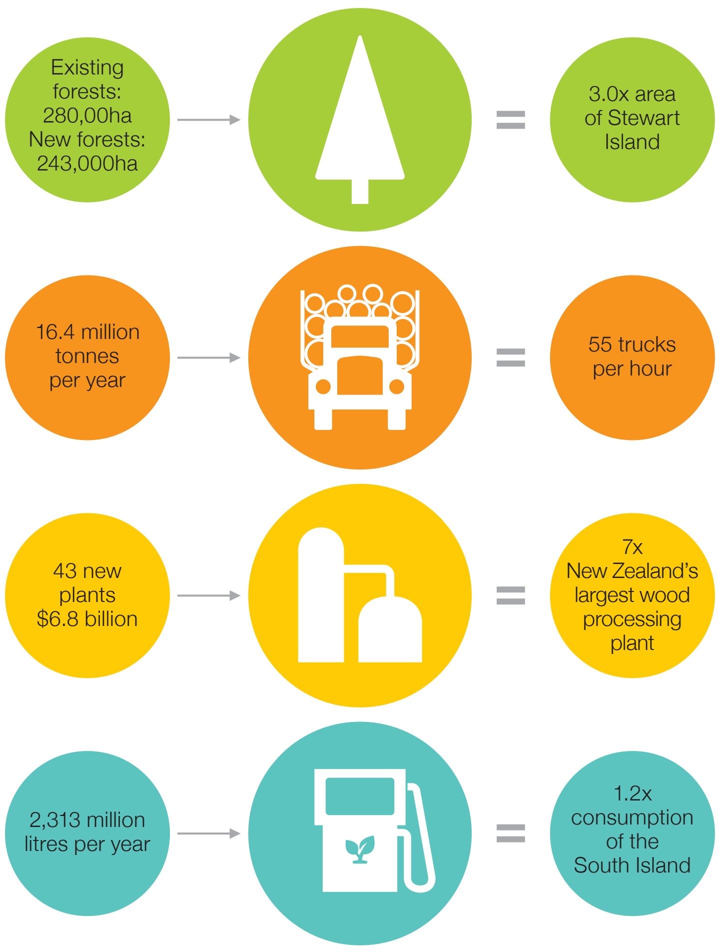
Consequently there is an optimal conversion plant size, depending on the specifics of each feedstock/conversion process combination.

The modelling considers this trade-off, and for both biodiesel and pyrolysis plants it chooses the largest possible plant size - indicating that the lower capital and operation costs of the bigger plants per unit of output outweighs the increased cost of biomass transport.

Understanding the scale of the opportunity

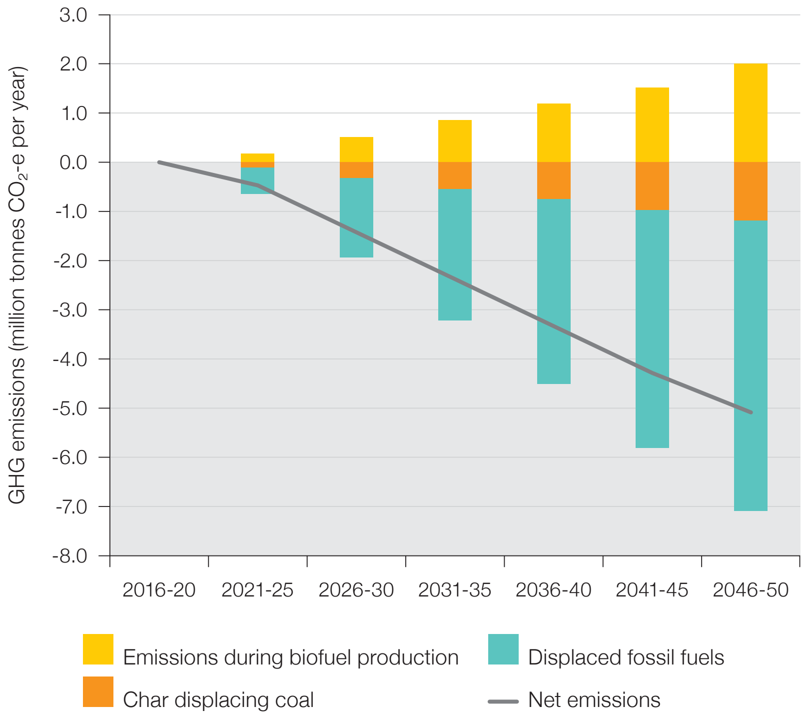
The scale of the Scenario 2 (30% of liquid fuels as biofuels, no arable land used) has a number of significant regional and national implications.

For the 2046-2050 time period, this would be equivalent to:



Greenhouse gas emission reduction

In both Scenario 1 and Scenario 2, net GHG emissions reduce as the amounts of biofuels increase. This is mainly because biofuels displace fossil fuels, but also because the model assumes the char produced during pyrolysis is used to replace coal burned for heat.



Net displaced greenhouse gas emissions in Scenario 2 (30% substitution, no arable land).

As seen in the table below, net average emissions from 30% substitution in both scenarios are reduced by 80% and 88% relative to the displaced fossil fuels.

GHG impact for the two 30% biofuel substitution scenarios		
	Scenario 1 No restriction on land use	Scenario 2 Non-arable land
Average emissions, relative to displaced fossil fuels (kilogram CO_2-e/L-e)	-2.1	-2.3
GHG emission reduction relative to displaced fossil fuels	80%	88%
2046-50 GHG savings, percentage of 2015 Energy sector emissions	15%	16%
CO_2 reduction in 2021-30 (million tonnes CO_2-e)	9.0	9.5

Thirty per cent biofuel substitution in 2050 would reduce New Zealand's annual energy-related GHG emissions by 15% over 2015 levels. The GHG reduction in 2030 under both scenarios would be much more limited, however.

Current projections show that between 2021 and 2030, New Zealand has a gap of 220 million tonnes of CO_2-e in our actual emissions versus Paris commitments. A cumulative reduction in emissions of 9-9.5 million tonnes is a step towards meeting these commitments.

The real potential for GHG reduction from biofuels is much more significant in the longer term.

Cost of biofuels

Levelised biofuel cost. To compare the relative costs of biofuel production across different scenarios, the levelised biofuel cost can be used.

This is an economic assessment of the average per litre cost of constructing and operating the whole value chain over the timeframe modelled (i.e. 2015 - 2050).

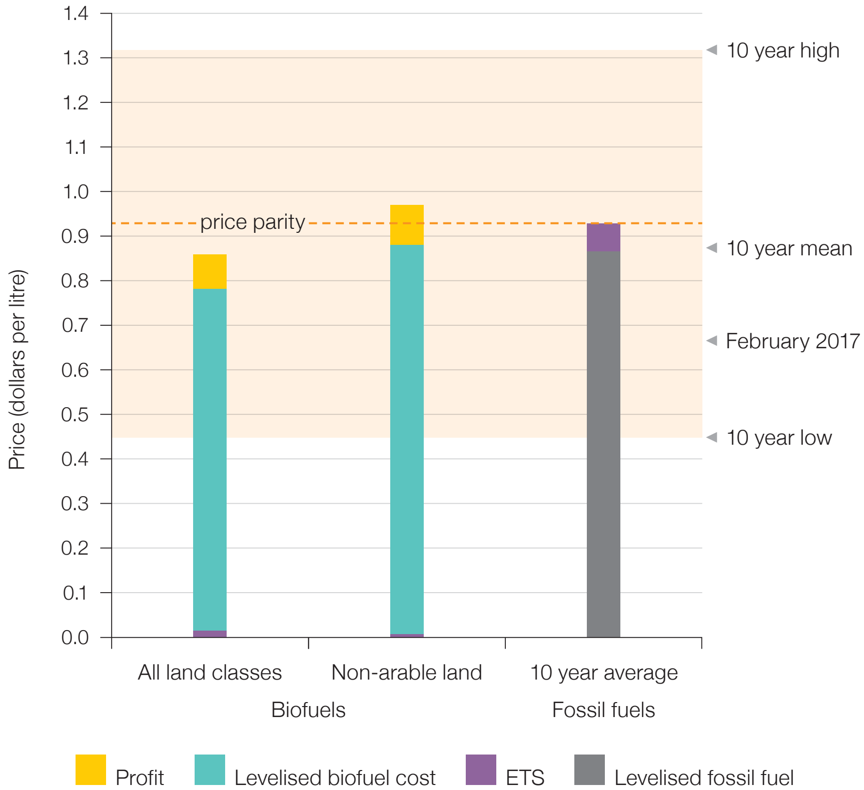
This type of analysis is widely used in the energy sector to compare different methods of energy production and takes into account:
- initial plant investment,
- cost of capital,
- plant operating costs,
- co-product revenues, and
- all costs for feedstock production and transport.

$$\text{Levelised biofuel cost (\$/L-e)} = \frac{\text{Sum of (all costs - all revenues) discounted over lifetime modelled}}{\text{Sum of discounted biofuels delivered over the lifetime modelled}}$$

Biofuel relationship to fossil fuel price. For biofuel production to be profitable relative to fossil fuels in the absence of any other incentives, then their cost at the plant gate must be less than the sum of the landed cost of their fossil equivalents, plus any carbon price they would incur under the ETS.

The figure below makes this comparison for the two scenarios discussed above. This shows that Scenario 1 is profitable, whereas Scenario 2, where no arable land is used, is not profitable.

The following diagram shows that while neither scenario would be profitable at current fossil fuel prices, there are many circumstances where biofuels would be economic given the range of fuel prices seen in the last 10 years.



Comparison of levelised biofuel cost for the two 30% substitution scenarios against the levelised displaced fossil fuel costs. Note: The mean and range of fossil petrol and diesel prices is indicated. Key assumptions: constant nominal price of $25 per tonne CO_2-e; an indicative profit to the biofuel producer of 10% of cost; constant nominal 10-year average landed prices for fossil petrol and diesel; and constant input prices and co-product revenues.

Average landed fuel prices	
Fuel type	Price cents per litre 10-yr average (range)
Petrol	84.4 (44.1 – 130.8)
Diesel	87.8 (38.3 – 157.4)
Jet	86.9
Marine (Heavy fuel oil)	72.0

Sources: Ministry of Business, Innovation and Employment & Hale and Twomey 2017.

Higher landed fossil fuel prices, or higher prices for carbon within the ETS, unsurprisingly, make the domestic production of biofuel more likely to be profitable.

Equally, government incentives to biofuel producers, or mandated levels of biofuel incorporation are commonly used overseas to encourage biofuel production. These can make a big difference to the biofuel producer. For example, bioethanol and electric vehicles are currently exempt from contributions to the National Land Transport fund. A similar exemption for other types of biofuel would be a substantial incentive.

Impact of co-products

The sale of co-products has a significant beneficial impact on overall cost of biofuels, as shown in the following table.

Impact of co-product revenues on the levelised biofuel cost for 30% substitution scenarios			
Scenario	Co-products	Levelised biofuel cost $/L-e	
		Including co-products	Excluding co-products
Scenario 1 All land classes	• Canola seed meal • Glycerine • Char • Sawlogs • Fibre logs	$0.77	$1.03
Scenario 2 Non-arable land	• Char • Sawlogs	$0.88	$0.99

Results of modelling - Different levels of biofuel substitution

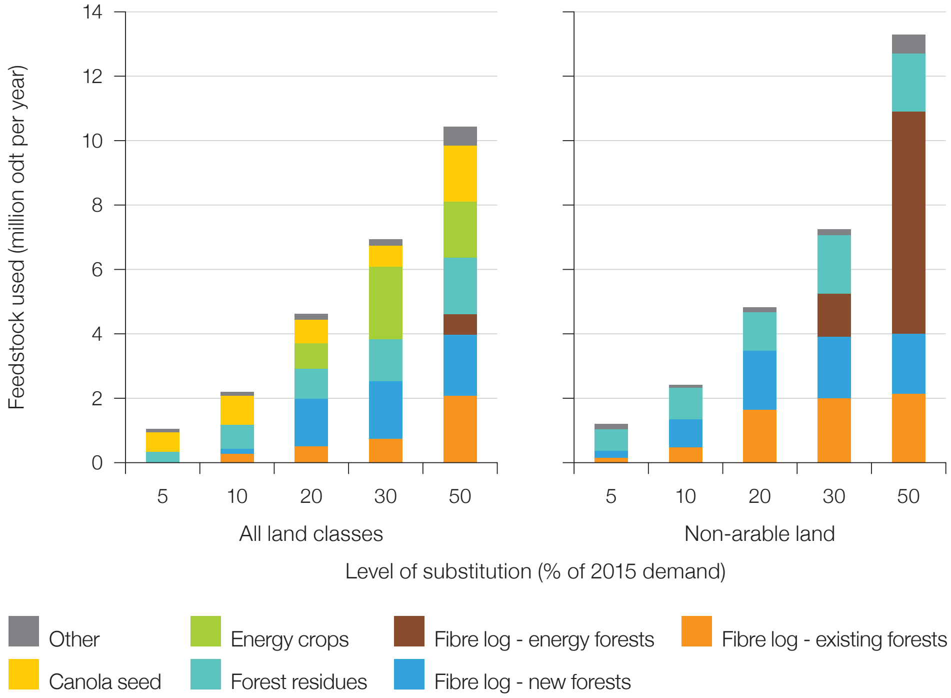
The implications of different levels of biofuels substitution, 5%, 10%, 20%, 30% and 50% by 2050, were compared. This produced differing effects on feedstocks, production, cost and reduction of GHG emissions.

The model compared two situations - all land classes available and when no arable land can be used.

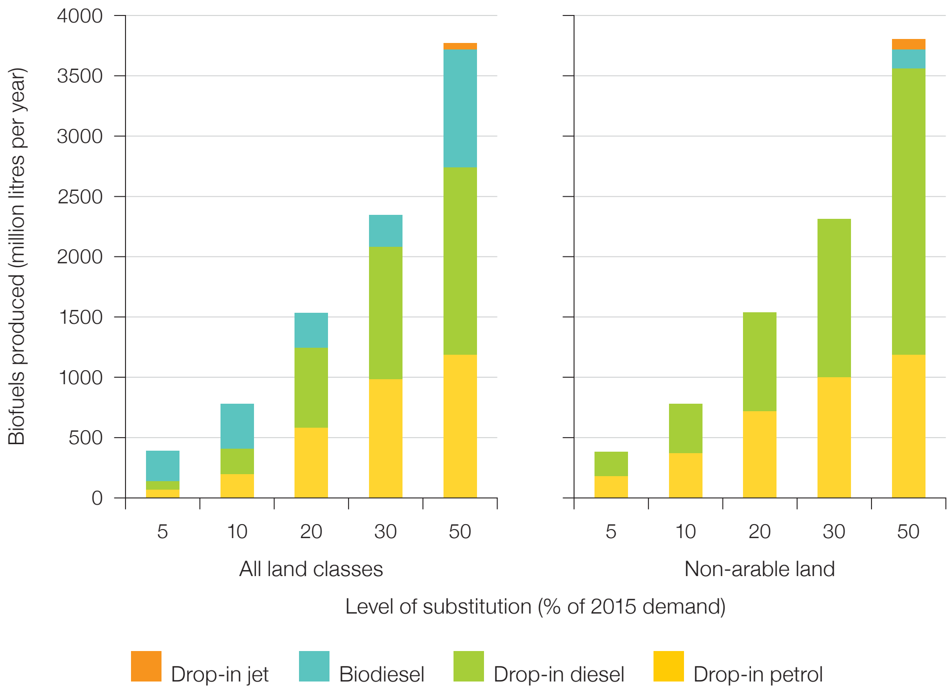
When all land classes are used and up to 50% substitution, the main biofuels are biodiesel from canola and drop-in petrol and drop-in diesel by pyrolysis/upgrading.

When no arable land is allowed, canola or energy crops (willow and miscanthus) cannot be grown and are substituted by additional existing feedstocks from new and existing forests.

The following graphs illustrate the different levels of biofuel substitution for different scenarios.



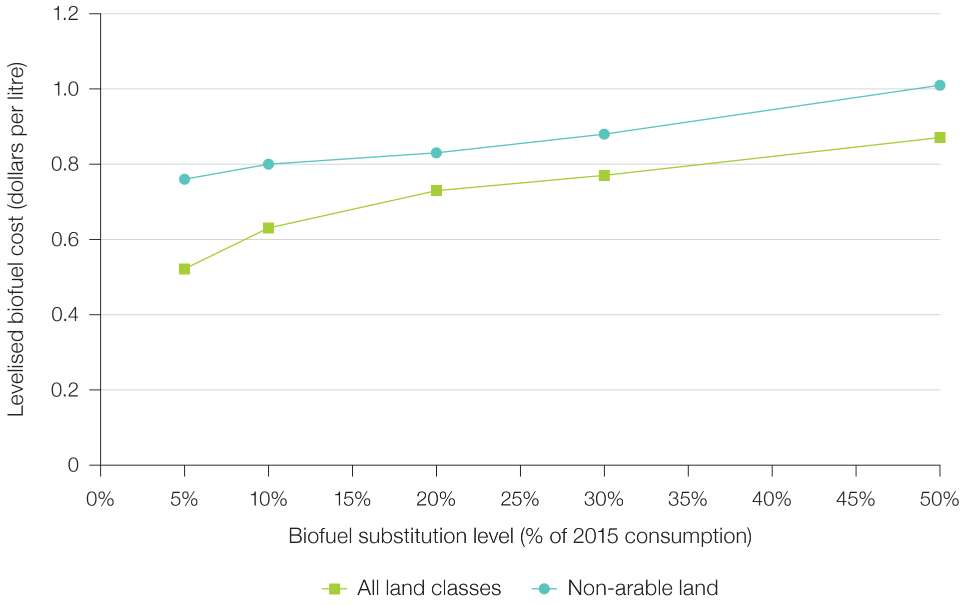
Feedstocks used in the 2046-50 period for different levels of substitution when all land classes are available, and when no arable land is allowed.

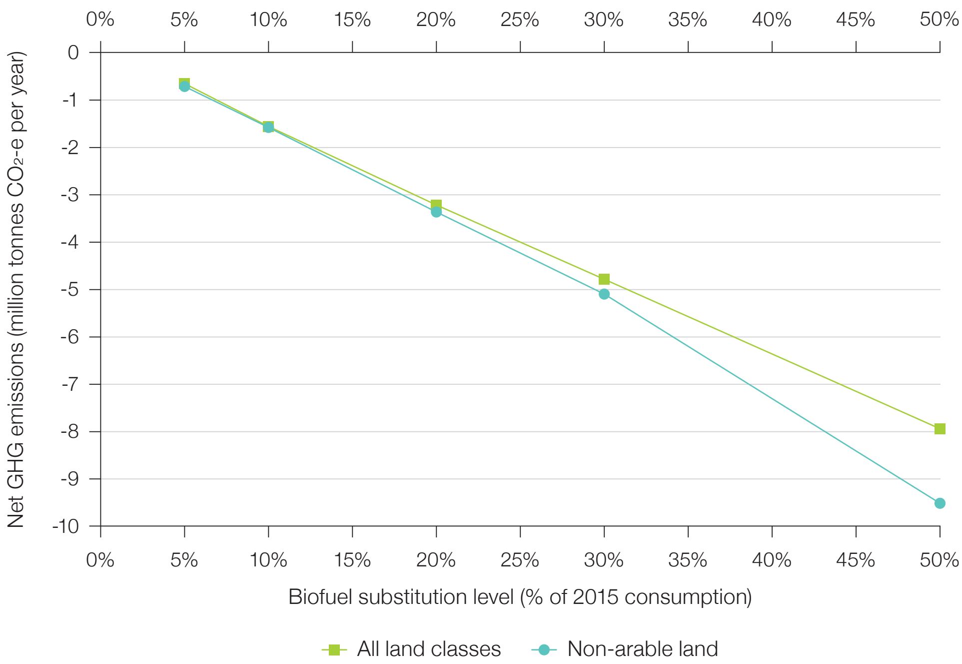


Biofuel production in the 2046-50 period for different levels of substitution when all land classes are available, and when no arable land is allowed.

The following table and figure shows that the levelised cost of biofuels increases when the level of substitution increases and is higher when non-arable land is used.

The levelised cost per litre goes up because such a lowest cost optimisation model will always choose the lowest-cost value chains first. Here, this is mainly because at low substitution levels co-product sales (particularly logs and rapeseed meal) are higher per litre of biofuel produced. The scenario where no arable land is used is more costly because while feedstock costs are lower, capital and operating costs are higher and co-product revenues are less.





Levelised biofuel cost and net displaced greenhouse gas emission at different substitution levels in 2046-50 period.

At 50% substitution, the model was forced to produce more costly diesel and even more expensive jet fuel. This is because conversion technologies like pyrolysis/upgrading produce fuels in specific ratios and once the demand for petrol (or diesel) in the fuel demand projection is met, then other more costly fuels must be produced. An assumption was made in this study that no biofuels are exported - exports of drop-in petrol would have allowed lower cost conversion technologies to be used.

The higher the level of biofuel substitution, the greater the reduction in fossil GHG emissions.

Cost metrics and GHG reductions for different levels of substitution						
Substitution level	Levelised biofuels cost		Total capital investment over the seven periods		Net GHG emission reduction in the period 2046-50	
%	Dollars per litre equivalent		Billion dollars (not discounted)		Million tonnes CO_2-e per year	
	All land classes	Non-arable land	All land classes	Non-arable land	All land classes	Non-arable land
5%	0.52	0.76	0.6	1.2	-0.7	-0.7
10%	0.63	0.80	1.4	2.3	-1.5	-1.6
20%	0.73	0.83	3.8	4.5	-3.2	-3.4
30%	0.77	0.88	6.0	6.8	-4.8	-5.1
50%	0.87	1.01	9.8	14.4	-8.0	-9.5

Results of modelling - Choice of specific fuel types

The preceding scenarios left the model free to choose which biofuels to produce to satisfy required demand at lowest cost. This was nearly always a mix of replacements for fossil petrol and diesel.

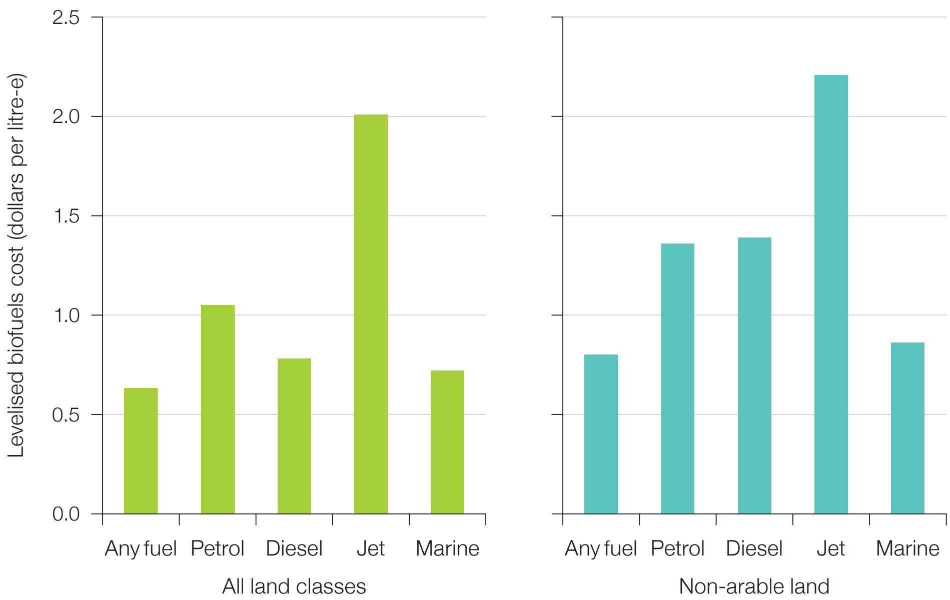
Strategically, it might be better to target replacements for specific fossil fuel types. For example, bio-jet fuel is one of the few options for decarbonising the aviation sector.

Targeting minimum volumes of specific fuels is more expensive than producing an equivalent volume of biofuels as any fuel mixture. When one fuel is specified, flexibility is removed from the system and more expensive technologies must be used.

When jet biofuel is specified, high cost results because the only option to make high proportions of this fuel is to make ethanol first, and convert this to a mix rich in drop-in jet fuel. This is very costly technology. Other technologies, such as gasification/Fischer-Tropsch, only make a small proportion of jet fuel and larger proportions of other fuels.

In reality, targeting a single drop-in biofuel, as is modelled in these scenarios, is unlikely. This is because most drop-in biofuel technologies actually produce mixtures of drop-in petrol, diesel and jet fuel, so would produce and sell this mix of products. In the scenarios shown below credit is only given for the targeted fuel type.

Production, 10% of 2015 demand of biofuels targeting specific fuel families				
Fuel type	Conversion technologies (non-arable land)	Main biofuels produced	Levelised biofuel cost, $/L-e	
			All land classes	Non-arable land
Any fuel	• Pyrolysis/upgrading	• Drop-in petrol • Drop-in diesel	0.63	0.80
Petrol	• Gasification/syngas fermentation • Cellulosic ethanol • Cellulosic butanol	• Bioethanol • Biobutanol	1.08	1.36
Diesel	• Catalytic depolymerisation • Biodiesel production	• Drop-in diesel • Biodiesel	0.78	1.39
Aviation	• Alcohol-to-jet • Gasification/syngas fermentation • Cellulosic ethanol	• Drop-in jet	2.01	2.21
Marine	• Pyrolysis-mild upgrading	• Oxygenated marine fuel	0.72	0.86



Levelised biofuel cost for production of 10% of 2015 demand as specific fuel types when all land classes are available, and when no arable land is allowed.

Wastes, residuals and by-products

Current biomass wastes and process residues could be good initial biofuel feedstocks.

Municipal solid waste, waste wood from construction and demolition, harvest residues left in forests, and co-products from existing biomass processing such as chips from sawmills, or tallow from meat-processing are examples.

Generally however, their feedstock potential is limited for large-scale biofuel production because:

- available volumes are low compared to expected total fuel demand, making up at most 8% of 2015 fuel demand,
- while some wastes and residues are not currently being used, tallow or sawmill chips already have existing end uses and established values, often making them too costly, and
- it might not be technically or economically feasible to collect geographically dispersed feedstocks such as forest residues.

The model frequently chooses to use forest residues and wood waste as feedstocks in the scenario modelling discussed above because of their lower cost.

The following table shows the maximum potential of residuals and by-products to produce biofuels.

Maximum potential of residuals and by-products		
	Amount produced (oven dry tonnes per year, 2015)	Substitution potential (% of total 2015 liquid fuel demand)
Tallow	178,000	2.2
Municipal solid waste*	235,000	0.7
Waste wood**	229,000	0.8
Forest residues	1,240,000	4.5
		Total 8.2

* Organic part only ** Currently disposed in landfills

3 Additional considerations

What the scenario modelling results reveal - risks, costs and implications

Modelling potential pathways for future biofuel deployment in New Zealand raises numerous issues.

While there is a richness of opportunity in pursuing low carbon fuel sources, the economic, environmental and social implications behind large-scale production need to be considered.

A small change in one component of the biofuel value chain impacts further up or further down the line. Everything affects everything, nothing changes in isolation from other parts of an integrated system.

Whether examined from a partial (5%, 10%, 20%, 30%, 50%) substitution of fossil fuels, or a total (100%) substitution, the feasibility, timing, feedstocks, processing, distribution and cost of various potential pathways needs to be understood and factored into any plan for biofuel manufacture and use.

The key for a successful commercial biofuel production process is that it must produce on-spec fuels, reliably, at large scale and competitive cost.

Technology

Technical risk

Although rapid developments are occurring internationally, many of the biofuel technologies of interest are not yet commercially proven. This is particularly so for drop-in fuel production from lignocellulosic feedstocks, including pyrolysis/upgrading, identified as one of the model's best options.

Before large-scale deployment of these new technologies can occur they will need to be proven to operate reliably at large scale and to produce fuels that meet required fuel quality standards.

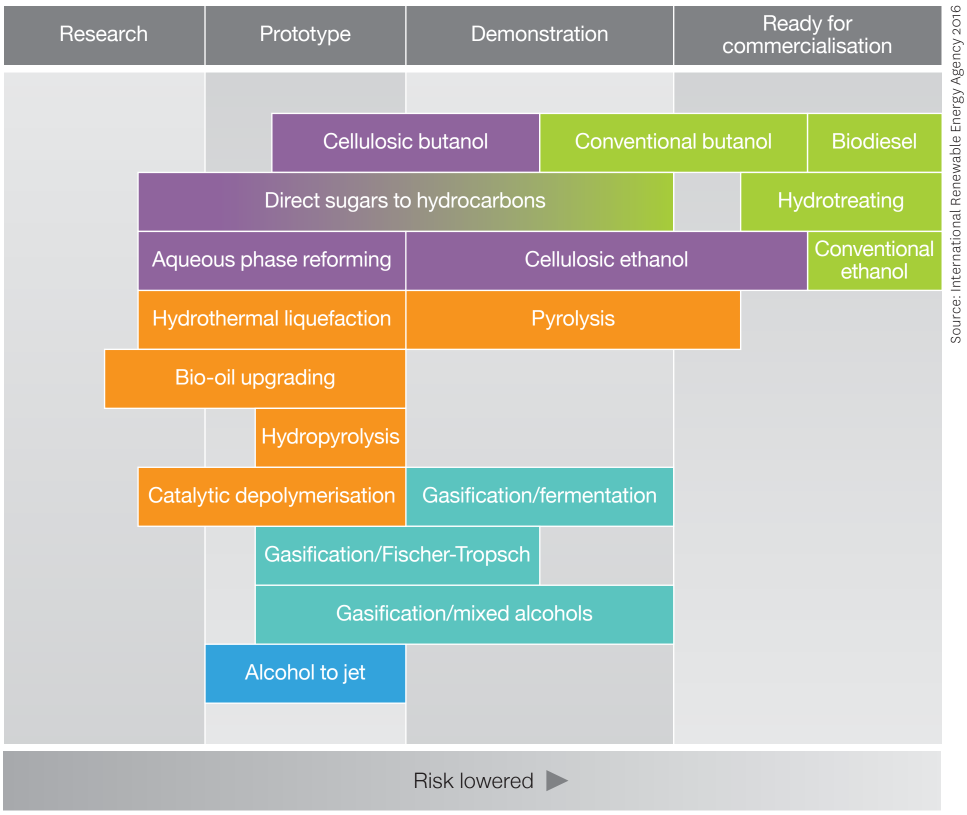
Such technical risks substantially add to the risk for an investor. However, such risk will fall with time as technologies are commercially proven. The technologies evaluated in this study are at a range of development level.

Government support has been widely used overseas as a mechanism to reduce the risk with immature technologies and encourage deployment of more environmentally sustainable fuels.

Multiple technologies to produce drop-in biofuels are under active development, reducing the risk of finding a commercially-viable technology.

The following diagram summarises the readiness of most of the conversion technologies considered in the scenario modelling, many of which have yet to have been proven at commercial scale.

Pyrolysis coupled with bio-oil upgrading to produce a mix of drop-in petrol and diesel is a prominent technology identified in many of the study's scenarios because of its low cost. While pyrolysis is relatively well-proven with a number of commercial-scale plants operating, upgrading of pyrolysis oil has only been demonstrated at a pilot scale.



Commercialisation status of various biofuel production technologies use in the study. The colours represent mature processes (green), process proceeding via sugar intermediates (purple), bio-oils (orange), synthesis gas (light blue) or alcohols (dark blue).

Implications of using only mature technologies

Technical risk could be reduced by deploying only todays mature conversion technologies. A scenario run assuming 30% fuel substitution using only today's mature technologies identified biodiesel from canola plus a little tallow, and ethanol from sugar beet as the sole fuels.

However, there are a number of significant negative implications with this scenario, including:

- biofuel cost is considerably higher, $1.02 vs $0.77/L-e,
- new vehicles with modified engines would be required,
- a total of 825,000 hectares of cropping land would be required to grow the canola and sugar beet, 1.7 times the current cropping plus horticultural land in New Zealand, and

- sales of co-products, particularly canola meal and sugar beet pulp are assumed to offset costs. Would there be markets for these products at this scale?

Feedstock

Energy crop risk

Energy crops such as miscanthus or willow have not been grown at large scale in New Zealand, and so would carry substantial technical and financial risk.

Being potential feedstocks, it would be prudent to obtain further information and experience on how successfully these crops could be grown at scale across the country.

Land use considerations

New Zealand land use is relatively dynamic and farmers will switch to more lucrative crops if the returns are higher and the risk not too great. It follows that if a given crop is not being grown now, it is not sufficiently profitable in the current market.

There are large opportunities for biofuel feedstocks to compete with established land uses experiencing economic challenges. For example, drystock land owners in the relatively inexpensive and flat lands of the East Coast and Northland have been looking for more profitable alternatives to sheep and cattle.

If biofuel demand increases, feedstock demand would lift, offering profitable land use alternatives.

Other environmental policies may also make the case for growing biofuel feedstocks more appealing. These currently include:
- attempts to mitigate climate change – ETS,
- decreasing erosion - Erosion Control Funding Programme and Afforestation Grant Scheme, and
- reducing freshwater nutrient loads - National Policy Statement for Freshwater Management.

Timing

Timing is critical. Biofuel deployment requires coordinated implementation across the value chain at large scale.

National leadership is crucial to this. The higher the level of biofuel deployment, or the quicker they are implemented, the more critical this co-ordination becomes.

Some of the key timing considerations are illustrated on the following page.

Key timing considerations in biofuel deployment		
Feedstock production and transport	Conversion plants	Fuel distribution and use
• Time for crop/forest to grow • Learning to grow new crops • Expanding crop production	• Consents and finance for plants • Construction time for plant • Infrastructure upgrades • Time to commission plant • Time for new technologies to be commercially proven (uncertain)	• Fuel demand changes • Upgrading of fuel distribution • Fuel certification (e.g for bio-jet) • Rate new vehicles enter market (if modified engines required)

If New Zealand wants to implement biofuel production as quickly as possible, the time required to construct the conversion plants will likely limit the rate at which biofuels could be deployed.

That would mean choosing mature technologies and a crop like canola that is already grown in New Zealand, matures quickly and could be upscaled rapidly. Likewise, the use of tallow as a biofuel feedstock is well understood.

While forest residues and fibre logs from existing plantation forests or biomass wastes are available immediately, their conversion technologies are not yet commercially proven.

This would limit the ability of biofuels to contribute to meeting 2030 GHG commitments.

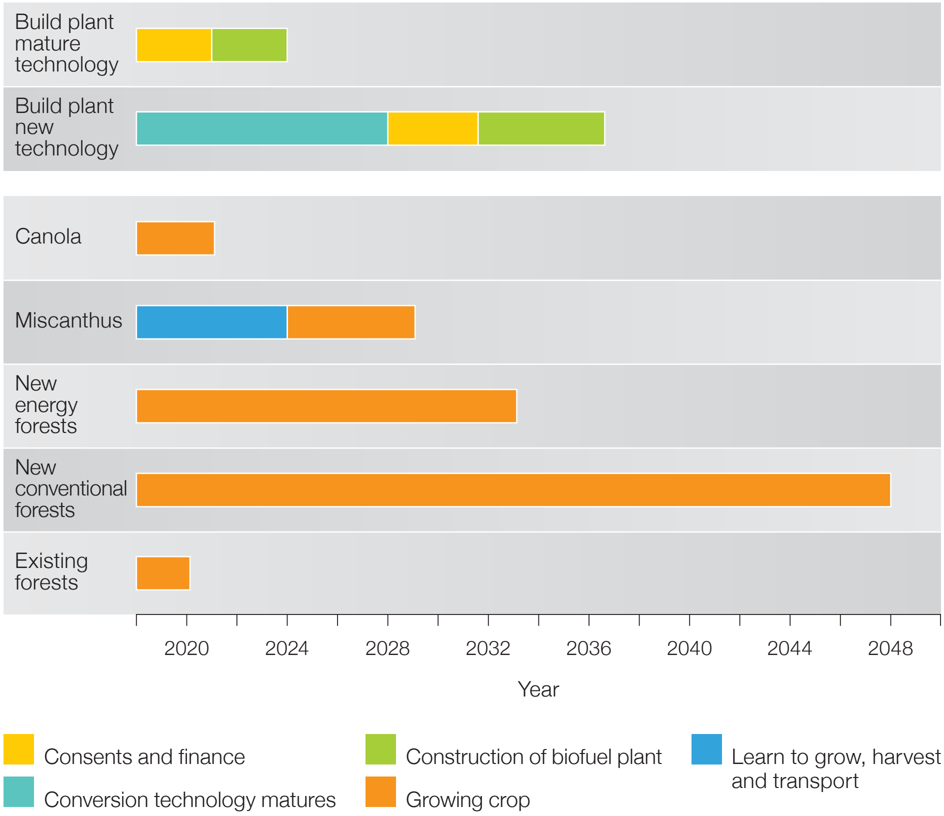
In the longer term, beyond 2030, deployment is likely to be limited by feedstock availability, particularly if forestry feedstocks are the preferred option. The required conversion technologies would be expected to mature within this timeframe.

Forestry feedstocks also offer timing flexibility because they can be harvested at a range of ages to match demand. They can also be grown in different ways - for energy production on a 15 year rotation, or 25 to 30 years for a conventional forest producing sawlogs, fibre logs and forest residues.

They can also be grown in different ways, not only for 25 to 30 years for a conventional radiata pine plantation forest producing sawlogs, fibre logs and forest residues, but also potentially for shorter times as a purpose-grown energy forests using different regimes or species.

The modelling identified that growing lignocellulosic crops, such as miscanthus, willow or energy forests, in the early years and then switching to fibre logs from new multi-purpose forests in later years would get around feedstock constraints.

The impact of timing on biofuel implementation from different crops is illustrated on the following page.



The impact of timing on biofuel implementation, assuming we start now.

Competition for biomass

Biofuel feedstock would have to compete with existing and future users of biomass.

Existing users include the pulp and paper, particleboard, fibreboard and wood pellet industries. These are major regional employers and exporters.

Replacing fossil coal and gas with wood waste for industrial heat is an attractive and easier to implement option to reduce New Zealand's carbon emissions, which would increase competition for this biomass.

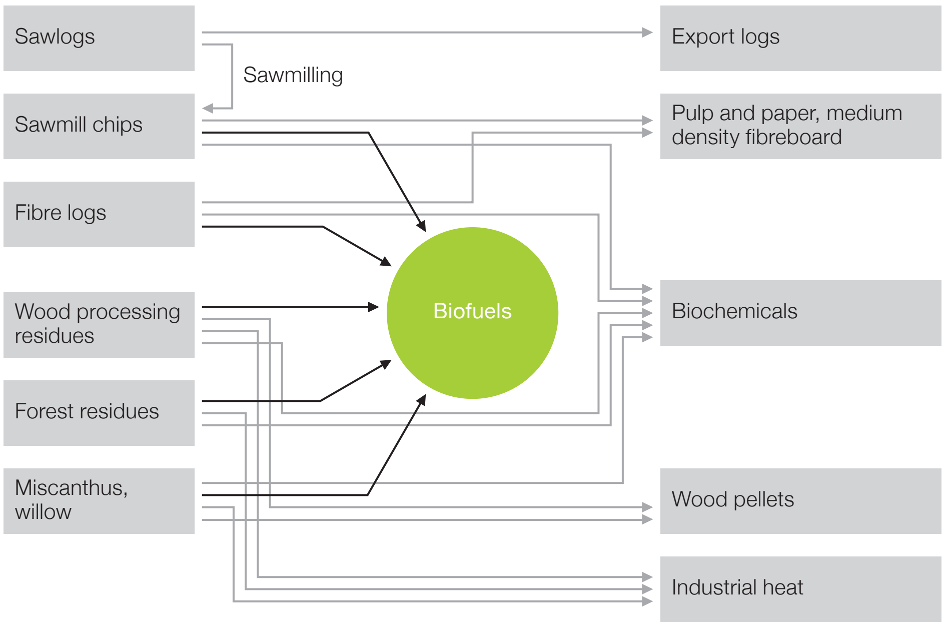
Production of naturally produced sustainable biochemicals for export and use in the global plastics, chemicals and other industries is another potential future competing use of biomass.

Future competition for biomass is likely to have impacts on the price of biomass feedstocks. While an important question, it is beyond the scope of this study to consider the impact of supply and demand on feedstock costs, or the best uses of biomass.

And this competition would have to be considered at a regional level, because generally it is not economic to transport such feedstocks over long distances.

It would only be under national leadership that the best uses for biomass could be considered, taking into balance economic, social and environmental factors.

The following diagram illustrates some of the multiple options for biomass utilisation.



Competing uses of biomass (residuals are available in limited volumes).

Green biochemicals as another output

The model was not specifically programmed to produce or reveal green chemicals that could be obtained as additional co-products of the biofuels programme.

However, it is clear that sustainable chemicals for use in the plastics and other industries will be increasingly in demand as fossil fuel use decreases across the world.

These green chemicals could be expected to add significant bottom line advantages to the modelling and its economics.

Environmental and social implications

Large-scale biofuel production would have significant positive environmental and social impacts, but there are issues that need to be considered.

Under a 'biofuels done right' policy, pathways selected for the production of biofuels should have demonstrable and significant carbon benefits compared to fossil fuels.

Crop production areas might need to be restricted to minimise the use of water for irrigation, and the spread of crops into areas of high conservation or amenity value halted.

The general public would have to buy into the benefits of addressing climate change and the ability of biofuels to achieve these benefits. The public would also have to understand and accept the possible risks and implications of biofuel production, such as the growing of monocultures on large areas of land.

4 Future narratives

What considerations should we make around biofuels?

Predicting the future is a difficult enough challenge even looking only a year ahead.

When the time frame is 35 years, the permutations and combinations become even more daunting.

However, decision-makers need to consider possibilities and impacts to enable the development of the 'best fit' biofuel deployment pathways.

'Future Narratives' templates can help inform these decisions around the 'right' biofuel strategy for New Zealand.

The following five narratives provide a basis for government, industry and communities (including project stakeholders) to explore biofuel opportunities, issues and trade-offs.

1. Meeting New Zealand's Paris commitments

New Zealand decides it must implement large-scale biofuel production and use to help fulfil its commitment to meeting its 2030 GHG emission target of 57.7 million tonnes CO_2-e per year.

To achieve this

- Biofuel production is focussed on reducing national emissions, so targeting domestically-consumed fossil transport fuels, rather than those used internationally (which are outside the ETS framework).
- Mature conversion technologies would likely be chosen, at least initially, as a way of ensuring these biofuels are actually produced, and to reduce the technical risks of less-mature conversion technologies.
- Feedstock choices would likely be dictated by the available conversion technologies.

Likely biofuels

- Biodiesel or renewable diesel produced from canola (and tallow).
- Bioethanol from sugar beet and/or corn.

Impacts and consequences

- Feedstocks would need to be grown on cropping land. Would lead to a major expansion on flatter land spread across the country; with possible impacts on the existing dairy sector.
- Neither biodiesel nor bioethanol are drop-in fuels. The levels to which these biofuels can be deployed may be limited to the extent they can be blended with fossil petrol or diesel and still operate in the existing vehicle fleet. Production of more costly renewable diesel from canola oil could allow blend limits to be overcome.
- This may not be an optimal long-term solution. Food feedstocks may not remain acceptable feedstocks and higher levels of deployment would require vehicle fleet modifications, possibly making it difficult to meet 2050 targets due to technology and feedstock lock-in.

2. Biofuels from non-arable land

New Zealand decides that food or energy crops grown on land capable of producing food crops are not acceptable feedstocks for biofuel production.

To achieve this

- Feedstocks would likely mostly originate from existing and future plantation forests and wastes.
- New forests likely to be grown on steeper land incapable of growing crops, mainly where land is cheaper such as Northland, the East Coast and the Central North Island.

Likely biofuels

- Mixtures of drop-in fuels produced largely from forestry feedstocks.

Impacts and consequences

- Technologies for producing drop-in fuels from lignocellulosic feedstocks are immature - making investment problematic. But, this is an area of intense global interest, so solutions will probably eventually be found.
- Economic development and employment growth occurs in regions where feedstocks are grown and conversion plants located.
- Could potentially lead to competition for feedstocks from existing wood processors.
- Potentially, all fuel families could be replaced by biofuels, and high levels of substitution achieved without requiring engine modification.
- There is a risk that sediment loss and debris flow after harvesting forests on steep land may see forestry restricted on some sites.

3. Leave it to the market

Government takes a hands-off approach to biofuels implementation. Fuel users make decisions based on price and are not prepared to pay a premium for biofuels over fossil alternatives.

To achieve this

- Biofuel producers and feedstock producers would only invest when the technical risks are low and biofuels are profitable.

Likely biofuels

- Decided on a case-by-case basis.

Impacts and consequences

- Level and timing of any deployment would be uncertain.
- Conversion plant investments unlikely until oil and/or carbon prices rise substantially and stay there for a significant length of time.
- First investments are built around specific opportunities such as utilising the limited amount of existing low-cost waste.
- If biofuel demand rises rapidly, the rate of deployment may be limited by access to the required feedstocks - with resulting market price responses.
- There is a risk that nothing happens until it is too late. Feedstock producers will not commit to growing a crop without a guaranteed market, while investors will not build conversion plants without a sustainable supply of feedstock. This is of particular concern for forestry feedstocks because the time to grow a crop to maturity is long.
- It could be difficult to impossible for the country to meet its GHG reduction targets.

4. International market pressure

Sustainability becomes increasingly important across the world, and market pressure from consumers of New Zealand goods and services (tourism in particular) about fossil fuel use drives biofuel implementation in the marine and aviation sectors.

To achieve this

- As biofuels from food crops or arable land would probably not be acceptable, feedstocks would probably mostly come from existing and future plantation forests.

- Biofuels to replace fossil marine and aviation fuels would be a priority.
- New forests on steeper land, particularly in Northland, the East Coast and the Central North Island.

Likely biofuels
- Technologies producing drop-in fuels, particularly jet and marine replacements, largely from forestry feedstocks.

Impacts and consequences
- Since marine and aviation fuel markets are global, such biofuels would need to fit with international developments, regulations and standards as they emerge.
- It might not happen if New Zealand biofuel producers target domestic road transport over international markets. Carbon emissions from fuels burnt outside New Zealand currently sit outside the ETS, so mechanisms to meet national emissions targets may provide a price premium for biofuels targeting domestic emissions.

5. Carbon zero by 2050

New Zealand decides there will be zero net carbon emissions by 2050.

To achieve this
- Fossil fuels must be replaced in nearly all applications.
- Electric vehicles and biofuels both need to be a significant component of the transportation energy mix.
- Long-term buy-in and commitment by government, industry and the public is required.
- Leadership is needed to plan and coordinate such a large-scale biofuel deployment.
- Long term stable government policies are essential to provide investment certainty.

Likely biofuels
- Drop-in biofuels from lignocellulosic biomass, produced by multiple technologies depending on local conditions.
- A focus on biofuels in the difficult-to-electrify transport modes of aviation, marine and heavy transport - although some bio-petrol is still required.

Impacts and consequences
- Afforestation and/or carbon capture from biofuel plants is used to compensate agricultural emissions.
- This is a large-scale undertaking with many significant social, land use and economic implications.
- Only lignocellulosic feedstocks are used to prevent lock-in situation.
- New Zealand leads global implementation of lignocellulosic biofuels.

5
Way forward

Where the modelling and stakeholder discussions lead us

The preceding scenarios demonstrate that credible routes exist for large-scale biofuel production and consumption in New Zealand. Biofuel use could also significantly reduce New Zealand's GHG emissions and underpin regional economic development.

These future-possible scenarios have narrowed down New Zealand's best options, and provide a basis for government, industry and communities (including project stakeholders) to explore the opportunities, issues and trade-offs associated with large-scale biofuel production and use.

Given the right strategic drivers, national consensus is needed on the answers to four key questions in order to pinpoint the best option(s) for biofuel deployment in New Zealand.

1. Which fuel families and which specific biofuels should we be targeting?
2. What are acceptable feedstocks for biofuel production?
3. What level of biofuel substitution is required and in what timeframe?
4. What are the best uses of biomass in New Zealand?

Discussion

Scenario modelling, international trends and stakeholder feedback suggests the following key areas for New Zealand to focus on.

1. Produce liquid biofuels to replace fossil fuels where there are few decarbonisation options

The best option to replace fossil fuels depends on the needs of the specific fuel sectors.

Battery-electric vehicles (EVs) are promising, particularly in urban settings. Travel distances are short, and the vehicles often sit idle so the recharge time is less critical. EVs also improve air quality and reduce noise.

EVs would reduce petrol demand in the first instance.

EV use may gradually spread to other sectors powered primarily by fossil diesel such as light trucks, long distance road haulage and off-road applications such as agricultural and forestry machinery. But because of distances travelled and loads transported with the associated demands on batteries, early electrification of these markets is less likely.

The high energy density of liquid fuels are well suited to applications in remote locations where fuel consumption is high, vehicles operate for a long time and battery weight would reduce payloads.

In some situations electrification of heavy duty vehicles may make sense - such as city buses, rail, city ferries and light trucks which return to base at frequent intervals.

Biofuels are currently the only real option to significantly decarbonise aviation, and even though alternative clean propulsion techniques are in development, these alternatives are unlikely to be ready for commercial use in 2050. Aircraft also have a long life span and are very expensive, so airlines typically want to use them as long as possible before replacing them.

In the marine sector, biofuels are one of the few options for decarbonising without installing new engines, particularly for large vessels such as container ships that export New Zealand's goods.

The IMO (International Maritime Organisation) has regulated to reduce sulfur levels in marine fuels from 3.5% to 0.5% in 2020. Biofuels inherently have a low sulfur content, so could be one way to reach this goal while also reducing carbon emissions. Marine engines are also tolerant of a wide range of fuels, making them an attractive biofuel option.

It should also be noted that though fossil fuel emissions from international aviation and shipping (1.4 billion litres in 2015) lie outside national climate change commitments (and New Zealand's ETS), decarbonising these sectors is strategically important to New Zealand.

As climate change increases in profile, consumers in our export markets may focus more on the carbon embedded in getting New Zealand's exports to market, or even the jet fuel used to bring tourists to the country.

For these reasons a strong focus should be on biofuel replacements for fossil jet, diesel and marine fuels.

2. Focus on drop-in biofuels that can be used in existing vehicles, ships and planes

While the technical risks and costs of producing drop-in biofuels are presently higher than for conventional biofuels, they offer substantial advantages for New Zealand. In particular, they allow both the existing fossil fuel distribution infrastructure and existing vehicles to be used, and for the biofuel to be introduced in gradually increasing levels.

These benefits are particularly compelling for international shipping and aviation where there are few viable non-drop in alternatives, and New Zealand is only a small part of global aviation and maritime fleets.

Ethanol and biodiesel, added as blends in petrol and diesel respectively could offer short-term options to increase New Zealand biofuel use. They are proven overseas, already available in limited quantities in New Zealand, but their ultimate deployment could be limited by the need for new vehicles.

3. Reduce future market risks by focussing on feedstocks grown on non-arable land

Large-scale biofuel use in New Zealand will require consumers to be convinced they are being produced in a 'sustainable' way before they buy them.

Given the long-term nature of investments in large-scale biofuel production, it would be prudent to reduce future market risk by avoiding food crops or using land capable of growing food crops (this would also exclude most of the land currently being used for dairying).

Lower-cost non-arable land would therefore be best for biofuel feedstocks. But lignocellulosic crops such as miscanthus or willow require arable land as they need to be mechanically harvested. This could be an option until the required volumes of forestry feedstocks become available.

4. Plantation forest feedstocks are New Zealand's best long-term large-scale biofuel production option

Wastes and agricultural feedstocks could play a short-term role, but logs and forest residues are the best option for large-scale production of biofuels in New Zealand. Plantation forests are one of the few profitable crops for lower quality non-arable land. They also offer significant flexibility around how they are grown, when they are harvested and what they are used for.

The scenario modelling showed conventional pine forests, where higher value sawlogs are sold into existing markets and lower value fibre logs and forest residues are used for biofuel production were preferred feedstocks at longer timeframes.

5. In the short term, focus on niche opportunities to build momentum, provide early wins and create a positive perception of biofuels

Currently only small volumes of biofuels are being used and produced in New Zealand. There is also a very limited understanding of biofuels' potential to address the country's GHG emissions.

If biofuels are to be produced at large scale, it is imperative to start now to build knowledge and experience around how to make and use biofuels successfully, and to build general public confidence they can be successfully used.

Niche opportunities to produce biofuels

- Use currently-unused low-cost biomass wastes such as municipal green waste, municipal wood wastes and forest residues.
- Where users such as brand owners and tourism operators may be prepared to pay a premium for using biofuels.
- Focussing on large fuel users where refuelling is possible at a single point. These include mining companies and where vehicles or vessels return to base each night. This greatly reduces the investment and risks required in fuel distribution and use.
- Target marine fuels where the technical requirements for a successful biofuel are less demanding.

Glossary

Arable land	Land, typically flat, capable of being ploughed and used to grow crops.
BEC2050	Study by BusinessNZ Energy Council: New Zealand Energy Scenarios, Navigating energy futures to 2050.
Biomass	Any organic matter, i.e. biological material, available on a renewable basis. Includes feedstock derived from animals or plants, such as wood and agricultural crops, and organic waste from municipal and industrial sources.
BVCM	Bioenergy value chain model
Cellulosic ethanol/butanol	Ethanol or butanol produced from lignocellulosic materials such as agricultural residues or wood.
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent is a unit to measure the global warming potential of different gases. For example, emission of 1 tonne of methane is equivalent to 21 tonnes of carbon dioxide.
Conventional forests	Forests grown in a traditional direct sawlog regime maximising timber production, but producing a range of different logs and forest residues. A 30-year rotation is assumed in the model.
Co-product	Material or energy that is produced at the same time as the main product.
Drop-in biofuel	A hydrocarbon fuel produced from biomass that is chemically identical to its fossil fuel equivalent. It can be used in existing engines and fuel distribution infrastructure without significant modifications.
Energy crops	Short term crops such as miscanthus or willow.
Energy forests	Short rotation forest plantations targeting maximum wood production. A 15-year rotation is assumed in the model.
ETS	New Zealand Emissions Trading Scheme
EV	Electric vehicle (battery powered)
GDP	Gross domestic product
GHG	Greenhouse gas
GST	[New Zealand] Goods and Services Tax
L-e of fuel	Litre equivalent in energy basis. Typically used to compare biofuels with different energy content. For example 1 litre of ethanol correspond to 0.62 litres equivalent of petrol, as the energy content of ethanol is lower than that of petrol.
Lignocellulose	A major structural component of wood and some other plants, consisting of carbohydrate polymers (cellulose and hemicellulose) and lignin.
Municipal solid waste	In the context of this study, this refers only to the putrescible or green part of the waste collected by municipalities (e.g. garden and kitchen waste).
Pyrolysis/upgrading	Combination of two processes in which the first one (fast pyrolysis) produces an intermediate bio-oil from lignocellulosic biomass and the second one (upgrading) produces a mixture of drop-in petrol and diesel by reacting the bio-oil with hydrogen.
Waste wood	Wood sent to landfill, including construction and demolition waste.

Appendix

Crops, feedstocks, transport, technologies and fuels used in the model.

Land classes

Arable land
High productivity flat
Medium productivity flat

Non-arable land
Rolling
Steep
Very steep

Forests/crops

Forestry
Conventional forest
Energy forest

Energy crop
Willow
Miscanthus

Arable crop
Corn
Maize
Canola
Sugar beet

Feedstocks

Sawlogs
Fibre log
Forest residues

Canola seed
Sugar beet
Maize
Corn
Willow
Miscanthus

Municipal solid waste
Waste wood
Tallow
Sawmill chips

Feedstock transport

Truck
Ship
Rail

Conversion technologies

Alcohol to jet
Aqueous phase reforming
Biodiesel production
Bio-oil upgrading
Catalytic depolymerisation
Cellulosic butanol
Cellulosic ethanol
Chipping
Conventional butanol
Conventional ethanol
Direct sugars to hydrocarbons
Gasification/fermentation
Gasification/Fischer-Tropsch
Gasification/mixed alcohols
Hydropyrolysis
Hydrothermal liquefaction
Hydrotreating
Mild bio-oil upgrading
Oil extraction
Pelletising
Pyrolysis
Torrefaction

Fuels

Petrol
Bioethanol
Biobutanol
Drop-in petrol

Diesel
Biodiesel
Renewable diesel
Drop-in diesel

Aviation
Renewable jet
Drop-in jet

Marine
Drop-in marine
Oxygenated marine fuel

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