Wood Fibre Futures

investment in the use of commercial forest biomass
to move New Zealand towards carbon-zero

Stage One Report

BIO PACIFIC PARTNERS

This report was produced by

In collaboration with

Maplesden Consultancy

Preface

In November 2019, the New Zealand Ministry for Primary Industries (MPI), Ministry of Business, Innovation and Employment (MBIE), and the Forestry Ministerial Advisory Group released a Request for Proposals (RFP) to deliver a global technology scan.

It sought a commercially oriented report that would:

> *"… support New Zealand's move to a net zero emissions economy by 2050 … identify internationally competitive investment opportunities using plantation forest biomass … substituting this renewable biomass as the feedstock in products and markets that would otherwise use non-renewable or petroleum-based feedstocks."*

The RFP defined further, specific deliverables as:

- Analyses on two time-horizons – 5-10 years and 20-30 years.
- A preliminary assessment of what might be required from commercial parties and the government to successfully execute these opportunities.
- A ranked short-list of 3-6 potential opportunities (for each time horizon) that would warrant further investigation.
- Recommendations for further work and next steps.

The RFP also forecast a Stage 2 of the project, subject to the findings of Stage 1, which would *"… be a significant piece of work focused on working with key stakeholders, potential investors and Government to develop a detailed implementation roadmap based on opportunities identified in Stage One."*

A Consortium of local and international experts as shown on the previous page was awarded the contract. It combined expertise at accessing difficult-to-find opportunities globally which could meet these aims, together with local experts from multiple forest industry sectors who understood the New Zealand landscape and its abilities, or limitations, to take on new technologies.

The Consortium scanned opportunities from around the world which used woody biomass, which could materially affect New Zealand's carbon emissions, and which would be investable given appropriate commercial and governmental backing. It screened them methodically, and described them in detail, before filtering them to a short-list. It also described, in depth, how the interests of investors and government would need to be aligned to make this concept a reality.

The scope of the work was stretched by the impact of the COVID-19 pandemic and came to include many elements of industry strategy which become critical as the sector, and the economy, was hugely disrupted. The Consortium acknowledges the many stakeholders who worked hard in the face of this unexpected challenge and is proud to deliver this broader report.

Executive Summary

This study recommends several internationally competitive investment opportunities using New Zealand's plantation forestry biomass to achieve two simultaneous outcomes:

Help move the country to carbon-zero.

Build on the forestry industry's current strengths and create higher value.

In the short-term (5-10 years) they are technologies which allow forestry to substitute imported fossil fuels by producing:

Biocrude oil, which brings options of refining it into transport fuels or multiple other products.

Liquid biofuels for use in heavy transport (truck & rail), aeroplanes and ships, not cars.

These technologies, chosen carefully, bring flexibility to pursue different markets or different carbon emission targets over time, and to use wider biomass sources than forestry, including municipal waste, which make their investment cases more robust.

Additional opportunities, addressing specific New Zealand market needs, can also impact the short-term:

Replacing coking coal in steelmaking.

Increasing the use of high-tech wood products in the built environment, an opportunity which has beneficial flow-on effects across the local industry, including increasing biomass for the technologies above, and they have potential for export.

In the longer-term horizon (20-30 years), there are directed actions which are recommended to lock-in the benefits of the short-term actions above by:

Sustaining focus on the technology areas selected – specifically biocrude, biofuels and the built environment.

Tracking international progress in biochemicals – specifically lignin, sugars, biomaterials, and extractives – to speed adoption when the time is right.

Currently the investment environment does not favour New Zealand because:

The residual woody biomass in New Zealand is expensive (around 20% more than key competitor countries) due to difficult terrain and transportation.

It is also limited in availability because of commitment to existing usage and the high proportion of trees that are exported as logs.

There is little price signal to lower carbon emissions – New Zealand's carbon prices (NZD \$25 / tCO2e) are a fraction of some leading bioeconomy nations in Europe and North America (>NZD \$250 / tCO2e).

Global competition for opportunities which attract the specialist, large-scale, international investors in this arena is high.

Local investors, both financial and strategic, are limited in number and in scale and some of these are focused on the status quo including log exports.

Uncertainty is high, especially in this post-COVID world, so investment attraction should focus on projects with flexibility (options).

This unfavourable environment needs to be addressed before investment will flow, by:

Adopting Low Carbon Standard regulations which stimulate biofuels, and extend such regulations to include carbon used in the built environment.

Stimulating the use of wood in the built environment using public procurement.

Developing targeted investment cases, including commitments on these new policy settings from Government, to attract international investors (Wood Fibre Futures project, Stage 2).

Ensuring these investment cases include export potential to overcome the small domestic market concerns.

Engaging with Refining NZ and New Zealand Steel to build a cooperative approach to their involvement.

Maintaining a national competitive advantage in this arena by focusing R&D, international investment attraction efforts, and local industry development to support these actions longer-term.

photo courtesy of Red Stag Timber

Glossary

Biochar	Charcoal made from biomass via pyrolysis
Biochemicals	Chemicals derived from biomass
Biocomposites	A material composed of two or more distinct biocompatible and/or eco-friendly constituent materials
Biocrude	Crude oil equivalent (unrefined hydrocarbons) produced by solvent liquefaction of biomass
Bioeconomy	Economic activity involving the use of biotechnology in the production of bio-based goods, services, or energy from biological material as the primary resource base
Bioelectricity/bioheat	Conversion of biomass materials into electricity or heat
Bioenergy	Any conversion of biomass materials into an energy source, such as power, heat or fuels
Biofuel	Fuel produced from biomass (organic matter) via various processing methods
Biogas	A mixture of gases produced by the breakdown of organic matter in the absence of oxygen, primarily consisting of methane and carbon dioxide
Biomass	Plant or animal material used as a raw substance for producing a range of products
Bioplastics	Plastic materials produced from renewable biomass sources
Biopolymer	Polymers are chemicals or molecules consisting of often large numbers of repetitive units; biopolymers are polymers produced by living organisms
BTX chemicals	Chemicals containing mixtures of benzene, toluene, and xylene
Built environment	Man-made structures, features and facilities viewed collectively as an environment in which people live and work
Carbon value	The cost a government or organisation attributes to the prevention of carbon-dioxide being released into the atmosphere – used in regulation
Cellulose	A polysaccharide which is an important structural component found in the primary cell wall of green plants
Coking coal	A grade of coal used to create coke, which is one of the key inputs for the production of steel due to its very high heat output
COVID-19	Coronavirus disease caused by SARS-CoV-2
Depolymerisation	In the context of biofuels, a process using pressure and heat to reduce complex organic materials into light crude oil
Feedstock	Raw material used to supply or fuel a machine or industrial process
Gasification	Process using high temperatures, without combustion, that converts organic- or fossil fuel-based carbonaceous materials into gases including carbon monoxide, hydrogen and carbon dioxide
Hog quality wood	Wood including branches, bark and stumps which are processed in a hogger into burnable fuel
Hydrothermal liquefaction	A thermal depolymerisation process which is used to convert wet biomass into biocrude under moderate temperature and high pressure
Hydrotreating	A process by which hydrogen, under pressure, in the presence of a catalyst reacts with sulphur compounds in the fuel to form hydrogen sulphide gas and a hydrocarbon
ktCO2e	Kilotonnes of carbon dioxide equivalent, a measure of the amount of greenhouse gas; all gases are converted to the amount of carbon-dioxide that would need to be present to have the same global warming potential, e.g. emitting 1 kg of methane is equivalent to 25 kg of CO2.
Lignin	A class of complex organic polymers that form key structural materials in the support tissues of vascular plants, such as in wood and bark
Pulp	A lignocellulosic fibrous material prepared by chemically or mechanically separating cellulose fibres from wood, fibre crops, wastepaper or rags

Glossary continued

Pyrolysis	Thermal decomposition of biomass occurring in the absence of oxygen, resulting in formation of various products such as biochar, bio-oil and gases
Renewable Natural Gas	A biogas which has been upgraded to a quality similar to fossil natural gas and with a methane concentration of 90% or greater; also known as sustainable natural gas (SNG) or biomethane
Residual Woody Biomass	Parts of trees and wood remaining once sawn timber has been removed
Sequestered carbon	Carbon-dioxide that has been removed from the atmosphere (by processes such as photosynthesis) and changed to a form (such as wood) that no longer contributes to greenhouse gas
Shovel-ready	A project where planning and engineering is advanced enough that, with sufficient funding, construction can begin within a very short time. In the context of this report, this would suggest that due diligence had been undertaken and assurance over resource supply, cost and market would be well advanced.
Shovel-worthy	These are projects that meet the targeted aims of the sponsor. They need to be subjected to due diligence to take them to being fully investor
STEEP analysis	An analysis framework that considers Social, Technological, Economic, Environmental and Political factors or measures
Supercritical	When a substance is at a temperature and pressure above its critical point, where distinct liquid and gas phases do not exist, it is described as supercritical
Technology Readiness Level	A scale of 1-9 developed by NASA in the 1970s to estimate the maturity of any given technology, where 1 is early research and 9 is fully commercial.
Thermoplastics	A material, usually a plastic polymer, which becomes softer when heated and harder when cooled
Torrefaction	A thermal process to convert biomass into a coal-like material, which has better fuel characteristics than the original biomass
Torrefied wood/pellets	Wood that has been through the torrefaction process, with an increased energy density and is more water resistant

List of Acronyms

AI	Artificial intelligence
AUD	Australian dollar
BPD	Barrels per day
BTU	British thermal unit
CAD	Canadian dollar
CFS	Carbon fuel standards
CHP	Combined heat and power
CI	Carbon intensity
CLT	Cross-laminated timber
CNC	Cellulose nanocrystals
CNF	Cellulose nanofibrils
CNI	Central North Island
COVID	Coronavirus disease
CPI	Consumer price index
DME	Dimethyl ether
EBITDA	Earnings before interest, taxes, depreciation, and amortisation
ETS	Emissions Trading Scheme
EU	European Union
EUR	Euro
EV	Electric vehicles
FTE	Full-time equivalent
GDP	Gross domestic product
GHG	Greenhouse gas
IP	Intellectual property
IPO	Initial public offering
IPPU	Industrial processes and product use
LCA	Life cycle assessment
LCFS	Low carbon fuel standards
LCOE	Levelised cost of energy
LLC	Limited liability company
LPG	Liquefied petroleum gas
LULUCF	Land use, land-use change, and forestry
MBIE	Ministry of Business, Innovation and Employment (NZ)
MDF	Medium-density fibreboard
MJ	Megajoule
MMT CO2e	Million metric tonnes of carbon dioxide-equivalents
MPI	Ministry for Primary Industries (NZ)
MT	Metric tonnes
MW	Megawatt
NASA	National Aeronautics and Space Administration
NFC	Nanofibrillated cellulose
NPV	Net present value
NZ	New Zealand
NZD	New Zealand dollar
PHA	Polyhydroxylalkanoate (plastic)
PHB	Polyhydroxylbutyrate (plastic)
PLA	Polylactic acid (plastic)
PLC	Public limited company
RCF	Revolving credit facility
RFP	Request for proposal
RNG	Renewable natural gas
ROCE	Return on capital employed
ROE	Return on equity
STEEP	Social, Technological, Economic, Environmental, Political analysis
TIMO	Timber investment management organisations
TRL	Technology readiness level
TW	Terawatt-hours
UAV	Unmanned aerial vehicle
UK	United Kingdom
UN	United Nations
US	United States
USA	United States of America
USD	United States dollar
VC	Venture capital
VGO	Vacuum gas oil
ZEV	Zero emission vehicles

Table of Contents

1. Introduction

» **This study contributes to a vision** where the forestry sector becomes a driver of New Zealand's low emissions economy and becomes stronger itself in the process.

The vision of Wood Fibre Futures is that New Zealand can use its commercial trees to catalyse the development of a low carbon economy in New Zealand and that this can simultaneously strengthen and grow the industry. This report reveals a series of careful interventions that could trigger this virtuous circle.

Trees can produce a wide range of products or even services (**Figure 1.1**). This report focused on woody biomass, which generally means the substance of the tree in all its parts. Often the term "residual woody biomass" is used too, which means parts not used for solid wood, although the definition of the term varies hugely depending on the perspective of different industry participants.

The focus of this study was on technologies that could utilise any or all elements of woody biomass, particularly that left over when trees are processed into timber (**Figure 1.2**).

The study sought new technologies to produce new products from our trees that could be marketed initially in the short-term time horizon (5-10 years). These technologies had to use woody biomass, make a substantial impact on carbon emissions, and be transformational for the forestry industry and more broadly for New Zealand. The technologies were described as shovel-worthy, rather than shovel-ready, as they required detailed due diligence and the development of an investment plan as part of Wood Fibre Futures Stage 2.

This report also describes the critical steps that commercial parties and Government need to take to unlock those opportunities.

For the longer-term time horizon (20-30 years), the report describes what technologies (or technology groupings and initiatives) New Zealand should start to focus on now to ensure we lock in these benefits. While technologies evolve more rapidly than the trees they feed on, the typical gestation period through development, prototyping and scale

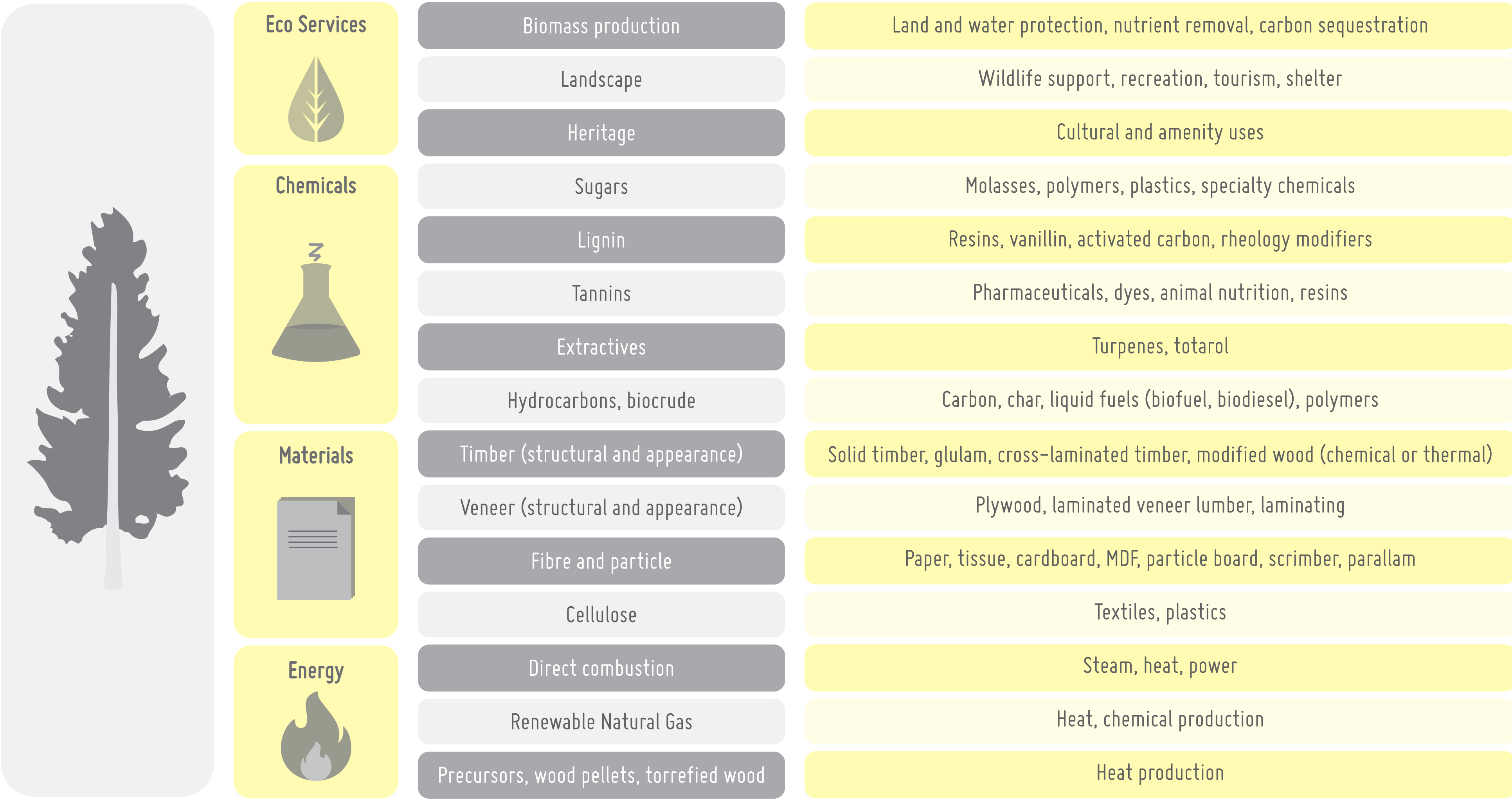


Figure 1.1 – Products that trees can provide

up often takes 10-20 years. So, a long view must be taken on finding and tracking technologies, collaborating in global R&D, and partnering with developers internationally.

New Zealand's commercial forest industry is uncommon in the world. It is dominated by Pinus radiata trees with their fast-growing, pale wood, it grows them quickly and well, and it exports many of them as unprocessed logs. It has the advantage of a small country where all the major participants can be gathered in a room, and where open government and ease of business can allow smart decisions to be made and actioned effectively.

In this context, the recommendations of this report have the potential to substantially increase the sector's contribution to the country. This is true for a wide range of reasons:

- Trees sequester carbon and are critical to meet climate change commitments
- Forestry delivers economic, social, environmental, and cultural benefits
- New products from trees align with the global move towards renewable and bio-based products
- Forestry is already an enabler of many other important activities in New Zealand. Forests, and forest products can:
    - provide packaging for food exports
    - protect land in the pastoral sector
    - sustain capabilities and tools that help to manage and protect conservation forests
    - provide backdrops to recreational activities and tourism
    - create most of the materials with which we construct our buildings, and
    - through all of these, provide regional economic benefit

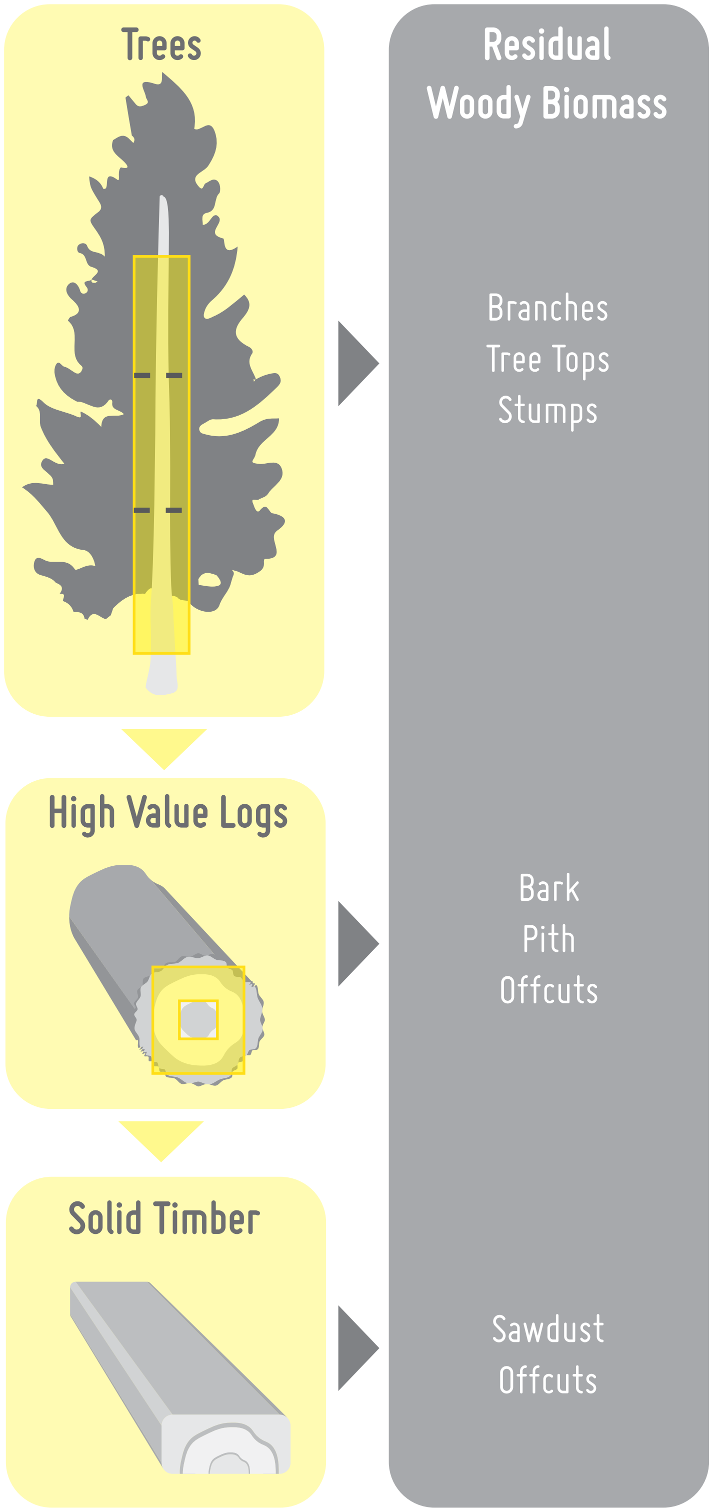


Figure 1.2 – Residues from solid timber production

As an indication of economic impact, the pulp, paper and wood manufacturing sectors provide a multiplier effect of 3-to-1 in broader economic activity[1].

Execution of the report's recommendations for pursuing new technologies will:

- decrease New Zealand's carbon emissions
- increase the scale of commercial forestry
- increase contribution to GDP
- increase contribution to export revenues
- provide more product offerings in timber and manufactured products,
- increase indirect contribution to other industries – sustainable packaging, low carbon fuels
- increase contribution to social goals through employment,
- allow New Zealand to become an innovation leader internationally
- grow "Brand New Zealand", and
- make the country more resilient in the face of environmental, social, legislative, and technological disruptors.

Note though, that the outcome will not be achieved by business as usual. It will require:

- substantial additions to the portfolio of products derived from woody biomass
- the development of a supporting policy structure
- modification of the current approach to innovation for this sector including how Government and industry can strengthen their partnership in innovation

New Zealand has great potential for forestry, and vice versa. Adopting the recommendations of this report will result in New Zealand moving not only towards zero-carbon, but also developing a circular bioeconomy with wood at its centre.

2. Technology Results

» **Four areas of technology are recommended**:

Biocrude oil
Liquid biofuels
Coal replacement, specifically coking coal for steelmaking
Increasing the use of wood in the built environment

» **Twelve new technologies are recommended for fuel substitution** to proceed to the development of investment cases. With careful selection and scale-up across New Zealand, a powerful optionality is created to flex production between petrol, diesel, aviation, and marine fuels.

» **Three commercial technologies are recommended for the built environment** supported by a flexible regulatory approach and recognition of the value of carbon stored in building.

» **Six directed actions are recommended for the longer-term horizon** (20-30 years) to lock-in the benefits by sustaining focus, tracking progress, and building capability in key specified areas.

» **Thirty-seven technologies which have low impact on emissions** should be screened for their short-term economic development potential.

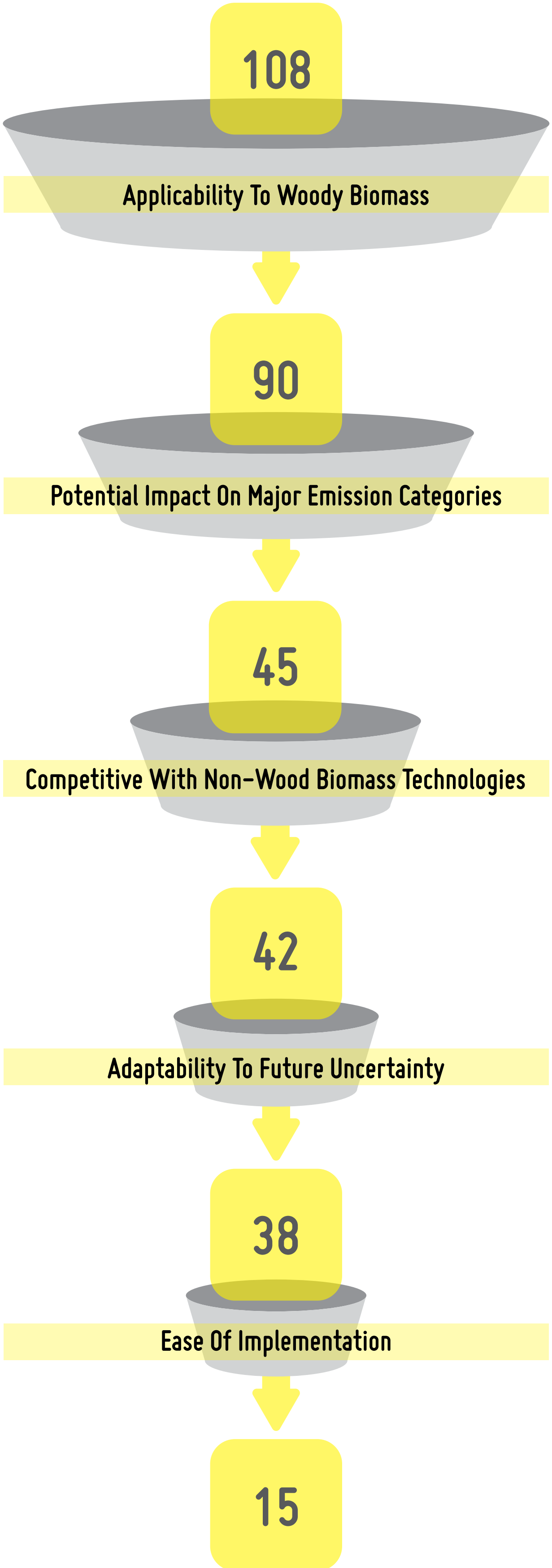


Figure 2.1 - Technology filtering process

The search for global technologies found 108 candidates. These were mostly embedded in development companies rather than research projects since our focus was on shovel-worthy investment opportunities.

The longlist was subject to a formal, objective filtering process which involved five screens:

- applicability to woody biomass in practise
- potential impact on New Zealand's major emission categories
- competitiveness with non-wood biomass sources
- adaptability to future uncertainty
- ease of implementation because of the partners or parties already involved

At each screen technology candidates were subject to inclusion/exclusion criteria to arrive at a shortlist. The numbers passing through each step are shown in **Figure 2.1**.

Full details of the screens used are given in the **Methodology Chapter** of this report.

Availability of woody biomass was also part of the review consideration. This is developed further in the **Woody Biomass Chapter.**

Shortlisted Candidates For The Short-Term Horizon (5-10 Years)

The assessment process resulted in four shortlisted focus areas:

- Biocrude oil (4 candidates)
- Liquid biofuels (3 candidates)
- Coal replacement, specifically coking coal for steelmaking (5 candidates)
- Increased use of wood in the built environment (bundle of commercial technologies)

Technologies to produce biocrude oil

Four lead candidates:

- **Envergent Technologies (Canada)**
- **Licella (Australia)**
- **BTG/BTL (Netherlands)**
- **Valmet/Fortum (Finland/USA)**

The opportunity to replace fossil fuel crude oil was one of the obvious targets for carbon reduction, and one with vigorous technology activity worldwide. While it was not as large a target for carbon reduction in New Zealand as liquid fuels, biocrude also addressed emissions currently occurring in the refining process, in addition to emissions from the final fuels.

It was estimated that New Zealand produces at least 10 million cubic metres of woody biomass in addition to sawlogs, and a further unspecified amount within sawmills and pulp & paper plants (see next Chapter: Woody Biomass Availability). For context, a typical commercial biocrude plant would require around 0.7 million cubic metres of biomass and would be agnostic as to the type – branches, offcuts, chips, sawdust, etcetera.

This typical plant would cost around USD $120 million (NZD $180 million) and produce around 75 million litres of biocrude per annum.

If a number of such plants were located to utilise most of the woody biomass other than sawlogs, they could replace up to 18% of New Zealand's total crude oil consumption. As detailed below, biocrude also has the optionality to feed into many other products such as liquid fuels (see below), biochemicals and various biomaterials.

Biocrude has several advantages as a target:

- It uses by-product streams from the forest and from mills to produce low carbon biofuel that has ~70%-80% lower carbon intensity than fossil fuel petrol and diesel.
- It allows production of a wide range of products (e.g. heat & power, transportation fuels, biochemicals and biomaterials), which give it optionality in a future-uncertain world.
- It leverages existing infrastructure in the oil refining and distribution sector potentially lowering the capital investment required to produce low carbon fuels.
- It can work with, instead of against, the oil refining industry, and it helps support existing employment in both forestry and oil refining industries.
- It aligns to decarbonising supply chains for New Zealand where carbon footprint is evolving as a trade or travel barrier.
- It has a significant export opportunity, which can leverage the carbon-pricing in other jurisdictions.

Some of the world's largest and most innovative companies in forestry and energy have already invested in biotech companies and plants focused on biocrude, including:

- Investment in Ensyn by Suzano (world's largest pulp company) and Chevron (major oil company).

- Investment in Steeper by Sodra (Sweden's largest forest-owner group) and Statkraft (Europe's largest producer of renewable energy).
- Investment in Licella by Canfor (world's largest lumber producer & significant pulp producer).
- Investment in Genifuel by Parkland Fuels (British Columbia's largest oil refiner).

Technologies to produce liquid biofuels

Three lead candidates:

- **CRI/Criterion Catalyst (IH2)(Norway/Sweden)**
- **Haldor Topsoe/TechnipFMC (Denmark/UK)**
- **Lanzatech/PNNL/Aemetis/InEnTec (USA)**

Liquid fuels were the largest single target in the energy category of New Zealand's carbon budget. Within the category, petrol (gasoline) was the largest contributor of emissions, followed by diesel, aviation fuel and then marine fuel.

Many technologies are being advanced globally to produce liquid fuels from woody biomass, and many countries are enacting regulations that reward or encourage the adoption of biofuels in transport, most notably low carbon fuel standards.

Liquid biofuels in this report include drop-in fuels involving diesel, petrol, aviation, and marine fuels. Although some technologies indicate that they are focused on one fuel, many of the technologies produce a blend of fuels as is the case in an oil and gas refinery. It is important to note that some technologies to produce liquid biofuels from woody biomass do not go through the intermediate step of biocrude.

In a similar approach to the context for biocrude described above, a typical commercial liquid fuel plant would require around 0.5 million cubic metres of biomass (compared to the 10 million available nationally), it would cost USD $340 million (NZD $520 million) and produce around 57 million litres of liquid fuel per annum (or either diesel, petrol, aviation fuel or marine fuel).

If a number of such plants were located to utilise most of the woody biomass other than sawlogs, they could replace up to 30% of New Zealand's total diesel consumption, or 35% of petrol consumption, or 70% of aviation fuel (at pre-COVID levels of consumption), or easily all of the marine fuel consumption.

Coal replacement, specifically coking coal for steelmaking

Five lead candidates but only one significant customer (New Zealand Steel)

- **Airex (Canada)**
- **CarbonScape (New Zealand)**
- **Cortus Energy (Sweden)**
- **Thyssenkrupp (Germany)**
- **Torr-Coal (Netherlands)**

Steel production requires carbon as a reducing agent in the process. There is a small but potentially fertile niche for utilising woody biomass to reduce carbon emissions in replacing coking coal in iron and steel manufacture. Coking coal used in the steel industry produces very high temperatures and has a very high intensity of carbon emissions as a result.

However, New Zealand has only one primary steel mill, New Zealand Steel, which provides 90% of the country's steel manufacturing and which supplies the second mill, providing the remaining 10%, Pacific Steel. As such, this opportunity is not so much a technology development as a bespoke solution.

Bio-coke or torrefied pellets are already being pursued internationally:

- Arcelor Mittal is working in the Netherlands to trial bio-coke produced by Torr-Coal.

- Arcelor Mittal Dofasco is working with several technology providers to build towards a demonstration in their Canadian steel mill.
- Cortus Energy is working in Höganäs AB in Sweden in using a bio-carbon in metal powder production; this approach is unique in that Cortus produces a syngas which is used to replace natural gas in the production process and a bio-based coke which could also be used on site.
- More locally, New Zealand Steel has worked with CarbonScape on a trial of their graphite material.

Increased use of wood in the built environment

During the assessment process, a special case emerged regarding the increased use of wood-based biomaterials in the built environment. It did not fit neatly into the screens and filters used for larger and more focused technologies. However, it emerged as a candidate that could concurrently meet needs in the forestry sector, the technology sector and the government sector while simultaneously reducing carbon.

The opportunity revolved around the ability to reduce carbon emission through carbon sequestered, carbon avoided, and carbon eliminated. Products derived from wood could play a role in all three of these categories.

The candidate technologies, mostly existing, some developing and some that would be new-to-New Zealand, were:

- Cross-Laminated Timber (CLT), Glue Laminated Timber (Glulam) and other wood-based construction materials, which are now able to replace concrete and steel in multi-storey buildings
- Wood Insulation such as Dieffenbacher or Siempelkamp's technologies from Europe
- Retro Fitting Existing Buildings such as the Energiesprong system or Factory Zero in Europe

A catalyst for this whole area is policy development to recognise the carbon emissions produced by construction and the carbon stored in the built environment. Flexible regulations would then be implemented to measure that carbon and incentivise behaviour to reduce emissions through smart material selection.

Full details of all the shortlisted technologies above, including back-ups beyond the lead candidates, are contained in **Appendix A**.

Results For The Long-Term Horizon (20-30 Years)

The selection process for the 20-30 year time horizon followed a more subjective process than the one above.

- Less developed technologies - lower Technology Readiness Levels (TRLs 4-7) were accepted as possible in the longer time horizon.
- Additional considerations were used involving social, technological, economic, environmental, and political trends (a STEEP analysis).
- The Consortium workshopped the future scenarios and used their combined insights to elaborate on future options and activities.

This resulted in the focus for the 20-30 year horizon being placed on what activities can and should be started now, rather than on what specific technologies should be pursued.

This approach resulted in six recommendations for action.

Sustain focus and maintain intelligence on biocrude and biofuels

Car engines which use petrol (gasoline) are already beginning to be replaced by alternatives such as electric engines. However, the replacement of diesel in trucks, farm vehicle and trains, is less imminent, and the replacement of marine fuels and aviation fuels are further away. Hence sustaining the focus on producing fuels from biomass could be important for New Zealand in the medium to long term.

Decarbonising transport lines such as heavy transport, shipping and aviation could be important in the future with the potential for consumers and tourists in export markets seeing carbon footprints as critical in their decision making. Ensuring a low carbon product could be a future market access issue.

The technologies providing biocrude, especially, provide optionality; for example, they could later pivot to producing biomaterials (plastics or resins) and biochemicals (products derived from biomass-to-liquid processing). Maintaining a close interaction with the major international players will ensure resilience.

If both biocrude and biofuel are considered together then a powerful optionality is created. As technology moves on in general, for example with increased electrification of cars, then the capability to direct woody biomass from petrol to diesel will be straight-forward. Similarly, if heavy transport begins to use less diesel (due to rail electrification or electric engines in trucks for example) then the focus could shift to aviation fuel or marine fuel where alternatives are further away. This thesis is expanded in the next Chapter: Implementation.

For each of the two major focus areas in the short-term horizon (biocrude and liquid biofuels), lists of less developed technologies were captured using the filtering process described earlier. This generated 11 additional technology candidates for biocrude and 14 additional candidates for liquid biofuels. However, the short-term candidates listed earlier are all candidates, in practice, for the longer-term horizon too, and it is acknowledged that the gestation period for early stage technologies could be at least 10 to 20 years.

Therefore, rather than pursuing these specific technologies, the recommendation is to track them by directing some of New Zealand's public R&D capability to this aim. Technologies will emerge as winners over time and it is important that New Zealand is engaged with those developments.

Sustain the focus on wood, and innovation with wood, in the built environment

Many of the major recent innovations using solid wood in the built environment are already in practice, for example Cross-Laminated Timber (CLT) and chemically/thermally modified timber. Radiata pine lends itself well to such technologies which leverages the current industry's base.

Sustainable and high-performance housing is expected to be an enduring need for New Zealand and expansion of timber offerings to naturally durable or high brand-value timbers are a potential export product. As mentioned elsewhere, a significant synergy occurs here which is to increase the market for solid wood, which generates more residual biomass and lowers its cost, which enhances the investment case for biofuels. This thinking also aligns well to the "volume to value" strategy already in place in the industry.

There is also increasing diversity of species such as eucalypts, or indigenous species, that can be pursued. The latter, while controversial, could be a source of unique competitive advantage for the country.

Track the development of technologies producing lignin and sugars (as precursors for specialty chemicals) from woody biomass

The production of biopolymers from agricultural crops has an inherent advantage over using wood as the starch in crop-plants is easier to convert to sugars than the cellulose from wood.

There are several approaches and technologies being developed, mostly in Europe, focusing on using wood for lignin and sugars. These projects appear to have substantial budgets. There are also at least two emerging proposals in New Zealand (NZ Bio Forestry and Futurity).

Packaging is an important area for New Zealand especially since food exports are such a major industry, and developments in this area could replace plastics from non-renewable resources.

Existing processes such as pulp manufacture have by-products that are rich in sugars or partially hydrolysed long chain polymers that could easily be converted to sugars or other specialty chemicals and hence provide an early adoption route.

Sustaining national capability in this general area and building close linkages with the main international actors is recommended.

Build on some of the smart technologies emerging within New Zealand such as Woodforce and Zealafoam™

Although these products use wood in variable quantities, they have short term potential to make an impact in areas such as sustainable packaging, material light-weighting, and insulation.

The potential to increase materials derived from woody biomass exists and hence their development creates an early entry for, for example, polymers derived from wood.

Expand approaches to using extraction technologies

Woods and bark, including those from native species, have valuable chemical components such as pinenes, tannins and tōtarol. Extraction techniques that can operate within the supply chain have the potential to add a high value product stream, and to decrease supply chain costs. Reactive extrusion is one such example.

Partner with industry to de-risk activities in key areas to transform commercial forestry

- Adopting plant biotechnologies including gene editing to increase tree uniformity, biomass production and resilience.
- Increasing technologies (e.g. robotics) into the supply chain to increase productivity.
- Developing new product offerings from the non radiata pine species.
- Piloting new approaches to wood processing in New Zealand.

Economic Development Opportunities (Out Of Scope)

In recognition of the COVID-19 pandemic and the rapidly emerging need for economic development, a list was assembled of opportunities that utilised woody biomass but did not materially impact carbon emissions. These were outside the scope of the study but, since they were surfaced by the study, they were briefly analysed and summarised to capture them for potential assessment as economic development projects. Notably, some of these already have New Zealand participants which may make them faster and easier to progress.

The majority of these were biochemical and biomaterial technologies. As a category, these suffer three significant issues:

- The difficulty in extracting sugars (the base element of most of these products) from woody biomass as opposed to higher-yielding, easier-to-process, starchier plants like agricultural crops

`

- The lack of commercial success, so far, at producing these products from wood
- The low demand globally (until very recently) for renewable biomaterials compared to fossil-fuel derived equivalents at lower prices

The full list of 37 technologies in this category is given in **Appendix B** together with a discussion on bioplastics and biocomposites and emerging international examples.

3. Woody Biomass Availability

- » **The availability of wood and woody biomass was modelled** out to 2050
- » **There are large volumes of material useable** by new technologies, sufficient to support the new industries which would arise
- » **Most technologies require residuals**, so a strong sawmill sector is key
- » **Three regions appear to be strong candidates** – Northland, East Coast (North Island) and Marlborough – but engagement with investors will be needed to make final decisions

In the short-term horizon (5-10 years) New Zealand has the capacity to supply additional industries requiring woody biomass. Those trees are already in the ground, hence the ability to secure biomass will be driven by its location and an investor's or user's ability to pay.

In the longer-term horizon (20-30 years) it is highly probable that such resources will still be available but there are many factors that could influence that, ranging from government policies, the value of carbon, market demand, the global trading environment, and the impact and speed of new technology implementation.

A Model Of Wood Availability

An approximate national model of wood availability was built by the Consortium, using current data, since the last comprehensive model was seven years old. The approximate model showed that although harvesting has dropped substantially in 2020 (due to COVID-19) it is expected to recover to about 37 million cubic metres per annum in 2021. It then declines to a low in 2036 because of the decline in replanting in the mid-2000s, and returns to the higher levels again from 2043 and increases from 2047. A summary graph is shown in **Figure 3.1**. These projections are based on National Exotic Forest Description (NEFD) data and are expanded in Appendix C including all the assumptions behind them.

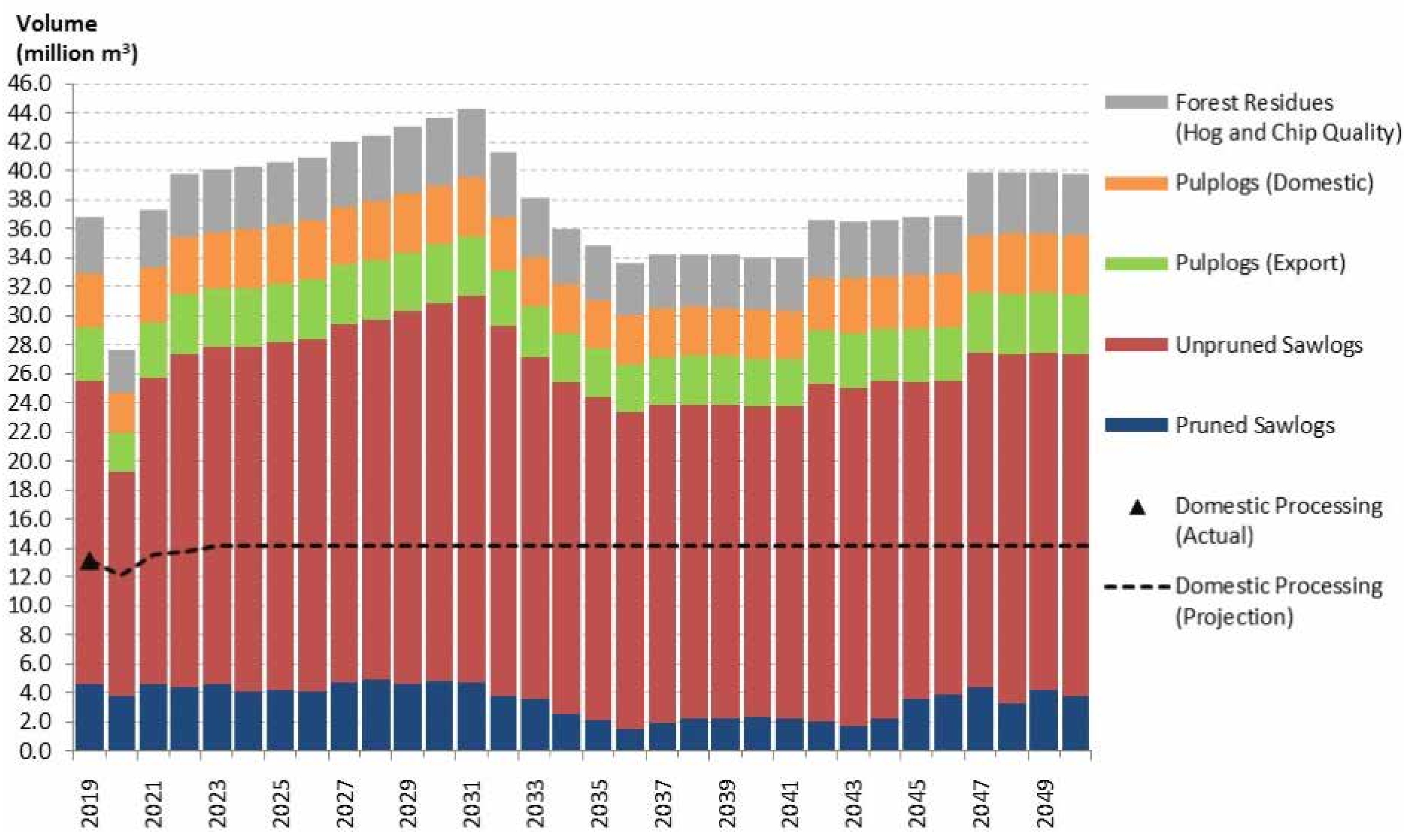


Figure 3.1. New Zealand wood availability forecasts by type of biomass, 2019–2050

The data shows that there is a consistent 10-12 million cubic metres of woody biomass produced every year in addition to sawlogs (this is the combination of Forest Residues and Pulplogs in **Figure 3.1**). Further residuals are produced in sawmills or pulp and paper plants not counted in this total although much of the latter are already utilised within the factories.

There is a virtuous circle possible if new technologies create new higher-value products, where today's residuals and low-cost products (for example small, export pulplogs) could begin to be used by those technologies. This could increase the price paid for those residuals and improve the viability of existing sawmills and plants, while simultaneously generating new products, replacing carbon, and creating exports.

This study did not attempt to quantify that virtuous circle; it will be an important detail to resolve in Wood Fibre Futures Stage 2. However, the base supply of 10 million cubic metres was factored in to analyses of the new technologies recommended, as seen in the previous **Chapter 2: Technology Results**, and expanded in the next **Chapter 4: Implementation.**

The model allowed an analysis of the volume of wood, the cost of extraction, the ease of export, and the local capacity for processing region-by-region across New Zealand. This is summarised schematically in **Figure 3.2**. with the data also contained in **Appendix C: Table C6**.

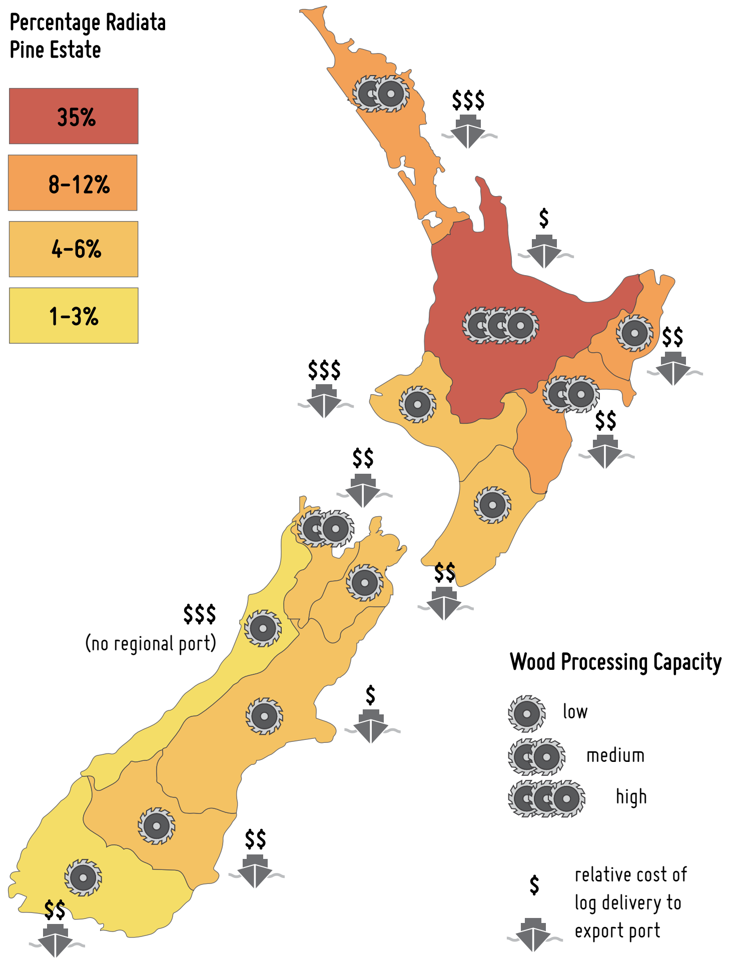


Figure 3.2 – Radiata pine estate, wood processing capacity, export ports and relative log delivery cost

Short-Term Horizon (5-10 Years)

In this time horizon the focus must remain on harvests of radiata pine already in the ground, which will predictably generate lower grade woody biomass from forest residues. These include "hog quality" material which includes branches, bark, and stumps (usually processed in a "hogger" into burnable fuel), wood chips, smaller and branched stems, and pulp logs. The technology candidates recommended earlier in the Results chapter, specifically those focused on biocrude and liquid biofuels, can use such material. Fortuitously, it is typically the lowest cost woody biomass.

The cost of logs in New Zealand is high. This is the result of forest growers selling logs in New Zealand at export parity pricing to domestic mills[2]. Adding to this is that in many regions' infrastructure is poor and the nature of the terrain increases costs further.

Compounding the above, an increasing amount of the harvest (40% in 2018-19[3]) is coming from smaller forests (less than 1,000 hectares) where forest owners, who are not reliant on forestry as their primary source of income, are more opportunistic as to when they sell. Roading, harvesting and cartage costs are often higher for these sources than for a larger estate.

The regional analysis (summarised in **Figure 3.2** above) suggested that Northland, East Coast, and Marlborough are regions where substantial resources are available, and which have the potential to accommodate new processing capacity due to lesser competition from existing facilities. In addition, there are more barriers to export from these regions in that port facilities are less able to handle logs than in other regions.

Northland and East Coast are regions where regional development projects would be attractive. Furthermore, Northland has an oil refining facility that could provide a useful connection should biocrude or biofuel be developed (acknowledging that this facility will be under pressure at this time).

The wood availability analyses themselves do not address changes in wood processing or the use of wood processing residues. In the last year, several mills have closed, and others are consolidating or expanding. Milling operations often have existing commitments to supply pulp mills or fibre mills with clean woodchips and/or to use their residues for heat or combined-heat-and-power (CHP) which uses parts of this resource to supply their own energy. As an example, residues already used in plants are estimated at four million cubic metres. This clearly affects biomass availability for new technologies, and it is acknowledged that exploration of this aspect would need to be undertaken in more detail when moving to an execution plan.

Long-Term Horizon (20-30 Years)

While uncertainty surrounds any forward projections, some things are certain:

- Change is inevitable.
- The future is seldom a simple extrapolation of the past.
- Technology development will continue its relentless pace; it will define the future either by increasing the effectiveness of existing business activities or shaping new business models.
- Markets and public attitude will shape the manufacturing industry which in turn will define the resources it requires and how they are produced.
- Commercial forestry will explore options such as the use of species other than radiata pine, including indigenous species.
- Changes could occur in the models of forestry towards using direct fibre regimes, coppicing, and mixed land-use.

There is a connection between new processes being developed which will influence the nature and type of resource that is created. Typically, resource

is modified/evolved to meet the needs of the customer.

In the 20 to 30-year timeframe the major negative influences will be:

- Risks associated with global change, the speed of recovery from COVID-19, the potential for more protectionist policies, the impact of climate change, and a myriad of other actions.
- The future availability of wood residues from the wood processing industry will be dependent on future levels of log exports and the scale of development in New Zealand's primary wood processing industry (sawmilling, plywood, and veneer).
- New Zealand's current level of log exports (nearly 50% of harvest) will be impacted by China's move (and other nations') to self-sufficiency in wood fibre supply[4].

There are also many positive opportunities:

- New Zealand is expected to remain a good place to do business.
- The potential transformational change that plant biotechnologies (including gene editing) can make to increasing biomass production, tree uniformity and modifying the chemical components within a tree to tailor them to certain processes.
- Increasing use of technology (e.g. robotics) in the supply chain to increase its productivity.
- Increasing technology within processing to increase wood recovery, using biorefinery principles to maximise value secured from each log.
- Innovation in wood use for the built environment.
- Forestry diversification to increase forest resilience and add product options.
- Expansion of forests to increase production from trees that have specialist properties such as natural durability (e.g. some eucalypts) or stiffness (e.g. Douglas-fir).
- Changes in harvesting methods will likely facilitate the collection of forest residues.
- Increasing use of indigenous trees noting that New Zealand has large estates of native trees that can be sustainably harvested providing high value timber, and other products including extractives[5].

The considerable uncertainty over the future, particularly poignant at the time of writing, would suggest that building options and resilience into forestry moving forward is critically important. The Government and industry working together in a formal partnership could best ensure that forestry continues to build the most resilient low carbon economy into the future.

4. Implementation

» **Implementation requires specific actions to engage investors** including new Government policy settings.

» **Two of the areas are synergistic — biocrude and biofuels.**

» **Investment cases for the shortlisted technologies can be commissioned** under Stage 2 of the Wood Fibre Futures project to engage international specialist investors, local investors and strategic investors from the industry.

» **A "flexible regulation" approach will be needed** to increase the value placed on carbon reductions and to set low carbon standards.

» **Six Case Studies showing successful implementation** in other jurisdictions are presented as models

Acting On Selected Technologies

The four focus areas recommended by this report, along with other technology areas studied, are summarised in the table below (**Table 4.1**) including a brief situation analysis of each. For each area, one of four strategic approaches was selected, plus a recommended priority for government investment.

The four strategic approaches are:

Accelerate investigation: To be prioritised for full investment analysis immediately (Stage 2 of Wood Fibre Futures).

These technologies are close to commercialisation but need support to cross to that final step. They have a significant impact on New Zealand's carbon budget.

Market Approach: No government intervention is suggested.

The technology is fully mature but may have challenging economics. The market can drive or limit the adoption of these technologies.

Sector Approach: Potential for joint development with the relevant sector.

These technologies can address a specific challenge in the New Zealand context rather than a wider impact. Should be developed along with the sector involved. These technologies are either commercially available or close to it (TRL 8).

Track: New Zealand should task its public service and research network with monitoring and strategically collaborating to create future options.

These technologies are at an earlier stage. New Zealand should track the global development of these technologies and carefully consider collaboration or co-investments in these areas. The trade-off between internal development (within New Zealand) versus leveraging global investment should be considered.

Technology Scale

To provide some context on the scale of these technologies, the following table (**Table 4.2**) has been developed.

It must be noted that the Wood Availability Model referred to earlier (**Chapter 3**) showed that volumes of woody biomass will be suitable for plants of these scales in many regions in New Zealand (from the total circa 10 million cubic metres available per annum). It should also be noted that the technologies selected are mostly agnostic as to the type of woody biomass, so will potentially cope with anything from branches, to pulp, to sawdust.

In the fuel arena, as detailed in **Chapter 2: Technology Results**, these volumes are capable of generating significant percentages of the current total consumption in New Zealand: 20% of current crude oil consumption, or 30% of diesel consumption, or 35% of petrol consumption, or 70% of aviation fuel consumption (and that is pre-COVID aviation), and easily all of marine fuel consumption. Once established in New Zealand, the technology/plants could pursue whichever target meets either market demand or carbon emission aspirations the best.

While these figures may seem optimistic, assuming the use of most or all the current biomass apart from sawlogs, there is a further virtuous circle that applies. The use of woody biomass in high value applications will drive demand for such biomass, which could draw in some sources of low-value feedstock currently going to waste (such as forest residues or hard-to-get thinings). By extension, it could even begin to draw in low-value products currently exported, such as pulp logs, which increases New Zealand's circular bioeconomy.

Government Investment Priority – High

AREA	SITUATION ANALYSIS	RECOMMENDATION
Biocrude	Most advanced plants (TRL 7) have been completed. Given the global trend in Low Carbon Fuel Standards focusing on the transportation fuel sector, major oil producers and leading forest product companies are investing in this area. Options for domestic use (Refining NZ) or export to west coast of North America to meet LCFS mandates in California or British Columbia. Significant impact on New Zealand's carbon budget. Given biocrude is an intermediate product that can be used in a range of applications (e.g. transport fuel, heat & power, biochemicals, biomaterials), it offers great optionality for the uncertain future.	Accelerate investigation
Construction – Energy/Insulation	Wood fibre insulation is fully commercial with several plants operating in Europe and other jurisdictions examining the opportunity. Needs market support which can be achieved though changes in energy codes and valuing stored carbon. Domestic market may not be sufficient to support a facility so an export-oriented strategy will be needed.	Accelerate investigation / Sector approach
Construction - Structural	Technologies such as CLT are fully commercial. Market development is needed to further growth in this area including code development and government demonstrations. Long-term competitiveness is needed to widen application by building height and type.	Accelerate investigation / Sector approach
Liquid Biofuels including Aviation	No large-scale facility has been built world-wide; however, it is the focus of several technology providers. Aviation Fuels could also be produced from biocrudes through Refining NZ. Significant impact on NZ carbon budget. Possible path to Aviation Fuel from ethanol using LanzaTech approach.	Accelerate investigation
Solid Fuel – Torrefied Pellets	An advanced facility (TRL 8) is being built for a biocoke application in Europe. Similar approach could be utilised in New Zealand. For heat or power, torrefied pellets may be preferred in situations with high transportation costs or where rain exposure is significant. If these factors are not in play, wood pellets are preferred as they do not come with a technology risk.	Accelerate investigation / Market approach

Government Investment Priority – Moderate

AREA	SITUATION ANALYSIS	RECOMMENDATION
Cellulose Derivatives (CNC, NFC, CNF, etcetera)	Wide range of approaches with various TRLs. Much of the development is private to existing companies. Challenges with market development although clear progress in areas of existing integration with a larger company's operations (packaging applications as an example).	Track
Construction – Appearance	There are several wood modification technologies in operation in Europe to produce a longer, more stable wood product (e.g. acetylation of radiata pine for decking applications). These technologies could be imported or operated in partnership. The domestic market is probably too small, so an export-oriented strategy will be needed – scale is important to be cost competitive.	Sector approach
Lignin	Commercial technology available. Challenge is market development. Needs integration with a pulp mill which is case-by-case.	Track / Sector approach
Solid Fuels – Wood Pellet	This is already a fully commercial technology driven by export markets in Europe, Japan and Korea which all have significant government support influencing pricing. Option for domestic coal replacement where natural gas is not available.	Market / Sector approach
Thermoplastics	Commodity thermoplastics are low margin commodities. Generally produced from sugars in which agriculture has a clear advantage. Higher value thermoplastics are niche products (PHA/PHB).	Track / Market approach

Table 4.1 – Summary of technology areas, situation analyses and recommendations

Government Investment Priority – Low

AREA	SITUATION ANALYSIS	RECOMMENDATION
Bioelectricity / Bioheat	Not cost competitive against solar, wind, geothermal or natural gas. May be useful in specific situations where bark volumes cannot be consumed by other technologies. Has local heat & power applications.	Market approach
BTX Chemicals	Early stage although upgrading Biocrude to BTX chemicals is being considered.	Track
Ethanol	Limited interest from woody biomass source. Other plant sources are much more cost competitive. Low value sales price.	Market approach
Methanol/DME	Requires significant changes to the fueling infrastructure and facilities are not being realised.	Track
Renewable Natural Gas (RNG)	Smaller scale facilities have been built. Largest facility is GoBiGas in Sweden. Challenge is cleaning gas for injection into a natural gas grid. Studies have shown that low-cost feedstock is required or high costs of RNG will result.	Market approach
Specialty Chemicals	Larger area with many smaller developers. Development timelines are long unless produced from a refinery model (i.e. from biocrude). Many niche markets exist where volumes may not justify the development expense.	Track

Table 4.1 – continued from opposite

Once established, these technologies are also capable of utilizing other feedstocks, which brings yet another optionality. For example, some leading candidates in the list already produce biofuels from municipal waste including plastic. This creates another layer of robustness around the business case for their development.

The catalogue of technologies capable of producing biocrude and liquid biofuels should be developed, through Wood Fibre Futures Stage 2, with this flexibility in mind.

Technology Implementation

Each of the areas with most immediate potential (Accelerate Investigation or Sector Approach) are further detailed below (**Table 4.3**) including the lead technology providers and a discussion of how such a technology could be implemented. If New Zealand's investment attractiveness can be improved, it will accelerate the timeframe of many of the options proposed by this report.

Recommendation – Accelerate Investigation

Area	Technology Readiness	Production Scale (/year)	Fibre Scale (/year)	Fibre Type	Employment (FTEs, approx)	Capital Scale (USD, approx)
Biocrude	TRL 8	75 million litres	625,000 m3	Residuals	30	$120 million
Liquid / Aviation Fuels	TRL 7-8	57 million litres	500,000 m3	Residuals	20	$340 million
Solid Fuel – Torrefied Pellets	TRL 7-8	50,000 tonnes	150,000 tonnes	Residuals	10	$55 million
Construction - Structural	Commercial	50-100,000 m3	90-170,000 m3	Solid Timber	30-60	$30-50 million
Construction – Insulation	Commercial	Varies	-	Residuals	20	$75-100 million

Recommendation – Sector Approach

Area	Technology Readiness	Production Scale (/year)	Fibre Scale (/year)	Fibre Type	Employment (FTEs, approx)	Capital Scale (USD, approx)
Solid Fuel – Wood Pellet	Commercial	25-200,000 + tonnes	20-225,000 tonnes	Logs	20	$50-150 million
Construction - Appearance	Commercial	Varies	-	Solid Timber	30-60	-

Recommendation – Market Approach

Area	Technology Readiness	Production Scale (/year)	Fibre Scale (/year)	Fibre Type	Employment (FTEs, approx)	Capital Scale (USD, approx)
Bioelectricity / Bioheat	Commercial	Up to 60 MW	Scale-dependent	Logs & residuals	Marginal	Scale-dependent
Renewable Natural Gas	TRL 7-8	No plants have been built to inject RNG into grid at scale. GTI analyzed an RNG to power facility in California. Project cost $340 million, 280,000 tonnes of fibre.				
Ethanol	TRL 7-8	No plants have been built at scale. Aemetis is in final engineering for 12 million litre facility and has secured $125 million to finance the project.				

Recommendation – Track

Area	Technology Readiness	Production Scale (/year)	Fibre Scale (/year)	Fibre Type	Employment (FTEs, approx)	Capital Scale (USD, approx)
BTX Chemicals	<TRL 7	No facilities have been developed. No information in the public domain.				
Methanol/DME	<TRL 7	No information in the public domain.				
Thermoplastics	TRL 7-8	No information in the public domain.				
Lignin	Commercial	West Fraser's 30 tonne/day facility cost $21.5 million.				
Cellulose Derivatives	TRL 7-8	Demonstration plants have been built. Investments range from $10-30 million.				

Table 4.2 – Summary of technologies with expected production, fibre usage and type, employment and capital

Understanding Investor Expectations

An understanding of investor expectations is critical in navigating the path to the large-scale, long-term investment that will be needed. Government has a key role interacting with private investors and this section illuminates the thinking required to engage with them.

The private sector needs to provide much of the capital in this technology area, given the large amounts required for the scale of technology required to "move the dial" on carbon emissions, and the desire for proper market discipline.

However, there is also a need for some public sector capital to serve as the catalyst in the early stage. The reason, specific to investments associated with carbon emissions, is that costs associated with climate change are generally not factored into market prices.

There is no shortage of capital at the global level, but much of it, especially that focused on investment associated with carbon emissions, is risk averse, and it will demand a significantly higher expected return for risky investments.

Recommendation – Accelerate Investigation

Area	Technology Provider	Implementation
Biocrude	Ensyn / Licella / etc.	With right conditions, facility could be built within 24-36 months. Work with Refining NZ for potential implementation for domestic market. Focus on export market if Refining NZ option is limited. Although it can be consumed directly in heat & power applications, biocrude is also an intermediate liquid which can be used to produce a range of transportation fuels (e.g. petrol, diesel, aviation fuel, marine fuel), biochemical and biomaterials.
Liquid /Aviation Fuels	CRI (IH2), Lanzatech consortium	Wait until first plant operational globally. Plant in New Zealand 24-36 months after that. OR try to attract Lanzatech back to NZ for first plant.
Solid Fuel – Torrefied Pellets	Torr-Coal, Airex	Discuss use of bio-coal with New Zealand Steel. If interested, potential is to develop a plant to provide New Zealand Steel and domestic market. If no interest, then no action.
Construction - Structural	Commercial	Short term focus on demonstrations and government procurement, medium term a value on carbon is needed.
Construction – Insulation	Commercial	Implement Net Zero energy codes and value carbon.

Recommendation – Sector Approach

Area	Technology Provider	Implementation
Solid Fuels – Wood Pellet	Commercial	No technology support needed. Energy policy to support conversion from coal may improve domestic demand. Provide access to latest low emission wood pellet technology from around the world (Europe) for a range of scales.
Construction - Appearance	Commercial	Commercial activity, standard economic development support (access to knowledge, business development support, access to financing, etcetera)

Table 4.3 – Summary of priority technology areas and their implementation

Understanding risk is therefore critically important. There are six key areas investors will focus on:

- **feedstock risk**
- **technology risk**
- **construction & commissioning risk**
- **market & merchant risk**
- **regulatory (sovereign) risk**
- **overall management risk**

Each of these areas warrants formal consideration and can be addressed proactively in any effort to attract such investors. A framework, developed by members of the Consortium and used by multinational investors, is described in **Appendix D**.

The stage of development determines the source for capital. As a technology moves from the first small-scale commercial plant of its type, to subsequent iterations, the role of government support declines and the ratio of debt increases (see **Table 4.4**).

The source of capital changes through this transition.

Initial small-scale 1st plants

Often funded by government development banks (for debt), strategic investors, high net worth families (family offices) or private equity funds (for equity), and governments for grants.

Medium scale 2nd plants

Typically funded by government development banks in partnership with corporate banks (for debt), and again strategic investors, high net worth families (family offices) or private equity funds (for equity).

Optimal-scale commercial 3rd plants

Funded by corporate banks and private debt funds (for debt) and private equity funds, public equity markets and retained earnings (for equity), often with pension funds and sovereign wealth funds for the full capital structure.

Strategic investors are industry or sector participants with a direct, strategic interest in the asset – also have a critical role to play. This is especially so for forestry where participants with strong balance sheets exist. One notable group with a variable attitude is the Timber Investment Management Organisations, or TIMOs. This variability stems from their variable risk appetite. Many are quite risk averse (pension fund backed) and will maintain their assets (largely in forest lands) without interest in value-adding or the introduction of new technology. However, some are taking a proactive approach to broadening their asset base within the sector.

Two notable examples of the latter are **New Forests Pty Ltd** from Australia and **Metsa Group**, a local forest owners' co-operative from Finland. Both are described in **Case Studies** below.

FORM OF CAPITAL	PLANT #1 (small-scale commercial)	PLANT #2 (medium- scale commercial)	PLANT #3+ (optimal- scale commercial)
Long-term Debt	30%	50%	65%
Equity	50%	50%	35%
Grants	20%	0%	0%

Table 4.4 – Typical capital structure, by stage of commercialisation of a bioproduct technology

Metsa Fibre

Case Study

Largest investment in the history of Finland's forest sector

Metsa Fibre, which is 75% owned by Metsa Group (a local forest-owners co-operative) and 25% by Itochu Corporation from Japan), is a producer of pulp, sawn timber, bioproducts and bioenergy. In 2015 the company announced its decision to build a bioproduct mill in Finland in the same area as an existing pulp mill in the town of Äänekoski. This required a substantial investment of approximately EUR €1.2 billion - the largest investment in the history of the Finnish forest industry[6].

Operational from 2017, the mill is the largest wood processing plant in the northern hemisphere and produces 1.3 million tonnes of pulp per year. The mill also produces a range of chemicals such as tall oil and turpentine, and bioenergy products including bioelectricity, process steam, district heat and bark-based solid fuel. In addition, Metsa Fibre is conducting research internally to develop other bioproducts and plans to work together with partners to develop various products including biocomposites and textile fibres[7,8].

Despite Finland being home to many multinational forest product companies, including Stora Enso and UPM, this is the first local investment at this scale. In part, this may have to do with the climate of Finland meaning wood growth is much slower, compared other countries like Uruguay which has attracted investment from the same two strategic investors[9]. However, another factor to note is company ownership, since Stora Enso and UPM are both controlled by international institutional investors. In comparison, Metsa Fibre is controlled by Finnish forest owners. Therefore, the decision to invest locally may not have been made purely based on financial criteria, but also on creating demand for locally grown timber as well as generation of wealth within local Finnish communities.

Although Metsa Fibre has cited a modest 2% improvement in the nation's renewable energy proportion, the investment has established a capability that over time can create wealth and sustainability[6]. Given the different forest land ownership patterns and incentives in Finland, it is not clear whether this kind of major investment could be replicated in New Zealand.

New Forests Pty Ltd

Case Study

The Australian experience of a new kind of TIMO

New Forests Pty Ltd is a TIMO which manages around 350,000 hectares of forest land in Australia valued at around AUD $800 million. It is also the third largest owner of forest land in New Zealand. New Forest sources its capital from pension funds, insurance & reinsurance companies and sovereign wealth funds who have a primary focus on forest land management.

New Forest applies a different business model than most TIMOs. While wishing to maintain its primary focus on owning and managing forest land, the biggest difference in approach is that it actively pursues value-creating opportunities in downstream processing sectors.

The best example of this is its purchase in 2013 of the sawmilling assets of Gunn's Timber Products for ~AUD $40 million, which it rebranded as Timberlink Australia. New Forests subsequently invested ~AUD $100 million to modernise and expand the sawmills in this enterprise, which are currently valued at ~AUD $400 million.

Building on this early success with Timberlink, the organisation is now moving into engineered wood products with an emphasis on cross-laminated timber (CLT) and glue-laminated timber (Glulam). By expanding its business model, management estimates that the post-tax tax return on its Australian assets has increased from ~7% to the mid-teens.

In order to successfully execute its business model, New Forests invests more in staff and has a higher overhead than most TIMOs. For example, it recruited the former head of innovation at European firm Stora Enso to guide its entry into the emerging bioproducts markets. In contrast, most TIMOs have a simpler model which entails securing the forest land, hiring solid local management to manage the forests, and passively overseeing the overall performance of their portfolio companies at the board level alongside other investors.

NZ Super is a special case in New Zealand – a predominant sovereign wealth fund within this small country – which could, and maybe should, play a pivotal role in funding national projects of this kind.

With NZD $44 billion in Assets Under Management, NZ Super is by far the largest institutional investor in New Zealand. The fund has a Climate Change Investment Strategy with the objective of reducing the carbon footprint of its portfolio[10]. This entails reducing its exposure to the fossil fuel industries and could include investing in opportunities that have a particularly low carbon intensity. As part of a coordinated New Zealand approach, the NZ Super Fund could play a significant role in helping New Zealand create a circular bioeconomy with wood at its centre, while still respecting its fiduciary responsibility.

Due to its large size and limited number of staff, NZ Super needs to focus on larger investments than those typically associated with small scale or early demonstration plants. A minimum investment of $200 million is a common practical requirement for large superannuation funds. There is potential for NZ Super's New Opportunities Assessment Hub (NOAH) – which focuses exclusively on climate-related opportunities – to participate in smaller financings that are associated with such projects? The fund may be able to justify this by considering follow-on investments in later plants that meet its financial, strategic, and minimum size criteria.

NZ Super is also engaged with the Climate Action 100+ investor initiative to ensure the world's largest corporate greenhouse gas emitters take necessary action on climate change. More than 370 investors with over USD $41 trillion in assets collectively under management are engaging companies on improving governance, curbing emissions and strengthening climate-related financial disclosures. Could there be a role for NZ Super in championing green opportunities in New Zealand's forestry sector to the other pension funds and asset managers that are part of Climate Action 100+?

Role Of Government

As described above, investors perceive significant risk associated with bioeconomy projects. If the potential of an expanded bioeconomy is to be realised and significant reductions in greenhouse gas emissions are to be achieved in New Zealand, the Government will have to be actively engaged to support the required investment. Fortuitously, this is aligned with rapidly growing public policies focused on curbing greenhouse gas emissions.

The New Zealand Government may play multiple roles in this effort. A very important role is that of a convener. In this role the Government has for some time been bringing together the major stakeholders in New Zealand's forestry industry sector and attempting to craft a shared vision and a strategic plan that could guide the transformational effort. This foundation would provide an anchor for an investment plan.

However, if the required capital is to be mobilised, the Government may also have to play the roles of regulator, quasi-banker, and co-investor.

A fundamental problem is that there is a disconnect between the private and public value of bioproducts – a market failure due to a low cost of carbon. As a result, most advanced bioproducts are currently not cost competitive on their own, a situation which is only expected to abate as technologies and supply chains mature, learning curves are leveraged, and economies of scale are achieved.

What are some of the different actions a government can take to address market failure and to support the development of a stronger bioeconomy? There are lessons to be learned from North America and Europe which are described below.

Direct price on carbon

Work by the Ecofiscal Commission shows that carbon pricing is the most practical and cost-effective way to lower greenhouse gas emissions while encouraging innovation in low-carbon projects[11]. As a result, the New Zealand Government's approach to putting a price on carbon, set using the Emissions Trading System, in terms of dollars per tonne of CO2 equivalent ($/tCO2e) is the right idea. However, as in most countries, it may not be politically acceptable to raise carbon prices high enough to change behaviour. As a result, it is likely that additional government action is required.

New Zealand's carbon price is currently around NZD $25/tCO2e (~USD $15). While this does send a price signal, it is far weaker than in countries like Sweden, Switzerland and Finland.

The three highest national carbon prices in the world (2019 values) are USD $127/tCO2e in Sweden, USD $96 in Switzerland and USD $70 in Finland. In these countries there is a relatively strong social consensus to fight climate change, and they are making progress in doing so. Interestingly, like New Zealand, none of them have a large fossil fuel industry which can lobby for protection against carbon pricing. Perhaps not surprisingly, countries with large fossil-based energy sectors tend to either have no economy-wide carbon pricing (e.g. USA, Russia, Saudi Arabia) or very low prices (e.g. Norway and Mexico with less than USD $3/tCO2e). Some would argue that New Zealand is still subsidising some emission-intensive industries, which could be addressed.

Most carbon pricing initiatives are still below the USD $40-$80/tCO2e range estimated by the Carbon Pricing Leadership Coalition as necessary to achieve the temperature goal of the Paris Agreement[12]. This point is underscored by the fact that carbon prices in 2019 only averaged ~USD $25 in the EU's Emissions Trading System, ~USD $17 in New Zealand, ~USD $16 in California and Quebec, and ~USD $11 in China (Beijing Pilot). Over 80 percent of the global carbon emissions subject to carbon pricing in 2019 were priced below USD $20.

Other instruments

In low carbon priced economies, carbon pricing remains well below the Social Cost of Carbon, which is defined as the economic damage done by one tonne of carbon dioxide emissions, inclusive of ‘non-market’ impacts on the environment and human health.

What are the main alternatives to support lower carbon bioproducts? The most frequently used policy tools include[13]:

- Clean fuel mandates and targets (e.g. X% of fuel must be biofuel).
- Capital incentives (e.g. grants, loan guarantees, capital cost allowances and accelerated depreciation through the tax system).
- Production/consumption incentives (e.g. Production Tax Credits or payments, reduced Fuel Excise Taxes).
- ’Flexible Regulations’ (e.g. Low Carbon Fuel Standards or LCFSs).

Many of these policies above focus on transportation fuels. The transport sector is a significant contributor to global CO2 emissions, representing 23% of all such global energy-related emissions, and over 75% of this is from road transport. A good summary of government policies from around the world that aim to support the production and consumption of biofuels can be found in the International Energy Agency Bioenergy Task 39 report[14].

Except for certain capital incentives, most of the above policy tools can be described as helping to create an attractive business environment for investors in bioproducts. More targeted tools like grants are often associated with a strategy of picking winners. It is instructive to note the relative success of these two approaches in the context of pursuing transformation change in forest industries.

Experience in Canada suggests that creating the right hosting conditions is a necessary, but not sufficient, approach to getting transformational change when technologies are emerging and there is still technical risk. In these circumstances more direct intervention may be needed. (See **Case Study: A Tale of Two Provinces: Government’s Role in Forest Sector Transformation**).

A Tale of Two Provinces

Case Study

Government's Role in Forest Sector Transformation

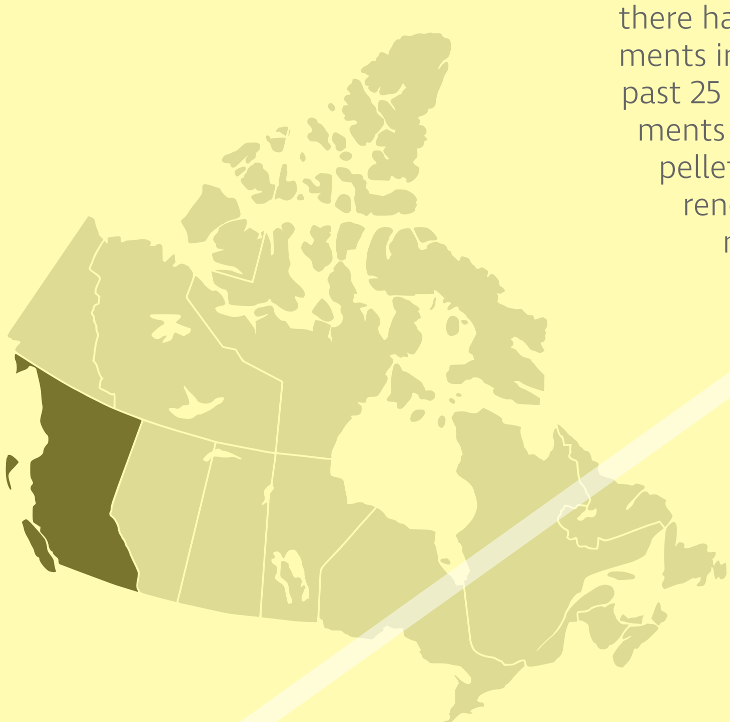
British Columbia (B.C) and Quebec are the two largest forestry-oriented provinces in Canada and both provincial sectors have been facing similar structural challenges to New Zealand. Yet the Governments of these two provinces have pursued different strategies from one another, which has led to different outcomes that are interesting to discuss when considering the New Zealand context.

British Columbia

The governments of B.C., regardless of the party in power, have consistently focused on creating the right hosting conditions for industries by avoiding picking winners or offering direct financial support to projects or companies. Rather, they have historically emphasised broader measures, such as:

- Provincial carbon taxes
- Low Carbon Fuel Standards
- Market development initiatives in China for B.C. timber

Despite the attractive hosting conditions, there have been no transformative investments in the B.C. forestry sector over the past 25 years, although several investments have been made in conventional pellet plants in response to subsidised renewable power prices in offshore markets.



A Tale of Two Provinces

Quebec

In contrast to B.C., governments in Quebec have provided direct financial support to specific private sector projects in addition to taking steps to create hosting conditions which support transformation of the forest sector (e.g. joining with California to form a joint Cap-and-Trade program for carbon). Initiatives have been achieved through government entities such as Investment Quebec and Fonds de Solidarité (FTQ) and can be in the form of grants and, more commonly, equity investments and low-cost loans. Once again, this has occurred regardless of the party in power. Examples of projects in the bioproducts space that have recently received government financial support in Quebec include:

- Conversion of paper machines from newsprint to packaging in Bromptonville and newsprint to recycled board in Trois-Riviéres, both of which belong to Kruger.
- Conversion of a pulp mill from kraft to dissolving pulp, and construction of a new hemicellulose/xylitol pilot plant at Fortress Paper's mill.
- Construction of a new cellulosic fibrils plant incorporating nanotechnology at Resolute's paper mill in Kenogami.
- Development of a new process which uses wood fibre in the production of wood-plastic composites at Papier Masson's mill in Gatineau.
- Construction of a new renewable fuel oil plant (from forest residues) in Port Cartier with AE Bioenergy.

Quebec generally co-invests in such projects in conjunction with the federally sponsored Strategic Innovation Fund, Investments in Forest Industry Transformation Fund and Sustainable Development Technology Canada programs. Quebec has been considerably more successful than B.C. in achieving transformation of its forestry sector, reflecting the outcome of providing direct financial support to encourage the best technologies to set-up in their area. Creating the right hosting conditions is needed, but more direct intervention will be required to fully transform an industry.

Flexible regulations

Low Carbon Fuel Standards (LCFS) are a newer policy approach that is proving to be more successful for driving increased production and use of biofuels, particularly lower carbon intensity advanced biofuels[14]. LCFS policies are often referred to as an example of flexible regulations. The reason is that the regulator sets a carbon reduction target for the fuels which must be met by the refiners and fuel distributors in the region (i.e. the obligated parties), and then the market determines the best way of meeting these targets. So, an LCFS is effectively a compliance measure which is enforced by the market.

Under LCFS policies, fuels that can be produced at a lower carbon intensity, compared to the petroleum-based fuels they displace, and generate higher carbon credits which results in higher market values for these fuels. In effect, the producers of high carbon fuels are subsidising the producers of low carbon fuels.

There are several advantages to this structure:

- From an efficiency perspective, it is agnostic with respect to what actions are taken to reduce the carbon intensity. It also employs the polluter-pays principle.
- Investors generally perceive regulatory risk to be lower with compliance measures than with direct production subsidies or tax subsidies. As highlighted in the previous section, the former is perceived to be stickier and thus less subject to change.
- From the government's fiscal perspective, the intervention is not a drain on the public treasury. This advantage will be increasingly important in future as fiscal pressures grow due to demographic changes, and the debt burden left from the COVID-19 crisis becomes apparent.

Note that under all the LCFS programs it is necessary to consume (but not produce) the low-carbon fuel in the home jurisdictions to realise the credit.

The State of California in the USA and Province of British Columbia in Canada are two jurisdictions at the forefront of implementing LCFS policies. Variants of this policy are also now starting to spread across the EU because of the revised Renewable Energy Directive known as RED II. This is the case in Germany and Sweden who have implemented greenhouse gas reduction quota obligations for biofuel use in their transportation sectors[15].

California pioneered the LCFS concept. Both the price and trading volume of LCFS credits in California have shown a clear upward trend since 2016, with prices up ~180% since early 2018. In Q1/2020 prices were hovering around USD $200/tCO2e (which is the regulated maximum), despite the dramatic fall in oil prices due to COVID-19. This is due to the stricter Carbon Intensity (CI) targets going forward, which are slated to decline by 20% from their 2010 level by 2030.

In April 2020, the price signal of ~USD $200/tCO2e sent by California's LCFS credit is an order of magnitude stronger than the <USD $20/tCO2e sent by California's Cap-and-Trade program. Where they exist, the LCFS programs in other jurisdictions tell the same story. For example, in Q1/2020 LCFS credit prices in British Columbia averaged ~USD $165/tCO2e (CAD $235), even during the COVID-19 crisis. This Case Study is described below.

Most striking is the price signal sent through Germany's new LCFS program. According to Argus Biofuels, German GreenHouse Gas credits used to meet 2020 compliance targets (which are tradeable in case of an excess or short fall) increased in value to EUR €430/tCO2e (~USD $470) in January 2020[16]. This is roughly double the 2019 prices. As in California and British Columbia, Germany's LCFS only applies to the transportation sector.

LCFS Program

Case Study

Stimulating The Market For Low Carbon Fuels

The California Air Resources Board (CARB) implemented a Low Carbon Fuel Standard (LCFS) program in 2011 to reduce the reliance on petroleum in the transportation industry and reduce greenhouse gas (GHG) emissions by encouraging the use of alternative low-carbon and renewable fuels over fossil-fuel derived gasoline and diesel[17,18]. The program is one of several initiatives implemented in California to reduce GHG emissions, such as the Cap-and-Trade and the Advanced Clean Cars Program.

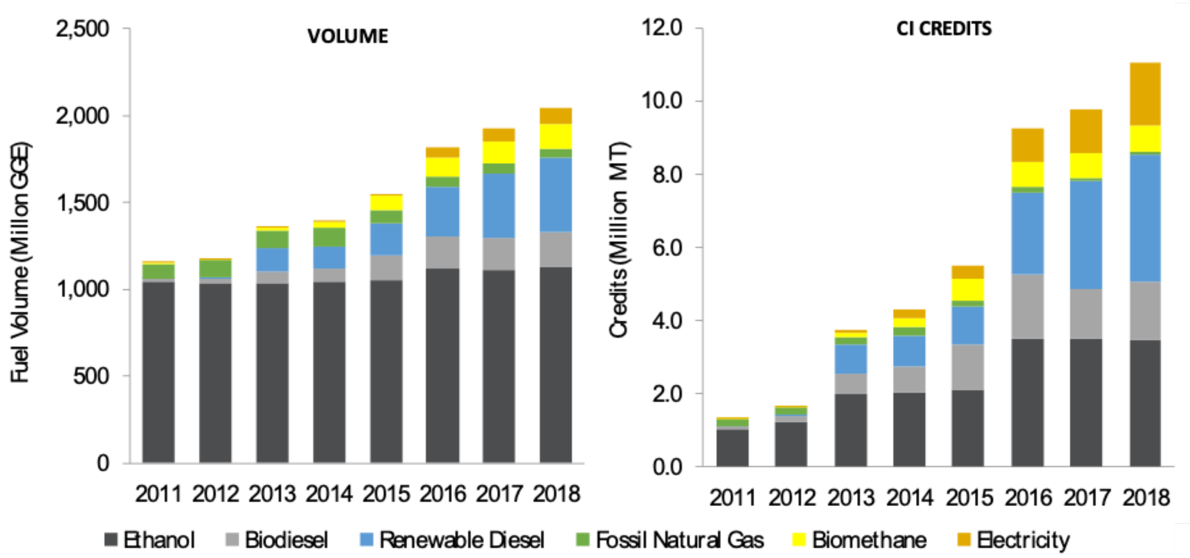


Figure 1 – Alternative fuels: volumes and credits

Under the LCFS program, different energy/fuel sources are rated in terms of their Carbon Intensity (CI) based on the GHGs associated with their production, distribution and consumption over the fuel life-cycle[17]. Regulated fuel providers must comply with declining annual CI targets set by the LCFS, to achieve an overall 10% and 20% reduction in the carbon intensity of gasoline

LCFS Program

and diesel fuel by 2020 and 2030, respectively, compared to a 2010 baseline[17,18]. To achieve CI targets, regulated parties can combine multiple strategies, including CI credit transactions where fuel providers can offset CI deficits by purchasing credits and, correspondingly, those exceeding targets can bank credits for future use. This encourages:[19]

- Substitution of conventional fuels with low carbon fuel
- Production of low carbon fuels
- Purchase of CI credits from alternative fuel producers
- Banking of CI credits (one credit accounts for one million metric tons of carbon dioxide-equivalents [millions metric tonnes CO2e])

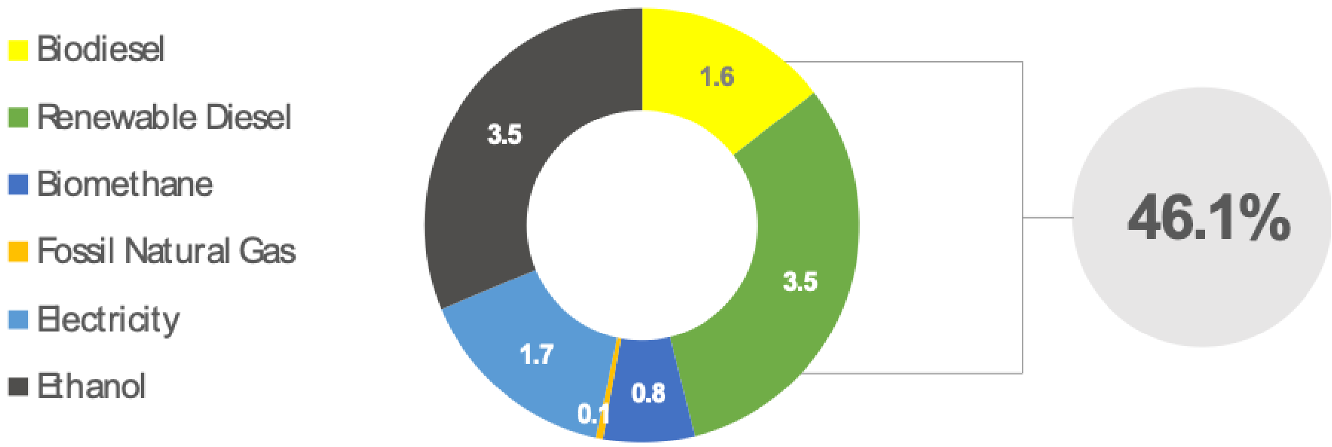


Figure 2 – Carbon intensity credits (millions metric tonnes) in 2018[18]

As a result of the LCFS program, there was an increase in the use of low carbon alternative fuels in California's transportation sector, from 6.2% in 2011 to 10.1% in 2018 (in terms of energy content)[19]. In 2017, California was also responsible for approximately half of all Zero Emission Vehicles (ZEV) sales in the US and 18% of all diesel was derived from biomass-based sources[20].

On a volume basis the decline in CI and increase in use of alternative biofuels has been largely driven by uptake of liquid biofuels. Ethanol remains the main alternative fuel used in each year of the program, accounting for over 50% of total alternative fuel volume in 2018, yet a notable increase in the use of biodiesel and renewable diesel has been observed, from 1.4% of the total volume of alternative fuels in 2011 to 30.8% in 2018 (**Figure 1**)[18]. While ethanol is the

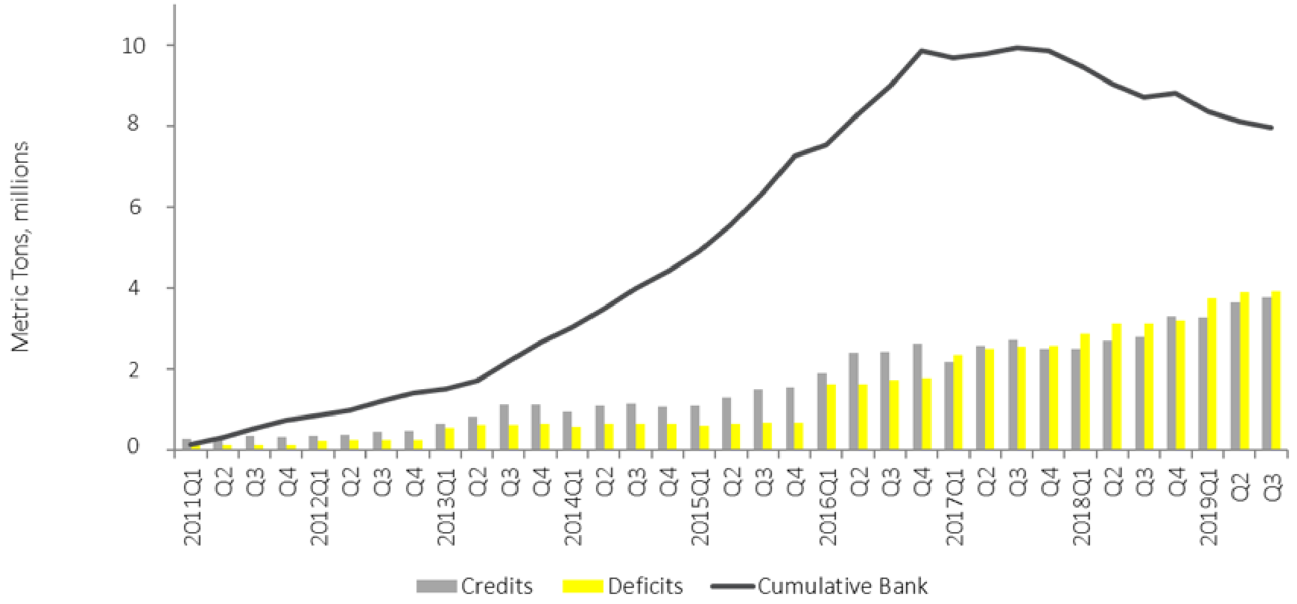


Figure 3 – Total credits and deficits across all fuel sources and cumulative banked credits from the LCFS system in California (2011–2019)[18]

most used alternative fuel by volume, CI rates differ by fuel type. The greatest proportion of CI credits (46.1%) in 2018 was in fact derived from biodiesel and renewable diesel fuels (**Figure 2**)[18].

Since its implementation, the programme has undergone several amendments, including a court-ordered freeze of CI standards from 2014 to 2015 to set the annual reduction rate to 1% (i.e. across 2013 to 2015) to reduce pressure on regulated parties to comply with the high initial targets. This was repeated in 2016 at a rate of 2%[19,21].

Under these freezes, credits outweighed deficits, leading to a surplus of nearly eight million CI credits banked in 2019 (**Figure 3**)[18,19]. CI credit prices have fluctuated overtime, rising from approximately USD $20-$25 per credit in 2013, up to USD $160 in 2018. High credit prices have further incentivised development of low-carbon transportation fuels and the total value of credits banked in 2018 was valued at over USD $2 billion[19,22]. Credit prices have been capped at USD $200 per metric tonne (2016 cost year, inflated in line with the consumer price index [CPI]), to prevent credit shortages and create price certainty in the CI credit market[21].

Overall, the Low Carbon Fuel Standard policy has been an effective way to reduce greenhouse gas emissions in the transport industry and encourage the production and use of alternative low-carbon fuels, through creating a market where Carbon Intensity credits and deficits can be monetised by the industry to reach carbon reduction targets.

It appears salient for New Zealand to pay attention to the approaches being taken in Canada and Finland. Highlights of the first are summarised in the **Case Study: Canada's Clean Fuel Standard**: The First Economy-Wide Flexible Regulation to Reduce Carbon Intensity. Finland has taken a different approach and adopted a portfolio of initiatives to support the development of its bioeconomy. In many ways this country "sets the bar" for biofuels and forestry. The most salient initiatives are summarised in the **Case Study: Finland**: A Model for New Zealand in the Bioproducts Sector?

Regardless of which kind of government intervention is taken to support the development of the bioeconomy, it comes with a financial cost to society. With Finland's various initiatives, the direct cost tends to be borne by the national treasury. With Canada's Clean Fuel Standard, the direct cost will be borne by the industrial parties who are obligated to meet the reductions in Carbon Intensity of their products.

Market-pull instruments (e.g. blending mandates, or fuel excise tax reductions) are effective in supporting technologies that are relatively mature. This is because they create a demand for biofuels that is typically met with commercial conversion technologies (e.g. ethanol). However, such instruments are limited in their capacity to pull early-stage technologies into the market. In contrast, regulatory frameworks such as California's LCFS, the EU's RED II, Brazil's RenovaBio and Canada's Clean Fuel Standard are examples of policies that aim to pull advanced biofuels into the market by providing fuel-agnostic financial incentives to produce biofuel products at the lowest carbon intensities.

Finland

Case Study

A Model for New Zealand in the Bioproducts Sector?

On the surface, New Zealand and Finland are quite similar. Both have significant forest sectors, and Finland has only a marginally greater population (+12%), surface area (+26%), GDP/capita (+18%) and carbon emissions/capita (+15%). However, Finland's focus on bioproducts is in a different league – the typical advanced biofuel plant can expect to receive grants in the order of 40% of total capital expenditure.

Basic Facts on Finland's Transport and Renewable Fuels Market

- Neste is the only refinery in Finland; it is also the European leader in producing renewable fuels.
- In 2015, the share of renewables in electricity generation was 45%; the largest share was hydro power followed by wood and wind power.
- Almost 80% of electricity generation is emission-free, and it is expected to rise to 90% by 2030 as the share of renewable production and nuclear power increases.
- Finland reached the national, binding 2020 EU-targets for renewables ahead of time, in 2014.
- By latest estimates the use of renewable energy sources will surpass fossil fuels during 2020.
- Transport faces the biggest challenges; fossil oil still accounts for almost 90% of fuels used in road transport.
- The goal for Finland is to have a minimum of 250,000 electric vehicles in total (fully electric vehicles, hydrogen-powered vehicles and rechargeable hybrids) and a minimum of 50,000 gas-fuelled vehicles in 2030[23].

Finland

National Biofuel Promotion Policy

- National obligation by 2030 is 30% of transport fuel sold to be renewable or bio based
- When biofuel is produced from waste, residues or inedible lignocellulose, the energy content is double counted when calculating the amount of biofuels.
- Penalty for non-conformance of fuel retailers is EUR €0.03/MJ (=EUR €1,284/t, or USD $190/ barrel of non-conformance sales).

Statement from Finnish Ministry of Transport[24]

"To meet the 30% target: Any additional demand will be covered by advanced biofuels produced in Finland. The need for additional production capacity will be approximately 7 TWh per year by 2030."

"Biofuels with the largest production volumes, which would account for some 80% of the production, would consist of so-called drop-in biofuels, such as renewable diesel and bio-gasoline. These fuels can be used in the existing fleet without restrictions, and no new distribution infrastructure need be constructed for them. To complement them, bioethanol and biogas (bio-methane) will be produced."

Finland

R&D Financing Schemes for Renewable Fuel & Energy — Examples

EU Innovation Fund

EU Innovation Fund is the largest funding mechanism available, with EUR €11 billion available between 2020-2030. The first call is currently under planning; the last meeting (Feb 2020) was focused on consortia Public Private Partnership applications. Finnish entities may apply in multi-country and multi-partner applications. Business Finland coordinates via Horizon 2020[25].

Business Finland

Business Finland is active in supporting funding of green energy projects examples:

- IntensVTT smart and green shipping project (EUR €13 million) won EUR €5.6 million Business Finland funding.
- Investment grants are available for new technologies built in Finland with a maximum of 40% grants available (large companies 30%).
- Green Fuel Nordic Oy invested EUR €25 million in a new Fast Pyrolysis plant and received EUR €7 million in local government support.

Nordic Innovation Fund

Nordic Innovation Fund supports cross Nordic innovation projects to a total of EUR €1 million per company over a 3-year period.

Spinverse Oy

Spinverse Oy is a leading builder of EU and National consortia programs with a very high investment success rate.

A Note On Government And Industry Working Together

The New Zealand Government has committed to see forestry at the heart of a strengthened bioeconomy. This implies a long-term commitment to forestry and the value chain associated with forestry and ensuring maximising benefit to New Zealand.

Future proofing or increasing the gains being made, ensuring optionality and resilience, will require continuous innovation. Acknowledging that funding an end-to-end innovation system is expensive then new models for innovation need to be developed.

This report has identified the potential transformational impact of:

Plant biotechnologies for New Zealand

- including gene editing and their potential to deliver more woody biomass, better tailored to the environment and to processes required, and able to ensure New Zealand's trees are resilient to the impact of climate change and new pests and pathogens

Increasing wood innovation in the built environment

- with its potential for multiple benefits in embedding carbon, reducing energy consumption in buildings, and creating export opportunities

The importance of working closely with other nations/ entities

- especially those with deeper pockets, to enable New Zealand to be fast adopters and adapters of those technologies applicable for New Zealand

Maximising value created in the above and future proofing a new New Zealand bioeconomy will require the Government and industry to forge a unified strategy and a partnership in innovation.

Case Study

Canada's Clean Fuel Standard

The First Economy-Wide Flexible Regulation to Reduce Carbon Intensity

An evolving regulatory framework for New Zealand to monitor is Canada, which is developing a national economy-wide Clean Fuel Standard (CFS). Implementation is currently targeted for 2023. It will be the first LCFS in the world to be so broad, targeting reductions from each of the transportation, building and industry sectors. Reductions will be achieved by setting separate carbon intensity requirements for liquid, gaseous and solid fuel streams, as well as through rules on credit trading. The obligated parties are the producers and distributors in the transportation, building and industry sectors that have greater than target Carbon Intensities. Such a broad coverage is likely to be advantageous to the forest sector since:

- Obligated parties in the transportation sector will be seeking lower carbon liquid biofuels.
- Obligated parties in the industrial sectors will be seeking lower carbon gaseous, liquid and solid biofuels.
- Obligated parties in the building sector will be seeking lower carbon materials like timber and engineered wood products.

Under this policy regime, the commercial forestry sector could be a meaningful problem solver.

In recognition of the unprecedented circumstances related to COVID-19, in late April, Environment and Climate Change Canada announced a delay to the publication of the proposed Clean Fuel Standard regulations for liquid fuels. It now plans to publish the proposed regulations in Q3 of 2020, with final regulations in late 2021 with the aim of coming into force in mid-2022[26]. Regulations for the gaseous and solids classes will follow about one year later.

There is no guidance yet on the target value of CFS credits; prior to the COVID-19 shock, industry pundits were predicting it to be in the CAD $50-$150/tCO2e range (USD $35-$107), with a likely near-term value of CAD $150-200 (USD $107-142).

5. Methodology

» **Methodologies developed and used in the study are described**, including a purpose-built Wood Availability Model and a New Zealand Carbon Lens detailed in depth in several Appendices.

Laying The Foundations

The purpose of this Stage 1 project was to search the world for technologies that could meet four intersecting needs: utilise woody biomass, reduce carbon emissions, and be strong candidates for both private and public investment. These therefore constituted the lenses used to identify those technologies that were worthy of further due diligence in building an execution plan for those in the 5-10 year timeframe and others that were worthy of direct action to develop that would fit into the 20 to 30 year time frame.

Wood availability forecasts were developed and derived from the National Exotic Forest Description (NEFD) as at 1st April 2019. The analyses are included in Appendix C including the assumptions used to derive these forecasts. Of note:

In the 5–10 year horizon the woody biomass will be dominated by radiata pine

In the 20–30 year horizon, radiata pine will still be the dominant species but it is possible that other species (exotics and indigenous) could be a larger part of the New Zealand commercial tree portfolio

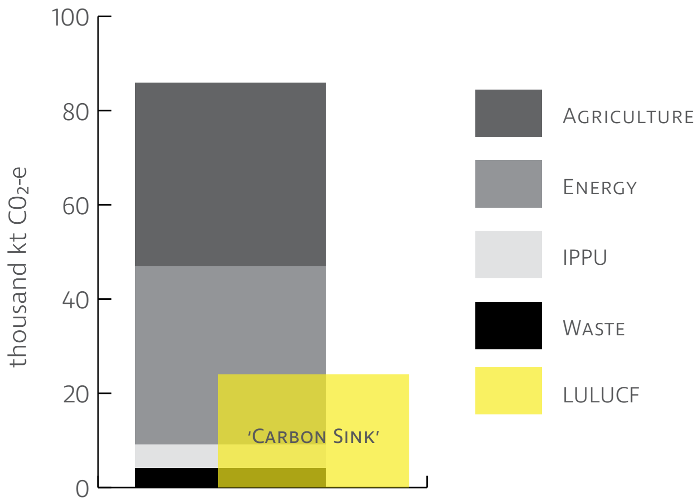
Regional analyses were undertaken indicating potential areas for new wood processing capacity using the lower value products from trees, where there are barriers to export, and less existing manufacturing capacity

Woody biomass

The New Zealand forestry landscape was described and the availability and flow of woody biomass of various kinds was modelled 30 years into the future, by region, by forest-ownership type, and aggregated. This is the first whole country model produced for many years, and is a major asset delivered by the Consortium.

Reducing the carbon footprint

A purpose-built approach to carbon emissions was developed, based on New Zealand's carbon budget, and aligning all technology candidates to the emission sources they could reduce. This led to a market-target approach, where technologies that could address a particular emission source were compared, rather than comparing specific technologies with each other as most previous reports have done. This was critical to align the selections with markets, and therefore with investor expectations as below.



IPPU = Industrial Processing and Product Use, LULUCF = Land Use, Land-Use Change & Forestry

Figure 5.1 – New Zealand's carbon footprint

Investor lens

The expectations of large-scale investors of various kinds were described, including a detailed framework that would have to be used to attract international investors who specialise in this arena. Case studies were developed to illustrate recent examples of successful funding mechanisms, and the careful interaction with government, which is a pre-requisite in this area, was detailed.

The role of government

The activities needed to create hosting conditions for large-scale international investment were described, along with further case studies illustrating some successful models.

Government lens

The technologies selected needed to have broad impact and reach into areas of critical importance to New Zealand for example into decarbonising the supply chain for exports, increase regional employment, or grow the value of exports and hence create a return on investment for New Zealand beyond the technology / process operation itself.

Considerations For The Two Time Horizons

5–10 years

Resource availability will not change significantly as the trees for this horizon are in the ground already and getting close to harvest.

The development of new products will need to be based on technologies that are very mature – demonstrated or proven in an operational environment.

They will also have supporting infrastructure or likely willing participants.

20–30 years

Resource availability and type could increase due to:

- incentives to plant trees, changes in forestry models (e.g. expansion of small forest ownership, great focus on biomass rather than solid timber, and potential increase in species diversity).
- the impact of plant biotechnologies including genetic engineering to increase biomass production and tailor the composition of wood to meet a product or process requirement.

The new processes to achieve those products could be less mature (e.g. currently only laboratory validated) or based on more complex mixes of processes.

The infrastructure or enabling systems could develop (e.g. changes in approaches to wood processing).

A STEEP (Social, Technology, Economic, Environment & Political) analysis was undertaken to identify changes that may affect New Zealand in the future with a specific focus on forestry. The STEEP analysis is fully reported in Appendix E.

Assembling A Longlist

The technologies relevant to this study – emerging, large-scale, biomass processes – are not typically found in research institutions, in literature reviews, or in public source lists. To be relevant to New Zealand's needs over the next 30 years they need to be well down the path of Technology Readiness Levels (TRLs). They are mostly to be found in start-ups or in development projects being supported by corporates.

As such they are invisible to most conventional searches; instead, they are found in the "next horizon" chapters of annual reports, in announcements about investment, or in IPO pitches. An initial technology list was provided by Nawitka Capital Advisors. This list has been maintained by the firm over many years and tracks many technologies and their progression along the development curve. The list was added to by members of the consortium, through discussions with stakeholders in New Zealand (both companies and research institutes), global contacts, and targeted internet searches. The focus of the technology list was to capture as many technologies as possible that could use woody biomass as a starting point.

Care was taken to ensure as many New Zealand based technologies were included in the list as possible, however, the primary concern was to ensure that the full range of global technologies was identified and included in the initial list.

Technology Readiness Level (TRL) was used as a criterion for reviewing technologies. Developed at NASA in the 1970's TRL is widely used internationally (See **Figure 5.2**)[27]. For those technologies expected to be implemented within 5-10 years the technology would need to be at least TRL7-9. Earlier technologies (TRL 4-6) were accepted in the longer-term (20-30 year) analysis.

Bench scale technologies or research projects were not included unless there was a commercial proponent actively developing the technology. The technologies included in the list covered a range of products and market targets. No attempt was made to exclude any technologies at this stage, however, established technologies which were not new-to-New Zealand, were not the primary focus of this exercise.

The total number of technologies on the longlist was 108.

Figure 5.2 – Technology Readiness Levels

Methodical, Objective Selection

To assess and identify those technologies that could meet the study's aim, a stepwise approach was taken to sort and filter the longlist through each of five stages to arrive at the shortlists.

Each of the aspects of Laying the Foundations (above) were used to develop criteria which were applied to select the best and most feasible technologies to meet the study's aim. The details of every step in this process, including lists of technologies surviving at each, is presented in **Appendix F**.

Adding A Broader Lens

A technology list was just one of the outcomes of this study; the complexity of the challenge required broader considerations.

For context, the scale considerations of the major technology areas – biocrude and biofuels – were aligned with the woody biomass availability. This was done at the national level, as a check on feasibility and impact, but not at a regional level where cost, volume and even species considerations interact.

Business as usual is not a winning strategy and many attempts to introduce new technologies into New Zealand have failed. New Zealand companies have already explored large chemical projects based on wood (e.g. Stump to Pump) and withdrawn. It was therefore imperative to consider what would need to change in the New Zealand environment to enable the identified technologies to be successfully implemented. These ranged from leveraging on the small, nimbleness of New Zealand to getting the key players engaged. Several international Case Studies were written to help guide the path.

This report lays the foundation for Wood Fibre Futures Stage 2 – from shovel-worthy to shovel-ready – to be able to commence immediately.

6. Next Steps

» **Next steps in each focus area are recommended** – Biocrude & Liquid biofuels, Coking Coal Replacement, Policy Development and Sustaining Long-Term Competitive Advantage

This final chapter of the report aims to distil the next steps for action.

The approach follows the original trajectory of Stage 1 through to Stage 2. This report (Stage 1) aimed to develop a short-list of technology candidates and related actions; Stage 2 intends to perform deeper investigation on the short-list to ascertain those which have viable investment cases.

Biocrude & Liquid Fuels

Deep investigation of each shortlisted technology

- Directly approach the shortlisted technology companies, with emphasis on those suitable for the medium-term (5-10 year) horizon.
- Communicate the opportunity that could exist for them in New Zealand.
- If positive response, go under confidentiality, including the New Zealand Government.
- Ascertain their suitability and interest in engaging in this region.
- Perform deep technical analysis, competitor analysis and financial diligence including assessment of the requirements they might have for woody biomass, the impact they could have on carbon emissions, and their flexibility to pursue multiple future markets.
- Confirm final candidates and assemble dossiers of materials on each.

Develop options for role of Government

- Considering the specific collection of shortlisted opportunities, develop options for the optimal role(s) of government in enabling investment (see more on this in 'Policy Development Opportunities' below).
- Consult New Zealand Government regarding the potential to deliver these roles.
- Determine what could be included in the investment cases in this regard.

Research potential private investors (especially international)

- Develop lists in various categories (e.g. strategic investors, green funds, high net worth families (family offices), infrastructure funds, development banks), with explanations regarding the different value propositions they are seeking; lists to include key individuals within each organisation.
- Rank lists into high, medium, low likelihood.
- Recommend key elements of an engagement campaign including recommended deal structures.

Coking Coal Replacement

Approach New Zealand Steel

- Research the case for replacing coking coal from the steel-mill perspective.
- Research successful case studies world-wide, which match those perspectives.
- Approach New Zealand Steel to ascertain interest.

Develop investment case (if positive response above)

- Perform deeper research on the five leading technology candidates in this report.
- Work with New Zealand Steel and New Zealand Government to ascertain if there is a mutual investment case.
- Determine deal structures that could work for both parties.

Policy Development Opportunities (Flexible Regulation)

Advice for New Zealand Government

- Further develop successful case studies of flexible regulations achieving carbon reductions; studies to include engagement with key individuals in each relevant jurisdiction.
- Focus specifically on broad carbon-reduction regulations which include the transport sector, but which also go beyond, specifically to include the built environment.
- Develop options for the New Zealand Government and present options with case studies.
- If positive, engage with Government and its regulatory drafters on international precedents and strategies.

The special case of increasing wood-based biomaterials in the built environment

- Design and develop a specific flexible regulation approach suitable for increasing wood-based biomaterials in the built environment, as part of a carbon-reduction programme.

Biochemicals, biocomposites and related technologies

- Perform deeper research on the list of these out-of-scope opportunities to determine preliminary investment cases for each; this would include quick analyses on uniqueness, market attractiveness, intellectual property, management team, and potential return on investment.
- Among viable candidates, rank them in potential speed of execution.
- Work-up the fastest candidates alongside both forestry industry participants and local and central governments to determine those that could be attractive to both parties for immediate start.

Sustaining Long-Term Competitive Advantage

- Direct both R&D resources and investment attraction agencies to include efforts on sustaining competitive advantage by focusing some attention on emerging technologies in the areas above.
- Provide that intelligence to the technology ecosystem locally, including industry bodies, strategic participants, and investor groups.
- Continue to adapt policy to maintain world-class performance in this area
- Develop the economic model which quantifies the role of forestry in the circular bioeconomy, including the specific strengths and weaknesses of New Zealand, and of radiata pine, for use with international investors and interested parties

References

(1) Knuckey, S. Manufacturing Matters; The Manufacturers Alliance, 2020; p 103.

(2) Can New Zealand Be Internationally Competitive in Selling Sawn Timber into the Chinese Market?; Forestry and wood processing spotlight report series; Ministry of Business, Innovation and Employment, 2019; p 9.

(3) Facts and Figures 2018 - 2019; Facts and Figures; The Forest Owners Association and The Ministry for Primary Industries; p 35.

(4) Lu, W. Trade and Sustainable Forest Management. Unasylva **2004**, 55 (219), 27–31.

(5) New website for Northland Tōtara Industry Pilot project | Scoop News https://www.scoop.co.nz/stories/BU1908/S00393/new-website-for-northland-totara-industry-pilot-project.htm (accessed Jun 9, 2020).

(6) Metsä Group to build next-generation bioproduct mill in Äänekoski | Bio-Based Industries Consortium https://biconsortium.eu/news/mets%C3%A4-group-build-next-generation-bioproduct-mill-%C3%A4%C3%A4nekoski (accessed Jun 9, 2020).

(7) Bioproducts https://www.metsafibre.com/en/about-us/Production-units/Bioproduct-mill/Pages/Bioproducts.aspx (accessed Jun 9, 2020).

(8) Metsä Fibre takes bioproducts to the multi-million tonne markets https://www.metsafibre.com/en/media/Stories/Pages/Metsa-Fibre-takes-bioproducts-to-the-multi-million-tonne-markets.aspx (accessed Jun 9, 2020).

(9) Uruguay attracting pulpmill investments https://fridayoffcuts.com/dsp_article.cfm?id=316&aid=2724 (accessed Jun 9, 2020).

(10) NZ Super Fund Annual Report 2019; NZ Super Fund; p 228.

(11) How does carbon pricing compare to other ways of reducing emissions? | Ecofiscal https://ecofiscal.ca/carbon-pricing/fast-facts/cost-effectiveness/ (accessed Jun 9, 2020).

(12) State and Trends of Carbon Pricing 2019; World Bank Group: Washington, DC, 2019; p 97.

(13) Roberts, D. Global Government Commitments to Bioenergy Subsidies and Incentives Relevant to International Forest Industries; 2011.

(14) Ebadian, M.; McMillan, J. D.; Saddler, J. (John) N.; van Dyk, S. Implementation Agendas: 2018-2019 Update Compare and Contrast Transport Biofuels Policies; IEA Bioenergy, 2019; p 256.

(15) Vågerö, O. Biofuel quota (obligatory biofuel shares in fuel) http://www.res-legal.eu/search-by-country/sweden/single/ (accessed Jun 9, 2020).

(16) Bioenergy market prices, forecasts & analysis | Argus Media https://www.argusmedia.com/en/bioenergy (accessed Jun 9, 2020).

(17) LCFS Basics | California Air Resources Board.

(18) Dashboard | California Air Resources Board https://ww3.arb.ca.gov/fuels/lcfs/dashboard/dashboard.htm (accessed Jun 9, 2020).

(19) Witcover, J. Status Review of California's Low Carbon Fuel Standard, 2011–2018 Q1 September 2018 Issue. UC Davis: Institute of Transportation Studies **2018**.

(20) Corey, R. The State of California's Programs; 2019.

(21) Marcucci, A.; Lyons, J.; Seymour, K.; Noda, L. Market Reactions to Low Carbon Fuel Standard Programs; Fuels Institute, 2019; p 71.

(22) California Climate Policy Fact Sheet: Low Carbon Fuel Standard; Berkeley Law; p 2.

(23) Renewable energy - Finnish Energy https://energia.fi/en/advocacy/energy_policy/renewable_energy (accessed Jun 9, 2020).

(24) Jääskeläinen, S. Renewable Energy in Transport until 2020 and Beyond / Finland.

(25) CABUZEL, T. Innovation Fund https://ec.europa.eu/clima/policies/innovation-fund_en (accessed Jun 9, 2020).

(26) Canada, E. and C. C. Clean Fuel Standard https://www.canada.ca/en/environment-climate-change/services/managing-pollution/energy-production/fuel-regulations/clean-fuel-standard.html (accessed Jun 9, 2020).

(27) Mai, T. Technology Readiness Level http://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html (accessed Jun 9, 2020).

(28) Dayton, D. C. (ORCID:0000000332443722). Catalytic Upgrading of Thermochemical Intermediates to Hydrocarbons (Final Report); DOE-RTI-5358-1; RTI International, Research Triangle Park, NC (United States); RTI International, Lyngby (Denmark), 2019. https://doi.org/10.2172/1525871.

(29) Ravn, S. Preem selects HydroFlex™ for renewable fuels plant with potential to save 2.5 million tons CO2 https://blog.topsoe.com/preem-selects-hydroflex-for-renewable-fuels-plant-with-potential-to-save-2.5-million-tons-co2 (accessed Jun 9, 2020).

(30) LanzaTech moving forward on scale-up of sustainable aviation fuels in US and Japan https://www.greencarcongress.com/2019/11/201091121-lanzatech.html (accessed Jun 9, 2020).

(31) World Pellet Map – European Pellet Council. European Pellet Council.

(32) 2015 NEFD Yield Table. Ministry for Primary Industries.

(33) Good Practice Guide Production of Wood Fuel from Forest Landings; The Energy Efficiency and Conservation Authority; p 44.

(34) Chandler, N. Observations on the Wood Availability Forecasts. NZ Journal of Forestry **2016**, 61 (1), 11.

(35) Log Price Report; AgriHQ, 2020.

(36) Clean Technology: Incentives & Financing; Nawitka Capital, Trinidad, 2012.

(37) Leveraging Sustainable Finance Leadership in Canada: Opportunities to align financial policies to support clean growth and a sustainable Canadian economy https://www.iisd.org/library/leveraging-sustainable-finance-leadership-canada-opportunities-align-financial-policies (accessed Jun 9, 2020).

(38) New Zealand's Fourth Biennial Report under the United Nations Framework Convention on Climate Change; Ministry for the Environment: Wellington, 2019; p 219.

(39) New Zealand's projected greenhouse gas emissions | Ministry for the Environment https://www.mfe.govt.nz/node/25012/ (accessed Jun 9, 2020).

(40) New Zealand's Greenhouse Gas Inventory; Ministry for the Environment: Wellington, 2019; p 481.

(41) Measuring Emissions: A Guide for Organisations. 2019 Summary of Emission Factors.; Ministry for the Environment: Wellington, 2019; p 19.


photo courtesy of Red Stag Timber

APPENDIX A: SHORTLISTED TECHNOLOGIES

The Wood Fibre Futures technology selection process focused on candidates which met all the criteria used in a formal filtering process:

- Applicability to woody biomass
- Alignment to major carbon emission categories
- Competitive position
- Future Uncertainty (Optionality)
- Ability to Implement

Four focus areas emerged with highest priority.

Biocrude Oil

- Four medium-term candidates and 11 additional long-term candidates
- Primarily from Europe and North America, with two in Australia
- Best candidates were fast pyrolysis and hydrothermal liquefaction technologies
- Most had multiple patents and were incorporated in private companies

The opportunity to replace fossil fuel crude oil was one of the obvious targets for carbon reduction, and one with vigorous technology activity world-wide. While it was not as large a target as liquid fuels, the ability to address it using woody biomass was more efficient (in emissions reduction per cubic metre of wood) than for liquid fuels.

Biocrude has several interesting advantages as a target:

- It uses by-product streams from the forest and from mills to produce low carbon biofuel that has ~70-80% lower carbon intensity than fossil fuel petrol and diesel.
- It allows production of a wide range of products (e.g. heat & power, transportation fuels, biochemicals and biomaterials), which give it optionality in a future-uncertain world.
- It leverages existing infrastructure in the oil refining and distribution sector potentially lowering the capital investment required to produce low carbon fuels.
- As a result, it can work with, instead of against, the oil refining industry, and it helps support existing employment in both forestry and oil refining industries.

In the New Zealand context, the specifics of these advantages were as follows:

- Biocrude could feed into existing infrastructure in New Zealand and the end-product could be integrated into the flow of crude into other products.
- The technologies short-listed are all capable of bolt-on to an existing refinery, although they varied in complexity and cost.
- Biocrude also seemed robust to future uncertainty. The value of biocrude, specifically as a low carbon replacement for fossil fuels, seems likely to be maintained for the long term, under-pinned by domestic consumption in New Zealand with its high use of heavy transport, aviation and shipping.
- Initiatives to implement the production of biocrude are currently underway in several centres in the world. Furthermore, its developers are targeting customers in both domestic and export markets, with the latter entailing long shipping distances (e.g. Brazil to California, Eastern Canada to Europe). This would be the answer to the scale question in establishing a plant in New Zealand – it would be under-pinned by efficient local production of wood fibre, and by domestic markets for fuels and/or other products, but it could also be exported into international markets. This could be especially attractive if it were from Marsden Point, the current entry port for oil for refining in New Zealand.

- Conversely, New Zealand is very exposed to societal reactions to climate change where long-distance travel may be reduced with flow-on effects on both tourism and shipping.
- Refining NZ Limited is clearly a key stakeholder in this arena, as New Zealand's only crude oil refinery. It is also located in Northland which was one of the attractive areas determined in the wood-flow analysis. Unfortunately, Refining NZ was severely impacted by the crash in fuel consumption due to COVID-19 and the Consortium was unable to engage strongly with them. While they have explored biofuels before (aviation fuel), that project did not proceed. Their current circumstances must also raise questions about the viability of refining in New Zealand, which would be a significant risk to biocrude production in this country. Exploring this issue deeply with Refining NZ becomes a key follow-up for Stage 2 of the project.

Some of the world's largest and most innovative companies in forestry and energy have already invested in biotech companies and plants focused on biocrude, including:

- Investment in Ensyn by Suzano (world's largest pulp company) and Chevron (major oil company).
- Investment in Steeper by Sodra (Sweden's largest forest-owner group) and Statkraft (Europe's largest producer of renewable energy).
- Investment in Licella by Canfor (world's largest lumber producer & significant pulp producer).
- Investment in Genifuel by Parkland Fuels (British Columbia's largest oil refiner).

Biocrudes are similar to crude oil extracted from ground sources. They have come to the forefront more recently as they provide an option for the oil and gas industry to utilise its existing assets and distribution networks in ways which lower the carbon intensity of its products.

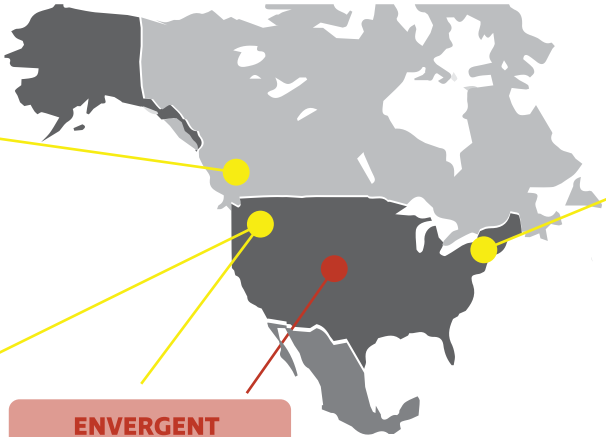
This shift in the viewpoint of several oil and gas producers has come from continued research and development into the processing of biocrudes in standard oil refineries. Major companies like Shell, Total, Exxon, Petrobras, Neste, BP and others are exploring this option.

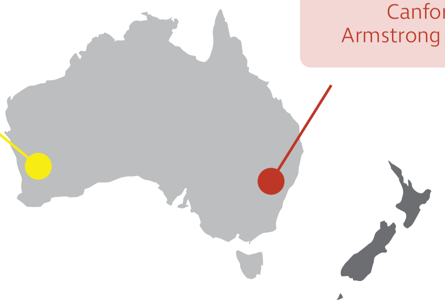
The advantage of biocrudes for companies that operate refineries is that it allows the refinery to generate credits under a low carbon fuel standard. Refiners that do not find a way to lower the carbon intensity must purchase fuel credits, which helps to fund the system. Those that do find a way, through using biocrude, can offset carbon emissions, reducing their costs in the carbon-pricing system. If a 'drop-in' fuel is utilised, that fuel will be downstream of the refinery, which means that the refinery remains the funder of the LCFS.

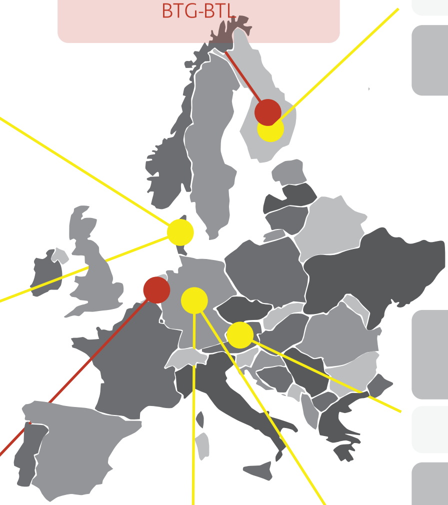
Biocrudes can be considered similar to heavy crude oil which needs to be upgraded in the refinery. This means that some refineries that are not set up to process heavy oil will find them challenging to process or will require capital investment to allow it. This will set a limit on how much a refinery can utilise. In addition, biocrudes also have a higher oxygen content than conventional crude oil. This is typical of products from biomass (driven by its greater variability and chemical structure).

Around 20 technologies were found by the consortium, mostly from the leading nations in biofuels and carbon reduction in Europe and North America. Of these, four were developed sufficiently to be included in the medium term (5-10 year) horizon and 11 others were also applicable to the longer term (20-30 year) horizon. The four medium-term candidates came from two technology pathways: fast pyrolysis and hydrothermal liquefaction.

Recommended Biocrude Technologies







Candidate (Location)	Organisation Type	Transformation Pathway	Strategic Partners (if applicable)	Candidate
HIGHBURY ENERGY (Canada)	Private Company	Gasification Fischer-Tropsch		Long-Term Candidate
RTI INTERNATIONAL (USA)	Research Institute	Hydrothermal Liquefaction		Long-Term Candidate
GENIFUEL (USA)	Private Company	Hydrothermal Liquefaction		Long-Term Candidate
RENERGI (Australia)	Private Company	Fast Pyrolysis		Long-Term Candidate
ENVERGENT (USA)	Joint Venture	Fast Pyrolysis	Suzano; Arbec; Kerry Group	Medium-term Candidate
LICELLA (Australia)	Public Company	Hydrothermal Liquefaction	Canfor Pulp; Armstrong Chemicals	Medium-term Candidate
ANELLOTECH (USA)	Private Company	Thermochemical Depolymerisation		Long-Term Candidate
BIO2OIL (Denmark)	Private Company	Hydrothermal Liquefaction		Long-Term Candidate
STEEPER ENERGY (Denmark)	Private Company	Hydrothermal Liquefaction		Long-Term Candidate
BTG-BTL (Netherlands)	Private Company	Fast Pyrolysis	TechnipFMC; Empyro; Biomass Tech. Group (BTG); Preem	Medium-term Candidate
VALMET/FORTUM (Finland/USA)	Public Company	Fast Pyrolysis	Preem; BTG-BTL	Medium-term Candidate
SUSTEEN TECH. (Germany)	Private Company	Thermochemical Fast Pyrolysis		Long-Term Candidate
NEXXOIL (Finland)	Joint Venture	Thermochemical Depolymerisation		Long-Term Candidate
BDI BIOENERGY (Austria)	Private Company	Thermochemical Depolymerisation		Long-Term Candidate
RECENSO (Germany)	Private Company	Thermochemical Depolymerisation		Long-Term Candidate

Medium-term Candidate

Long-Term Candidate

detailed information on all candidates may be found in the appendix

Biocrude Oil Technologies

Technology pathways to biocrude

Fast pyrolysis

Fast pyrolysis technology has been used for many years and used by many different companies for different applications.

Envergent (an Ensyn / Honeywell joint venture) has been a leading developer of pyrolysis technology and is an example of a technology developer who has scaled-up its approach.

Pyrolysis oil is generated by different approaches often labelled as slow or fast pyrolysis. In general, fast pyrolysis produces a higher percentage of oil while slow pyrolysis produces more char (which some companies, such as Susteen, propose to process into ethanol).

In general pyrolysis oil technology requires a dry feedstock (hence an early drying stage) although its final product contains both oxygen and water. These two components are problematic to a refinery. Also, pyrolysis oil is generally acidic which requires purposeful choice of metals in the processing equipment.

Over time, pyrolysis oil's path to market has evolved (as with most technologies). Initial approaches were focused on fuel oil replacement, for use in industrial burners (like cement kilns), and as a bunker oil replacement for marine fuels. Various challenges (especially the need to lower the oxygen content) have caused many developers to consider upgrading pathways. Today, given the interest from some refineries, the co-processing of biocrude along with fossil-based crude is being actively considered.

Hydrothermal liquefaction

Hydrothermal liquefaction is a technology that uses high pressure, high temperature water with a catalyst to convert the biomass to a biocrude. This approach has been gaining attention in the past five years as it is better at dealing with wet biomass, has lower oxygen content, and does not result in the acidity problems of pyrolysis oil.

Hydrothermal liquefaction technology providers are at different stages of development which includes progress on the base technology as well as progress on utilising different feedstocks. Licella is an example of one of these. The base technology has gone through several scale-ups from the pilot stage through to the demonstration stage. Licella has also moved from working on lignite coal, to working on biomass and is now working on a demonstration facility to process plastic to crude oil in the United Kingdom.

Although hydrothermal liquefaction does allow the use of wet biomass, it does have its challenges as well. For example, it produces a biocrude with a higher oxygen content than conventional crudes (this is true for all biocrudes, the management of oxygen in the final product needs to be managed), and as it is a water based process, water treatment is necessary.

Biocrude economics

Biocrudes are generally considered less capital intensive than liquid biofuels although until a full-scale plant has been completed that case has not been proven. In modelling completed with the Bio Pathways model, biocrudes can be economic, utilising woodchips at the high end of crude oil prices providing there is a high enough carbon price.

Medium-term (5-10 year horizon)

For the medium term (5-10-year horizon), three high ranking candidates, each with strong development partners, were found using the filtering process described in **Chapter 5**: Envergent Technologies, Licella and BTG/BTL.

ENVERGENT TECHNOLOGIES (INCLUDING ENSYN & HONEYWELL UOP)

Transformation Pathway:	Thermochemical: fast pyrolysis
Organisation Type:	Joint venture
Location:	Canada / USA
Stage of Development:	TRL 7-9
Market:	USA fuel
IP Status:	Multiple patents
Strategic Partners:	Suzano, Arbec, Kerry Group

Technology Summary

Envergent's Rapid Thermal Processing (RTP) technology converts biomass to bio-oil/pyrolysis oil. Envergent is a joint venture between Ensyn and UOP Honeywell. Ensyn is a leading developer of pyrolysis technologies, and over 60% of the world's petrol and diesel is produced using UOP Honeywell's refining technology.

The technology is based on a circulating fluidised bed reactor system where hot sand vaporises the biomass, the gases are then rapidly quenched, and yields are around 65-75wt% RTP oil. With further upgrading RTP oil can be used to produce transportation fuels. RTP technology also produces char and a non-condensable gas, both of which can be used to provide process energy in the reheater to maintain the RTP process and/or in the dryer to condition the biomass.

The company is looking to develop multiple biocrude production facilities. Before the joint venture, the Ensyn team commissioned 12 small commercial plants (11 in the U.S. and 1 in Canada). The US plants are focused on biochemicals for the food flavouring market.

The joint venture company has implemented one larger scale Canadian plant with a fibre partner, Arbec Forest Products in Quebec. This facility produces 40 million litres per year. The future commercial plant has a capacity of 80 million litres per year, but Suzano is doing detailed engineering work on bio-oil for a much larger plant in Brazil energy markets. Co-processing trials of the biocrude in conventional oil refineries have also been conducted.

LICELLA

Transformation Pathway:	Thermochemical: hydrothermal liquefaction
Organisation Type:	Private company
Location:	Australia
Stage of Development:	TRL 7-9
Market:	Australia/USA/Canada/UK crude oil
IP Status:	Multiple patents
Strategic Partners:	Canfor Pulp; Armstrong Chemicals

Technology Summary

Using water at near or supercritical temperature and pressure, the catalytic hydrothermal reactor, Cat-HTR™, converts a wide variety of low-cost, waste feedstocks and residues into biocrude. Licella™ can process numerous feedstocks including biomass, waste oils, plastics and lignite coal.

The process delivers a highly consistent and high-quality oil. The process is aqueous so there is no need to dry the biomass before processing, Licella indicates that it uses inexpensive catalysts, and the process is a net producer of water (that is, it can utilise the water within the feedstock).

Licella established a large pilot plant in 2012 with capacity to process 10,000 tonnes of waste slurry per year and is constructing a larger demonstration plant at the same site. It also has a 17 million litre plant in Canada under development with its joint venture partner Canfor and is commissioning a plant in the UK capable of processing 20,000 tonnes of waste plastic into a crude oil. The processing of biomass or plastic wastes seems to use the same base technology. Significantly, Licella has an MoU with Oji Fibre Solutions in New Zealand with a focus on using end-of-life plastics, although no concrete project has emerged.

BTG-BTL

Transformation Pathway:	Thermochemical: fast pyrolysis
Organisation Type:	Private company
Location:	Netherlands
Stage of Development:	TRL 7-9
Market:	Sweden fuel
IP Status:	Multiple patents
Strategic Partners:	TechnipFMC; Empyro; BTG (Biomass Technology Group), Preem

Technology Summary

BTG-BTL is a subsidiary of BTG and uses BTG's fast pyrolysis technology based on intensive mixing of biomass particles and hot sand in the absence of air in a modified rotating cone reactor. Pyrolysis oil, char and gas are the primary products from the process. The charcoal and the sand are recycled to a combustor where the charcoal is burned to reheat the sand. The vapours leaving the reactor are rapidly cooled in the condenser yielding the oil and some permanent gases. The permanent gases and the surplus heat from the combustor can be used to generate steam for power generation, biomass drying or external use.

BTG-BTL has indicated that it has tested more than 45 different kinds of biomass feedstock. In 2005 it established a plant producing two tonnes per hour in Malaysia and in 2015, a plant (at demonstration scale producing five tonnes per day) in the Netherlands. BTG-BTL has a plant being constructed in Finland for Green Fuel Nordic Lieksa Oy (marine fuel). The company is also collaborating with TechnipFMC to design and build a 20 million litres per year plant in Sweden for Pyrocell (contract signed), due to start construction in Q4 2021. The oil will be sent to one of Preem's refineries.

ADDITIONAL CANDIDATE AS BACK-UP

One other technology candidate met the criteria for medium-term (5-10 year) impact. While not as strong in terms of corporate momentum as the leaders above, it forms a back-up option as the technology assessment progresses into Stage 2.

The candidate was Valmet/Fortum. Valmet is an OEM (original equipment manufacturer) focused on the pulp and paper industry and Fortum is a European energy company. The companies collaborated to build a pyrolysis plant to feed one of Fortum's power facilities. In 2018, they announced a partnership with Preem (oil refiner in Sweden/Finland) to construct biocrude facilities. Valmet/Fortum will focus on the biocrude production while Preem will upgrade it in its refinery. No projects have been announced in the public domain since the initial announcement.

Long-term (20-30 year horizon)

All candidates in the medium-term list must be considered viable in the long-term horizon. This is especially true given the long maturation period for investment in, and establishment of, new technologies involving forestry. Often multiple years will be needed to develop a strong investment case, align stakeholders, raise funds, and then site, permit, build and commission a facility. As described previously in this report, long-term investors then look for stable returns over the life of the asset. So, all candidates for medium-term investment will likely still be active in the long-term.

However, a further list of earlier stage technologies becomes candidates for this longer horizon. These were technologies which passed the screens of utilising woody biomass, alignment with sizeable carbon reduction targets, competitiveness with other non-wood technologies, robustness to future uncertainties, and efficiency at reducing emissions. However, they were assessed as being below TRL 7, which adds some years to their path to commercialisation.

There were 11 technologies in this list shown below.

ANELLOTECH

Private company in USA using Thermochemical Depolymerisation.

Bio-Tcat (Thermal Catalytic Biomass Conversion) is Anellotech's core technology which produces chemicals and fuels from non-food biomass. The reactor uses industrial fluid bed reactor technology and a zeolite catalyst to convert pre-treated feedstock into a liquid product containing over 98% C6+ aromatic chemicals (benzene, toluene and xylene (BTX)).

Currently Anellotech is focusing on using loblolly pine as a feedstock for its development program and first commercial plant. The company established a pilot plant in Texas in 2018 which has operated for over 7,500 hours with regular 24/7 runs. Anellotech is currently in the process of planning a commercial scale plant. The company also has developed the MinFree technology for biomass pre-treatment, which can significantly reduce the mineral content of wood and other biomass. MinFree technology has been used at a multi-tonne scale in continuous pilot plant operations.

BDI BIOENERGY

Private company in Austria using Thermochemical Depolymerisation.

In their patented bioCRACK process, solid biomass (e.g. wood or straw) is converted into short-chain hydrocarbons by liquid-phase pyrolysis, using a hot carrier oil at temperatures up to 400°C and under atmospheric pressure. Due to the interaction between biomass and heat transfer oil, hydrocarbons with a high hydrogen saturation are produced, which originate both from the carrier oil itself and from the biomass.

In the bioCRACK process, a low-cost intermediate product from the petroleum refinery (Vacuum Gas Oil (VGO)) is used as heat carrier oil. Normally, VGO is converted only to a small extent into diesel fuel and increasingly into short-chain gasoline.

BDI has established a pilot plant in Austria in 2012-2014 with input capacity of 2.4 tonnes biomass per day fully integrated into a mineral oil company refinery.

BIO2OIL

Private company in Denmark using Thermochemical Hydrothermal Liquefaction.

In collaboration with researchers at Aarhus University in Denmark, Bio2Oil has developed a range of technologies which improve on the conversion and energy efficiency of the hydrothermal liquefaction process to achieve greater scalability, cost efficiency and energy recovery. These include a plug flow reactor with no constrictions, a continuous feed pump allowing pumping of high dry matter streams, a patented oscillatory flow system improving heat recovery, reducing viscosity and improving plug flow characteristics, a proprietary solid state heat recovery system with demonstrated heat recovery up to 85%, and a unique take-off system eliminating the need for failure prone back pressure regulators.

The company has a pilot plant in Denmark with 100 litres per hour capacity.

GENIFUEL

Private company in USA using Thermochemical Hydrothermal Liquefaction.

The company's technology can convert wet wastes to biofuels and clean water. The technology uses pressurised subcritical hot water (no solvents) in order to improve the overall economics. This is a continuous process that converts more than 99% of feedstock organic content in 30-45 minutes. Feedstock is processed as a wet slurry and therefore does not need to be dried.

Genifuel can also recover all the plant nutrients in the feedstock, including the primary nutrients: nitrogen, phosphorus and potassium (NPK). It also recovers micro-nutrients such as calcium, magnesium, iron, copper, boron, etc. These nutrients can be used as renewable fertiliser.

The technology has been tested on over 100 feedstocks but seems to be in development with a focus on sludge from wastewater treatment plants as a feedstock (thus the importance of nutrient recovery). The company is constructing a pilot plant in British Columbia, Canada with its partners Metro Vancouver and Parkland Fuels.

HIGHBURY ENERGY

Private company in Canada using Gasification Fischer-Tropsch.

Highbury Energy has developed the Bia Generator which converts biomass to liquid fuel. The generator includes a Fischer-Tropsch process developed by the Korean Institute of Energy Research (KIER) which includes a novel nanocomposite catalyst. Highbury indicates that liquids derived from the Bia process will carry a BTU of 36 mJ per litre – nearly identical to Suncor Synthetic A crude and other pooled mixed-crude blends. Highbury claims a carbon intensity of ~5.0, the produced liquid contains aromatics below 1% and sulphur below 1ppm wt (Carbon intensity is a measure used in several low fuel standards. In California, carbon intensity is generally measured on a delivered basis, and we were not able to confirm if Highbury's CI was done on a delivered basis). Highbury has indicated that if the syngas is not converted to liquids, the syngas can be used to generate electrical power or as direct substitute for natural gas in kilns.

Highbury has licensed this process from KIER for use in all of Canada which is used as part of Highbury's wider processes. Highbury claims their process is highly competitive at a smaller scale with a proportionally lower capex and lower opex. The process results in a fully fungible and refinery-ready biocrude. Highbury targets the production of a medium BTU, low sulphur, nitrogen free, high value syngas.

NEXXOIL

Joint Venture in Finland using Thermochemical Depolymerisation.

Nexxoil uses the READi process which involves thermochemical decomposition of feedstock in a solvolytic self-regenerating heavy oil phase. This is followed by evaporation of the product molecules in the middle- and short-chain range which are condensed into a biocrude oil. The READi process operates in fully continuous mode at low conversion temperatures (between 250°C and 500°C). Greater than 80% of the primary feedstock energy can be conserved in the crude oil product. The minerals of the feedstock can be separated during the conversion process and collected for fertiliser applications (feedstock dependent).

This technology was developed by researchers at Hamburg University of Applied Sciences, however, Nexxoil has entered an exclusive co-development agreement with the university and acquired all patents. A pilot plant is in operation with up to 200kg per week capacity.

RECENSO

Private company in Germany using Thermochemical Depolymerisation.

Recenso uses a one step, direct liquefaction process by applying Catalytic Tribo-chemical Conversion (CTC) which uses a combination of thermal, catalytic and physical forces for cracking hydrocarbon. This process is used to convert biomass into a liquid resource. Limited information was available online about the process and the IP situation.

Recenso markets biomass conversion with the CTC technology under the CONVERBIO brand. It has a pilot plant and a test facility for biomass tests.

RENERGI

Private company in Australia using Thermochemical Fast Pyrolysis.

Renergi has developed a grinding pyrolysis technology to convert biomass to bio-oil, non-condensable gases and solid biochar. Renergi highlights that a key feature of its pyrolysis technology is simultaneous pyrolysis and particle size reduction (grinding). They claim the technology can accept biomass feedstock with a wide range of particle sizes ranging from microns to a few centimetres in one mixture, or separately. They claim that this greatly reduces the grinding cost. The technology is modular which minimises the cost to transport bulky biomass.

Developed by a researcher at Curtin University, Western Australia, the technology can accept a wide range of biomass feedstocks, however the current technology development is focused on Mallee biomass (an Australian indigenous plant) and straw. The demonstration plant has a capacity of 100 kg per hour.

RTI INTERNATIONAL

Research Institute in USA using Thermochemical Hydrothermal Liquefaction.

The technology is based on catalytic fast pyrolysis which converts woody biomass into biocrude. The research institute has validated the technology using loblolly pine as a feedstock and at a lab scale with a 450g/h fluidised bed reactor. The resulting biocrude is rich in hydrocarbons with a low oxygen content and is thermally stable. The researchers are developing novel catalysts and also looking to improve efficiency of the process.

STEEPER ENERGY

Private company in Denmark using Thermochemical Hydrothermal Liquefaction.

Hydrofaction™ is Steeper Energy's proprietary hydrothermal liquefaction process. This process subjects wet biomass to heat and high pressure to generate renewable oil. They indicate that the process conditions, with the operating temperature and pressure well above the critical point of water, and the use of homogeneous catalysts, promote chemical reactions which lead to the formation of low-oxygen renewable crude oil. They claim that Hydrofaction™ achieves biomass-to-oil conversions of 45% on a mass basis and 85% on an energy basis.

The company is currently focusing on hardwood and softwood forest and mill residues, but Steeper Energy has tested over fifty different feedstocks and mixtures. Their pilot plant was established in 2013 in Denmark.

SUSTEEN TEHCNOLOGIES

Private company in Germany using Thermochemical Fast Pyrolysis.

Proprietary TCR® technology that was developed at the Fraunhofer Institute for Energy Research UMSICHT. Susteen has licensed the technology from Fraunhofer UMSICHT.

TCR converts biomass in a multi-stage process (thermal drying, pyrolysis and catalytic reforming) with product treatment and final coal gasification. They indicate that the process produces high-quality syn gas, bio-oil and biochar. The product coal is discharged from the reactor system and can be converted into a coal gas, if necessary, in a direct downstream gasifier for generating electricity and heat. TCR® systems can be completely heated by the combustion of syngas or coal gas. Susteen indicates that TCR® can process almost any solid organic residue after proper processing, with an output of ~60% gas, 30% char, 10% biocrude. The char is gasified in a second stage, and combined with the initial gas production, which is then processed into ethanol.

Currently the group is developing several projects that involve sewage sludge as the feedstock, and is pursuing development opportunities in Canada with a focus on using biomass.

Liquid Biofuels

- Three strong medium-term candidates and four back-up candidates, plus ten additional long-term candidates
- Almost all from Europe and the USA
- Technology pathways were mostly Fischer-Tropsch along with thermochemical depolymerisation
- The strongest had multiple patents and were incorporated in a variety of corporate entities

Liquid fuels were the largest single target in the energy category of New Zealand's carbon budget. Within the category, petrol (gasoline) was the largest contributor of emissions, followed by diesel, aviation fuel and then marine fuel.

In traditional oil refining, crude oil is used to produce more refined liquid fuels. However, technologies for producing liquid fuels from woody biomass do not need to go via biocrude as an intermediate step. This important distinction would impact on the role of Refining NZ, since that company – while a very valuable collaborator – is not a necessary participant in creating liquid fuels from woody biomass.

Liquid fuel used in transport, especially petrol, is clearly facing competition from electric vehicles (EVs), although total emissions from this sector rose considerably in the period 1990-2017. There are also moves to reduce the emissions per litre and the litres per kilometre used in transport.

In New Zealand's forward projections, the penetration of EVs is mostly in personal vehicles. The projections indicate that EV replacement is more uncertain in commercial transport although there are significant worldwide initiatives in these areas. This makes the liquid fuel sector more future-uncertain than biocrude. Based on the relative lack of commercially feasible alternatives, as also reflected in New Zealand emissions forecasts, the outlook for diesel fuels is more attractive than petrol.

Many technologies are being advanced globally to produce liquid fuels from woody biomass, and many countries are enacting regulations that reward or encourage the adoption of biofuels in transport, most notably low carbon fuel standards.

Liquid biofuels are defined in this report as drop-in fuels including diesel, petrol, aviation and marine fuels. Although some technologies indicate that they are focused on one fuel, many of the technologies produce a blend of fuels like an oil and gas refinery. As a result, the technologies could not be split between diesel or petrol.

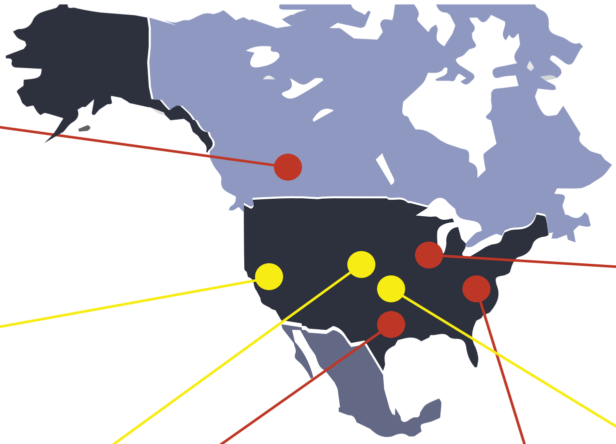
Alternative biofuels like dimethyl ether (DME) were not included in this section. Although they are under development, it was determined that these options would require significant changes to the fuelling infrastructure or transportation fleet, which would place them in a different category for competitiveness. Ethanol was also excluded as its primary use is as a 'drop-in' additive and, furthermore, it is not easy to produce cheaply from woody biomass.

An underlying challenge for liquid biofuels is to produce a product that meets the standards set by the petroleum industry for the quality of fuel.

Around 30 technologies were found world-wide which produced, or could produce, liquid fuels. Some were well-developed and already supported by governments and private investors. Three were strong candidates for the medium-term horizon with another four which had less commercial momentum. Ten additional technologies, less well developed, were deemed suitable for the longer-term time horizon. They originated from both major technology hubs – Europe and North America – and were in a variety of corporate forms – public and private companies, joint ventures and consortia.

Recommended Liquid Biofuel Technologies

CANDIDATE (Location)
Organisation Type
Transformation Pathway
Strategic Partners (if applicable)



CIELO WASTE SOLUTIONS (Canada)
Public Company
Thermochemical Depolymerisation

SIERRA ENERGY (USA)
Private Company
Gasification

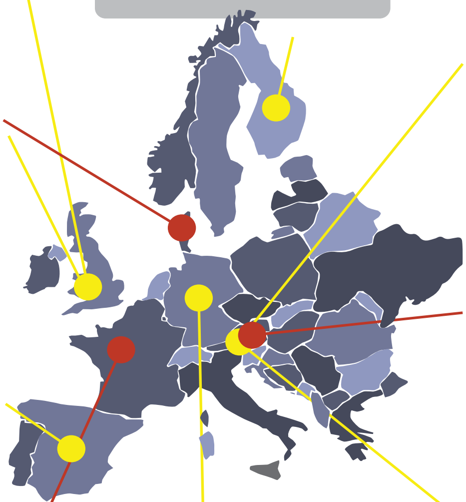
TCG GLOBAL (USA)
Private Company
Gasification

THERMOCHEM RECOVERY INT. (USA)
Private Company
Gasification

CRI CATALYST COMPANY (USA)
Public Company
Thermochemical Depolymerisation
KBR
Preem

LANZATECH/PNNL/AEMETIS/INENTEC (USA)
Consortium
Microbial Fermentation
Tsinghua University, China National Offshore Oil Corporation

EMERGING FUELS TECH. (USA)
Private Company
Gasification Fischer-Tropsch



HALDOR TOPSOE/TECHNIPFMC (UK/Denmark)
Joint Venture
Thermochemical Fast Pyrolysis
BTG-BTL
RTI International
Preem

JOHNSON MATTHEY/BP CONSORTIUM (UK)
Consortium
Gasification Fischer-Tropsch

VELOCYS (UK)
Public Company
Gasification Fischer-Tropsch

GEFS (Spain)
Private Company
Thermochemical Depolymerisation

BIOTFUEL (France)
Private Company
Gasificaton Fischer-Tropsch

KAIDI (Finland/China)
Private Company
Gasification

ALPHAKAT (Germany)
Private Company
Thermochemical Depolymerisation

BDI BIOENERGY (Austria)
Private Company
Thermochemical Depolymerisation

AICHERNIG ENGINEERING GmbH/REPOTEC (Austria)
Private Company
Gasification

GOBIGAS/REPOTEC (Austria)
Research Institute
Gasification/Methanation

Medium-term Candidate

Long-Term Candidate

detailed information on all candidates may be found in the appendix

Liquid Biofuel Technologies

Technology pathways to liquid fuels

Liquid biofuel technology pathways are mostly based on using a Fischer-Tropsch process. Technology developers generally use one technology to breakdown the biomass to a gas, then put it through a clean-up process and through Fischer-Tropsch conversion. This combination of technologies often leads to consortia of technology developers with each member of a consortium providing expertise in their relevant field.

This process requires that the gas going into the Fischer-Tropsch process is clean and that the process is efficient at the required scale. Gas clean-up is a significant challenge and hence development is focused on different biomass breakdown technologies to help optimise these stages of the process.

Fischer-Tropsch is a well proven technology, however it benefits from scale. Fischer-Tropsch processing is standard technology used by the petrochemical industry, but this scale is too large for biomass facilities. Biomass-oriented developers therefore focus on improving the scalability of Fischer-Tropsch, and on addressing the gas quality challenge by optimising catalysts.

Most, but not all, technologies shortlisted utilised Fischer-Tropsch. The consortium of LanzaTech/PNNL/Aemetis/InEnTec utilises similar techniques but instead of using Fischer-Tropsch, this step is replaced by LanzaTech's technology.

Liquid fuel economics

Plants for producing liquid biofuels are capital intensive. For this reason, technology developers are very focused on improving the gas clean-up economics and on improving the Fischer-Tropsch process. Companies like Velocys are developing smaller reactors and optimising catalysts to improve capital efficiency and operating costs. Biofuel economics are like biocrudes in that they require fuel pricing at the higher end of the scale and carbon pricing support.

Medium-term (5-10 year horizon)

For the medium term (5-10 year horizon) three high ranking candidates, each with strong development partners, were found using the filtering process described in the previous chapter: CRI/Criterion Catalyst Company (IH2), HaldorTopsoe/TechnipFMC, and Lanzatech/PNNL/Aemetis/InEnTec.

Four more companies were categorised as back-ups for the medium term (5-10 year), typically because of less commercial momentum.

CRI/CRITERION CATALYST COMPANY (IH2)

Transformation Pathway:	Thermochemical: Depolymerisation
Organisation Type:	Public company
Location:	USA
Stage of Development:	TRL 7-9
Market:	Norway/Sweden fuel
IP Status:	Multiple patents
Strategic Partners:	KBR, Preem

Technology Summary

The IH2 technology is a thermo-catalytic conversion route for woody biomass and forest residue feedstock that has been estimated to produce drop-in renewable fuels at around ~USD $2.25 per gallon. This typically involves pre-conditioning of the feedstock followed by the first stage reactor, a bubbling fluidised bed that removes most of the oxygen. However, the process can also consume externally produced biocrude, which results in a significantly lower capital cost for the facility. The second reaction takes place in a pressurised reactor which removes sulphur and nitrogen. This reactor operates under more moderate pressures (350-500 psi) and slightly lower temperatures than conventional pyrolysis.

The IH2 process was developed by the Gas Technology Institute and has been licensed exclusively to the CRI Catalyst Company, which is the catalyst company owned by Shell. CRI reports that "the process equipment is not new or novel nor does it require special materials to construct. It can be refinery or mill integrated although the refinery integration model may have better economics."

Demonstration plants (5 tonnes per day) have been established in India as well as two commercial scale licenses. They are currently developing a project in Norway with Biozin which is at the investment decision stage.

HALDOR TOPSOE/TECHNIPFMC

Transformation Pathway:	Thermochemical: Fast Pyrolysis
Organisation Type:	Joint venture
Location:	Denmark/UK
Stage of Development:	TRL 7-9
Market:	Unclear
IP Status:	Multiple patents
Strategic Partners:	RTI International, Preem, BTG-BTL

Technology Summary

Haldor Topsoe and TechnipFMC are both major service providers to the oil and gas industry and have worked with several projects, especially in Europe. They have been included in this assessment based on their expertise in liquids and gases. They are focused technology providers and would work with additional partners to bring a solution forward.

Haldor Topsoe offers its TREMP process which gasifies a range of materials including biomass and is currently involved in several research projects including one with RTI in the United States[28]. This project was focused on utilising catalytic biomass pyrolysis (RTI's technology) and using hydrotreating (Haldor Topsoe) to upgrade it to a liquid fuel blendstock. Haldor Topsoe also offers its HydroFlex technology to upgrade bio-oils to fuels. Preem has selected this technology for its refinery in Gothenburg, Sweden[29].

TechnipFMC is a major E&C provider to the oil and gas industry. TechnipFMC has collaborated heavily with BTG-BTL and is working with them on their two bio-oil facilities. TechnipFMC is also involved heavily in several research projects around the world which use various feedstocks.

Given the experience of both companies in either linking parts of projects together or in providing key technology, it was important to include them in the shortlist. Both groups work with a range of feedstocks beyond just biomass so they could be key players in strategies that include other bio-oil supplies (e.g. tallow, waste oils).

LANZATECH/PNNL/AEMETIS/INENTEC

Transformation Pathway:	Gasification/Microbial Fermentation/Thermocatalytic process
Organisation Type:	Consortium
Location:	USA
Stage of Development:	TRL 7-9
Market:	USA aviation fuel
IP Status:	Multiple patents (including those licensed from 3rd parties)

Strategic Partners: Tsinghua University; China National Offshore Oil Corporation

Technology Summary

Aemetis is developing a project in Riverbank, California. Aemetis has the license for InEnTec's gasifier which is potentially being used to gasify wood biomass. The resulting gas can be converted by Lanzatech's patented microbial fermentation technology into ethanol. The project is in the engineering phase with an investment decision expected soon.

Lanzatech has partnered with PNNL to develop a technology to upgrade ethanol to jet fuel. Virgin airways has flown on this fuel and the US Department of Energy is negotiating with LanzaTech for a $14 million demonstration facility at their existing site in Soperton, Georgia[30]. This site has the capability to process biomass in its pilot plants. Lanzatech has also completed several scale-up facilities globally.

Based on Lanzatech's experience in scaling-up technology and its ability to generate aviation fuels they were included in the shortlist.

ADDITIONAL CANDIDATES AS BACK-UP

Beyond these three recommended technologies there were a further four technologies which would be reasonable back-ups as candidates for the medium-term horizon. These candidates were generally not as strong as the top three in terms of corporate backing and momentum. They would form a useful back-up list for the deeper investigations in Stage 2 of this project.

The first back-up candidate was AICHERNIG Engineering GmbH/Repotec, a private company from Austria using gasification technology. It uses a steam-blown fluidised-bed gasifier to create a nitrogen-free and low-tar gas with high calorific value. The process, which was jointly developed with the Technical University of Vienna, has proven its feasibility successfully with the long-standing CHP-plant Güssing. They are currently in the development phase on converting their syngas to liquids through Fischer-Tropsch technology.

The second candidate was BioTfuel, a consortium based in France using Fischer-Tropsch technology. They are focused on developing an innovative process for converting biomass into high-quality biodiesel and aviation fuel. The biomass is torrefied and shipped to Total's refinery where it is used for the gasification process. ThyssenKrupp provides both the torrefaction and gasifier stages. The gasification technology used is ThyssenKrupp's PRENFLOtechnology, which is flexible over a range of solid fuels. ThyssenKrupp also has a second gasifer technology called HTW which is designed to work directly with biomass. The resulting biofuels, which will not contain any sulphur or aromatics, will be usable pure or blended in all types of diesel and turbojet engines (biodiesel and biokerosene). The set of processes developed by BioTfuel will be transposable on an industrial scale at the end of the project, which is anticipated in 2020.

The third candidate was Cielo Waste Solutions, a public company from Canada using Thermochemical Depolymerisation. Cielo holds the exclusive licence for the global rights to a technology capable of converting multiple waste streams to produce high cetane, ultralow sulphur, renewable diesel, kerosene and naphtha fuels. Waste materials or biomass are blended with used motor oil and a powdered chemical catalyst. The mixture is then heated to a temperature that breaks down the molecules and "cracks" them into a blend of distillate fuels. The fuels are then further processed into renewable diesel, aviation fuel and naphtha fuel. Cielo indicates that the technology utilises atmospheric pressure and low heat and is therefore expected to be lower cost. They are in the final stages of building out their first demonstration facility that uses sawmill waste as a feedstock.

The fourth and final candidate was ThermoChem Recovery International (TRI), a private company in the USA using Gasification technology. TRI technology utilises an indirectly heated medium temperature, low pressure, fluidised bed steam reformer primary stage and a higher temperature second stage to generate syngas. TRI has demonstrated that the technology can transform garbage into aviation fuel in a demonstration unit, and can use waste wood, energy crops, agri-waste, or animal waste to create gasoline, aviation fuel, diesel, chemicals, green power and other renewable energy. The process results in the production of medium calorific value syngas. TRI has a demonstration unit operating over an extensive run time (10,000+ hours) and has converted wood waste and forest residues into high quality, clean syngas and in turn into Fischer-Tropsch liquids, ASTM spec diesel and aviation fuel.

Long-term (20-30 year horizon)

As explained earlier in the section on biocrude, all candidates in the medium-term list must be considered viable in the long-term horizon due to the long lead times for investment and operation.

For liquid fuels, there were 10 additional technologies at an earlier stage of development (TRL below 7) which were candidates for this longer horizon. These 10 are described below.

ALPHAKAT

A private company in Germany using Thermochemical Depolymerisation.

Alphakat's KDV technology is based on a catalytic low temperature, pressure-less process. KDV use a catalyst and the process takes place in an oil cycle instead of a water cycle. The company indicates that it is initially targeting a commercial scale plant at 20 million litres per annum, utilising 45,000 oven dried metric tonnes of woody biomass at a capital cost of ~USD $45m.

BDI BIOENERGY

Private company in Austria using Thermochemical Depolymerisation (note, also mentioned under biocrude, which BDI can also produce).

BDI Bioenergy's technology is referred to as bioCRACK. Solid biomass (e.g. wood or straw) is converted into short-chain hydrocarbons by liquid-phase pyrolysis, using a hot carrier oil at temperatures up to 400°C and under atmospheric pressure. Due to the interaction between biomass and heat transfer oil, hydrocarbons with a high hydrogen saturation are produced, which originate both from the carrier oil itself and from the biomass.

In the bioCRACK process, a low-cost intermediate product from the petroleum refinery (Vacuum Gas Oil (VGO)) is used as heat carrier oil. Normally, VGO is converted only to a small extent into diesel fuel and increasingly into short-chain gasoline.

BDI has established a pilot plant in Austria in 2012-2014 with input capacity of 2.4 tonnes biomass per day fully integrated into a mineral oil company refinery.

EMERGING FUELS TECHNOLOGY (EFT)

Private company in USA using Fischer-Tropsch technology.

EFT is developing an Advanced Fixed Bed FT Catalyst/Reactor System. EFT focuses on developing reactor that optimises the catalyst and the reactor. As part of this development, EFT has a patented process to optimise activation and regeneration of an FT catalyst. EFT's FT catalysts have demonstrated continuous runs of 1 year without regeneration, and the catalyst can be regenerated "in situ" at low temperatures. Pilot and demonstration plants range from 2 BPD to 70 BPD. There is a full-scale commercial reactor at ThermoChem Recovery International's demonstration facility and EFT has licensed its technology to Claeris Development and Red Rock Biofuels.

GEFS

Private company in Spain using Thermochemical Depolymerisation technology.

The company has developed mechanical catalytic conversion technology, which involves a one-step process at low temperatures to convert biomass into biodiesel. GEFS indicates that resulting biodiesel complies with diesel regulations such as EN590 and ASTM. Their plant design is modular with design capacity between 150-2400 litres per hour. The company has a pilot plant in Spain with capacity to produce fuel at a rate of 150 litres/hour and has worked with Boral since 2019 to run feasibility studies for a plant in Australia, using sawmill and forest residues.

GOBIGAS/REPOTEC

GoBiGas (Gothenburg Biomass Gasification Project) is a project that is based on Repotec's existing small gasification plant in Austria – this was covered earlier in the report. GoBiGas is touted to be the first plant of its kind in the world to integrate large-scale gasification with methanation. The process involves indirect gasification of forest residues using Repotec and Metso Power's gasification technology. Haldor Topsoe's patented TREMP methanation technology and catalyst are then used to produce biomethane with a methane content of more than 95%.

JOHNSON MATTHEY/BP CONSORTIUM

Consortium based in UK using Fischer-Tropsch technology.

BP and JM are developing FT technology that can operate both at large and small scale to economically convert syngas, generated from sources such as municipal solid waste and other renewable biomass, into long-chain hydrocarbons suitable for the production of diesel and aviation fuels. According to the consortium the fixed-bed FT reactor has no moving parts and requires no continuous catalyst addition or separation. The proprietary BP catalyst runs at constant conditions and delivers a high-purity product that is easy to upgrade. They indicated that the system delivers three times the productivity of a conventional multi-tubular fixed bed reactor and at half the capital expenditure.

Working together, BP and JM won both the Research Project Award and the Oil and Gas Award at the prestigious IChemE Awards in November 2017 for their work on FT technology. They signed an agreement with Fulcrum BioEnergy to license their technology and have developed relationships with multiple engineering/fabrication firms to provide syngas systems to EFT.

KAIDI

A Finnish subsidiary of Sunshine Kaidi New Energy Group in China using Gasification technology.

Kaidi utilises plasma gasification to convert biomass to syngas in their current plant. The plant can use wood, sawmill by-products and bark. A China-based demonstration plant was established in 2013 that processes approximately 100 tonnes per day of biomass waste. The parent company acquired AlterNRG in July 2015.

SIERRA ENERGY

Private company in the USA using Gasification technology.

Sierra Energy's FastOx gasification employs a fixed-bed system with gasification occurring at temperatures around 2200°C. Instead of ash the process produces melted inorganics in a stone product that can be used in construction and landscaping. The company indicates that the process can handle almost any type of waste with minimal preparation, including medical waste, municipal solid waste, tyres, coal & petroleum coke, biomass, industrial & construction waste, and hazardous waste.

Sierra Energy claims that a key innovation of FastOx gasification is the optimised rate and position of oxygen and steam injection into the gasifier. This drives the complete conversion of waste into its molecular constituents without the production of any major by-products that require additional disposal. The ultrahigh temperatures and the use of purified oxygen (as opposed to nitrogen-rich ambient air) avoids greenhouse gas emissions because it eliminates nitrogen from the process and prevents formation of harmful substances such as nitrogen oxides (NOx).

The FastOx gasifiers can convert 10-2,000 metric tonnes of solid material a day. The company has installed a commercial plant in the USA which takes municipal solid waste and biomass, with the capacity to process 20 tonnes per day.

TCG GLOBAL

Private company in the USA using Gasification technology.

The TCG process integrates several individual technologies to convert carbon-containing feedstock to syngas. They indicate that it utilises external heating rather than combustion to deliver a high-quality syngas with feedstock rates are about 500-1,000 tonnes per day of wet biomass. It is designed for a 70%-74% BTU conversion efficiency from feedstock to syngas. However, in commercial scale, the US Department of Energy documented efficiencies exceeding 89%. Additionally, the design has a 16%-20% production advantage when producing liquid fuels, as compared to other internally fired gasifiers. Design simplicity results in construction costs that are significantly lower than other gasification technologies, typically half the cost of competing solutions.

Thermo Technologies, LLC owns the patents and pending patents underlying the gasification technology. TCG Global has an agreement to develop, own and operate gasification plants. The company has built, demonstrated and sold a commercial scale reference plant and working with Red Rocks Biofuels to construct a full-scale plant. The plant is schedule to be operational in 2020 at which TCG Global could move up in its TRL level.

VELOCYS

Public company in the UK using Fischer-Tropsch technology.

Velocys has a proprietary Fischer-Tropsch process which includes a novel microchannel reactor and a novel catalyst. They claim that this results in a very stable, high performance FT synthesis system. They indicate that the very high heat removal capability of the microchannel structure, stable, single pass conversions near 80% can be realised. Further, the catalysts are shown to be stable under these high conversion conditions even with exit ratios of $H_2O:H_2$ as high as 7–8. The slow loss of catalyst performance with time-on-stream can be completely reversed using an oxidative regeneration approach and this cycle can be applied to the catalyst multiple times without issues. The company has also run an integrated demonstration, coupling the Velocys reactor with a gasifier to convert wood waste to hydrocarbons. It has a commercial scale demonstration plant in the USA (Red Rock Biofuels) and several pilot-scale plants.

Gaseous Fuels

- No strong candidates due to weak competitive position and future uncertainty
- Renewable Natural Gas prices fare unfavourably with fossil fuels in New Zealand
- RNG also faces future uncertainty due to declining niches, and cannot easily be exported
- An exception relating to the use of wood in building construction was developed and is reported in Chapter 2: Technology Results.

Gaseous fuels include both natural gas and propane. This section will focus on natural gas since propane usage is low and therefore few emissions are generated from propane.

Natural gas is used in New Zealand for three main purposes: electricity production, methanol production and the generation of heat. Replacing natural gas for electricity production and methanol would require the use of renewable natural gas (RNG). To address the heating use of natural gas using woody biomass there are two options, using renewable natural gas or improving the energy efficiency in buildings.

Renewable natural gas

Renewable natural gas can come from several sources of biomass including waste, agricultural material, and woody biomass. RNG from wastes or agricultural material comes predominately from methane released during decomposition or processing. RNG from waste is generally from landfill emissions while agricultural RNG can come from anaerobic digestion of farm wastes.

RNG from woody biomass is predominately generated through gasification. RNG has similar challenges to liquid biofuels produced through gasification in that the gas needs to be cleaned up before injection into the natural gas distribution and burning system.

Technology developers face the decision of optimising the capital employed in the entire system. Some developers focus on the gasification stage to reduce the gas clean-up while others focus more on the gas clean-up; often this reflects the background of an individual technology developer. In general, the challenge is optimising the entire system for capital and operating cost efficiency.

RNG has the advantage of being able to be produced anywhere along the natural gas network within New Zealand, however, the cost of interconnection is often high. The cost of interconnection encourages a larger scale to be achieved to cover this cost. This is often the challenge of waste-based solutions; the interconnection cost is too high based on their smaller scale.

Renewable natural gas economics are challenging considering the low price for natural gas. In New Zealand, wholesale and industrial prices of natural gas have averaged around NZD $6.00-6.50/Gj. This pricing is generally below the range needed for renewable natural gas.

The price of renewable natural gas is heavily influenced by the feedstock used. A study in Quebec, Canada showed that RNG from first generation landfills could be priced below CAD $10/Gj, however most agricultural sources require CAD $15/Gj or more to be viable. Second generation production (gasification) requires a price CAD $10/Gj or more.

Regardless of the jurisdiction, there is not a significant volume of low-cost residuals. In this study, the feedstock supporting a CAD $10/Gj price was urban wood waste. To produce RNG under $15/Gj, material from fire or beetle killed wood was needed. If forest residuals or unharvested wood was used, the required price of natural gas rose to CAD $25/Gj.

To put this in a New Zealand context, to produce renewable natural gas from logs currently exported, the carbon price in New Zealand would need to bridge the distance between the local price of NZD $7.29 NZ/Gj and NZD $25/Gj.

Given the scope of this challenge, renewable natural gas was screened out of the priority list.

Energy efficiency in building

One clear opportunity for New Zealand was to reduce its use of natural gas consumed for heating in buildings. This can be achieved by increasing the energy standard to which buildings are constructed and by retrofitting older buildings with a more energy efficient envelop. This can be achieved today with currently available technologies (TRL 9) and technologies that are TRL 7 or 8. This approach also allows for the potential to sequester carbon and potentially avoid carbon emissions from steel and cement production.

While this opportunity did not lend itself to the objective filtering process, it was appealing due to potential multiple impacts on carbon emissions. It was therefore separated from the technology assessment process and is analysed and reported separately in the next chapter.

Solid Fuels

- No strong candidates for new technology due to weak competitive position and future uncertainty
- Coal usage is geographically scattered and falling in volume; coal prices are low
- Existing technologies, notably compressed wood pellets, are available and are serving some local markets
- One opportunity is the use of woody biomass to replace coking coal, covered in the next section

Solid fuels are either coal or biomass for heat or power. In this section we focus on coal which has the highest carbon emissions per unit of the fuels considered in the report (see **Table 7.1**). Coal is used in New Zealand for power, heat and steel making. Of the 2.8 million tonnes of coal consumed in New Zealand, 1.2 million tonnes are used for power generation and another 1.1 million tonnes used for heat (industrial, commercial, and residential). The remainder is used in steel making which will be discussed in the next section.

The replacement of coal using biomass is straightforward. Wood pellets are used around the world to offset coal use. Wood pellet consumption is growing rapidly with the European Pellet Council indicating that 35 million tonnes were consumed in 2018 (excluding China)[31]. They are generally used in conjunction with coal use in co-firing (pellets would represent 10-20% of the total feedstock). Co-firing pellets with coal in power generation would see a demand of over 100,000-200,000 tonnes of pellets.

Wood pellets also provide an opportunity for smaller scale fuel switching especially in the South Island where there is no easy natural gas option available.

Torrefied pellets are different from wood pellets in that they have had water and oxygen-containing components removed and consequently they are close to coal in energy value. Torrefied pellets also have the advantage of being more water resilient. Torrefied pellets differ in the degree to which they are processed.

Different manufacturers may target different end-energy values. Continuing to torrefy the wood reduces the overall yield and affects the process economics. The price a customer is willing to pay on an energy basis would be the deciding factor unless it was important to protect the pellets from water, for example, during transport.

In general, for local consumption it is not significantly better to produce torrefied pellets. The longer the shipping distance the more torrefaction makes sense.

In this analysis, the small and declining size of the market (for coal) in New Zealand, the availability of satisfactorytechnologies, and the poor competitiveness of new technologies led to this area being excluded from the analysis and no new technologies candidates are proposed (with the exception of the specific case of coking coal which is covered next).

Commercial use	kg CO2e/kg
Coal – default	1.77
Coal – bituminous	2.66
Coal – sub-bituminous	2.01
Coal - lignite	1.43
Industrial use	
Coal – default	2.05
Coal – bituminous	2.66
Coal – sub-bituminous	2.01
Coal - lignite	

Table A1 – Summary of carbon emission from combustion

Source: Ministry for the Environment

Coke For Steel Making

- Five technology candidates were found that met all criteria; one was a New Zealand company
- All were suitable for the medium-term time horizon
- Most used torrefaction technology
- The singular nature of the opportunity, with New Zealand’s dominant steel mill meant the opportunity should be progressed separately

Bio-coke is not an easy application as the chemical makeup of the pellet is critical to the steel production process. Not only does the bio-coke need to have the right elemental composition (trace materials can help or hinder the steel quality) but that composition needs to be predictable and consistent. This is the core challenge in making a bio-coke.

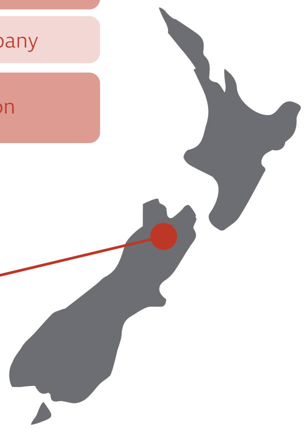
The Consortium noted that using bio-coke or torrefied pellets is already being pursued internationally.

- Arcelor Mittal is working in the Netherlands to trial bio-coke produced by Torr-Coal.
- Arcelor Mittal Defasco is working with several technology providers to build towards a demonstration in their Canadian steel mill.

Recommended Biocoke Technologies

CANDIDATE (Location)
Organisation Type
Transformation Pathway

AIREX (Canada)
Private Company
Torrefaction

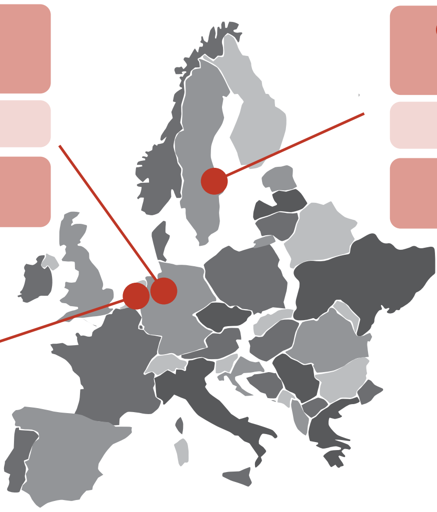


CARBONSCAPE (New Zealand)
Private Company
Microwave Torrefaction

detailed information on all candidates may be found in the appendix

THYSSENKRUPP (Germany)
Public Company
Torrefaction

CORTUS ENERGY (Sweden)
Public Company
Gasification



TORR-COAL (Netherlands)
Private Company
Torrefaction

- Cortus Energy is working in Höganäs AB in Sweden in using a bio-carbon in metal powder production; this approach is unique in that Cortus produces a syngas which is used to replace natural gas in the production process and a bio-based coke which could also be used on site.
- More locally, New Zealand Steel has worked with Carbonscape on a trial of their graphite material.

The five technologies that were identified came from private and public companies in Europe, Canada, and New Zealand. Three used torrefaction technologies, one used gasification and one used a combination including microwave technology. Most of them were at TRL 7 and would be able to construct a demonstration plant at scale. They were therefore all relevant to the medium-term time horizon. Cortus Energy, Torr-Coal and Airex all have demonstration plants. Airex's plant has a capacity of 15,000 tonnes per annum. Torr-Coal's corporate presentation indicates its capability is at 35,000 tonnes per annum although this may not be the capacity for pellets of high enough quality for bio-coking applications. Torr-Coal is also working to build a 50,000 tonne facility in partnership with Arcelor Mittal.

Coking For Steelmaking Technologies

Both medium-term and long-term horizons

All five technologies could be practical in the medium-term (5-10 year) horizon. No earlier stage technologies were proposed for the longer term because the opportunity, or lack of it, is likely to be resolved quickly by exploring the five candidates with New Zealand Steel.

AIREX

Private company in Canada using Torrefaction technology.

Airex indicates that CarbonFX torrefaction technology allows industrial scale production of a wide range of value-added biocarbon products. This includes bio-coal, biochar, lightly torrefied wood flour and highly carbonised biocoke. The process involves pre-drying of biomass, conditioning and then torrefaction in a cyclonic bed reactor. Total residence time in the torrefaction reactor is around 2-3 seconds. An industrial scale bio-coal plant is established in Canada that uses woody biomass. Airex has worked with CCRA (Canadian Carbonisation Research Association) which is an association involved with the steel industry in Canada. Part of its research program is in bio-coke applications.

CARBONSCAPE

Private company in New Zealand using chemical synthesis with microwave technology. This patented technology converts waste biomass into graphite, which provides lithium ion battery performance that is similar or better than fossil derived graphite.

CarbonScape has apparently engaged with New Zealand Steel previously. The consortium did not seek to establish the facts around this engagement because of privacy issues and communication challenges due to the COVID-19 pandemic. CarbonScape has a patented technology to convert waste biomass into graphite. CarbonScape provided 9,000 tonnes to NZ Steel for trials in 2013-15. It has built and operated a pilot plant and has plans to build a demonstration plant.

CORTUS ENERGY

A public company in Sweden using Gasification technology.

Cortus Energy's WoodRoll technology involves utilising pyrolysis gas to generate heat and gasify char with steam, resulting in a zero-tar ultra-clean renewable energy gas. Furthermore, the technology offers feedstock flexibility and does not require pre-drying of the biomass, as this is incorporated into the process. The technology was developed initially through a partnership with the Karlsruhe Institute of Technology; the market rights now belonging to Cortus

Energy. The company established a test facility in 2011 in Koping, Sweden and demonstration facility in Hoganas, Sweden which delivered quality approved syngas in March 2020 to the Höganäs AB metal powder facility it is co-located with. Its public information indicates that it is working with Höganäs AB on bio-coke.

THYSSENKRUPP

Thyssenkrupp is a diversified industrial company with a long history in steel making. One of their business units produces over 13 million tons of crude steel per year.

Thyssenkrupp's torrefaction technology POLTORR is designed to handle multiple feedstocks. The feedstock is crushed, pre-dried and then roasted in a multiple-hearth furnace in the absence of air. This process produces biocoal that carries similar properties to coal and allows production at an industrial scale. It is currently being used in BioTfueL's program of work to torrefy biomass in Venette, France for shipping to Total's refinery in Dunkirk. The torrefied wood will be ground and introduced into Thyssenkrupp's PRENFLO PDQ gasifier. Thyssenkrupp indicates that POLTORR is commercial but the consortium found no public links between the torrefaction technology and utilising it for steel making. Given Thyssenkrupp's expertise in steel making this technology option was included.

TORR-COAL

Private company in Netherlands using Torrefaction technology.

Torr-Coal has developed a torrefaction process where the biomass is heated between 280°C and 310°C in an oxygen-free environment. The company has a demonstration plant in Belgium processing biomass feedstock and torrefied product and a project in Indonesia.

Torr-Coal used its demonstration plant to provide bio-coal to ArcelorMittal's steel making plant in Ghent. Currently ArcelorMittal has announced that it will use Torr-Coal's technology to build a plant capable of providing 50,000 tonnes of bio-coal to its Ghent facility.

APPENDIX B: ECONOMIC DEVELOPMENT OPPORTUNITIES, BIOPLASTICS & BIOCOMPOSITES

The study's primary focus was to find technologies from around the world which could utilise woody biomass to reduce New Zealand's carbon footprint. That process selected only the best of a long list of technologies which could meet this aim. However, many of technologies that were found, failed principally on their small impact on carbon emissions.

As a result of the economic imperatives caused by the COVID-19 pandemic, technologies that did not address New Zealand's carbon budget were not discarded but were collected, further analysed and placed in this non-priority Appendix for potential further screening.

Special mention is made of New Zealand origin technologies from this list, since they not only might serve the economic development agenda but could also be easier to kick-start than international technologies and may have local momentum already. To assist this further analysis a discussion of the bioplastics and biocomposites arena follows.

The full list of opportunities is given in **Table B1**.

Further Information On New Zealand Associated Opportunities

Short-term (immediately available)

Woodforce - Scion

As with many of the Scion technologies, this project will have most of its developers already present in New Zealand and embedded in a research institute (Scion) that has a mandate to assist the forestry industry. It is a natural fibre useful to reinforce thermoplastic materials, which provides an alternative in MDF manufacture to produce a glass fibre reinforcement. It has already been in a commercial partnership in Europe to trial the technology. The issues which have so far prevented its scale-up will need to be investigated, but if they could be overcome, the technology should be able to start up in New Zealand very quickly.

Medium-term (requires final development)

PLA by NZ Bio Forestry

NZ Bio Forestry Ltd has collaborated with partners in Taiwan and Singapore to access technologies to support their vision of building an integrated forest products processing facility, including timber processing and a biomass refinery. One of the technologies they propose to integrate into the biomass refinery is wood derived polylactic acid (PLA) resin production, one of the most widely used biobased plastics. This technology derives from a Taiwanese R&D institute and has been tailored to use woody biomass in collaboration with a major forest industry participant from South-East Asia. Of the New Zealand technologies found, this one has the most developed commercialisation plan, including local partners, seed investment, a commercial framework, and a larger scale investment plan (as part of their overall processing facility concept). It would undoubtedly be accelerated by immediate investment, although the sums required could be substantial.

Furfurylated Wood - Scion

As with the previous example, this project also will have most of its developers already present in New Zealand and embedded in a research institute (Scion) that has a mandate to assist the forestry industry. The technology has been proven to work and currently is in pilot scale in Europe with a forest/wood industry partner. The product it produces is aimed at building construction, so could be synergistic with another of this report's recommendations to encourage the increased use of wood-based biomaterials in construction. This technology needs further development but could possibly be taken to commercialisation in New Zealand with immediate investment.

Long-term (requires significant development)

Futurity

A proposal from New Zealand parties to license and scale-up technology from Sweetwater, USA, as part of a plan based around solid wood production. Production focused on advanced lignin technology combined with other existing technologies to produce a range of potential end-products. Appears to have strong local support including industry participants and local investors and is actively seeking additional private investment and government support.

Bark Refinery – Scion

Ligate – Scion

PHA & Biopolymers – Scion

Reactive Extrusion – Scion

This collection of longer-term technologies emerging from New Zealand's forestry research institute, Scion, all have longer development pathways than those mentioned above. Among them are some which address particularly interesting targets such as:

- extracting high-value chemicals from pine bark (Bark Refinery) – pine bark is a problematic waste stream in NZ's forestry industry
- producing interior wood panels which do not require hazardous chemicals during manufacture (Ligate) – this technology has been examined by industry participants both in NZ and off-shore and will require further development to reduce costs
- producing niche biopolymers (PHA & Biopolymers) – Scion has built on very active research in this area globally to develop NZ-specific opportunities
- novel, solvent-free ways to break wood down to component molecules (Reactive Extrusion)

Being further back on the development pathway, all these technologies would be high risk and could require larger, long-term investment to become commercial. There is an opportunity though to develop them as a group, allowing fast-fail and converging resources onto the others remaining to fast-track their development.

Avantium

Netherlands origin technology but with New Zealand parties interested to license and develop further in NZ. Focused on the production of industrial sugars and lignin. Early stage of advancement, but NZ opportunity could be crystallised with addition of development partners and resources from New Zealand.

Discussion Of Bioplastics & Biocomposites

The use of woody biomass to produce lignins and sugars creates building blocks for many bioproducts including chemicals and plastics. Biomass can also be used directly to create plastic biocomposites.

The substitution of conventional plastics with bioplastics not only reduces dependence on fossil resources but also reduces greenhouse gas emissions. However, as this pathway was not likely to significantly impact carbon emissions in New Zealand, compared with other areas, the potential to produce bioplastics and composite materials was not seen as a major component of this study.

The essential attributes of the opportunity include:

New Zealand is not a large plastics market

- The industry imports raw material and manufactures finished products at around 250,000 tonnes per annum
- All raw materials are imported

The market is addressable

- If bioplastics were able to be produced competitively to consumer markets then a local production plant could address the domestic market and potentially export, particularly within Oceania where supply chains and trading relationships are already strong and where few other local manufacturers would compete

Set-up costs of such plants are generally high

- Although this is, of course, driven by scale.

It is an area of interest to certain investors

- This has occurred globally in clean tech or green technologies
- Bioplastics are of interest to many investors
- Particularly if operated in conjunction with other, more traditional, lower risk processing which reduces risk of the investment

There are new developments constantly emerging

- It can be difficult to get good information about their status as they transition from lab based to commercial production
- Generally, development is a high risk, expensive and time-consuming process
- It is recommended that technologies should be accessed that are already in, or close to, full-scale implementation
- These may use a different feed stock such as a different species but with relatively straight forward conversion to using woody biomass
- Such technologies should be accessed via partnerships or licensing rather than through a research and development process

Processing is likely to be implemented in conjunction with more traditional processing

- Such as timber or pulp production
- Aim is to use the by-products of that processing as a feedstock
- For example, pulp plant derived waste streams, sawmill residues, bark
- With potential to add in additional other low value fibre available such as unutilised harvesting residues

Products will come from lignins, sugars and composites plus other niche compounds like tannins

The use of lignocellulosic feedstocks has challenges

- Likely requires a larger number of processing steps then crops like sugar-beet and sugarcane
- Which drives higher operating and investment costs
- And decreases the competitiveness of woody biomass versus other feedstocks

Difficult for plant derived materials to compete economically with fossil derived products

- Particularly with the current trends in oil prices

However, other consumer drivers are operating

- Demand for more sustainable, greener, and safer products
- In packaging, durables, and chemicals
- Can be driven by factors such as consumer demand, corporate sustainability policies, and government regulations

Detailed information would be needed for assessment

- Much of which could only be sourced from the technology owner
- Would need to cover aspects such as sustainability, carbon impact, minimum plant volumes, Technology Readiness Level, specific feedstocks and their availability, market attractiveness, and cost competitiveness
- The appetite of the technology provider to partner or licence

Short-term (available now)

Organisation Name	Technology summary
Sappi	Sappi is the world's largest manufacturer and seller of dissolving pulp. This is used as a raw material for viscose and lyocell. The company also produces papers and is developing new business through biomaterials and bioenergy is part of its 2020 plan.
Scion - Woodforce	Natural Fibre to reinforce thermoplastic materials. Alternative/additional use for medium-density fibreboard (MDF) and presents an alternative to glass fibre reinforcing. Lightweight and producing more sustainable content.

Medium-term (5-10 years)

Organisation Name	Technology summary
CRI/Criterion Catalyst Company (IH2)	The IH2 technology is a thermo-catalytic conversion route for woody biomass and forest residues feedstock that has been estimated to produce drop-in renewable fuels at around ~$2.25/gallon (in 2014 dollars), based on a 2000 tonne dry feed/day scale on a US Gulf Coast basis (USGC) using a stand-alone design basis. This involves pre-conditioning of the feedstock followed by the first stage reactor, a bubbling fluidised bed but without the use of sand, which removes most of the oxygen. The second reaction takes place in a pressurised reactor which removes sulphur and nitrogen. This is supposedly under more moderate pressures (350-500 psi) and a slightly lower temperature than conventional pyrolysis.
Enerkem	Material is fed to proprietary bubbling fluidised bed gasification vessel to break down the shredded waste into its constituent molecules, a process that is called thermal cracking. In the same reactor, these broken-down molecules with steam under specific conditions produce syngas. This is a patented technology that can break down chemically and structurally dissimilar waste and plastic materials and converting them into a pure, chemical-grade, stable and homogeneous syngas. The resulting syngas is rich in hydrogen and carbon monoxide. The crude syngas is fed into a proprietary syngas cleaning and conditioning process which upgrades it to chemical grade. This is then catalytically converted into liquid methanol and then fuel-grade ethanol.
Licella	Using water at near or supercritical temperatures, the catalytic hydrothermal reactor, Cat-HTR™, converts a wide variety of low-cost, waste feedstocks and residues into high-value products. This process takes only 20-30 minutes to produce biocrude oil. Licella™ can process numerous low-cost products, waste and biomass residues and strategically targets feedstocks that are already aggregated. This includes waste oil residuals, agricultural residues (non-edible), sugar cane trash, algae, end-of-life plastics, energy crops (purpose grown) and pulp mill residues. The process delivers a highly consistent and high quality oil, there is no need to dry the biomass before processing, no need to add external hydrogen, uses inexpensive catalysts and the process is a net producer of water (utilises water within the feedstock).
Renmatix	Renmatix has developed Plantrose® supercritical hydrolysis process that coverts raw plant biomass into a range of ingredients that can be used in food, beauty, or industrial products. The technology uses heat and pressure to turn water into a supercritical state that can break down plant biomass. Renmatix has also developed three industrial products, Crysto™ Cellulose, Plantro® sugars and Omno™ Polymers (clean lignin) using its Plantrose process. The resulting cellulose from plant biomass is re-precipitated into Crysto cellulose. The Crysto cellulose has several applications including in oil field compositions, industrial fluids, composites, and coatings. Crysto cellulose could also potentially be used in medical materials, aviation, electronics and building materials.
Scion - Furfurylated Wood	Product is a modified wood with high performance characteristics akin to Accoya, Kebony, Thermowood etc. Manufactured by furfurylation of pine clearwood. Currently existing products exist (Accoya etc) which are made in Europe using NZ pine then re imported as finished product. Scion technology allows for different colour ranges which are attractive to market.

Table B1 – Technologies identified for potential to impact economic development in New Zealand

Sweetwater	Sunburst™ is patented technology that extracts cellulose, hemicellulose, and lignin from several types of biomass including agricultural residues and harvested wood. This process is cost effective especially compared to other pre-treatment processes currently available. Plant material, such as chipped hardwood, is fed into one end of Sunburst™ where it is compressed, ground, heated, and a dilute acid is added. In a mere 20 seconds, the wood is ejected from the other end with up to 97% of the hemicellulose and 20% of the cellulose monomerised. The system is based on extrusion which is very reliable.
InEnTec/Aemetis/ LanzaTech (Ethanol)	Aemetis has key exclusive rights for the use of InEnTec's Plasma Enhanced Melter (PEM) advanced gasification technology to produce cellulosic ethanol. The company is integrating PEM with Lanzatech's patented microbial fermentation technology that converts waste, carbon-rich gases into fuels and chemicals such as ethanol.
American Process Technologies	American Process owns two patented cellulosic technologies, Green Power+® and AVAP®. The GreenPower+® technology produces low cost cellulosic sugars by extracting only hemicelluloses from biomass. The rest of the biomass is used downstream to produce renewable power, pellets, wood or pulp products. The technology is feedstock agnostic, and can work with hardwood, softwood, bagasse and other agricultural residues. The AVAP® technology produces low cost pure cellulosic sugars by converting all the cellulose and hemicelluloses of biomass to cellulosic sugars. These sugars can then be converted or fermented by bacteria or yeast in to bio-based chemicals and biofuels. Furthermore, the company has developed a single, cost-effective IP protected process for production of cellulose nanocrystals (CNC) and cellulose nanofibrils (CNF) along with novel, hydrophobic, lignin coated versions of each. With the AVAP® Biorefinery pre-treatment technology, these cellulose nanomaterials are produced from woody or non-woody biomass at a fraction of the cost for competing nanocellulose production processes.
Woodly	Woodly is a clear cellulose-based granulate, with 40 - 60% bio-based content. While the wood is sourced from Finnish production forest, it is not clear if it is hard or softwood. The target market is packaging, providing plastic pellets for use on conventional equipment - extrusion, injection moulding etc. It was developed in collaboration with VTT and it is in prototype production.
TECNARO	This material contains lignin which is mixed with natural fibres (flax, hemp or other fibre plants) and natural additives to produce a fibre composite that can be processed at raised temperatures and pressure and made into mouldings on plastic injection moulding machines. This product has been in commercial production since 2015.
DuraSense (by Stora Enso)	A wood fibre-based bio composite blending wood fibre (spruce and pine) and polymers (virgin, recycled or bio based). DuraSense Enso is a material based on bio-based polyethylene filled with 40% wood fibre (currently produced from Swedish spruce and pine. The material is used in injection moulding lines, extrusion or 3D printing and it is in commercial production.
INEOS	A bio-attributed polyolefin made from the residue of wood pulp processing. The material is used to make a range of products including plastic food packaging and pipes.
Sulapac	A Finnish plastic replacement made from wood and plant-based binders, suitable for injection moulding and aimed at packaging and other durable applications. It is 100% bio based and industrially compostable. There is product in the market however scale is unclear.
Paptic	Tringa is a reusable, recyclable packaging film made from wood fibres along with biobased, biodegradable man-made fibres. There is no plastic in the material. This is made with conventional paper machines but with a patented foam forming technology which is more resource efficient and environmentally friendly compared to production of conventional paper. The company is aiming to use the material to produce bags for packaging. It is biodegradable and can be disposed of in industrial composting facilities.
PLA (by NZ Bio Forestry)	Converting forestry biomass waste (Pinus radiata) into high value products including alternatives to petroleum and fossil-derived products. The target market is to convert Pinus radiata into decorative ply/laminates.

Table B1 – continued

Long-term (20–30 years)

Organisation Name	Technology summary
Air Liquide/Bioliq	The bioliq® pilot plant covers the complete process chain required for producing customised fuels from residual biomass. For energy densification of the biomass, fast pyrolysis is applied. The liquid pyrolysis oil and solid char obtained can be processed into intermediate fuels of high energy density. Fuel and chemicals production from syngas requires high pressures. Therefore, syngas production is already performed at pressures up to 80 bar by entrained flow gasification. Gas cleaning and conditioning are conducted at the same pressure at high temperatures allowing for optimal heat recovery and thus improved energy efficiency. In the bioliq® pilot plant the purified syngas is firstly converted into dimethyl ether and then further to gasoline.
Anellotech	Bio-Tcat (Thermal Catalytic Biomass Conversion) is Anellotech's core technology which produces chemicals and fuels from non-food biomass. The reactor uses industrial fluid bed reactor technology and a zeolite catalyst to convert pre-treated feedstock into a liquid product containing over 98% C6+ aromatic chemicals (benzene, toluene and xylene or BTX. Currently Anellotech is focusing on using loblolly pine as a feedstock for its development program and first commercial plant.
Attis Innovations	Attis has developed a lignin recovery process that conserves the quality of lignin during extraction and purification. The resulting lignin is a meltable thermoplastic material. Attis claim that they are the only company to have developed a process that results in a meltable lignin material. In addition, functional additives can be incorporated during the recovery process to enable the lignin to perform better in various applications (e.g. bioplastics, adhesives, carbon fibre, renewable fuels, green chemicals etc.). The Attis technology requires less capital compared to other commercial lignin recovery systems and is also scalable to allow cost effective processing at low flow rates (e.g. as low as 200 tonnes/day).
Chempolis	Chempolis biorefining technologies are based on a multi-product platform. The platform is based on formico-technologies, which rapidly impregnate bio-solvent into the raw feedstock and allow highly selective delignification (i.e. the yield and quality of cellulose, hemicellulose and lignin are optimised). Formicobio, formicofib, formicochem, and formicodeli are all technologies that enable delignification and fractional of feedstock. Formicopure is a distillation purification system for bio-solvent recovery. Foricocont is an automation and control system for optimisation of the processes. Chempolis is constructing a biorefinery in India that will be capable of converting bamboo into cellulosic ethanol and bio-based chemicals.
GEFS	The company has developed mechanical catalytic conversion technology, which involves an efficient one-step process at low temperatures to converting biomass into biodiesel. The resulting biodiesel complies with diesel regulations such as EN590 and ASTM. The plants are modular and therefore scalable, anywhere between 150-2400 litres/hour and potentially even more.
Global Bioenergies	Global Bioenergies converts bio-based feedstocks into fuel and cosmetic ingredients. Global Bioenergies has developed a process to convert feedstock (sugars, agricultural and forestry waste) into isobutene. Isobutene is the building block for a variety of ingredients including petrol, LPG, cosmetics, and plastics. Global Bioenergies created a joint venture, IBN-ONE, with Cristal Union to commercialise its biofuel production process. Global Bioenergies licensed its isobutene production technology to IBN-ONE. IBN-ONE's first plant project has demonstrated that the production site could achieve a 69% reduction in CO2 emissions compared to fossil gasoline.
Johnson Matthey/BP Consortium	BP and JM have developed a simple-to-operate and cost-advantaged FT technology that can operate both at large and small scale to economically convert synthesis gas, generated from sources such as municipal solid waste and other renewable biomass, into long-chain hydrocarbons suitable for the production of diesel and jet fuels. The Johnson Matthey DAVY/BP fixed-bed FT reactor has no moving parts and requires no continuous catalyst addition or separation. The proprietary BP catalyst runs at constant conditions and delivers a high-purity product that is easy to upgrade. The system delivers three times the productivity of a conventional multi-tubular fixed bed reactor and halves the capital expenditure when compared to traditional FT reactors. The technology also delivers significant environmental and operational benefits.

Table B1 – continued

GoBiGas/Repotec	The process involves indirect gasification of forest residues using Repotec and Metso Power's gasification technology. Haldor Topsoe's patented TREMP methanation technology and catalyst are then used to produce biomethane with a methane content of more than 95%.
LTU Green Fuels	LTU Green Fuels converts pyrolysis oil together with black liquor. By converting forest residues into a liquid, called bio-oil or pyrolysis oil, energy density is increased, and transportation facilitated. The conversion of the pyrolysis oil to a renewable transportation fuel is made through a process called gasification. It is performed in combination with black liquor that is a by-product from pulp and paper production and available in large volumes in Sweden and elsewhere. The project "Catalytic gasification" is financed by the Swedish Energy Agency and an industry consortium.
Scion - Bark refinery	Scion is leading a five-year research program to evaluate potential of extracting high-value chemicals (e.g. antioxidants, antibacterials, waterproofing chemicals) from bark using green-chemistry. In addition to the extraction of chemicals, the bark could potentially be processed into bark briquettes i.e. bio-coal. The research program began in late 2018.
Scion - Ligate	Product (Ligate) is a bio-based adhesive for use in interior wood panel manufacture. The advantages are it contains no formaldehyde or hazardous chemicals and as a result can be manufactured in facilities requiring low safety compliance (versus traditional urea-formaldehyde adhesives).
Scion - PHA and biopolymers	Production of specialty chemicals for use in production of niche biopolymers. Involves conversion of wood to C6 sugars, followed by fermentation and purification.
Scion - Reactive extrusion	Known as Reactive Extrusion or mechanochemical processing. Continuous chemical process that allows wood to be converted into specific molecules. Solvent free so environmentally benign.
TreetoTextile	Tree to Textile is a new sustainable low-cost textile fibre made through a new innovative chemical process – using renewable forest raw material and regenerating the cellulose into a textile fibre by spinning the dissolving pulp. The process uses less chemicals and does not produce sulphur emissions. Water and chemicals used are recycled. The company is moving into the next phase of scaling up the production.
Advanced BioCarbon 3D	This product is made from cellulose from waste wood fibre (currently poplar) and therefore not known whether it could be adapted to a radiata feedstock however media noted that the process "also works well with softwoods". Their target market is 3D printing filament.
LignoPure	Offering lignin-based solutions for a range of product ideas. They have used lignin as a biopolymer composite for injection moulding, 3D printing, food additive and micro particles for cosmetics. Protype production but a spin-off company seeking investors.
Mobius	A US company producing lignin-based plastic pellets - both biodegradable and compostable. Lignin is added to other biopolymers using Mobius' proprietary process. Mobius sell the resin to production companies.
Lixea	The Bioflex process uses ionic liquids to extract lignin and cellulose from wood waste. These can then be used in a variety of other processes. The process is flexible, allowing use of a range of biomass types including hardwoods and softwoods, and heavy metal contaminated mixed waste wood. Other by-products include furfural and acetic acid which can be isolated.
Futurity	Futurity uses Sweetwater's technology to break down wood chips into lignin, cellulose, and hemicellulose. An additional technology then valorises this into higher value products.
Avantium	Avantium has developed the Dawn Technology which converts forest residues into industrial sugars and lignin. Avantium is planning building of a commercial refinery. The company also has two other complementary technologies which convert plant-based sugars into plastics and glycols. It is understood that IKB Consulting and Lincoln Agritech are looking to establish a linkage with the company.

Table B1 – continued

APPENDIX C: WOOD AVAILABILITY MODEL

Generating the wood availability forecasts

An approximation of wood availability over the next 30 years was modelled. This was a small part of the 8-week WFF Stage 1 report, and was completed solely to confirm wood availability, at the national level, for the purposes of aligning with any new technologies that were being assessed (the primary aim of the study). They were built from regional data and existing MPI databases, as described below.

This model does not, in any way, substitute for the formal wood availability forecasts which have been done at intervals over recent decades. The last formal forecast was performed in 2013 for the period 2014 onwards. One of the authors of the last formal study (Kenneth Tsang) led this work as part of PF Olsen's contribution to the consortium. The Consortium hopes that this work could help accelerate progress of the next formal report. It may also form a basis for more detailed modelling in Wood Fibre Futures Stage 2.

In interpreting the results of the wood availability forecasts, it is necessary to understand the base inputs, assumptions, and methodology behind the forecasts.

1. The forest description used for the forest estimate modelling was based on the MPI National Exotic Forest Description (NEFD) as at 1 April 2019.
2. The MPI NEFD details the planted area of radiata pine by territorial authority and silvicultural regime (pruned and unpruned).
3. Douglas fir was not included in the model for several reasons:
    a. It is currently negligible in volume except in Southland and Otago
    b. In those two regions it is currently <5% of harvests although that will increase to around 25% by the 2040s before reducing again

		Large-Scale Forest Owners		Small-Scale Forest Owners	
MPI Region	Species	*Unpruned*	*Pruned*	*Unpruned*	*Pruned*
Northland	Radiata pine	5,310	-	162	54
Central North Island	Radiata pine	11,569	3,856	279	279
East Coast	Radiata pine	-	3,371	85	85
Hawke's Bay	Radiata pine	449	1,346	50	50
SNI (East)	Radiata pine	141	1,273	41	76
SNI (West)	Radiata pine	484	25	47	47
Nelson	Radiata pine	1,678	186	38	38
Marlborough	Radiata pine	1,771	197	62	62
Canterbury	Radiata pine	704	302	274	14
West Coast	Radiata pine	746	-	-	-
Otago	Radiata pine	1,539	1,026	47	110
Southland	Radiata pine	683	455	37	85

Table C1 – Forest Area Replanted in 2019 in hectares

c. It has a much longer lifespan to harvest, especially in those colder climates – often 40-50 years; thinnings are taken during that time albeit often used for firewood

d. As a different species it will have different attributes, markets, and residual biomass issues than radiata, and industry's adaptation to those differences are uncertain.

As a result of this exclusion, the model under-represents total wood availability in Southland and Otago which should be, and will need to, be considered in any deeper investigation of supply from these regions.

4. The area replanted in 2019 was estimated based on averaging the planted areas in 2018 and 2017; the silvicultural regime (pruned or unpruned) for these replanting areas is based on the assumptions applied in the MPI Wood Availability Forecasts 2014/15.

5. The assumed replanted area in 2019 by region, size of ownership, and silvicultural regime (pruned and unpruned) are summarised in **Table C1**.

6. In the forecasts there is a distinction made between 'large-scale' forest owners and 'small-scale' forest owners; large-scale owners are those with 1,000 hectares or more of radiata pine plantation forests while small-scale owners are those with less than 1,000 hectares and/or who are part of a syndicate investment scheme.

7. Replanting by small-scale forest owners was modelled on the NEFD raw data extracted in March 2020, modified by considering trends from the last few years. Small-scale forest owners were not replanting in 2017/18 due to high dairy prices and political uncertainty re carbon pricing. The rate increased quite recently but, to be conservative, a lower planting rate was assumed in this long-term model.

   Similarly, a recent increase in nursery plant numbers showed an apparent increase in plantings in 2019. However, with a severely depressed harvest in 2020 (due to the Covid pandemic), a conservative view was taken to model at the lower replanting rates.

8. Radiata pine planted areas that were older than age 35 years (as at 1 April 2019), in large-scale forest ownership, were excluded in the forest estate modelling.

9. Radiata pine planted areas that were older than age 40 years (as at 1 April 2019), in small-scale forest ownership, were excluded in the forest estate modelling.

10. In the forest estate model, the target rotation age for radiata pine was set at 25 years for all regions; the minimum and maximum harvest ages were set at 25 and 40 years respectively.

    The rationale is twofold. Firstly, harvest age is steadily declining: in the 2005 Wood Availability model, harvest age was estimated at 30 years; in the 2014 model, it was estimated at 28 years; so this model used 25 years. Secondly, industry practises, specifically purchasing and harvesting decisions, have lowered harvest age especially recently. Log buyers are beginning to purchase well under 25 years recently, and as low as 20 years.

11. To incorporate the actual harvest level and export volume in the forest estate model, the harvest level for 2019 (YE December) for each MPI region was set based on the actual harvest level in 2019 (provisional) and the export volume was set based on the export statistics by port from Statistics New Zealand. It is acknowledged that these harvesting intentions are dating, but the estimate was deemed sufficient for the purposes of this report.

		Log Specifications	
MPI Yield Table Log Grade	Market Log Grade	*Min Small-End Diameter (cm)*	*Knot Size (cm)*
Pruned Sawlogs	P40, P35, Pruned Export	35+	0 cm
Unpruned Sawlogs	S30, S20, A, K	20+	7-12 cm
Pulp-logs	KI, KIS, Pulp-logs (Domestic)	10+	Unlimited

Table C2 – MPI Yield Table Grades

12. The harvest level for 2020 (YE December) is estimated as 25% less than the 2019 harvest level for each MPI region due to the low expected levels of harvest between February and April 2020.

13. The harvest level for large-scale forest owners between 2019 and 2023 was based on harvest intentions published in the MPI Wood Availability Forecasts in 2014/15; the large-scale owners' expectations on yield and harvest levels have a significant impact on the wider forecasts.

14. The MPI yield tables calibrated in the MPI Wood Availability Forecasts 2014/15 have been used and assigned in the forest estate model (**Table C2**)[32].

15. In order to better estimate the availability of domestic pulp-logs and forest residues, MPI's pulp-logs grade (which accounts for all logs with minimum s.e.d. of 10cm–20cm) has been split into 50%:50% pulp-logs (export) and pulp-log (domestic); pulp-logs (export) are KI and KIS grade pulp-logs, and pulp-log (domestic) are logs which cannot meet the export specifications and are used for the domestic pulp-log market or for wood pellets, firewood, or left in the forest or landings.

16. Four forest residue grades have also been incorporated into the forest estate model; we have assumed that the potential recoverable forest residues in the forest will be approximately 15% of the total recoverable merchantable log volume which can be further defined into the following five categories[33]:

- Chip Quality Roadside (5% - easiest to collect): cut-over, rejects, treetop, bin-wood at roadside or landings,
- Chip Quality Cut-Over (1% - more difficult to collect): cut-over, treetop in the forests,
- Hog Quality Roadside (1% - easy to collect): bark, branches, and dirt at roadside or landings,
- Hog Quality Cut-Over (5% - more difficult to collect): bark, branches, stumps, and dirt in the forests,
- Waste (3% - non-recoverable): non-commercial waste.

It is acknowledged that these recoverable percentages will be lower for pruned forests, but the error was not deemed critical for the purposes of this study.

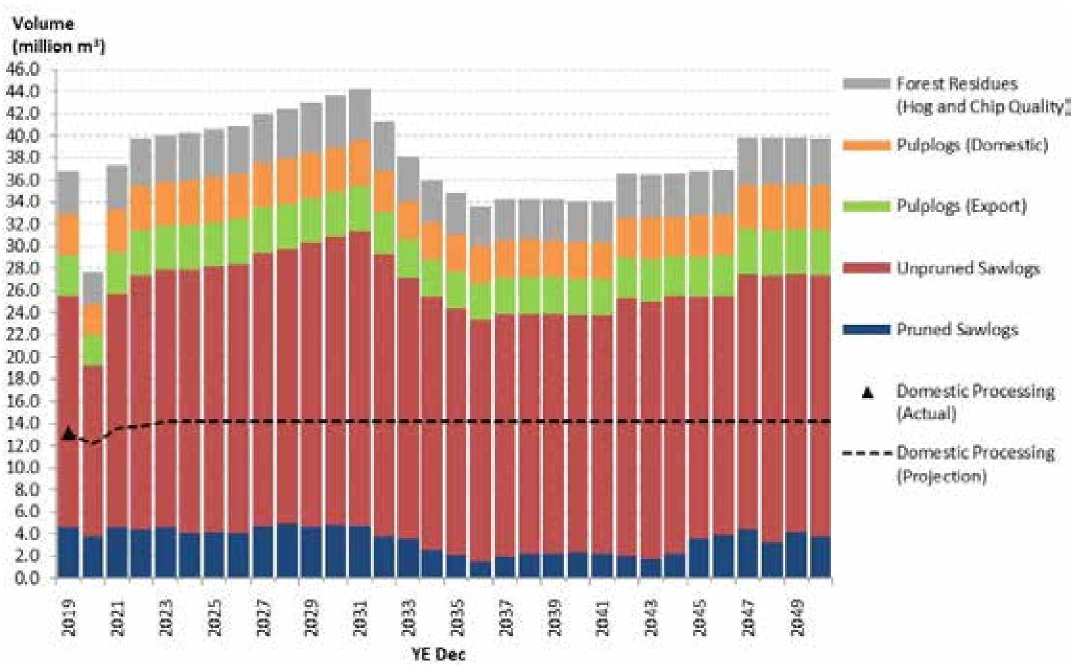


Figure C1 – New Zealand Wood Availability Forecasts by Type of Biomass, 2019–2050

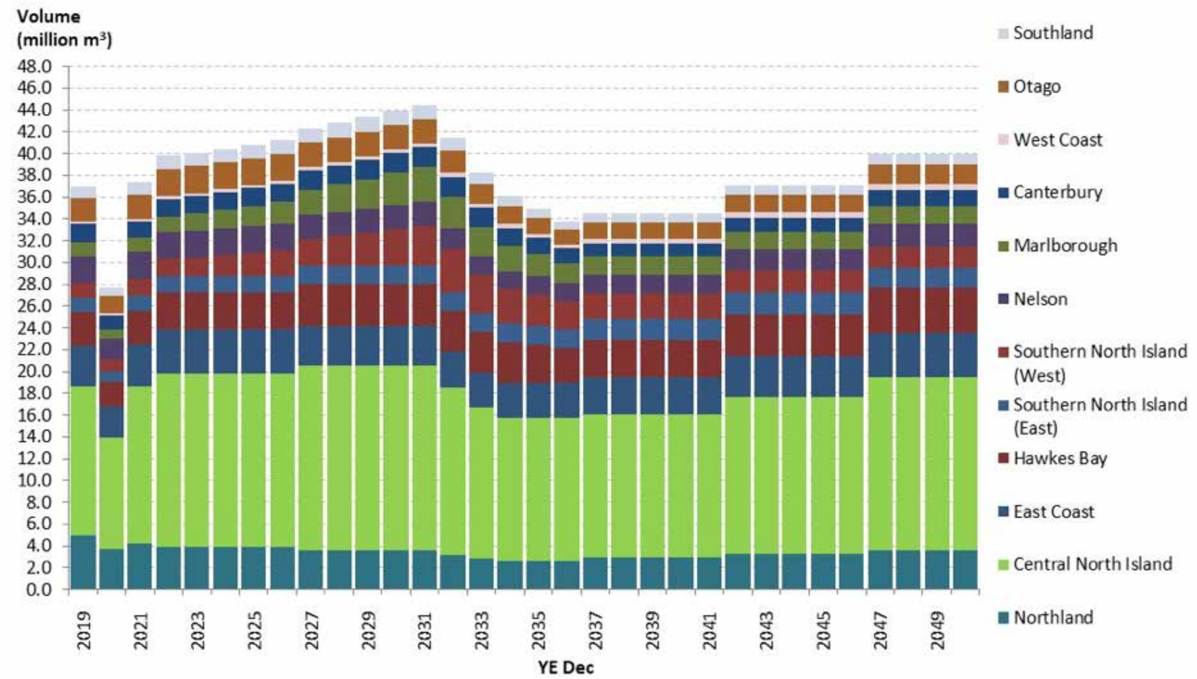


Figure C2 – New Zealand Wood Availability Forecasts by Region, 2019–2050

17. Other Harvest and Smoothing constraints in the forest estate model include:

   a. Large-scale forest owners were subject to more sustainable non-declining yield, cash flows, and harvest crew constraints, therefore, a non-declining yield constraint has been applied to the large-scale forest owners' wood flows in each MPI region (whenever possible); however, for those regions where this is not feasible, the harvest level may increase or decrease by 10% from year to year after 2023 (or 2024).

   b. Small-scale forest owners were not subject to cash flows constraints as they tended to harvest their forests when the log prices were attractive; however, the availability of harvesting crews and other production capacities (i.e. trucks and ports) cannot increase dramatically from year-to-year; as a result, regional smoothing constraints have been applied for each MPI region in the model to constraint and smooth the regional harvest level after 2020.

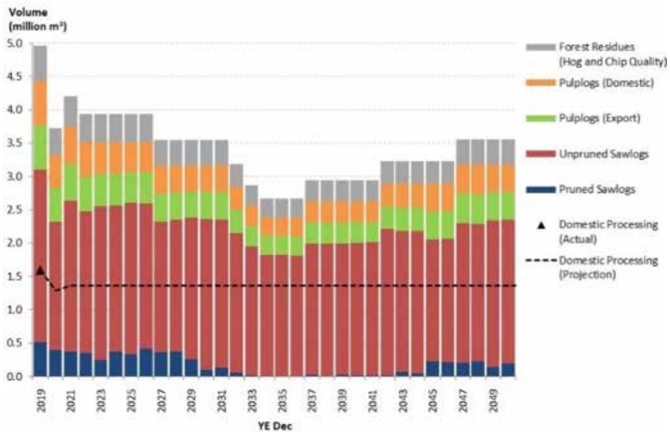
   c. As mentioned above, Douglas fir harvesting from Southland and Otago during the 2040s will likely fill some of the dip in the wood-flow which occurs at that time for radiata harvests, but only to a maximum of around 1 million cubic metres per annum at peak.

Wood Availability Forecast Considerations

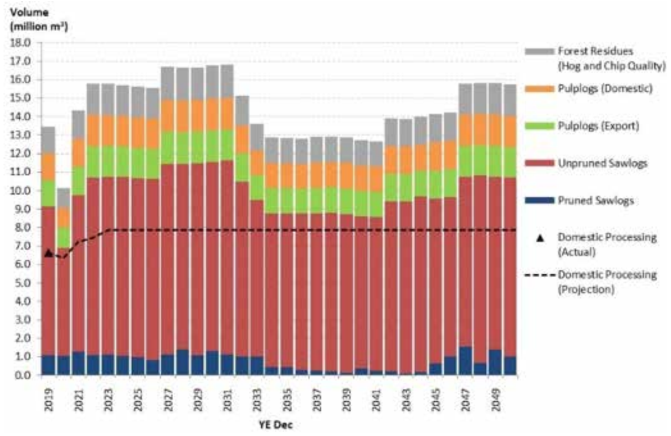
The availability of woody biomass from New Zealand's radiata pine estate has been forecast to 2050 based on MPI's National Exotic Forest Description (NEFD) regional area descriptions as at 1 April 2019, harvest intentions from the large forest owners, and the NEFD yield tables (**Figure C1**).

New Zealand woody biomass supply forecasts show a sharp decline in 2020 to about 28 million cubic metres, resulting from curtailments in harvesting following the effects of the severe downturn in log demand from China from mid-2019

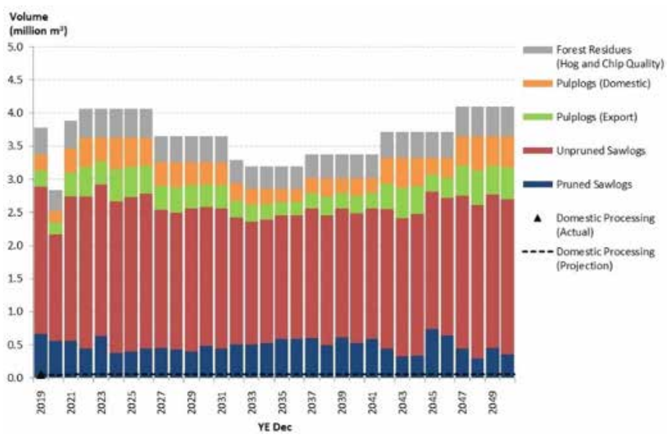
Northland



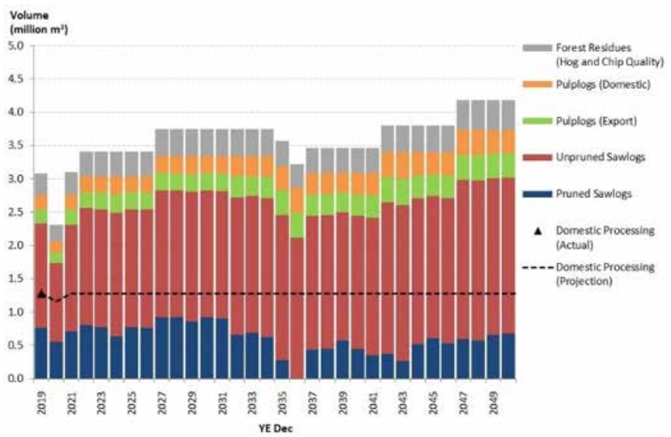
Central North Island



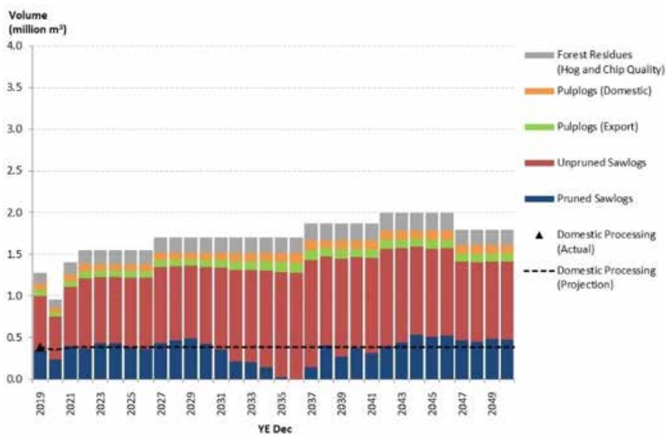
East Coast



Hawke's Bay



Southern North Island – East



Southern North Island – West

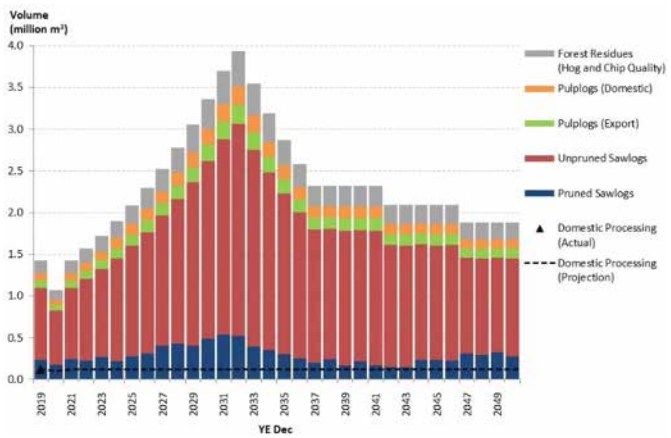
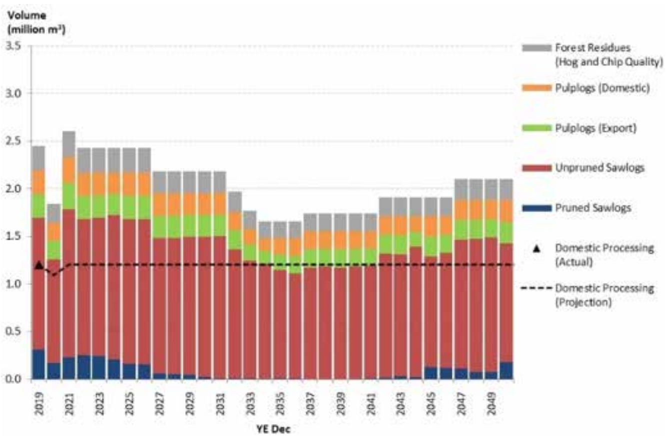
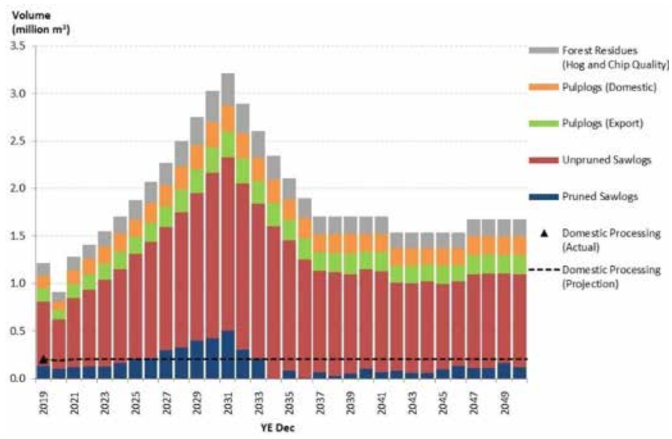


Figure C3. Radiata Pine Wood Availability Forecasts (North Island)

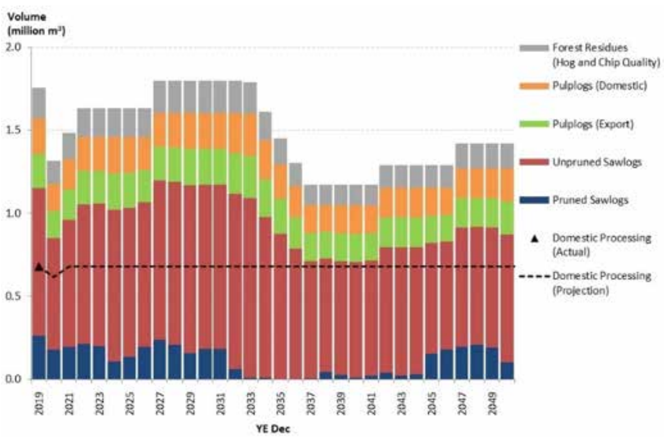
Nelson



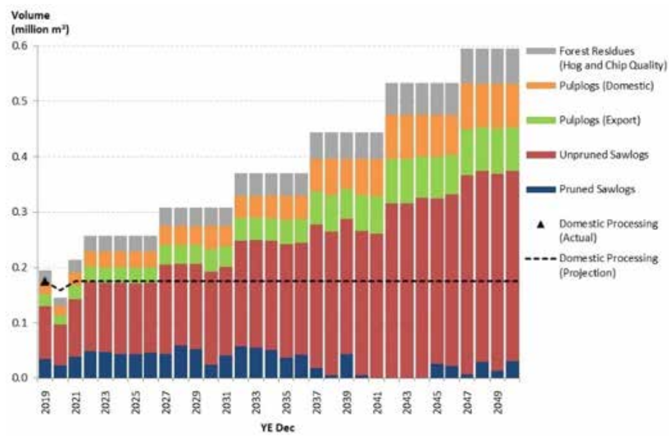
Malborough



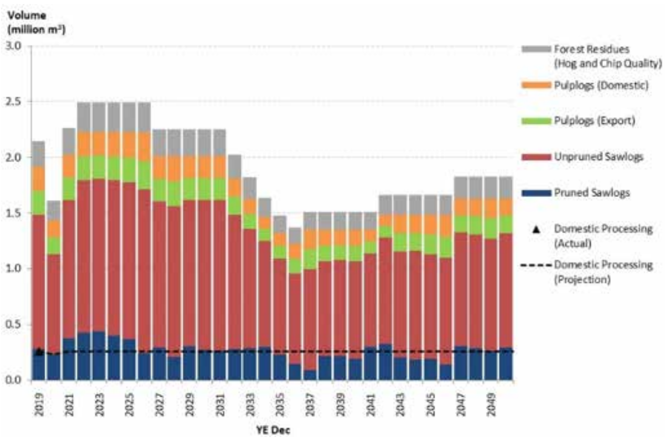
Canterbury



West Coast



Otago



Southland

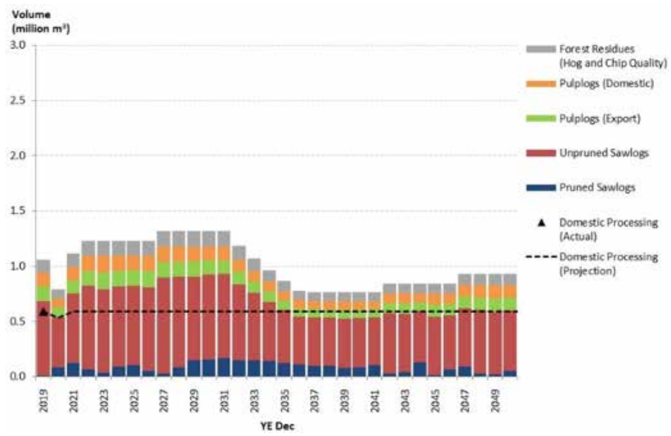
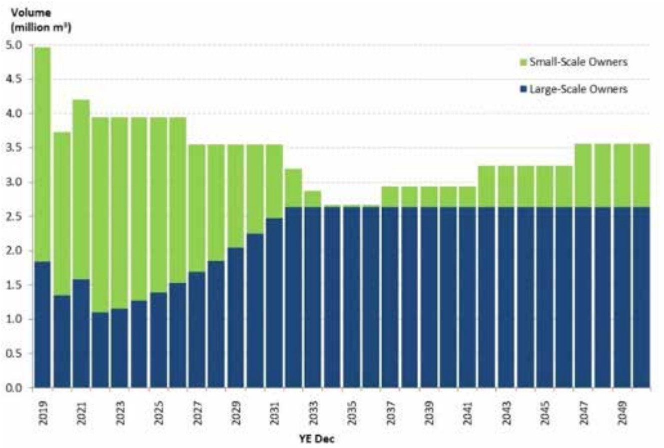
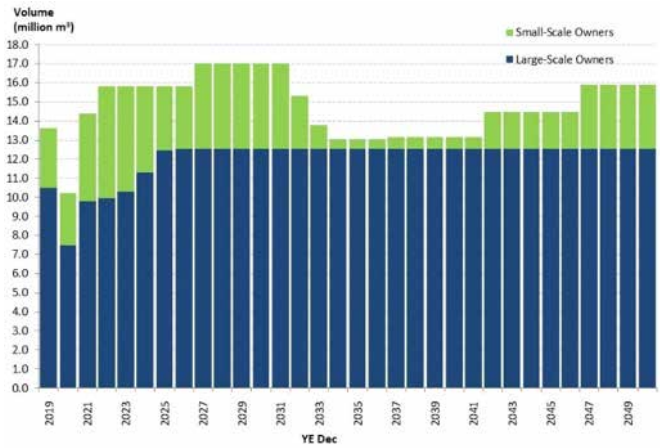


Figure C4 – Radiata Pine Wood Availability Forecasts (South Island)

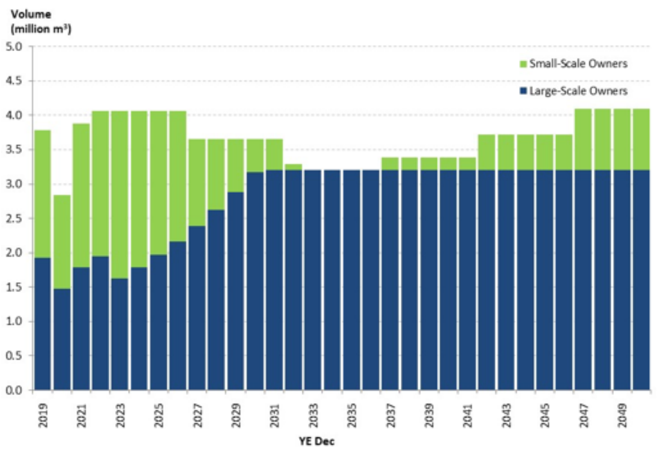
Northland



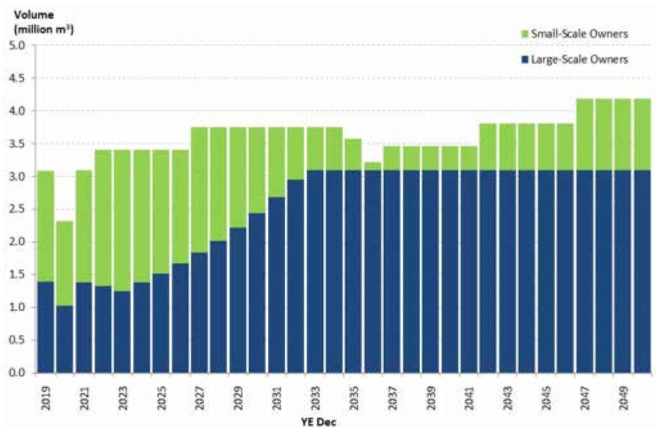
Central North Island



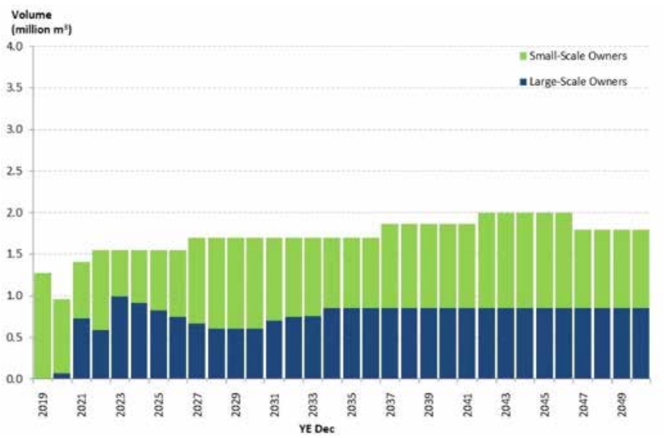
East Coast



Hawke's Bay



Southern North Island – East



Southern North Island – West

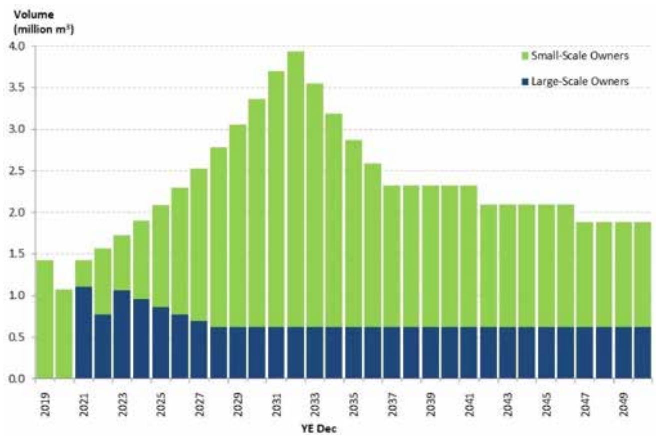
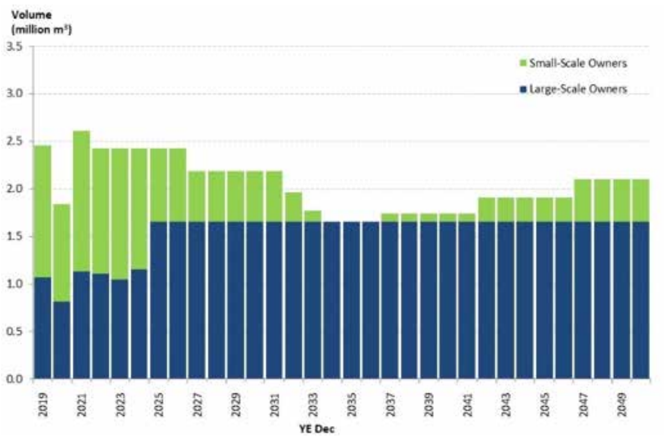
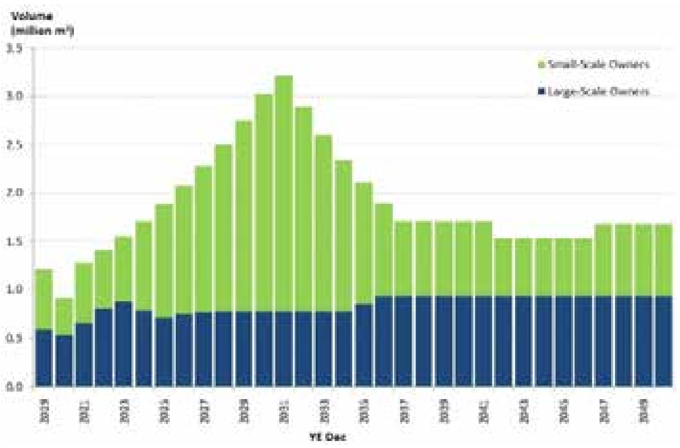


Figure C5 – Radiata Pine Wood Availability Forecasts by Forest Ownership Scale (North Island)

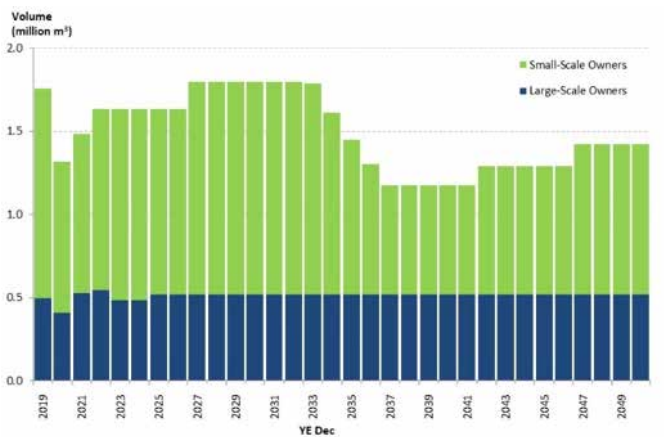
Nelson



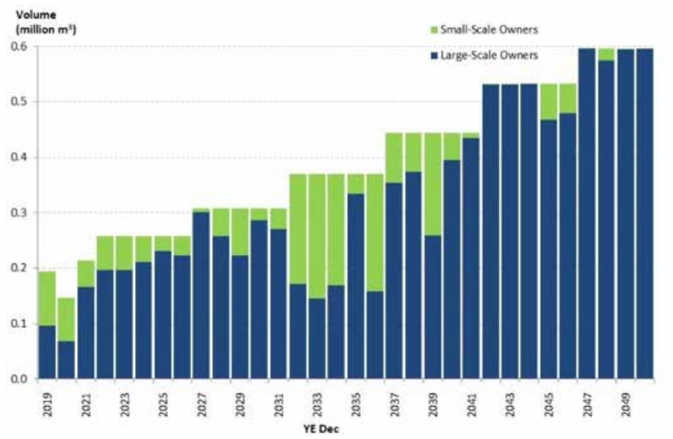
Malborough



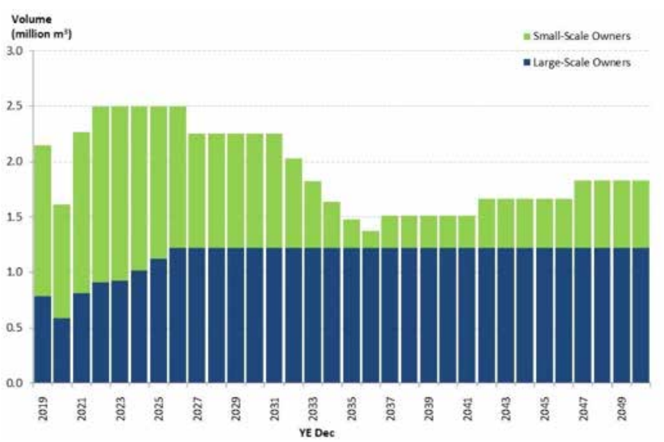
Canterbury



West Coast



Otago



Southland

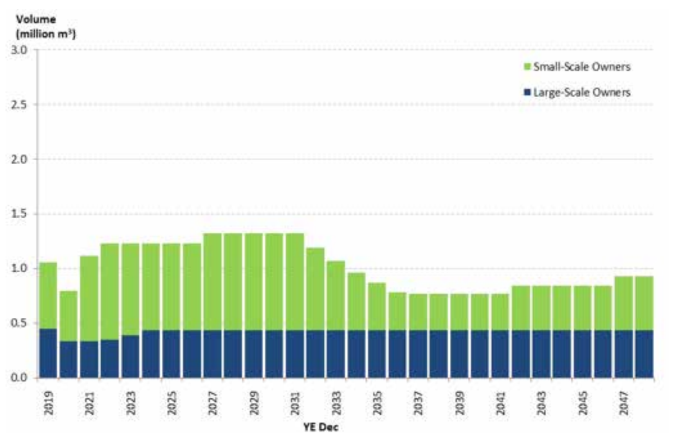


Figure C6 – Radiata Pine Wood Availability Forecasts by Forest Ownership Scale (South Island)

and the New Zealand lockdown in March and April 2020. Overall, harvest levels from 2021 are expected to rise over the next 10 years to 2031, reaching about 44 million cubic metres, dropping to a low in 2036 at about 34 million cubic metres. These trends reflect the 1990s planting boom and the marked decline in replanting and stocked areas from the mid-2000s. The forecasts are based on a target rotation age of 25 years and include merchantable logs and forest residues, which have not been included in previous forecasts. They also only account for reforestation of existing forest areas and do not reflect any significant planting of new areas.

The forecasts assume the same silvicultural regimes employed in 2019, which have been trending to a decline in clear-wood silvicultural regimes. However, the proportion of pruned to unpruned logs harvested and future levels of pruning will be determined by market conditions, notably the differential between pruned and unpruned log prices. According to the projections, pruned log availability reaches a low in 2036 of about 2 million cubic metres. The volume of low-grade biomass available includes domestic pulp logs (which cannot meet export specifications), chip, and hog quality residues. Except for 2020, low grade biomass availability increases from 7.5 million cubic metres in 2019 to a peak of 8.8 million cubic metres in 2031.

The forecast woody biomass supply trends differ by region (**Figure C2, C3 and C4**). The Central North Island (CNI) remains the most significant, accounting for 37% of the harvest in 2019 and expected to increase to 39% in 2030. Northland, East Coast, Hawkes Bay, Southern North Island (SNI) and Nelson each accounted for 14%, 10%, 8%, 7% and 7% respectively in 2019. Wood availability from Marlborough and SNI (West) is forecast to increase sharply between 2021 and 2032, reflecting a boom in planting by small forest owners in the 1990s (**Figures C5 and C6**).

The New Zealand forest ownership profile has been changing. The proportion of small-scale forest owners has grown in recent years with significant plantings by this ownership class in the 1990s. As a proportion of the total, their ownership is highest in Northland, East Coast, Hawkes Bay, SNI, Marlborough, Canterbury, Otago, and Southland (**Figures C5 and C6**). Harvesting in these forests is more uncertain and tends to be opportunistic, i.e. harvesting will most likely occur when market conditions allow net profit returns to reach a threshold[34]. For small-scale owners, age class ranges are typically narrow, forestry is less likely to be the primary source of income, and there are fewer economies of scale available with roading, harvesting and cartage costs often higher. The forecasts do not present any significant changes in market conditions, which could push the small owner resource out of the economic classes with a subsequent reduction in harvesting activity.

Indicative market prices of woody biomass by grade (delivered at mill/at port, or on-truck) from AgriHQ and PF Olsen Ltd are shown in **Table C3**.

More detailed information on delivered wood costs, showing the range in costs and variations by region is given in **Table C4**. There are regional differences in delivered wood costs, mainly due to differences in harvesting and cartage costs, and the location of and distance to existing regional wood processing facilities and ports. Indicative logging costs can vary from $19/tonne to $38/tonne depending on topography, and cartage costs from $35/tonne to $89/tonne depending on topography and the distance to the mill/port[35].

Delivered wood costs are lowest in CNI, where harvesting costs are lower, there are economies of scale in harvesting infrastructure, significant existing wood processing facilities and proximity to a highly efficient export port (Port of Tauranga). However, CNI regional average wood costs may increase in the future as the level of harvesting in Opotiki District and Ruapehu District increases, where harvesting costs are higher, and there are longer distances to the port and processing plants.

Delivered wood costs are highest in the South Island West Coast, which does not have a regional export port facility, and the SNI, both of which have relatively steep topography and associated high harvesting costs. SNI harvesting is also forecast to be increasingly from small-scale, first-rotation forests with higher roading construction costs.

Forest Estate Model Grade	Market Grade	Indicative Price (NZ$/m3)
Pruned Sawlogs	P40, P35, Pruned Export	$160 - $210
Unpruned Sawlogs	S30, S20, A, K	$100 - $140
Pulp-logs (Export)	KI, KIS	$80 – 110
Pulp-logs (Domestic)	Pulp-logs (Domestic)	$45 - $70
Residues (Chip quality, hog quality)	Binwood, Hog, etc	(On-Truck) $5-$45+

Source: AgriHQ, PF Olsen Ltd

Table C3 – Indicative Prices (2019 annual average) of Roundwood by Grade (Delivered at Mill Gate/at Port, or On-Truck)

The variations in wood residue prices (of both chip and hog quality) are due to the differences in location of residues and the relative difficulty in accessing residues.

Estimates of domestic wood consumption have been derived from current wood processing demand and known planned expansions and closure of facilities (data are shown within **Table C5**).

A general overview of radiata pine resource and wood processing by region is described in **Table C6**.

Wood processing demand in CNI, which accounted for half of the New Zealand total in 2019, is forecast to increase to 7.87 million cubic metres in 2025, 56% of New Zealand's total domestic wood consumption. Wood processing demand in Northland, the second largest regional consumer, is forecast to decline from 1.59 million cubic metres in 2019 to 1.36 million cubic metres in 2025, about 10% of New Zealand's demand, based on closure of the CHH Woodproducts' Whangarei sawmill in 2020. All other regions' demand forecasts remain level, assuming no planned expansions or contractions in wood processing capacity.

The levels of uncommitted merchantable logs have been based on forecasts of the availability of merchantable logs and estimates of domestic wood processing demand. The average annual volume of uncommitted merchantable logs will reach 23.14 million cubic metres in 5–10 years, declining to 18.94 million cubic metres in 20–30 years, based on the model and wood processing demand assumptions.

	Indicative Average Delivered Log Cost (in NZ$/m3 At Wharf Gate)			Indicative Average Chip-Quality Forest Residue Cost (in NZ$/m3 On-Truck)			Indicative Average Hog-Quality Forest Residue Cost (in NZ$/m3 On-Truck)		
MPI Region	LQ	M	UP	LQ	M	UP	LQ	M	UQ
Northland	49	78	110	20	21.67	30	5	13.33	15
CNI	43	61	100	25	26.67	35	5	13.33	15
East Coast	50	70	115	15	16.67	25	5	13.33	15
Hawke's Bay	45	69	100	25	26.67	35	5	13.33	15
SNI (East)	55	84	110	10	11.67	20	5	13.33	15
SNI (West)	55	83	110	10	11.67	20	5	13.33	15
SNI (West-Taranaki)	55	83	110	10	11.67	20	5	13.33	15
Nelson	45	67	85	25	26.67	35	5	13.33	15
Marlborough	50	74	95	15	16.67	25	5	13.33	15
Canterbury	40	65	90	25	26.67	35	5	13.33	15
West Coast	45	85	110	10	11.67	20	5	13.33	15
Otago	45	73	105	15	16.67	25	5	13.33	15
Southland	45	73	95	20	21.67	30	5	13.33	15

LQ lower quartile M median UQ upper quartile

Note: Indicative costs have been determined from PF Olsen Ltd. personal communications with industry representatives and are based on prices before the COVID-19 economic downturn in China, from early 2020

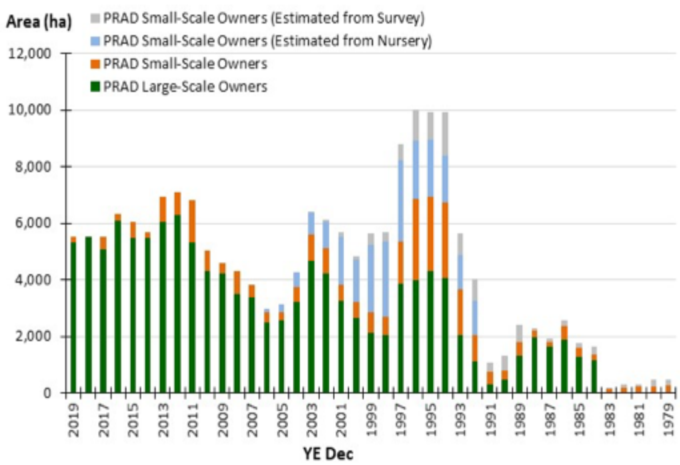
Table C4 – Wood availability forecasts: indicative delivered wood costs by region (in NZD/m3)

Table C5 – New Zealand wood availability forecasts, by region, by volume (in million m3 RWE)

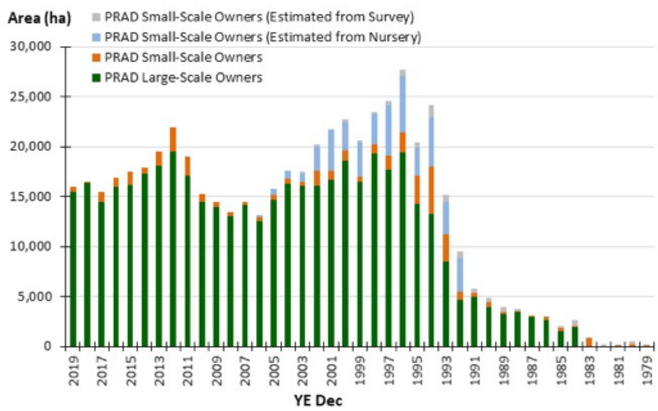
MPI Region	2019[p] Harvest Volume	2019[p] Export Logs	Total Forest Biomass[1 a]		Merchantable Logs[a]		Chip-Quality Forest Residues[2 a]		Hog-Quality Forest Residues[3 a]		Domestic Wood Processing Demand[4]		Uncommitted Merchantable Logs[5]	
			short-term[b]	long-term[c]	short-term	long-term	short-term	long-term	short-term	long-term	2019[f]	2025[f]	short-term	long-term
Northland	4.87	2.56	3.7	3.27	3.31	2.92	0.2	0.18	0.2	0.18	1.59	1.36	1.94	1.56
CNI	13.35	7.09	16.24	14.29	14.5	12.76	0.87	0.766	0.87	0.766	6.63	7.87	6.63	4.89
East Coast	3.6	3.13	3.82	3.76	3.41	3.36	0.2	0.2	0.2	0.2	0.06	0.06	3.35	3.3
Hawke's Bay	2.87	2.53	3.61	3.85	3.23	3.44	0.19	0.21	0.19	0.21	1.28	1.28	1.95	2.16
SNI (East)	2.64	1.73	1.64	1.91	1.46	1.71	0.09	0.1	0.09	0.1	0.12	0.12	1.07	1.32
SNI (West)			2.55	2.08	2.28	1.85	0.14	0.11	0.14	0.11			2.16	1.73
SNI (West-Taranaki)		0.94												
Nelson	2.42	1.27	2.28	1.94	2.04	1.73	0.12	0.1	0.12	0.1	1.2	1.2	0.84	0.53
Marlborough	1.19	0.57	2.29	1.61	2.05	1.44	0.12	0.09	0.12	0.09	0.21	0.21	1.85	1.24
Canterbury	1.72	0.47	1.73	1.31	1.55	1.17	0.09	0.07	0.09	0.07	0.68	0.68	0.87	0.49
West Coast	0.19	-	0.29	0.53	0.26	0.48	0.02	0.03	0.02	0.03	0.18	0.18	0.08	0.3
Otago	2.1	1.16	2.35	1.68	2.1	1.5	0.13	0.09	0.13	0.09	0.26	0.26	1.84	1.24
Southland	1.04	0.64	1.28	0.86	1.15	0.76	0.07	0.05	0.07	0.05	0.59	0.59	0.56	0.18
Total NZ	**35.99**	**22.09**	**41.78**	**37.09**	**37.31**	**33.12**	**2.24**	**1.99**	**2.24**	**1.99**	**13.17**	**14.17**	**23.14**	**18.94**

a annual average
b 5-10 years (2025-2029)
c 20-30 years (2040-2049)
p provisional
f forecast
1 Total forest biomass is the sum of merchantable logs plus total forest residues
2 Chip quality residues are utilised in the manufacture of MDF, wood pulp, particleboard, and wood panels
3 Hog quality residues include bark, branches and stumps and are mainly utilised in co-generation plants, landscaping, and as fuel
4 Domestic wood-processing demand is based on current wood processing roundwood demand plus planned expansion and contractions in processing in that region
5 Uncommitted merchantable log volume is the volume of merchantable logs minus the volume consumed in wood processing in that region

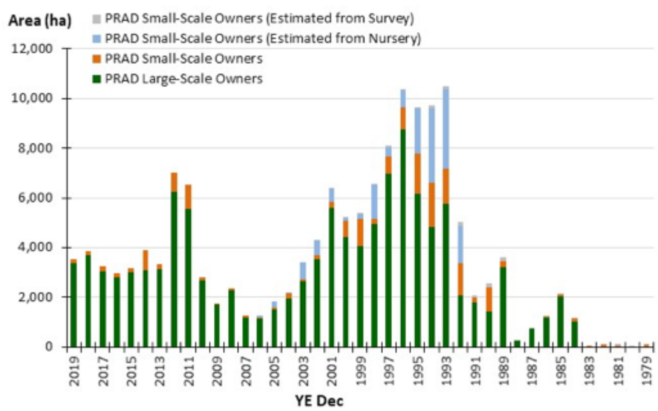
Northland



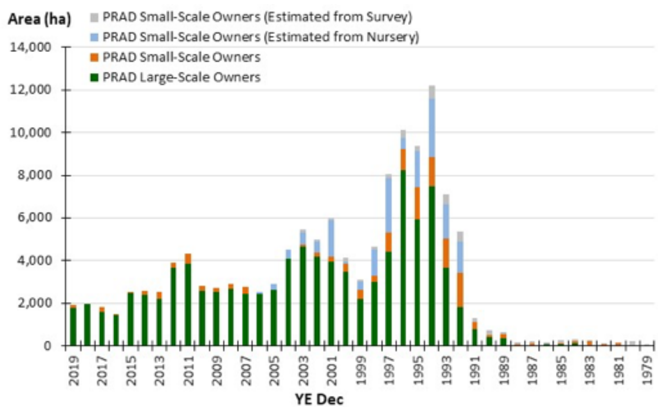
Central North Island



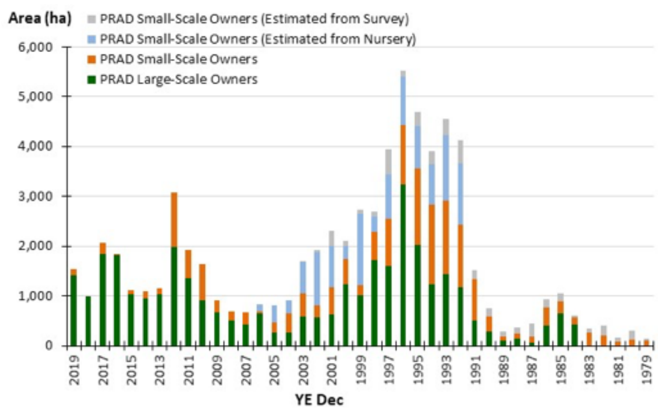
East Coast



Hawke's Bay



Southern North Island – East



Southern North Island – West

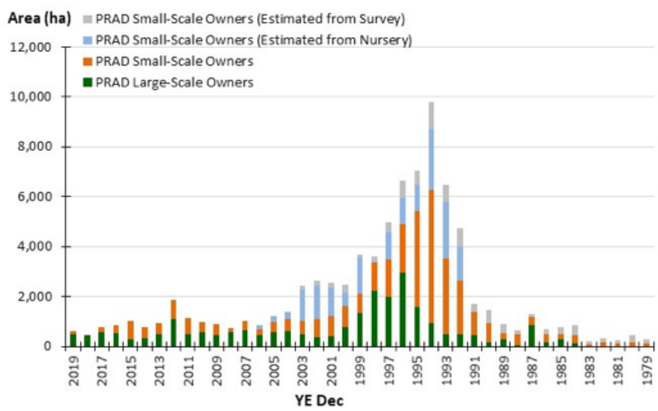
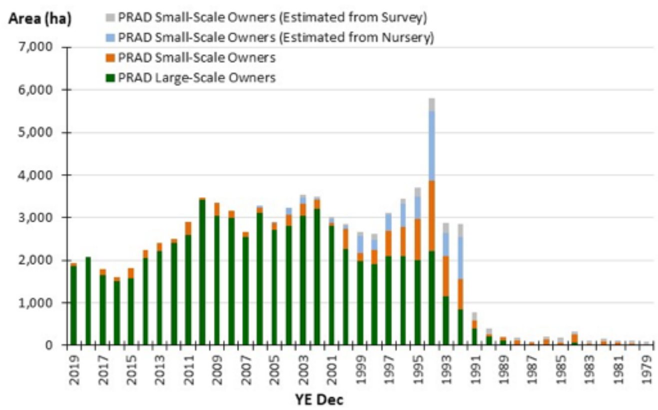
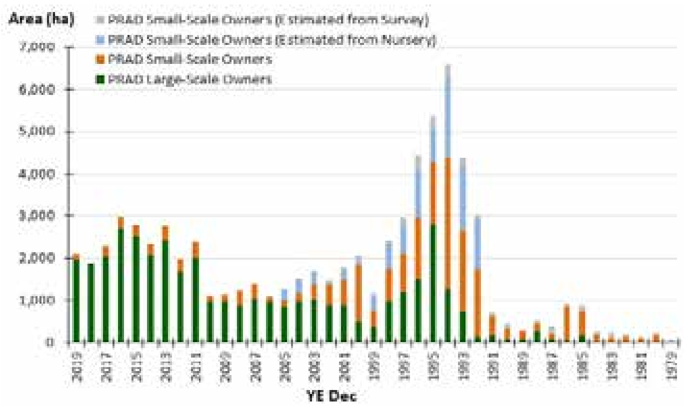


Figure C7 – Age-class distribution by MPI region (North Island) — radiata pine

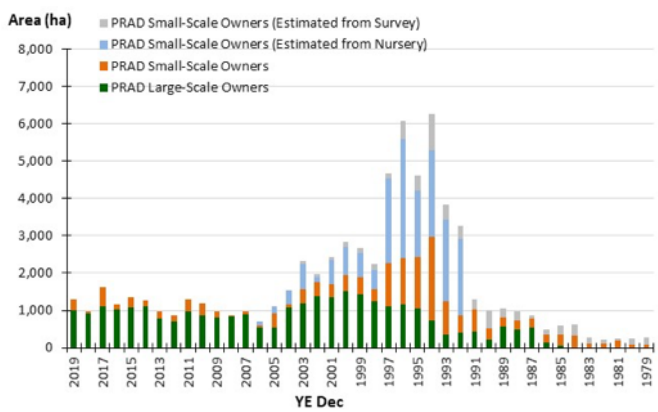
Nelson



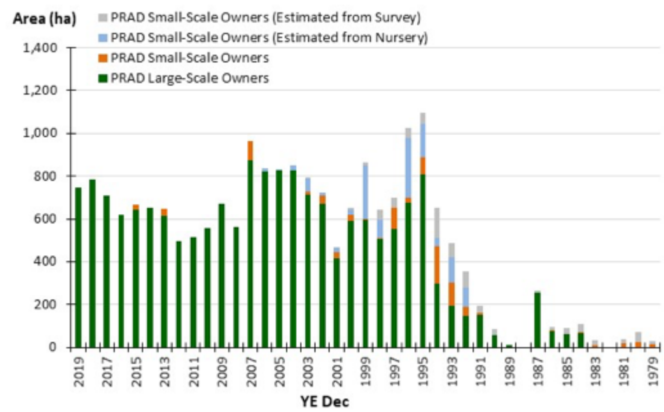
Malborough



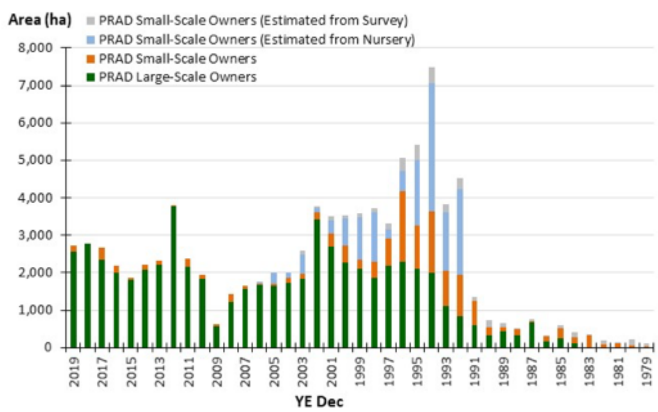
Canterbury



West Coast



Otago



Southland

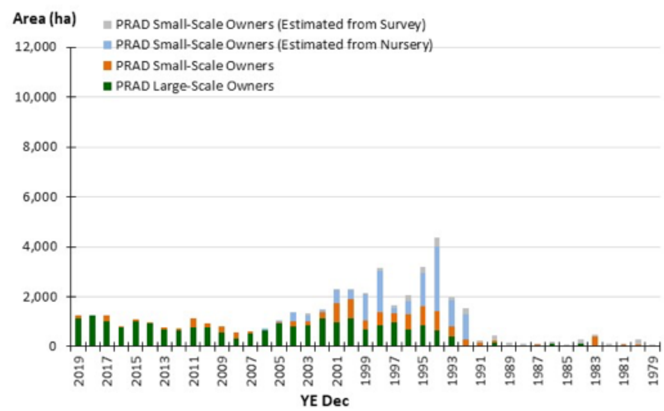


Figure C8 – Age-class distribution by MPI region (South Island) — radiata pine

MPI Region	Average Age of Forest Stock (Years)	% of NZ Total Area of Radiata Pine	Forest Age-Class Distribution	Existing Wood Processing Facilities using Low Grade Logs or Forest Residues	Export Port	Planned Facilities
Northland	15.9	12%	Abnormal	Juken New Zealand Ltd - Triboard and veneer mill (Kaitaia); Marusumi Whangarei Company Ltd - Woodchip exports (Portland); Mt Pokaka Timber Products Ltd – Sawmill and roundwood (Kerikeri); Croft Poles – Roundwood (Whangarei); Waipapa Pine Ltd – Sawmill (Kerikeri)	Marsden Point	No
CNI	15.1	35%	LGE - Normal SML - Abnormal	5 major pulpmills: - Oji Fibre Solutions (Kinleith) - Oji Fibre Solutions (Kawerau) - Norske Skog (Kawerau) - Whakatane Mill Ltd (Whakatane) - Ernslaw One Ltd's subsidiary - WPI International (Karioi) Kopine Ltd - Particleboard (Kopu) Laminex NZ – Particleboard (Taupō) Nature's Flame – Wood pellets plant (Taupō)	Tauranga	Particleboard mill (Kawerau); Expansions: Red Stag and CHH Woodproducts Kawerau
East Coast	17.8	10%	LGE - Normal SML - Abnormal	Small-sized sawmills	Gisborne	Particleboard (Pre-feasibility stage only)
Hawke's Bay	17.8	8%	LGE - Normal SML - Abnormal	Pan Pac Forest Products Ltd - Pulpmill (Napier)	Napier	No
SNI (East)	18.7	4%	Abnormal	Small/medium-sized sawmills	Wellington	No
SNI (West)	21.1	4%	Abnormal	Small/medium-sized sawmill; Some pulplogs go to WPI International's Pulpmill at Karioi	Wellington	No
SNI (West-Taranaki)		1%	Abnormal		Taranaki	No
Nelson	15.5	6%	Normal	Nelson Pine Industries Ltd - MDF plant and LVL plant (Nelson); Azwood Energy - Wood pellets plant (Nelson)	Nelson	No
Marlborough	16.7	5%	LGE – Normal SML – Abnormal	Small-Medium sized sawmills	Picton	Woodchip export (Pre-feasibility stage only)
Canterbury	19.6	5%	LGE - Normal SML - Abnormal	Daiken NZ Ltd - MDF plant (Rangiora) City Firewood – Firewood (Christchurch)	Lyttleton	No
West Coast	14.6	1%	Mostly planted in the 90s	Small-sized sawmills	No (via other regions)	No
Otago	17.0	6%	LGE - Normal SML - Abnormal	Small/medium-sized sawmills	Dunedin	No
Southland	17.6	3%	LGE - Normal SML - Abnormal	Daiken Southland Ltd – MDF plant (Gore); Niagara wood pellet plant (Invercargill)	Bluff	No

LGE = large-scale forest owners, SML = small-scale forest owners

Table C6 – General overview of radiata pine resource and wood processing, by region

APPENDIX D: MEETING INVESTOR EXPECTATIONS

Stages In Capital Sourcing

Before discussing where the capital is likely to come from to fund an investment plan, it is important to clarify the form of capital which is appropriate (e.g. debt versus equity). This is particularly relevant when we are dealing with long time horizons, and where the risk profile of technologies changes over time.

Given most investment in forest products tend to be capital intensive, there is an incentive to use debt financing to reduce the overall cost of capital and raise the return on equity. However, it is important to prudently limit the use of financial leverage (the use of debt) so that it matches the risk profile of the project. This is especially the case in the early stages when there is technology risk and the future cash flows are particularly uncertain. As a result, it is most difficult to secure financing for the first commercial project where the technology risk is highest.

Based on global experience, some form of government capital support is required to construct the first small-scale commercial plant (i.e. Plant #1) which deploys a transformational technology in the bioproducts space. Grants on the order of 20% of total capital expenditure are typical, and seldom is more than 30% long-term debt used. Greater financial leverage at this early stage is generally not prudent considering the uncertain future cash flows.

Other salient points to note are:

- While developers will call this a small-scale commercial plant, it can often also be seen as a large-scale demonstration plant.
- The higher the perceived risk, the greater the grant support required. In some cases, some form of government support or guarantee is also needed to secure the long-term debt.
- The key sources of capital are:
    - government development banks (often in partnership with corporate banks) for the long-term project debt
    - strategic investors, high net worth families (family offices) or private equity funds for the equity
    - governments for the grants.
- Strategic investors are generally corporations which have a unique interest in the project because it may help them address a strategic problem. Unlike investors with primarily financial motivation (financial investors), strategic investors can often contribute technical and market expertise in addition to simple capital. They also generally have a longer-term time horizon than financial investors. The most relevant strategic investors in New Zealand are likely established companies in the forest, petroleum, chemical, polymer, steel, and transportation industries.

The second commercial-scale plant (i.e. Plant #2) is typically larger (but still below optimal scale) and has incorporated some of the key learnings from Plant #1.

Other salient points to note are:

- The capital can often be financed by maintaining the same share of equity (e.g. ~50%) and substituting long-term debt for the government grants.
- The private debt providers may still require some form of favourable terms or government guarantees.
- The key sources of capital are:
    - government development banks in partnership with corporate banks for the long-term project debt.
    - strategic investors, high net worth families (family offices) or private equity funds for the equity.

An example of such a plant is AE Cote Nord's ~CAD $75 million investment in Quebec to produce bio-crude oil. A much larger (but not perfect) example is Metsa Fibre's EUR €1.2 billion project in Finland which combined the construction of a new pulp mill with various bio-product technologies that have not yet been fully commercialised (see **Metsa Case Study** in **Chapter 4: Implementation**).

Plant #3 and above should be at full commercial scale and completely optimised, and the financing should be weaned off direct and indirect capital support from the government. Provided the other key sources of risk are mitigated (e.g. feedstock & market risk), a debt-to-total-capital ratio of 65% is reasonable for bioproduct projects.

Other salient points to note are:

- By this stage, the overall risk profile of the project should be approaching that of more mature manufacturing facilities and, ideally, infrastructure-like investments.
- Projects may start to qualify as clean infrastructure – an emerging asset class which is highly favoured by the biggest sources of capital. Investors in clean infrastructure focus on low-risk projects which have a light environmental footprint and generate an acceptable financial yield or dividend.
- Examples of existing clean infrastructure projects are:
    - renewable power projects
    - transmission lines to carry green electrons
    - facilities for storing and transporting low carbon fuels.
- These investors are looking for infrastructure-like risks and returns and, as a result, the associated cost of equity is significantly lower.
- The key sources of capital are:
    - corporate banks and private debt funds for long-term project debt
    - private equity funds, public equity markets and retained earnings for equity
    - pension funds and sovereign wealth funds for the full capital structure
- As indicated above, it can be expected that strategic investors will be the primary source of equity capital for Plants #1 and #2. However, not all potential strategic investors have common attitudes to this. When it comes to innovation, a common refrain in the global forest industry is the desire to be 'first to be second', and thus avoid taking high risk from being first. This is typical in capital intensive industries, however, in practice, if organisations are not actively involved in new technologies, they are generally slow to see opportunities evolve. As a result, they may become 'first to be sixth' when it comes to adopting technologies. This means that they are adopting new approaches simply to keep up with their leading competitors, instead of getting ahead of them. This may not be a problem in periods when technological change is muted, but it is a bigger issue during times of disruptive change.
- One can identify 'continental leaders' when it comes to innovation related to bioproducts in the forest industry. The following are candidates for that title:
    - UPM in Europe
    - Suzano in South America
    - Georgia Pacific in North America
    - Itochu in Asia.

Within this hierarchy, the leading strategic investors in Europe and South America appear to be ahead of their counterparts in North America and Asia.

Note that venture capital (VC) is unlikely to play a meaningful role in the development of the bioeconomy in New Zealand. The reason is that VCs are not generally well suited when there is a combination of high risk, high capital intensity and longer time horizons – which is inherent in many bioeconomy projects which focus on using woody biomass. This is because VCs focus mostly on equity investments and have limited time horizons – typically a VC fund lasts only 10 years from first investment to last realisation. This is also an important reason why governments have a role to play in financing the early developments in bioeconomy projects.

Public equity markets are not a good source of capital for earlier stage bio-product companies. One reason is that there are material direct and indirect costs associated with becoming and remaining a publicly traded company. Public markets are also vulnerable to confidence swings among investors, which drive listed companies to produce frequent, positive results. For long-term investments, long periods of silence can be expected which risks the stock being ignored by analysts and under-valued by the market.

As a general guide, bio-product companies should only consider listing on the public markets (via an initial public offering or IPO) after they have at least two commercial plants in operation, and several more in the pipeline. This helps maintain the company's profile in the public equity market by providing a more frequent and dependable flow of news. By that stage they also tend to be large enough to cover the additional cost of being a public company. There is also precedent within New Zealand for infrastructure-like stocks to be treated as blue-chips (with large long-term holdings by institutional investors), following the IPOs of several government utility companies in recent years.

Although they have historically been the largest private investors in New Zealand's commercial forestry, the landscape of Timber Investment Management Organisations (TIMOs) has changed in recent years with contractions in number and changes in focus. It is unsure whether they will now be a significant source of capital for the forest sector's transformation. TIMOs generally manage capital on behalf of large institutional investors who are seeking stable long-term returns (i.e. yield) through investments in the ownership and management of forest land. When these institutional investors allocate part of their capital to be managed by specialised funds (such as TIMOS), they typically restrict the fund managers to stay within their narrowly defined asset class. They then try to optimise the mix of assets in the overall portfolio.

Historically, this strategy has worked quite well with TIMOs operating in New Zealand. Given the strong log prices offered in offshore markets in Asia, there has been limited incentive to consider investment in wood processing, or to change their marketing strategy and divert timber to domestic processors.

Despite the above reasons for not engaging in the transformation of New Zealand's wood processing sector, TIMOs should not be ignored as a potential source of capital and assistance in New Zealand. One of the key reasons is that there are arguably synergies to be captured by managing across asset classes (i.e. forest land and wood processing) which would enhance the return of TIMOs. A good example of this is illustrated in the case study: New Forests Pty Ltd: Australian experience of a new kind of TIMO in the Implementation Chapter. It should be noted that New Forests is the third largest TIMO in New Zealand, and already operates a medium-size sawmill in the country.

A Note Of Caution

While there have been some clear success stories in green investment (e.g. Solar City), the global clean technology sector as a whole has not generated attractive financial returns[36]. This is especially the case for those involving advanced bioproducts (e.g. Kior). As a result, it is unlikely capital will be committed to transforming New Zealand's forest sector unless a business case is sufficiently attractive, credible, and clearly articulated.

According to the International Institute for Sustainable Development (IISD), three of the reasons that Canadian clean technology firms are generally unprofitable are:[37]

- Emerging firms are struggling to operate in the low-carbon economy, where prices for the commodities they replace – including energy derived from oil and gas – are volatile; and where prices for the pollution they address – such as carbon emissions – remain low and are also subject to volatility.
- Regulators assume low innovation in setting environmental standards.
- Public infrastructure investments often predetermine how products and services (e.g. electricity, transportation) are delivered, and procurement criteria stipulate how solutions should be delivered; in doing so, they often tilt the playing field away from innovation and toward legacy solutions.

The same challenges would seem to exist in New Zealand.

It is encouraging that some strategic investors are working with the financial community to develop new ways of financing the bioeconomy.

A good example of this is the **Case Study: UPM-Kymmene** – Creative financing linked to the environment. To help finance its transformation agenda, in March 2020 UPM signed a EUR €750 million revolving credit facility with a margin tied to long-term climate targets and biodiversity.

Investment Framework

The lens through which investors view investment

Large-scale, long-term investors have a special lens through which they view investment. The lens is not consistent between investors, and the underlying assumptions are made with varying degrees of objectivity, but there are common elements throughout the industry.

To align with the worldview of these investors, a specific framework should be adopted by New Zealand. The following approach was developed to guide investment decisions by multinational companies, but it is equally applicable for use by MPI, MBIE or other investment attraction agencies. We recommend a framework with five key elements:

1. **Strategic Criteria**: any project under consideration must meet the strategic goals of the coordinated approach across New Zealand (i.e. be consistent with its vision and strategic plan).
2. **Financial Criteria**: clear financial criteria should be put in place so that projects can be assessed objectively and comparatively, with a common set of assumptions.
3. **Technology Criteria**: a clear boundary should be established regarding technology readiness (i.e. a minimum which would eliminate very early-stage technologies which have longer timeframes and higher risk – typically described by the well-defined Technology Readiness Level (TRL)).
4. **Risk Criteria**: well documented assessment of risk is needed to inform the overall decision on the project, with risk being explicitly incorporated into the financial analysis.
5. **Pathways Assessment**: calculations should be done of financial metrics (e.g. Return on Capital Employed (ROCE), etc.) for all projects based on a consistent set of assumptions; this explicitly recognises that the overall capital budget is always constrained.

The starting point of an investment analysis is to quantify the cash flow streams over the life of the project, and clearly identify the key sources of risk. The latter has become particularly important in recent years where there is an abundance of capital at the global level, but it is quite risk averse.

The Project Consortium, specifically through FPInnovations and Nawitka Capital Advisors, has developed an analytical framework for evaluating bioeconomy projects. It considers the various sources of risk to quantify a 'risk premium' which is then incorporated into the overall financial analysis.

When assessing investments in bioeconomy projects, the main types of risk are:

- **feedstock risk**
- **technology risk**
- **construction & commissioning risk**
- **market/merchant risk**
- **regulatory risk**
- **overall management risk**

Once the perceived risks of a specific investment opportunity are identified, the next steps are to quantify the risks and then identify ways to mitigate them. The proposed risk framework within the overall investment framework

UPM Kymmene

Case Study

Creative financing linked to the environment

Finnish UPM-Kymmene Oyj (UPM) is the largest forest products company in Europe and operates across six business areas including biorefining and energy, employing 18,700 people globally with annual sales of EUR €10.2 billion.

In March 2020, UPM announced it was among the first companies to link the pricing mechanism of a syndicated Revolving Credit Facility (RCF) to both biodiversity and climate targets.
UPM will have its repayments on the EUR €750 million credit facility linked to its performance against biodiversity and climate targets.

It has outlined two key performance indicators that will affect its finances:

- Achievement of a net positive impact on biodiversity in the company's own forests in Finland.
- A 65% reduction in CO2 emissions from fuels and purchased electricity by 2030 compared to 2015 levels.

The five-year facility has two one-year extension options.

UPM has used BNP Paribas, a French banking company, as a sustainability coordinator for the RCF.

"Linking the sustainability performance to the business's finances will demonstrate the importance of responsible business practices to our long-term value creation", says UPM chief financial officer Tapio Korpeinen. *"UPM is committed to achieving a net positive impact on biodiversity and we have developed indicators and methods to monitor it."*

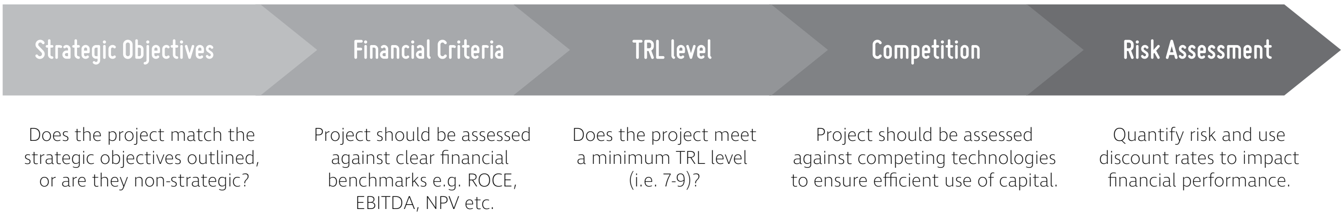
UPM uses raw materials originating only from sustainably managed forests where biodiversity is secured. It carries out and develops sustainable forestry operations and safeguards the biodiversity in its own forests through its biodiversity programme (established in 1998) that covers environmental guidelines concerning operational activities, forest conservation and collaboration projects with stakeholders.

UPM is committed to the UN Business Ambition for 1.5°C and the science-based targets to mitigate climate change. It has moved to significantly reduce its CO2 output by 2030 following other Finnish companies in response to the Finnish government's ambitious target of net-zero carbon emissions by 2035.

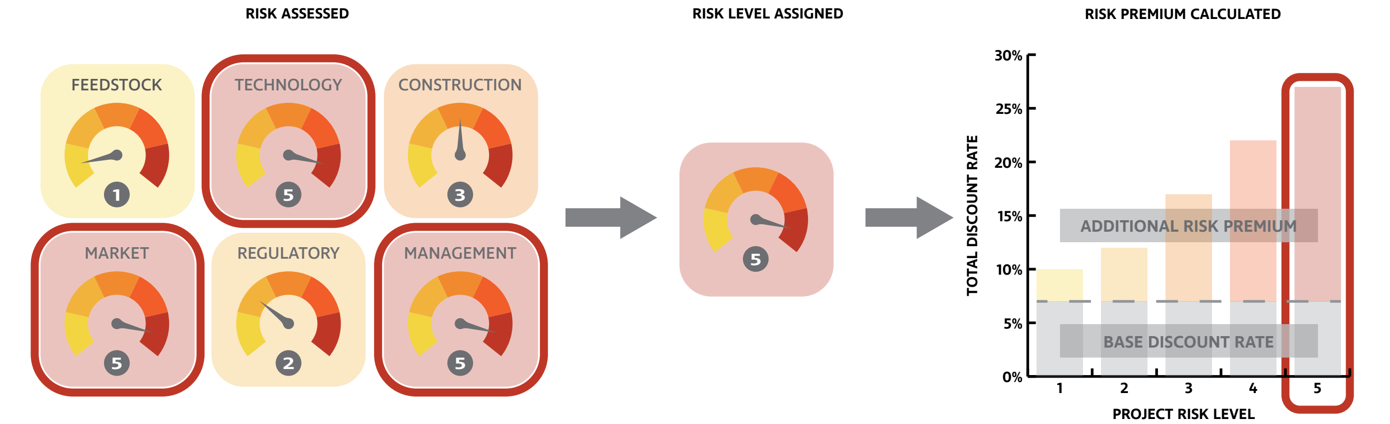
is designed to follow a structured path to measure project level risk. In the framework, each risk can be assessed, according to specific guidance, and assigned a numerical rank. The rank then corresponds to an appropriate risk premium that accounts for the risk.

As illustrated in **Figure D1**, risk is explicitly incorporated into investment decisions by adding a ‘risk premium’ to the base discount rate used in the financial analysis. For example, using a base discount rate of 7%, the additional estimated risk premiums could range from 3-20% depending on the perceived risk. In that case, the discount rate to be used in the financial analysis could range from 10% (7+3) to 27% (7+20). These discount rates reflect the cost of capital used in calculating net present value, and the expected returns that investors will look for.

Figure D1 – Investment framework



Risk assessment



A Consortium-developed analytical framework assesses six key risk types: feedstock risk, technology risk, construction & commission risk, market/merchant risk, regulatory risk, and overall management risk.

Highest category risk level is applied to the project.

Risk premium associated with risk level is used in financial analysis. Total discount rate is a combination of base discount rate, and an additional premium proportional to risk.

To use a real example, forest land is arguably the most capital-intensive segment of New Zealand’s forest sector, and it is perceived as a low-risk asset. As a point of reference, based on conversations with Timber Investment Management Organisations (TIMOs) active in the country, their expected post-tax returns are roughly 7%. This is consistent with a 600-700 basis point premium over the yield on ten-year government bond yields in the U.S. (which was 0.63% in late April 2020). Forest land investments in New Zealand are believed to command roughly a 2% risk premium over those in the benchmark southern USA due to lower liquidity, higher volatility due to export exposure, and currency and tax issues.

Note that the risk premium is set by the highest (as opposed to the average) risk rating associated with the various sources of risk. Taking an average of the individual risk premiums is not recommended because it could lead to an averaging out of the 'show-stoppers' (e.g. a very high merchant risk associated with the lack of a market), which is undesirable.

Once the risk rating exercise is completed, various financial performance metrics can be calculated (e.g. Net Present Value (NPV), Return On Capital Employed (ROCE), Return On Equity (ROE), capital expenditure/EBITDA, etc.), and the bioeconomy projects can be assessed against the five criteria in the investment framework highlighted above. This is illustrated in **Figure D1**.

This Risk Framework should be employed in Stage 2 of this project as a first step in conducting the financial analyses for a range of competing projects.

Key sources of risk

To develop the business case for investing, it is important to gain some high-level understanding of each of the sources of risk identified above, and how they can be mitigated.

Feedstock risk

Given the forestry supply chain is unfamiliar to most investors, it is seen as a unique risk associated with many bio-product investments. Furthermore, it is often critically important since the delivered cost of biomass typically accounts for 50-60% of the variable cost of producing bioproducts.

The concern is further amplified in New Zealand where around half of the annual harvest is exported to China in the form of logs (thus log prices are subject to greater than normal trade risk). Other key points to note from an investor's perspective are:

- Lenders typically require a detailed regional feedstock supply study. Typically, they would like to see 2-3 times more volume available within the catchment area than is required. They also look for long-term supply agreements (with fixed pricing if possible) to mitigate the risk.
- Some equity investors prefer long-term wood supply agreements in which the delivered cost of the wood is tied to the prices of the product being produced.
- It is possible to mitigate the feedstock risk by ensuring wood suppliers have an equity stake in the processing plant. This serves to align incentives.

Technology risk

Most of the technologies in carbon-reducing biomass conversions, as targeted in this report, have yet to be fully commercialised, so technology risk is quite high in the minds of prospective investors. This is particularly true for traditional project debt financiers who have a strong bias against technology risk. As a result, it is important for project developers to accurately gauge the technology readiness level (TRL) associated with their projects and mitigate the associated risk where possible.

Some of the key steps developers can take to mitigate technology risk, and thus improve their access to capital, are:

- Do not stretch too far in moving from the demonstration plant to the first commercial plant.
- If possible, partner with a well-established technology company which has experience in the space.
- Explore technology risk insurance policies from experienced financiers (e.g. Munich Re, New Energy Risk). Such policies guarantee a level of production sufficient to meet debt service, or the warranty obligation of the technology provider. The insurance premium depends critically on what is insured and over what period of time, and is often equivalent to 5-8% of capital cost (i.e. it is quite expensive).

Construction & commissioning risk

Advanced bio-product plants can be quite large and complex, so construction and commissioning risk is a concern. To minimise the capital at risk, there is a clear advantage to making investments on brownfield sites to take advantage of existing infrastructure. Before approaching investors, developers should get cost estimates produced by a Front-End Loading engineering firm (ideally FEL-3, the third and final phase of engineering and design estimation) to accurately gauge the magnitude of their exposure.

To minimise the construction and commissioning risk, investors will want the developer to:

- Employ a project management team which has experience in deploying the type of technology in question. This could include an Engineering, Procurement and Construction (EPC) contractor with a strong track record in the space to be engaged. If a developer engages an EPC contractor, they should ensure that a fixed-price contract is in place and that there is clear language around:
    - project delays and specific liquidated damages
    - how changes to the work are handled & related responsibilities
    - EPC contractor and original equipment manufacturer (OEM) warranty obligations
- Hire a third-party engineering consultant which will be engaged throughout the construction and commissioning process to represent the interest of the lender.
- Consider purchasing insurance policies related to construction and commissioning. There are various providers of such policies (e.g. IMA), and they typically cover: builder's risk; delay in start-up; equipment breakdown; testing/commissioning; business interruption; and catastrophic loss.

Market and merchant risk

One of the more important forms of risk relates to market and merchant risk – the risk of not selling the product at the expected price. To assess this risk, it is necessary to understand the market forces that will influence the success of the project. A useful way to do this is to employ Porter's five forces framework which entails an assessment of:

- bargaining power of suppliers
- bargaining power of customers
- threat of new entrants
- threat of substitutes
- competitive rivalry between existing players

For commodity products, this will include an assessment of the plant's cost relative to the rest of the industry.

From an investor's perspective:

- Project debt financiers will try to manage this risk by requiring long-term off-take agreements. They do this to obtain a guaranteed margin for the project and minimise the probability of default. While this may be possible to approximate in the regulated power market, it is less feasible in most bio-product markets.
- Equity investors will be more inclined to consider market diversification strategies or employ hedging strategies with financial instruments where applicable.

Regulatory (sovereign) risk

The business case for many low-carbon products depends on some form of government action to send a meaningful price signal for carbon reduction. As a result, regulatory risk is generally higher for the emerging bioproducts sector than other parts of the economy. This risk is compounded by the fact that bioproducts are often costlier to produce than their fossil-based counterparts, and the life of the asset is typically much longer than the political cycle. Government inconsistency is a common issue which make investors justified in being concerned.

Some of the key strategies investors can follow to mitigate regulatory risk are:

- focus on jurisdictions in which there is a strong bi-partisan support for the intervention, and in which there is not a heavy financial burden on the public treasury
- target products that are supported more by compliance measures than direct subsidies since the former tend to be stickier and less transparent
- produce and sell in different jurisdictions
- develop a long-term plan to produce products that are not dependent on government regulations & policies.

Overall management risk

To some extent, this risk relates to the particulars associated with individual companies. Almost all earlier stage bio-product technology companies have thin management teams and are chronically short of cash – it is the nature of the sector.

To identify this risk, it is useful to ask the following types of questions:

- Has the senior management team done this type of thing before?
- Do they have experience in developing, financing, constructing & operating a commercial size plant or, if not, are there potential partners and/or advisors in place that could provide this expertise?
- What are the incentives of the senior management team, and are they aligned with the investors?

APPENDIX E: FUTURE SOCIAL SYSTEMS, MARKETS, NEEDS AND TECHNOLOGIES

A scanning exercise has been used to understand future challenges, opportunities and risks that will influence the New Zealand planted forest and wood fibre industry to 2045. The major trends on the horizon were established and the implications in terms of both opportunity and risk were extrapolated.

A STEEP (social, technology, economic, environment and political) framework was used to guide the search for issues. STEEP scanning is a global standard method used in foresight and strategy development.

The analysis determined the drivers of change in both the international and New Zealand landscapes and their implications for wood fibre markets, businesses, industry, and production, in a 20-30 year timeframe.

The wood fibre markets of interest were biofuels, bioenergy, biochemicals, biopolymers, solid-wood and engineered wood products.

The analysis collectively considered megatrends – which may have an impact across societies, industries, and economies – and macro trends, which have a specific impact on the New Zealand planted forest and wood fibre industry. This provided a broad framework of forces that may influence our future, which could then inform the analysis of technology/processing opportunities in a 20-30 year horizon.

Trends	Implications
Society	
Demographic change: Global population will reach 9.8 billion in 2050 but growth will be unbalanced, Europe and Japan's populations will shrink and age. India and China's populations will grow to 1.7 billion and 1.6 billion, respectively. Significant ageing in the developed economies and China. Population growth and ageing in NZ: There is a 95% probability that the NZ population will increase from 4.94 million in 2019 to between 5.29 million and 6.58 million in 2043 depending on migration levels, with 25% aged over 65.	Ageing of the skilled and semi-skilled workforces in many economies. Productivity will drive economic growth in developed economies. Demographic pressures will lead to increased scarcity of non-renewable and renewable resources, demand for more efficient utilisation of residues. South-south trade flows continue to increase.
Urbanisation: By 2030 two-thirds of the world will live in cities. Social impacts of this will include: the rise of single people; later parenting and smaller families; better education; an expanding middle class; better connectivity; high costs of housing; pressure on infrastructure; and pollution.	Smart cities. New infrastructure, building materials required for high density building and construction. Conflicting interests and attitudes – the widening urban/rural divide; varying attitudes to land use change; increased awareness of environmental footprints to reduce urban pollution.
Inequalities and income disparity	Rising populism and disaffection, trade and tariff wars increasing, geopolitical and socioeconomic risks; escalating market uncertainty and volatility. Reduction in middle classes in the USA and Europe, potential loss of productivity and global competitiveness. Affordability an issue for many consumers.
Value-based consumption: Rise in ethical, minimalist, consumers buying sustainable, purposeful, and local products. Empowered customers with strong drivers for value-based consumption. Dematerialisation.	Greater willingness to pay more for sustainable and eco-friendly products. Declining consumption/capita in the developed economies. Mounting consumer expectations around social conscience and corporate ethics. Demand for industries that minimise waste generation, are technically and economically feasible and environmentally friendly Investors demand circular solutions and sustainability.
Rising importance of public and community opinion; increasing connectedness	The forest industry's social license to operate impacted by public and community opinion on several issues including land use change, air and water quality, logging residues, fire hazards, etc. Demand for integrated land use options. In some NZ regions, lifestyles regarded as more important than economic development, leading to tighter air and water quality standards. Greater value and recognition of the ecosystem services of forests, including carbon.
Expanded and unregulated information space	Individuals more susceptible to misinformation; forest industry needs to continuously update a truthful and compelling narrative to proactively shape the debate on the sector.

Trends	Implications
Consumers concerned about the health impacts of products they consume and how they affect the natural environment over their lifetime.	Demand for sustainable solutions to plastic packaging materials Requirement for industry transparency, from fibre composition (for composites), fibre origin, environmental and social footprint, and LCA. International and domestic industry commitment to 100% reusable, recyclable or compostable packaging in their New Zealand operations.
Iwi land and forest ownership	Significant levels of Maori participation and governance in all aspects of the NZ forest industry. Maori business models mainstream in forestry sector.

Technology

Industry 4.0 (the Fourth Industrial Revolution), the application of a range of technologies to create advanced manufacturing systems. Accelerated technological change through automation, the Internet of Things (IoT), intelligent connected devices, virtual, augmented, and extended realities, artificial intelligence (AI), 3D- and 4D-printing, data analytics, big data, cloud-enabled ecosystems, blockchain and cybersecurity.	Transformation of industries, value chains, end markets and consumption patterns. New business models required: entrepreneurs and start-ups have advantage over established businesses.
Advanced digital technologies extending to the entire supply chain.	Adoption of advanced analytics; improvements in manufacturing processes, more accurate demand forecasts leading to improvements across the entire sales- and operations-planning process, improvements in transparency/traceability – an increasing demand of consumers. Speeding-up of innovation, enabling a more efficient "idea-to-market" process that results in faster industry responses to market and customer demands.
Adoption of advanced analytics; improvements in manufacturing processes, more accurate demand forecasts leading to improvements across the entire sales- and operations-planning process, improvements in transparency/traceability – an increasing demand of consumers. Speeding-up of innovation, enabling a more efficient "idea-to-market" process that results in faster industry responses to market and customer demands.	Use of microorganisms to break down biopolymers to produce hydrogen gas
Advances in the understanding of wood as a naturally occurring, fibre-reinforced biocomposite material.	Higher performing biocomposite materials such as structural biomaterials with exceptional strength, toughness, and with greater dimensional stability e.g. wood composites with a specific strength higher than most structural metals.
Isolation of woody fibres for biocomposites.	Different combinations of isolated fibres with new matrix materials leading to higher performing wood composites (e.g. Woodforce™, hemp-based composites) which are potentially stronger than non-biobased, fibre-reinforced materials such as glass fibre composites.

Trends	Implications
Isolation of the chemical constituents of woody material in the form of micro-fibrillated cellulose or nano cellulose.	Developments in new micro- and nano-fibrillated, cellulose-based biomaterials based on utilising the relative strength of cellulose, which is stronger than glass fibre. Use of micro-fibrillated cellulose to produce viscose, a cloth fibre made from wood.
Improvements in chemical pre-treatment techniques for biofuels and biorefineries e.g. developments in the enzymatic hydrolysis of lignocellulosic substrates	Reduction in production costs of cellulosic biofuels
Advances in sustainable packaging solutions	Packaging solutions based on multi-layer structures using cellulose nanofibril (CNF) films and bio-based plastics which compensate for the hydrophilic properties of cellulose by combining with a water tolerant material (although currently production and investment cost constrained). Foam-formed, cellulose fibre-based materials as cushioning material
Developments in the analysis and identification of novel extractives from unique flora such as New Zealand tōtara for foodstuffs, flavouring and medication using advanced techniques such as meta-analysis of data, combined with supercritical CO2 extraction to isolate key compounds.	New, novel food additives and medicinal products
Additive manufacturing technologies: 3-D printing of wood	Improved wood designs and high performing wood-based materials such as lighter weight, moulded materials, and key packaging componentry.
Additive manufacturing technologies: 4-D printing of cellulose and hemi-cellulose based materials; smart sensors.	Design of cellulose-based material that are responsive to humidity or other environmental triggers.
Artificial intelligence, automation and robotics in forest silviculture and harvesting system; developments in drone technologies (UAVs) and remote sensing systems (LiDAR).	More accurate forest mapping and inventory assessments; precision spraying with UAVs. Increased quality and reduction in costs of forest management decisions. Improvements in worker safety in silviculture and harvesting. Increased requirements for flexible, specialised, skilled labour.
Advances in technologies for modifying wood properties of radiata pine solid-wood, such as thermally treated wood, acetylated wood, supercritical CO2 treated wood and supercritical CO2 dewatering followed by improved drying schedules.	Improvements in stability, durability, and colour of radiata pine and some other species; extending market size and value of solid-wood products.
Improvements in genetic gain from breeding and biotechnology	Improvements in radiata pine growth rates, quality, uniformity and resilience to pests and diseases. Improvements in breeding of specialty wood species; improved opportunities for species diversification.
Improvements in the efficiency of harvesting and log sorting systems; integrated forest residue harvesting systems.	Improvements in the cost, value, and efficiency of the overall biomass supply chain.
Safer nuclear reactors: e.g. accident tolerant fuels that are less likely to overheat	Safer, more cost-effective nuclear power.
Improvements in lithium ion batteries: utility scale storage of renewable energy	Declining costs of wind and solar power technologies.
Improvements in fuel cell technologies and associated fuelling systems	Reduction in costs and greater uptake of hydrogen-fuelled vehicles.
Improvements in battery technology, design architecture and manufacturing systems of electric and hybrid vehicles.	Reduction in costs of electric and hybrid vehicles.

Trends	Implications
Economy	
Risk of global economic recession from COVID-19 and its aftermath; downgraded forecasts of economic growth, rising unemployment and uncertainty about the timing and extent of economic recovery. Continued risk of other pandemics influencing global economy before 2045.	Decline in consumer purchasing; reduced demand for aviation fuels, reduced energy consumption, disruption of complex supply chains; exposure of cost reduction strategies such as just-in-time manufacturing. Country competitiveness will be influenced by relative rates of economic recovery in New Zealand and competitor countries, and in export markets. Short to medium term restrictions in international finance to power the shift to a zero-carbon economy. Recovery efforts will focus on employment opportunities Opportunities: rationalisation of inefficient processing technologies and inefficient businesses operating in the forest sector.
Dramatic increase in levels of national debt associated with financing economic recovery measures designed to offset the negative impacts of the Covid pandemic.	Unsustainable high government debt at an international level must be paid for through the creation of unexpected inflation. In such a scenario there would be a shift in wealth from lenders to borrowers, and a shift in investor preferences from financial to real assets. Within the forestry sector two of the main beneficiaries would be owners of forest lands, and producers of solid wood products that would be consumed in buildings – the latter being the main real asset owned by most families.
Decline in demand levels for NZ primary wood product exports in traditional markets, slowdown in exports.	Heightened awareness of NZ reliance on China market, and need for diversification of markets Reduced finance for NZ R&D, biosecurity, fire prevention programmes from the Forest Growers Levy Trust.
Continued rebalancing of economies and markets; shift of economic activity south and east, to cities within these markets.	Asian markets will continue to grow in importance for New Zealand exporters.
China's economy continues its shift towards a consumption-based model, and the region's connectivity expands – through integrated cyber-physical systems, and also in infrastructure such as China's Belt and Road Initiative.	Trade, investment, and capital flows are increasingly intra-Asia Pacific, causing the global economy to reshape. In all manufacturing industries, the competitive landscape will change accordingly, and worldwide value networks will need to evolve to upweight presence in Asia-Pacific.
International oil price volatility; low carbon prices. NZ's economic risk position from reliance on imported oil, limited oil exploration and development (no new offshore oil exploration permits since 2018), with NZ fully integrated in the international trade of oil and oil products.	Heightened concerns about energy security Commercial viability of biorefineries compared with petrochemical refineries dependent on international oil prices. Commercial viability of NZ-produced biofuels will be dependent on government interventions (e.g. carbon prices, low carbon fuel standards, capital subsidies).
Government incentives and reductions in costs of electric and hydrogen fuelled vehicles	Increase in electric and hydrogen-fuelled vehicle uptake and reduced demand for alternative fuels in the passenger transport sector
NZ country competitiveness low in terms of market size and innovation capability	Economic growth dependent on export competitiveness; exceptional R&D efforts and/or R&D investment models involving partnerships, licensing, or other technology access models involving offshore technology companies.

Trends	Implications

Environment

Increasing cost and disruption of climate change	Supply chain interruptions from natural disasters – fire, wind, weather events, droughts, floods, storm surges, pests and diseases. International commitments to meet global climate targets, reduce GHG emissions to achieve a climate-resilient, zero-carbon economy although uncertainty whether climate talks (COP26) will be stalled following COVID-19 outbreak. New Zealand climate change commitments under the United Nations Framework Convention on Climate Change (the Convention), the Paris Agreement and the Kyoto Protocol.
Resource scarcity	Production of more products using less resources Decarbonising energy systems Using energy more efficiently Decline in carbon-based mobility Heightened concerns about energy security
NZ ETS reforms	Reduced complexity and other barriers to forest owners being part of the ETS.
Growing acceptance of the circular bioeconomy concept, with an emphasis on recycling and reusing products at each point along the production value chain.	Demand for circular plastics, energy, and biobased products economy. Continued replacement of disposable plastic items, including expanded polystyrene (EPS) with paper-based substitutes; thermal insulation performance, providing a moisture barrier for fat, and cost being inhibitors to uptake.
New business models to establish company green credentials	Green bonds, sustainability-linked loans, and bonds
Heightened risk of forest pests and diseases	Tightening of biosecurity controls

Politics

Trends	Implications
Changes to the global powers; growing dissatisfaction in democracy; populism on the rise while on the other hand communities protesting for action and social equality. Current rules, norms and institutions are being challenged.	Changes to political and regulatory environments. Regulatory uncertainty. Reordering in global trade – China the new superpower. Increasing community engagement in NZ policy development. Political unrest leading to insecurity in oil supplies; price volatility.
Change in political agendas post COVID-19 economic shock	Changing political priorities with emphasis on employment opportunities, economic growth, national resource (energy) security.

photo courtesy of Red Stag Timber

APPENDIX F: TECHNOLOGY SELECTION PROCESS

Technology list

An initial technology list was provided by Nawitka Capital Advisors. This list has been maintained by the firm over many years and tracks numerous technologies and their progression along the development curve. This list was then added to by members of the Consortium, through discussions with stakeholders in New Zealand (both companies and research institutes), global contacts, and using internet search techniques. The focus of the technology list was to capture as many technologies as possible that could use woody biomass as a starting point.

Care was taken to ensure as many New Zealand based technologies were included in the list as possible, however, the primary concern was to ensure that the full range of global technologies was identified and included in the initial list.

The list developed included technologies that were fully commercial, as well as those at lower TRLs. Laboratory scale technologies or research projects were not included unless there was a commercial proponent actively developing the technology. The technologies included in the list covered a range of products and market targets. No attempt was made to exclude any technologies at this stage, however, established products derived from wood such as timber, engineered wood products, pulp, and paper were not included. The total number of technologies on the list was 108.

The Technology Readiness Level (TRL) framework was used to assess how far a technology was along the development curve from research to commercial implementation. This methodology was developed by NASA (the USA's National Aeronautics and Space Administration) to provide a consistent, structured approach in assessing technology. The TRL methodology ranks technologies from TRL 1 to 9.

Technology Levels 1-3 are considered 'proof of concept' technologies. Through this range, the individual components of a technology would transition from concept through to lab testing. For example, in a biofuel technology like gasification, initial lab testing on the gasification stage would be undertaken, and separate testing would be completed on gas clean-up.

As technologies transition from Levels 4-6, the various components of the technology would be integrated and tested in a more rigorous fashion. When a technology reaches TRL 6, all the components would have been integrated together and piloted.

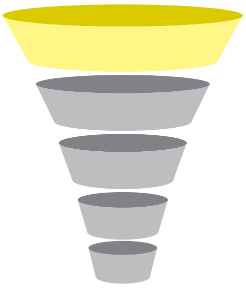
TRLs 7-9 represent the transition from a demonstration scale technology through to a fully commercial implementation. TRL 7 is essentially a demonstration scale operation which means that the technology has been deployed at a larger scale and placed into an operational setting. TRL 8 is essentially the first commercial-scale plant and when TRL 8 is proven successful, the technology can be considered at TRL 9 or a fully commercial technology.

The TRL system has been adopted by innovation agencies around the world, particularly in engineering innovation. Within the USA it has been adopted by the US Airforce and Army and the Department of Defence. The TRL approach is also used by organisations in the EU, Canada, Australia and many other countries. In New Zealand, the Science for Technological Innovation National Science Challenge uses it as part of its funding assessment.

The TRL methodology was not used to screen out technologies but to establish the timeline a technology would need before being built at a commercial scale. As an example, at TRL 7, large scale investors would expect 1,000 hours of continuous operations to prove that a technology is ready for the next scale. To get to 1,000 hours requires time to build the facility, and to do test-runs of different durations. Typically, building the facility takes 12 months, followed by 6-18 months to ramp up the facility to 1,000 hours. Therefore, it usually requires 18-30 months to get to the next TRL level. From TRL 8, time is required to build a full-scale commercial plant including time to raise funds, to complete revised engineering, to site and permit the facility, and to construct it. The total time required is therefore typically around five years.

As the Wood Fibre Futures project required the identification of technologies in the 5-10 year time horizon and then the 20-30 year horizon, it was decided to use TRL level as an estimate of which technologies would be available when. Technologies that had a TRL of 7-9 were included in the 5-10 year horizon while anything at TRL 6 or below was put in the 20-30 year horizon. Technologies were not excluded based on TRL, simply put in the longer time horizon if they had not reached TRL 7 level.

Although this is an imperfect scale (some technologies take longer, some shorter and some fail), it is a consistent structured approach. As evidence of the time it takes to progress a programme in New Zealand, Woodscape (a programme between FPInnovations, Scion and the local industry) examined many technologies as part of an economic analysis of various woody biomass pathways in 2013. Many of the emerging technologies assessed in 2013 have not yet made it to TRL 9. In fact, a large proportion of them are no longer being pursued.

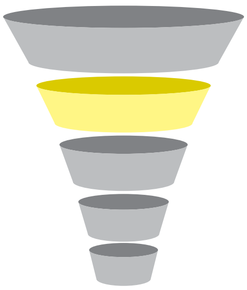


Screen 1: applicability to woody biomass

The ability of technologies to use woody biomass was the primary goal of the study and hence was the first screen in the process. Technologies not primarily based on woody biomass were then screened out of the technology list. If a technology was listed as agnostic to feedstock, but its development was solely focused on biomass other than wood, it was either excluded (if no evidence existed of significant work with woody biomass) or its TRL was reduced to reflect that its potential to use woody biomass was further back down the development curve.

Technologies that utilised products from primary facilities (predominately from pulp and paper mills) were also screened out at this point. There has been a significant amount of development in this area that includes products such as cellulose nanocrystals or lignin adhesives. Although they are valid for potential consideration in New Zealand, the additional carbon savings from using wood processing by-products would be marginal.

The type of woody biomass was not used as a screen and could include harvest residuals, chips, bark or whitewood.



Screen 2: alignment to major emission categories

Once the technologies were split between the two time horizons, they were aligned against a projected carbon budget. The goal was to identify which technologies could reduce New Zealand's carbon emissions and which technologies would have more impact on economic development such as GDP growth, exports or job creation. Again, this criterion was used to sort technologies, not exclude them.

As described earlier, many niche technologies such as biopolymers or bioplastics would have been excluded in this step since they had little material impact on carbon reduction. However, following the COVID-19 pandemic, the Project Consortium agreed to retain them to provide the New Zealand Government with quick-to-implement economic development opportunities.

The collection of economic development projects is detailed in **Appendix D** including special mention of those which originated in, or are already engaged in, New Zealand.

In addition, **Appendix E** includes a discussion of wood-derived bioplastics and plastic composites in general, including international examples which illustrate that sector.

The projected carbon budget used was compiled from several sources to provide a current picture and projections out to 30 years (2050).

- The current carbon budget was derived from New Zealand's Fourth Biennial Report[38]. It was used as the source of 1990 and 2017 figures; it was published in December of 2019 and represented the most recent carbon emissions available.
- To project the carbon budget forward to 2050, New Zealand's projections from the Ministry of Environment were used[39].
- The data used are summarised in **Table F1**

Carbon Source (Carbon Inventory + International Aviation & Marine Fuels) - (kilo tonnes of CO2 Eq.)		1990	2017	2025	2030+
New Zealand Total		34,503	56,892	78,189	72,377
Energy		**23,786**	**32,877**	**38,506**	**36,589**
	Energy			16,591	15,333
	Transport			15,763	14,949
	International Aviation & Marine Fuels			6,153	6,307
IPPU	**Industrial Processes and Product Use**	3,580	4,969	5,699	5,568
2.C.1	Metal Industry – Iron and Steel Production	1,307	1,758		
2.C.3	Metal Industry – Aluminium Production	910	61		
2.F.1	Product Uses as Substitutes for ODS – Refrigeration and Air conditioning	-	1,397		
Agriculture		34,257	38,881	36,665	35,456
3.A.1	Option A – Dairy Cattle	5,928	13,560		
3.A.1	Option A – Non-Dairy Cattle	5,723	5,298		
3.A.2	Other (please specify) – Sheep	14,086	8,253		
3.A.4	Other livestock – Goats	197	21		
3.B.1.1	Option A – Dairy Cattle	376	1,256		
3.H	Agriculture – Urea Application	39	588		
3.D.1.1	Direct N2O Emissions From Managed Soils – Inorganic N Fertilisers	230	1,366		
3.D.1.3	Direct N2O Emissions From Managed Soils – Urine and Dung Deposited by Grazing Animals	5,138	5,435		
Waste		4,042	4,125	3,998	3,956
5.A	Waste – Solid Waste Disposal	3,711	3,725		
LULUCF		(31,162)	(23,958)	(6,680)	(9,193)
4.A.1	Forest Land – Forest Land Remaining Forest Land	(10,615)	(5,587)		
4.A.2	Forest Land – Land Converted to Forest Land	(19,434)	(16,252)		
4.C.1	Grassland – Grassland Remaining Grassland	(155)	1,215		
4.C.2	Grassland – Land Converted to Grassland	263	2,437		
4.G	Land Use, Land-Use Change and Forestry – Harvested Wood Products	(2,073)	(6,519)		

Notes:

(1) Total do not add up. Some categories are excluded in the inventory as they represent 1 company and the data is protected.

Table F1 – Projected carbon budget 1990, 2017, 2025(p), 2030 (p), 2050 (p)

The current COVID-19 pandemic has triggered many reports indicating that carbon emissions have been reduced worldwide. In addition, there have been numerous articles proposing that fiscal stimulus should be focused on improving the environmental situation. It was outside the scope of this study to address this volatile situation. However, the carbon methodologies used could easily be updated at any future time when New Zealand revises its projections.

To get a better understanding of the full opportunity, one adjustment was made to the official New Zealand figures. International Aviation & Marine Fuels was added to the projected carbon budget. This does not comply with the methodology of the New Zealand's Greenhouse Gas Inventory which is built based on UN reporting guidelines (FCCP/CP/2013/10/Add.3)[40]. However, many of the technologies included in the long list could provide products that would meet the market needs of aviation and marine industries and as a result it was important to include the opportunity in the assessment.

Once the projected carbon budget was established, the carbon emissions reported in the UN format were translated into products. To achieve this, the energy sector greenhouse gas emissions were accessed through the New Zealand open data portal. These data break down the energy sector emissions by source and fuel type.

Fuel type was important as it allowed a direct alignment between the technologies and the emissions, for example between diesel and petrol. This was not possible in the other emission categories (Agriculture, Waste, LULUCF) but as most of the technologies were not able to address emissions in these areas, or because the size of the emissions targets were already small, it was less important to break them out further. The IPPU category's subdivisions were detailed enough to identify the carbon opportunity, for example, IPPC Category 2.C.1 Metal Industry – Iron and Steel was specific enough to identify steelmaking as the primary source of carbon. Table F2 provides the breakout of the energy emissions into fuel type.

Carbon Source (Carbon Inventory + International Aviation & Marine Fuels) - (kilo tonnes of CO2 Eq.)		1990	2017	2025	2030+
New Zealand Total		**34,503**	**56,892**	**78,189**	**72,377**
Energy		**23,786**	**32,877**	**38,506**	**36,589**
	Energy			16,591	15,333
	Transport			15,763	14,949
	International Aviation & Marine Fuels			6,153	6,307
Crude Oil Refining	Oil	780	676		
Liquid Fuels	Diesel	1,522	6,979		
	Liquid Fuels Unknown	2,622	3,353		
	Regular Petrol / Petrol	2,659	5,823		
	Premium	4,628	1,765		
	Aviation Fuel	2,281	4,699	5,172	5,326
	Marine Fuels	1,304	1,239	981	981
Gaseous Fuels	Natural Gas - Transport	148	1		
	Natural Gas - Fixed (includes power generation)	5,419	7,814		
	LPG	102	15		
Solid Fuels	Coal	3,262	3,145		
	Biomass	103	143		
Fugitive Emissions		1,337	1,940		

Table F2 – Energy sector emissions by fuel type.

Once the projected carbon budget was established, the technologies were then aligned based on the emission that they could address. In some cases, a technology produced a mixture of products. In these cases, the technology was left in all relevant product categories so that it was not eliminated by poor performance in just one category. **Table F3** shows the alignment of time horizon and emission source in the Energy Sector.

Carbon Management Opportunity

Carbon Source		1990	2017			
Energy (Carbon Inventory + International Aviation & Marine Fuels)		23,786	32,877	**Commerical**	**~2025**	**2030+**
Crude Oil Refining	Oil	780	676		BTG-BTL; Envergent Technologies (Ensyn/Honeywell UOP); Licella; Valmet/Fortum	Anellotech; BDI Bioenergy; Bio2Oil; Genifuel; Highbury Energy; Nexxoil; Recenso; Renergi; RTI International; Steeper Energy; Susteen Technologies
Liquid Fuels	Diesel Liquid Fuels Unknown Regular Petrol / Petrol Premium Aviation Fuel Marine Fuels	1,522 2,622 2,659 4,628 2,281 1,304	6,979 3,353 5,823 1,765 4,699 1,239		AICHERNIG Engineering GmbH – Repotec; BioTfuel Consortium; Cielo Waste Solutions; CRI/Criterion Catalyst Company (IH2); HaldorTopsoe/TechnipFMC; LanzaTech/PNNL/Aemetis/InEnTec (Aviation); ThermoChem Recovery International (TRI)	Alphakat; BDI Bioenergy; Emerging Fuels Technology (EFT); GEFS; GoBiGas/Repotec; Johnson Matthey/BP Consortium; Kaidi; Sierra Energy; TCG Global; Velocys
Gaseous Fuels	Natural Gas - Transport Natural Gas - Fixed (includes power generation & heat)	148 5,419	1 7,814	Nexterra Energy/GE Energy	AMEC-Foster Wheelers (Wood PLC); Andritz Carbona/Technical Research Centre of Finland (VTT); Cortus; Metso;	Biokraft; Concord Blue; Highbury Energy; InEnTec; Ineratec; G4 Insights
	Natural Gas - Building Heat			Dieffenbacher; Siempelkamp	Factory Zero	
	LPG	102	15		HaldorTopsoe/TechnipFMC	
Solid Fuels	Coal	3,262	3,145	Wood pellets	Airex; Cortus; Thyssenkrupp Industrial Solutions; Torr-Coal	
	Biomass	103	143			
Fugitive Emissions		1,337	1,940	Movement to RNG could impact fugitive emissions		

Table F3 – Technology alignment with energy sector emissions

Once technologies were aligned against carbon emissions, the remaining technologies were then considered to be aligned with economic development opportunities such as GDP growth, exports, or other social values such as job creation. **Table F4** shows this split, including by time horizon.

Carbon Alignment		Commerical (TRL 9)	~2025 (TRL 7-8)	2030+ (Less than TRL 7)
Crude Oil Refining			BTG-BTL; Envergent Technologies (Ensyn/Honeywell UOP); Licella; Valmet/Fortum	Anellotech; BDI Bioenergy; Bio2Oil; Genifuel; Highbury Energy; Nexxoil; Recenso; Renergi; RTI International; Steeper Energy; Susteen Technologies
Liquid Fuels (Diesel, Petrol, Aviation Fuel, Marine Fuel)			AICHERNIG Engineering GmbH – Repotec; BioTfuel Consortium; Cielo Waste Solutions; CRI/Criterion Catalyst Company (IH2); HaldorTopsoe/TechnipFMC; LanzaTech/PNNL/Aemetis/InEnTec (Aviation); ThermoChem Recovery International (TRI)	Alphakat; BDI Bioenergy; Emerging Fuels Technology (EFT); GEFS; GoBiGas/Repotec; Johnson Matthey/BP Consortium; Kaidi; Sierra Energy; TCG Global; Velocys
Gaseous Fuels	Natural Gas - Fixed (includes power generation & heat)		AMEC-Foster Wheelers (Wood PLC); Andritz Carbona/Technical Research Centre of Finland (VTT); Cortus; Metso; Synova	Biokraft; Concord Blue; Highbury Energy; InEnTec; Ineratec
	Natural Gas - Transport	Nexterra Energy/GE Energy		
	Natural Gas - Building Heat	Dieffenbacher; Siempelkamp	Factory Zero	
	LPG		HaldorTopsoe/TechnipFMC	
Solid Fuels	Solid Fuels - Coal Solid Fuels - Biomass	Wood pellets	Airex; Cortus; Thyssenkrupp Industrial Solutions; Torr-Coal	
Fugitive Emissions	Fugitive Emissions	Movement to RNG could impact fugitive emissions		
IPPU	Metal Industry – Iron and Steel Production		Torr-Coal, Airex	
	Metal Industry – Aluminum			

GDP/Export/Social Value	Commerical (TRL 9)	~2025 (TRL 7-8)	2030+ (Less than TRL 7)
BTX (Benzene, Toulene, Xylene) Chemicals		Licella; CRI/Criterion Catalyst Company (IH2)	Anellotech; Johnson Matthey/BP Consortium
Ethanol		CRI/Criterion Catalyst Company (IH2); Enerkem	Johnson Matthey/BP Consortium; Chempolis
Methanol / DME			Air Liquide/Bioliq; GoBiGas/Repotec; LTU Green Fuels
Asphalt			GEFS
Isobutene			Global Bioenergies
Thermoplastics	Scion - Woodforce	INEOS; NZ Bio Forestry; Paptic; Stora Enso; Sulapac; TECNARO; Woodly	Attis Innovations; Advanced BioCarbon 3D; Futurity; LignoPure; Mobius; Scion - PHA and biopolymers; Scion - Reactive extrusion
Sugars		Renmatix; Sweetwater	Attis Innovations; Chempolis; Avantium
Pulp & Bio Chemicals	Sappi		Chempolis; Lixea
Lignin(1)		Renmatix	Chempolis; Avantium
Speciality Chemicals, Food, Cosmetics		Renmatix	Scion - Ligate; Scion - Bark refinery
CNC(1)		American Process Technologies	
Cellulose Nanofibrils / Microcellulose fibrils (1)			
Textiles			TreetoTextile
Modified Lumber - Decking		Scion - Furfurylated Wood	

Notes: (1) there are many technology developers in these fields however most utilise a downstream input.

Table F4 – Technologies aligned against carbon budget or economic development

An additional perspective on carbon impact was included in the analysis – carbon intensity – measured as the volume of product (e.g. crude oil, liquid fuel, natural gas, among others) that would be needed to be substituted by renewables to reduce the emissions from that product to zero. Using yields from various studies, the volume of the biomass needed to replace each was then calculated.

This analysis quickly showed that, even if all the potential wood harvest was utilised (35-45 million cubic metres), forestry can only offset a limited amount of carbon emissions.

Recognising there was a significant upper limit on the volume of woody biomass available, it becomes important to prioritise the technologies based on the efficiency with which they are able to impact carbon emissions and this became the next screen employed on the technologies.

To achieve this, it became necessary to estimate the emissions offset per cubic metre of wood consumed. To do this the emissions in the carbon budget were divided by the volume of biomass needed. In some cases, the emissions data from the carbon budget was used, while in others, especially in the IPPU categories, it was impossible to split the carbon budget by the application.

In the case of carbon emissions from steel making, insight was gleaned from New Zealand Steel's website and the Government Markets team's Evidence and Insights Branch, on coal consumed. This volume was then converted into emissions using data from the Ministry of Environment for stationary use of carbon. Although this is an approximation, it sufficed for this analysis[41].

The technology market sectors were then ranked in priority with one exception.

Residential, commercial, and industrial heat reduction did not follow this analytical approach. The key challenge is that wood can be used in construction and result in carbon sequestration (in buildings), carbon avoidance (substitution of other materials) and, if used in conjunction with net zero designs, can also reduce carbon emissions from operating building. Within the scope of this project it was not possible to estimate these emissions savings. Based on the triple effects of this activity on carbon reduction and the flow-on impact it could have on timber prices (and therefore woody biomass availability), it was decided to advance this opportunity to the selected list.

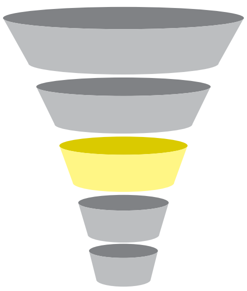
The table below (**Table F5**) shows the differences in emissions per cubic metre.

Coal replacement has the highest impact per cubic metre of biomass, however, in the previous screens, coal's low price eliminated most of the candidates as non-competitive. Only the bio-coking application for steel remained.

This screen prioritised the potential technologies for the final step.

RANKING	CARBON ALIGNMENT	EMISSIONS/M3
1	Solid Fuels – coal power / co-firing	0.57
2	Metal Industry – coking application	0.44
3	Crude Oil Refining (1)	0.38
4	Liquid Fuels	0.22-0.29
5	Natural Gas	0.01
Not ranked	Use of wood-derived products in construction	Multiple Impacts on study's aim

Table F5 – Carbon emissions per cubic metre of woody biomass

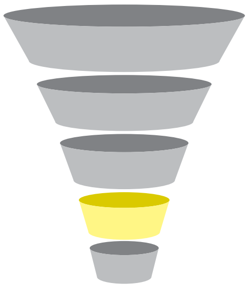


Screen 3: competitive position

The next criterion, Competitive Position, was based on the relative competitiveness of the technologies to address a market application compared to other competing technologies.

This analysis was completed at the market application level rather than the individual technology. That is, the ability of technology advances to compete with non-biomass technologies was assessed in each target product area.

For example, biopower (the use of biomass for heat, electricity and power) has been examined extensively by governments, research institutes and commercial organisations in many parts of the world. With biopower, the challenge resides in its ability to compete on cost, usually measured by Levelised Cost of Energy (LCOE). In most cases of successful biopower implementation, a feed-in-tariff was established, and a low-cost fibre supply was identified. Given the wide range of technology options (wind, solar, geothermal) available to New Zealand, the relatively small proportion of the electricity supply generated from fossil fuels, and the competition for other applications of woody biomass, the competitive landscape for biopower is extremely challenging. As indicated earlier, this target market was deemed non-competitive.



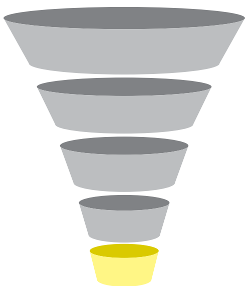
Screen 4: future uncertainty (or optionality)

One of the most challenging aspects of identifying a short list is to deal with future uncertainty. Over the next five years uncertainty is usually manageable, although quite extreme now due to COVID-19. Uncertainty expands exponentially over time which especially affects the 20-30 year time horizon. Technology developments, infrastructure changes, differences to resource forecasts, and changes in international trade are just some of the factors that create future uncertainty. The risk of not dealing with future uncertainty is paralysis.

Our approach to future uncertainty was to look at the optionality of the technology stream since optionality generally creates resilience. Optionality refers to the ability of that technology to adjust to different conditions in its marketplace. Within optionality there are two key questions that were considered:

- Is the technology option tied to New Zealand's current operating environment? For example, a Renewable Natural Gas (RNG) facility would be producing solely for the domestic marketplace as the potential for export is low. If there was a significant shift to electrification in the future, the demand for RNG might fall significantly, leaving that asset stranded. Compared to this, a biocrude or liquid fuel facility could export its products if demand patterns shifted domestically.
- Is the technology upgradable? In this case, a technology might be currently targeted for one type of commodity use but it has the potential to be upgraded to another. For example, biocrude could shift from targeting transportation fuels to biochemicals or biomaterials.

Technologies with more optionality were preferred and moved forward to the next criterion for shortlisting.



Screen 5: ability to implement

The last criterion was identifying technologies that are backed by entities that have a proven ability to implement a project. There were three questions asked of relevance to investors, both private and government:

- Is the technology provider also a 'project developer' or only a 'technology provider'?
- Has the technology provider implemented at scale?
- Is the technology provider actively working on the application?

The first question was necessary to separate companies that provide technology and equipment from companies that actively worked to develop projects. Companies that actively developed projects with proponents were favoured.

The second question was used to determine if the company had built a plant at scale (at least demonstration scale) or was currently constructing such a facility. Preference was given to companies with more experience in this area.

The third question was to prioritise companies actively working on a solution for a specific application. For example, Torr-coal is building a facility in partnership with a steel manufacturer (ArcelorMittal) to provide a coking solution, but Thyssenkrupp had no evidence that they were working on this application.

Following this seven-step process of sorting and filtering the longlist of technologies (**Table F6**), the results were clear, and are presented in **Chapter 2** in the main body of the report.

Carbon Alignment	Include on Short List	Short List	Project Developer	Equipment Provider	Facility Constructed at Scale	Facility Under Construction	Active Application
Gaseous Fuels - Natural Gas Residential Heat		Dieffenbacher		X	X		
		Siempelkamp		X	X		
		Factory Zero	X		X		
Metal Industry – Iron and Steel Production	Yes	Torr-Coal	X		X		X
		Airex	X		X		
		Cortus	X		X		
		Thyssenkrupp Industrial Solutions		X	X		
		CarbonScape	X				
Crude Oil Refining	Yes	Envergent Technologies (Ensyn/Honeywell UOP)	X	X	X		X
	Yes	Licella	X	X		X	X
	Yes	BTG-BTL	X	X		X	X
		Valmet/Fortum		X			
Liquid Fuels	Yes	LanzaTech/PNNL/Aemetis/InEnTec (Aviation)	X		X		
	Yes	HaldorTopsoe/TechnipFMC		X	X		
		CRI/Criterion Catalyst Company (IH2)	X				
		Cielo Waste Solutions	X				
		BioTfuel Consortium		X	X		
		ThermoChem Recovery International (TRI)		X	X	X	
		AICHERNIG Engineering GmbH – Repotec	X		X		

Table F6 – Final technology filter