Greenhouse gas emissions reduction from transport biofuels

Introduction

In 2017, transport (including local supply to international transport) used 45% (297PJ) of New Zealand's energy supply. This is virtually all fossil fuel and so represents a staggering 63% of New Zealand's fossil fuel use. Its domestic use released 15.6 million tonnes of CO_2-e, which amounts to 50% of the gross GHG emissions from the New Zealand energy sector[1]. (By comparison in Australia only 17% of emissions are from transport fuels)

Use by type of fuel in 2017 was: petrol (113PJ all domestic); diesel (100PJ domestic, 2PJ international); aviation fuels (14PJ domestic, 54PJ international); and marine fuels (4PJ domestic, 11PJ international). Nearly all this fossil fuel is currently imported, either as crude oil for processing at Marsden Point, or as a finished fuel. [2]

Currently only a very small proportion of transport fuel is sourced sustainably. Some retailed petroleum-based vehicle fuels already include a regulated low-blend rate component of bioethanol or biodiesel and bulk purchases are available throughout New Zealand. From this low-level starting point, there is a huge opportunity to either import and/or increase biofuel production and use in New Zealand. A shift to biofuels for transport will have significant environmental benefits, particularly in reducing New Zealand's GHG emissions and in meeting New Zealand's international commitments. Moreover, biofuels are also a sustainable solution and in shifting to local production they broaden security of supply options. Local production offers significant development opportunities for regional economies and provides for a just transition away from fossil fuels.

While liquid biofuels are a particular solution for low carbon transport the 'crude' biofuels also are ideal for replacing some liquid fossil fuels producing process heat. The use of biofuels for process heat can be a valuable part of the transition pathway to create volume adequate for crude biofuels to be refined into higher value liquid fuels. (The amount of process heat that could convert from using fossil fuels to using biofuels has not yet been quantified so this paper focuses on liquid biofuels for transport.)

New Zealand is a long narrow country that relies upon international commerce and is a long way from markets, New Zealand being one of the most isolated countries in the world. New Zealand trades on its clean-green image. Continued use of fossil fuels for transport will create international market risks,

[1] Source: New Zealand's Greenhouse Gas Inventory 1990–2016, MfE

[2] Source: Energy Balance Tables 2018, MBIE

particularly for high value food producers and tourism operators with their customers seeking cleaner alternatives closer to their homes. Flight shaming is gaining momentum and NZ tourism would be significantly impacted by people flying less.

Air New Zealand have a high percentage of their operating cost related to fuel and around 40% of it is related to New Zealand's remoteness so the public good benefit of a government led biofuels programme has advantages across tourism and transport.

Internationally biofuels are extensively used for land, sea and air transport but New Zealand is lagging behind the US and Europe, yet our renewable energy profile and available land and feedstock are actually advantages and could be utilised. We also have commonality with many countries already adopting biofuels. Some of these such as Sweden can be a benchmark as biofuels technology is mature in Europe, especially Sweden where almost 99% of heavy transport operates on alternatives.

Drop -in biofuels have a timing advantage in that they can leapfrog straight into Euro 6 when the 'dirty' imported fuel is taken into consideration. This will also give a major reduction in CO_2 emissions thus making a difference to GHG emissions.

We also need to understand that that while OEMs are part of the problem they are also part of the solution. Large heavy vehicle manufactures such as Scania are leading the shift and are keen to partner and assist wherever there is interest. Scania have provided New Zealand and Australia with their 2050 'Pathways Roadmap' where, as a company they are committed in driving the shift towards sustainable transport solutions. Scania vehicles' will be zero emission by 2050. They see alternative fuels as the here and now solution.

While the lead times to establish large quantity feedstock supply chains are relatively long, and New Zealand lags in research and development to improve conversion technologies, New Zealand's fast biomass growth rates and scale would allow biofuel markets to be quickly established.

Biofuels, along with hydrogen and electricity, will be part of the evolving low carbon fuel mix for transport through to 2050. Biofuels deliver different outcomes from electricity, and unlike electricity and hydrogen is a drop-in fuel to existing vehicle engines. Some applications such as marine, aviation, rail and long-haul heavy road transport are where biofuels have a comparative advantage.

For all these reasons there will be public benefits with regard to greenhouse gas emission reductions, clean air and regional economic growth in helping to encourage and de-risk the adoption of biofuels. In what follows we describe the main New Zealand markets and available products for transport fuels (including non-bio based), and then look at how these might develop on three scenarios of private sector and government action: business-as-usual; transitional; and transformational out to 2050.

A key theme that comes out of analysis is that there are no silver bullets and we have to make sure that we target a well-to-wheel approach. It also reinforces that to get biofuels across the line will require 'partnerships' i.e. Government, Transport industry, Fuel producers etc. No party can do it alone.

Development of a low carbon transport strategy requires that we maintain a level playing field across all fuel and technology types as this can provide confidence to vehicle owners and thus assist with greater uptake. However:

"Electric vehicles run on power derived from clean energy will be crucial in propelling road freight towards sustainability, but such transport solutions are still years away – while alternative fuels have the potential to deliver real benefits, both environmental and commercial, today."

The market for biofuels

Because New Zealand is not particularly constrained in renewable electricity generation it is well positioned to use electricity directly to replace fossil fuels in the light vehicle transport fleet. Direct electricity use is one of the most efficient fuels, it is mature technology, and gets close to 60% of the generated electricity onto the road. Other fuels like biofuels, fossil fuels and electrolytic hydrogen only get 20-30% of their input energy onto the road.

However, vehicle batteries have limitations when it comes to long trips or uses that don't allow regular stops for refuelling ("high duty cycle land transport"). The problems are more acute with heavy and volume-limited loads. There are also physical and social limitations to the number of new electricity power stations that could be built across New Zealand to replace the large quantities of transport fuels required. So, alternatives need to be found for high duty cycle land transport, coastal, some rail applications and domestic and international shipping and aviation.

Gaseous and liquid biofuels are part of the low carbon solution set, alongside improved electric vehicles and charging, and hydrogen produced from renewable electricity. The various options are summarized in Appendix 1 along with an indication of prospective fits between applications and technologies, and the areas of challenges in getting to market. The main issues for biofuels are around the supply chain for feedstocks and improving the cost and efficiency of upgrading the fuels.

Despite the limitations there is a significant growing biofuel market evidenced by sales of biodiesel from Z Energy and Greenfuels NZ, and bioethanol from Anchor Ethanol.

Internationally the growth of biofuels for transport have been built on supportive Government policies and assistance. For example, Brazil has demonstrated that by mandating that cars sold be flexfuels you immediately create a market, all the manufacturers you'd want are able to sell into the Brazil market. Ethanol is now ~30% of the vehicle fuel used in Brazil (obviously they have a lot of sugar but the government assistance was necessary to bring all the different parts of the market together.)

Based on these drivers, and in approximate order of closeness to market, the indicated biofuels for New Zealand are:

Biomethane for vehicles running close to a source of supply

Biomethane can be manufactured from biogas from anaerobic digestion (AD) of waste food, sewage etc. Running vehicles/small vessels on biomethane is a mature technology, and a more valuable use for biogas than just flaring or using the gas for heat where other renewable energy heating options are available. The biomethanol option is available today - for a number of years the Christchurch Waste Water Treatment Facility vehicles were all fuelled with biomethane – but the feedstock is ultimately limited. AD is an off-the-shelf technology that works at large or smaller, local scales and is a good solution to derive value from wastes in small, isolated communities. For example in Sweden biomethane from waste water treatment is used to fuel buses[3].

Also typically 50% of MSW is organics as such this should processed into biomethane which would be a high value use of the biogas in the New Zealand and Australian context.

Processing of non-recyclable plastics to fuels delivers considerable GHG savings, diverts these troublesome plastics out of the oceans, and these plants have dramatically better economics that will help get the industry kick started.

First generation bioethanol and biodiesel

Biofuels from starch, sugar, animal fats, vegetable oil etc. are proven but there are limits to the quantities available. Currently bioethanol is produced in New Zealand from whey by Anchor Ethanol. Biodiesel is manufactured by Greenfuels New Zealand from used cooking oil and by Z Energy from tallow. Gull imports their biodiesel in Australia. Gull and Z Energy retail bioethanol-blended petrol and/or biodiesel-blended diesel. Kiwirail has recently announced the intention to trial biodiesel in their trains and ferries. While first generation biofuels can only satisfy a small portion of New Zealand's transport fuel demand because of feedstock limits, its use can provide a very valuable transition path as it gives transport operators experience in using alternative fuels, and suppliers to the various ways the biofuel can be incorporated in the fuel supply chain. First generation biofuels are also an immediate, available solution that enables carbon reduction with the only significant barrier to further uptake being the slightly higher cost of manufacturing biodiesel that many customers find difficult to absorb into their business.

Similarly, imports of ethanol are feasible and have happened in the past, resulting in broadening the experience of vehicle owners in the use of alternative fuels.

Aviation biofuels

Bio-based fuels for aviation are currently in market internationally, used mainly in low blends. The future focus will be on 100% drop-in biojet which has a significant benefit of avoiding the need to duplicate storage and infrastructure which blending requires. The International Air Transport Association (IATA) has set ambitious targets to reduce emissions including the deployment of sustainable low-carbon fuels:[4]:

- An average improvement in fuel efficiency of 1.5% per year from 2009 to 2020
- A cap on net aviation CO2 emissions from 2020 (carbon-neutral growth)
- A reduction in net aviation CO2 emissions of 50% by 2050, relative to 2005 levels

In 2020, international aviation will be subject to a carbon offsetting and reduction scheme[5], that will put an effective price on carbon emissions, and low carbon sustainable fuels will be eligible for credit under this scheme.

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[3] http://scandinavianbiogas.com/en/project/henriksdal-and-bromma/

[4] https://www.iata.org/policy/environment/Pages/climate-change.aspx

[5] In 2016, the International Civil Aviation Organization (ICAO) adopted a global offsetting scheme to address CO_2 emissions from international aviation. The scheme, called CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation) aims to help address any annual increase in total CO_2 emissions from international civil aviation above 2020 levels.

Due to the high technical standards, manufacturing these aviation biofuels is complex, and current sustainable aviation fuel on the market has a higher cost of production. Nevertheless, airlines are entering into supply partnerships for these fuels, especially in jurisdictions where government support for low-carbon fuels provides an incentive that closes or narrows the gap on the premium for the sustainable product. For example:

- Lanzatech has just announced (2019) an agreement with All Nippon Airways (ANA) to supply fuel based on its gas fermentation conversion technology.
- Norway has now mandated that a specific percentage of aviation fuels will be renewable.
- Swedish government set aside 100 million SEK to research and development of aviation biofuels between 2018-2020.
- There is a World Fuels facility in Paramount, Los Angeles and the ANA example or Neste in Singapore could be another.

In each of these examples there is a link to political / commercial environment assistance to get these off the ground.

Heavy marine biofuels

The International Marine Organisation (IMO) has also set targets in an Initial Strategy[6] for GHG reductions[7] and has also established limits on Sulphur emissions from 2020. Both are encouraging the use of biofuels. Larger vessels that use MFO, either diesel or diesel-electric, will be able to use biocrude-based blends from sustainable feedstocks with limited upgrading.

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[6] The Initial Strategy envisages for the first time a reduction in total GHG emissions from international shipping and identifies levels of ambition as follows:

1. **carbon intensity of the ship to decline through implementation of further phases of the energy efficiency design index (EEDI) for new ships**
   to review with the aim to strengthen the energy efficiency design requirements for ships with the percentage improvement for each phase to be determined for each ship type, as appropriate;
2. **carbon intensity of international shipping to decline**
   to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; and
3. **GHG emissions from international shipping to peak and decline**
   to peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out as called for in the Vision as a point on a pathway of CO_2 emissions reduction consistent with the Paris Agreement temperature goals.

The Initial Strategy represents a framework for further action, setting out the future vision for international shipping, the levels of ambition to reduce GHG emissions and guiding principles; and includes candidate short-, mid- and long-term further measures with possible timelines and their impacts on States. The strategy also identifies barriers and supportive measures including capacity building, technical cooperation and research and development (R&D).

[7] http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/GHG-Emissions.aspx

Heavy marine is an ideal entry point for biofuels- there is often no need to go through a refinery, buyers happy to buy on energy content, and engines are often capable of burning 'crude' fuels. The IEA Bioenergy Task 39 are working on development of a suitable marine standard for biofuels. The IMO drivers are key drivers in this 330MT p.a. market. Without a solution a lack of supply of suitable low sulphur fuels will also drive up prices for conforming diesel fuels which will have significant impacts on agriculture, forestry and other major diesel users.

Advanced/second generation biofuels[8]

Pyrolysis[9] of biomass and waste to produce crude liquid biofuels has been done in New Zealand at a pilot level. Other pilot level technologies such as undertaken by Solray[10] in Christchurch can produce a West Texas Intermediate type crude oil from biomass and organic wastes. Licella[11] have also developed a hydrothermal liquefaction (HTL) process and have partnered with Oji Fibre Solutions. However, none have progressed through full commercialisation to provide a market ready useable transport fuel because of the challenging economics.

In Singapore, Neste are producing renewable diesel and this technology could be used in New Zealand and Australia if the market drivers were stronger.

The processing of plastics into a fuel is a good transition pathway to using organics and biomass feedstocks as the economics for processing plastics into fuel is better and assists adoption of circular economy principles to business and communities. Although further analysis and R&D are needed to address the processing technologies and feedstock supply chain options from our wide range of sources of biomass, previous work by Scion and partners has demonstrated the potential for large scale supplies in NZ without impacting food production.

Going beyond the fuels from plant-based feedstocks already mentioned, pyrolysis and upgrading of lignocellulosic feedstocks (generally miscanthus[12], willow, fibre logs and forest residues) has been identified as the best option for large-scale deployment of drop-in liquid biofuels such as renewable diesel. The comprehensive Scion Biofuels Roadmap[13] scenarios show that fuel volumes of the scale required to competitively service New Zealand's 2050 heavy duty cycle transport fuel demand[14] can be achieved.

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[8] Advanced biofuels are fuels that can be manufactured from various types of non-food biomass to produce a "drop-in" fuel which has the same molecular characteristics as petroleum based fuels..

[9] Pyrolysis is a process of chemically decomposing organic materials at elevated temperatures in the absence of oxygen.

[10] www.solraysystems.co.nz

[11] https://www.licella.com.au/

[12] https://www.bioenergy.org.nz/news/miscanthus-renewable-diesel-the-fuel

[13] https://www.liquidbiofuels.org.nz/resource/web180315-nz-biofuels-roadmap

[14] 30% of total liquid fuel demand, \$100/t CO_2-equivalent, non-arable land only.

Refining NZ have the capability at the Marsden refinery of processing crude bio-oils into transport specification fuel provided adequate volume of bio-oils can be supplied.

Scion's roadmap also makes the point that the economics for advanced biofuels favour situations where the liquid biofuel is a co-product from an integrated biorefinery that also produced other products, some with higher value[15]. New Zealand can anticipate a situation where the future circular bioeconomy provides domestically sourced biochemicals, resins, lignin and polymers alongside biofuels all produced in regional biorefineries.

Neste is able to produce renewable diesel, and Licella and Solray are already able to produce bio-oil[16] which can be refined into drop in transport biofuels at the Marsden refinery. Solray also produce high value pure lignin as part of the biofuel production process. Other technologies, such as being developed by GreenChem, utilising biomass and waste are also emerging.

Sustainability

In the New Zealand context feedstock for biofuels production will generally be sourced from forest plantation residues, wood processing residues, or waste. In Australia the feedstock will principally come from high sugar or starch crop residues or purpose grown crops. In both countries, biofuels can be produced very sustainably, avoiding issues which have occurred in some other countries because of poorly administered incentives.

Over the past decade rigorous sustainability certification schemes have been developed, so that users and stakeholders can be assured that a qualifying biofuel is produced sustainably. Additionally, where governments provide incentives for biofuels production there are qualification criteria to assure that any biofuel receiving that support avoids any negative outcomes.

Beyond the 'do-no-harm' aspect of biofuel sustainability, the nature of the biomass supply chains actually affords significant opportunity to generate additional benefits, aside from the low-carbon fuel supply:

- Diverting wastes to biofuels can avoid pollution or land-use capacity issues.
- Novel integrated sustainable farming practices can generate food, fibre and fuel, while regenerating soil health and water quality.
- Regional supply chains can support isolated communities with energy security and economic development.

In New Zealand and Australia, there is considerable potential to develop large-scale supplies of biofuel sustainably, while also providing these co-benefits. In particular, concerns around diverting arable land to biofuel production can be avoided by focusing on wastes, plantation forest harvest residues and energy crops grown on non-arable land such as some of our hill country or as a rotation crop.

Advanced biofuels produced from organic waste, such as Enerkem do in Canada for the production of bioethanol[17], can build on the challenge of finding solutions for waste. Some of the emerging technologies

[15] Biofuels from pulp and paper processing wastes supply ~25% of NZ's industrial energy demands.

[16] Bio-oil, is a synthetic crude fuel substitute for petroleum obtained by heating dried biomass.

[17] https://enerkem.com/

not only use biomass feedstocks but can process waste plastics and tyres, thus providing wider benefits and economies of scale.

Scenarios for future biofuel supply and demand

This information sheet sets out what the Bioenergy Association's Liquid Biofuels Interest Group believes is achievable under a business as usual situation, a transition scenario and a transformation scenario, if associated policy options are adopted.

The transport biofuels market is characterised by:

- feedstock supply value chains with significant lags where long rotation crops are sourced
- a large number of participants,
- issues related to sourcing the feedstock input, converting it into a useable form, distributing the product and using it.

Developing this complex value chain and achieving scale requires significant and coordinated investment in developing the individual components of the supply chain, which may pose risk when other upstream or downstream components are not yet in place.

As a result of this feedstock supply risk combined with typically high capital costs, there is a reluctance to invest. For investors there are also opportunities for alternative uses for land and investment in other sectors that are much better understood. These issues of information and coordination could be addressed by the government providing leadership and facilitation, thus speeding up market development. The complexity of the market is too great for the private sector to take the lead. If left to the private sector alone to develop, the market will result in targets for 2050 not being achieved. In addition, as climate change, economic development and energy security/independence are important community wide concerns the benefits are primarily a public good so government needs to take the lead on behalf of communities.

How well this development opportunity to reduce greenhouse gas emissions is coordinated across stakeholders will be a significant determinant of the speed of growth of the liquid biofuels market. A failure to pursue the national benefit opportunities for domestic production of transport biofuels will likely result in a best case scenario of importing liquid biofuels from Queensland or Singapore where the State Government has produced a biofuels roadmap which it is very actively pursuing. A more likely scenario is the continued use of fossil fuels in transport with lost opportunities to displace with lower carbon biofuels.

The resources

The existing biomass and organic waste resource markets for supply of feedstock for biofuel production are already highly competitive and will continue to be so through to 2050. However, there are significant amounts of organic waste which can be diverted from landfill and potentially adequate quantities of residue biomass from plantation forests and farm forestry which is currently being wasted or not being utilized. In fact, if not utilised these residues may pose environmental and social risks, as was seen during the East Coast floods in June 2018, with forest slash destroying houses, stock and infrastructure. With the right incentives, such biomass would be economically collected and diverted to low-carbon sustainable fuel production.

Analysis shows that as demand for biomass and organic waste increases more will become available, but at a progressively higher price. Constraints on availability of biomass and organic waste can be reduced if there is significantly greater recovery, planting and harvesting. Although wastes can be directly recovered, significant expansion will require long-term investment in energy crops, with short-rotation crops providing a near-term opportunity to quickly enhance feedstock supplies. Because trees in NZ grow 3 times as fast as they do in Scandinavia this is a massive natural advantage and should be exploited.

In developing supply chains, there can be a Catch-22; demand won't emerge without a suitable supply, but the lack of prospective demand makes the necessary long-term investment in supply risky. Risks in developing a supply of biomass as a feedstock can be managed by integration with other sectors so that there are multiple revenue streams eg logs plus fuel from harvest residues. In addition, biomass from farm forestry associated with managed shelterbelts, riparian planting, erosion control and planting on low productive areas of farms could fill the transition gap as integrated food plus fuel revenue streams for farmers can provide a strong incentive for early additional planting.

Companies such as Neste are already demonstrating that the technology is available and that biofuels can be produced from a wide range of organic resources. It is not the resource availability or the technology which is the barrier, it is the under developed markets for alternative fuels.

Role for government

All the studies show that in all countries where biofuel markets have evolved its because of government policy. The leading projects are happening in California, Finland and Sweden, and Brazil, and these are all driven by policy. If there is no strong policy, nothing will happen!

Because transport biofuels are significantly more expensive than mineral fuels and thus need either subsidy or mandate or both. Other Government assistance could reduce the level of financial support required.

Government can help manage the biomass supply risk by various mechanisms that encourage the availability of feedstock supply, for example. better pricing of waste resources, incentivizing biomass integrated with the use of wastes, developing fall-back uses for unused crops, assuming some of the objectives of other sectors. An across-government programmes approach is required so that the cumulative multisector benefits support each other and provide economies of scale. Approaching the supply of biomass for production of biofuels as a solely energy opportunity will result in a long drawn out timeline and failure to meet the 2050 greenhouse gas emissions because the energy drivers for use of biofuels are weaker than the environmental and societal drivers.

Government has supported the significant planting of trees to act as a carbon sink and this could provide an additional economic benefit if some of those trees were planted as a source of feedstock for the production of biofuels. This would require a multisector approach to forestry, greenhouse gas sinks and energy. Similarly utilisation of organic waste for the production of biogas which can be used as a transport fuel requires a linking of the waste and energy sector policies.

A multisector approach to assisting farmers offset biological greenhouse gas emissions by linking bioenergy and biofuels solutions to land use would increase opportunities for improving farming resilience and increase net greenhouse gas emission reductions.

The opportunities

An active transport biofuels programme which is integrated with other government programmes such as in forestry, agriculture, waste, climate change and regional economic development will encourage the use of renewable natural resources such as land and plants to produce bio-based materials including biofuels. In many cases the biofuel will be the coproduct of more valuable products.

Scion has outlined the theoretical potential in the Biofuels Roadmap, and the Woodscape [18] analysis for the Wood Products and Manufacturers has shown the range of high value products that can be produced from biomass, particularly from plantation forestry.

Organic waste is also an untapped resource which is currently wasted by disposal to landfill. Essentially this is akin to burying thousands of dollars in the landfill. The production of gaseous biofuels from organic waste uses a feedstock which can be used in multiple applications including heat, electricity, transport and as a feedstock for bio-based product manufacture, and in New Zealand is already subsidised through the avoidance of the waste levy.

A strength of the use of gaseous and liquid biofuels is that they provide fuel for applications where alternative renewable fuels such as electricity and hydrogen are either not technically adequate or are an uneconomic solution.

Export

New Zealand has developed capabilities for export of knowledge and experience in the farming, food processing, and other areas where a comparative advantage has evolved. The international export opportunities from developing and applying emerging biofuel related technologies and selling the expertise from the biofuels sector has already been shown by Lanzatech and Neste. Companies such as Carbonscape, Crawthon and Solray are following but need demonstration from applications having been built and operating.

The Scenarios

Scenario 1: Business as usual

This scenario assumes that Government makes no particular efforts to maximise the gaseous and liquid biofuels production and utilisation potential for New Zealand. There are few incentives for the private sector to enter the market. Carbon price and electricity price are assumed to remain low and thus not an incentive for change.

[18] https://www.bioenergy.org.nz/resource/woodscape-study-regional-wood-processing-options

Assumptions for this scenario are:

- Based on existing policies and market conditions. No policy changes
- Uses existing technologies and an extension of current trends
- Existing sector participants' activities continue.
- Assumes current ETS. No significant other changes.
- Government continues low level support for biofuels R & D

In particular:

- Biomethane. No uptake as a vehicle fuel. Changes to industrial wastewater treatment is limited to only what is required to maintain resource consents and there is only minimal processing of agricultural or food processing waste residues. No incentives to use waste as fuels or upgrade to Biomethane.
- First generation biofuels. No growth, Potential contraction of current production as New Zealand plant competes for tallow with overseas biofuel production operating in, or selling into subsidised markets.
- Aviation. Growth lags international growth because of limited local biofuel supply. Airlines left to import (e.g. Queensland or Singapore) and/or rely on offsets.
- Marine heavy fuel oils. No penetration, with shipping using higher priced lower sulphur distillates initially and then largely relying on the ETS for coastal shipping.
- Advanced biofuels. Slow uptake lagging the rest of the world because of need to establish supply chains even once the technologies have been demonstrated at scale.

Scenario 2: Transition policies

Government signals that it wants to encourage domestic mitigation, broadening of the low carbon transport policy to include gaseous and liquid biofuels, and takes steps to actively encourage biofuels i.e.

- Targets for a low carbon transport market and some complementary measures to the ETS adopted.
- R&D funding increases in areas where New Zealand needs to lead.
- Short-rotation energy crops bought into the ETS and billion trees programme with appropriate controls.
- Appropriate financial support for investment in domestic biofuel production to develop new supply chains, attract international capability and deliver the technological learning required to achieve cost competitiveness.
- Support growth in additional domestic added-value processing of wood in the forestry sector that includes biofuels and coproducts.
- Increased consumer education from the sector on the sustainability and suitability of biofuels in existing vehicles and the development of appropriate fuel quality standards.
- Procurement guidelines biased towards low carbon fuel/energy
- Tax incentives / production subsidies?

In particular:

- Biomethane. Good growth in both the quantity produced and use in transport. Use of biogas from landfill and waste water treatment plant actively encouraged as a local transport fuel instead of flaring, heat and generation of low value electricity.
- First generation biofuels. Some use for fishing vessels, rail and heavy road transport to the limits of fuel available.
- Aviation. Import from Queensland. Growth at the average of global uptake. Investment into research on appropriate feedstocks for New Zealand and conversion techniques with a view to attracting international investment and encouragement to airlines to assist a supply chain to develop.
- Marine heavy fuel oils. Lower cost MFO coming available the mid-2020s based on investment in R&D to upgrade biocrudes to a suitable heavy marine fuel.
- Advanced biofuels. Scion's 10% scenario (non-arable land) [19] achieved by investing in the required R&D and feedstock development.

Scenario 3: Transformation policies

Government adopts the same policies as for the Transitional Scenario but goes further. In particular; sets up cross-sector group and associated action plan to ensure that low carbon transport goal, including biofuels, is achieved by 2050 through use of mandates that all transport is to be low carbon by 2050, and establishes programme to achieve bioeconomy by 2030.

In particular:

- Biomethane. Elimination of organic waste disposal to landfill by 2040 mandated
- First generation biofuels. Some use for fishing vessels, rail and heavy road transport to the limits available
- Aviation. Public-private risk-sharing mechanisms are established early to encourage capital investment in larger biorefineries that can provide significant share of aviation fuel needs (as well as other heavy fuel needs). These take the form of government loan guarantees or purchase contracts to reduce perceived risk and therefore cost of institutional finance for pioneering projects, or outright grants.
- Marine heavy fuel oils. Lower cost MFO coming available in the mid-2020s based on local investment in R&D to upgrade locally produced biocrudes to a suitable heavy marine fuel.
- Advanced biofuels. Scion's 30% scenario 2 (non-arable land) achieved by greater investment in the required R&D and feedstock development and accelerated feedstock through faster introduction of bioeconomy, land use optimisation strategy and encouraging landowners to go beyond the billion trees.

The uptake of gaseous and liquid biofuels by 2050

Analysis is based on the data from the Scion New Zealand Biofuels Roadmap[20].

[19] See Fig 5.2 https://www.scionresearch.com/__data/assets/pdf_file/0017/63332/Biofuels_TechnicalReport.pdf
[20] https://www.liquidbiofuels.org.nz/resource/nz-biofuels-roadmap

The use of liquid and gaseous biofuels for heavy transport (Marine, aviation and rail), sourced by import or domestic production, could by 2050 under an accelerated transformation scenario replace 68PJ of fossil energy and reduce greenhouse gas emissions by 5000 kt CO2-e pa.

The level of reduction in greenhouse gas emissions from bioenergy and biofuels below 2017 levels and the amount of energy produced are set out in Tables 1 and 2.

Table 1: Greenhouse gas emission reduction below 2017 levels (kt CO_2-e pa)

	Emissions reduction from use of biofuels in transport (kt CO2-e pa)		
Year	BAU	Transition[3]	Transformation[4]
2030	140	200	1500
2040	350	400	3500
2050	700	800	5000

Table 2: Biofuel energy increase above 2017 levels[7] (PJ)

	Energy increase from use of biofuels in transport (PJ)		
Year	BAU	Transition[3]	Transformation[4]
2030	3	3	20
2040	5	6	48
2050	10	12	68

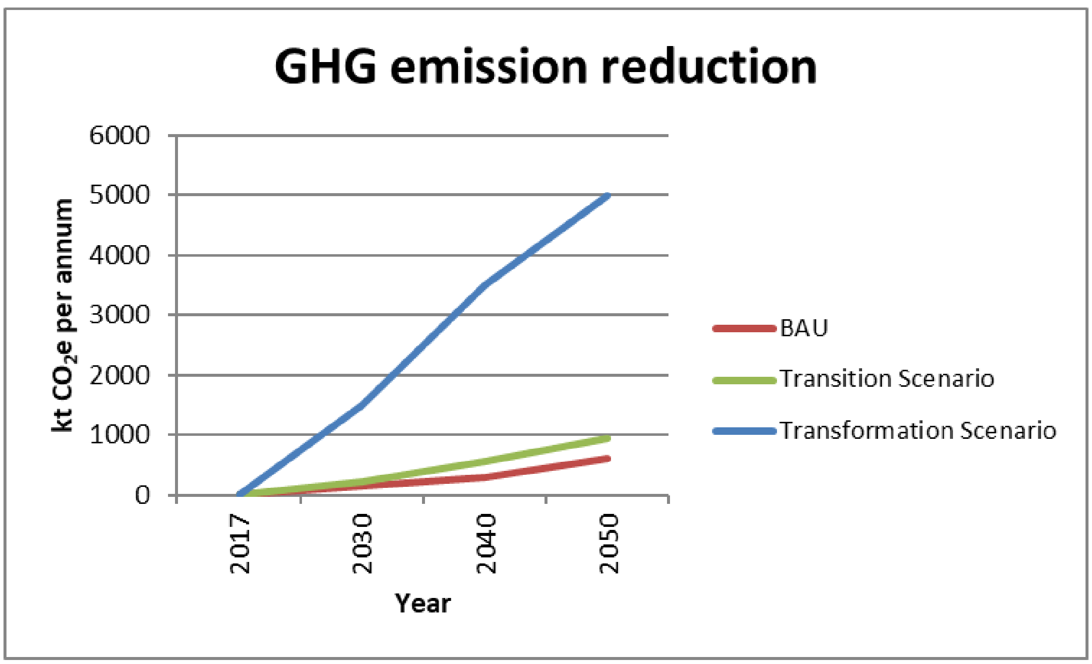

Figure 1: GHG emission reduction under business as usual and accelerated scenarios

The strategic benefits and co-products of production of advanced liquid biofuels

The extraction or production of biochemicals from biomass and organic waste, such as resins, lignin etc., could also catalyse the production of transport biofuels as these higher value co-products will assist the economics of producing lower value commodity type biofuels. This effectively lowers the feedstock cost for biofuel production and is expected to be a significant driver for biofuel production.

Companies such as Solray use the extraction of co-products such as lignin to improve the efficiency of biofuel production.

National security of fuel supply risks indicate that development of the biofuels sector as a strategic contingency measure would be prudent.

Actions required

To get above business as usual and the transition scenario to the outcomes of the transformation scenario and beyond requires some key actions. These include the following measures complementary to the NZETS:

1. Government strongly signals to local government and industry that it wants to encourage domestic mitigation of CO_2-e to avoid the need for purchase of international units and emissions from export industries and makes this an objective of the Climate Change Commission.
2. Government specifically supports the reduction of GHG emissions in domestic industries, similar to that given to export and high growth industries. This would be supported by:
    a. Explicitly providing support to businesses engaged in GHG reduction of transport activities – widen scope of low carbon transport programme so not just focused oh hydrogen and electric vehicles;
    b. Establishing a programme for progressing transition to a bio-economy including production of biofuels within a wider transition to the manufacture of bio-based products based on wise use of renewable natural resources.
    c. Providing accelerated depreciation and/or suspensory loans for capital investments resulting in greenhouse gas emission reduction;
    d. Government does an annual cost-benefit of forward offshore purchase of GHG obligations vs acquiring domestic mitigation – includes recognition of the public good component of transitioning low carbon transport fuels.
    e. Use imported biofuels as a transition pathway to provide an incentive for domestic manufacture.
    f. Refocus the 1 Billion Trees Programme so that species and plantings of wood have a greater emphasis on added value products additional to greenhouse gas absorption.

3. Introducing central and local government procurement policies so that renewable energy (including biofuels) and efficient energy use options must be considered when making investment decisions and all additional benefits are included in a full life cycle analysis of options.
4. Government sets a Transport Strategy to achieve low carbon transport targets:

   a. Rail to use low carbon fuels by 2030 with total use of low carbon fuels by 2050
   b. Fishing and coastal shipping to be using low carbon fuels by 2030 with total use of low carbon fuels by 2050
   c. Domestic aviation to be using low carbon fuels by 2035 with total use of low carbon fuels by 2050

5. Government and industry develop a transport biofuel development programme based on the results of the Scion led New Zealand Biofuels Roadmap project to assist meet the Transport Strategy targets.
6. Government encourages additional domestic added-value processing of wood with the consequence that greater volumes of high-quality wood fibre residues are available for biomaterial and biofuel production.
7. That the rules for recognition of biomass produced on farms and sold as a feedstock for biofuels are changed so that farmers get credit for carbon absorption offsetting their biological emissions liability.
8. Government R&D funding increases for:
    - Advanced liquid biofuels research having regard for the likely areas of application in New Zealand that will be economic over the next decade (eg targeting biofuels for industrial, marine and aviation applications, for strategic reserves and for their lower health related emissions)
    - High value bio-products where biofuels are a co-product
    - Provide guidance on the use of biomethane as a vehicle fuel.

APPENDIX 1:
NZ CLEAN HIGH DUTY CYCLE[1] TRANSPORT: RESEARCH CHALLENGES

	Land		Marine		Aviation			Indicative Challenges[2]		
	Road	**Rail**	**Short e.g. Waiheke**	**Coastal +**	**Short e.g. drones**	**Regional**	**Long-haul**			
Supply - Fuel								**Fuel production**	**Storage/ distribution**	**End use**
Fossil fuels + CCS → Hydrogen (H_2)[3] → Fuel Cell (FC)	?✓?	?✓?	✓✓?		✓✓?			Conversion mature and sets the benchmark for potential alternative fuels. CCS not mature.	H_2 energy density & containment. H_2 carriers are address H_2's weaknesses, but not mature.	FC cost, efficiency and scale up of production still issues.
Power → H_2 → FC	?✓x	✓✓x	✓✓x		✓✓?			Conversion mature, but cost and efficiency issues remain.	As for fossil fuel H_2. [But distributed production an option].	As for fossil fuel H_2.
Power → Electric Vehicles (EV) + enhanced charging (incl. gantries etc)	✓✓?	✓✓✓						Mature	Battery energy density and specific energy, charging technology & speed. Distribution of power mature.	Mature. The addressable market will be defined by the economics of the enhanced charging system.
Biomass → Biogas (e.g. biomethane)[4]	x✓✓	?✓✓	✓✓✓		✓✓?			Feedstock availability (e.g. waste), dispersed resource, cost and efficiency of pre-processing and upgrading (but both mature).	Mature. Liquid fuels likely to be preferred in the long haul marine and aviation applications.	Biomethane in an Internal Combustion Engine (ICE) mature. Challenges in other gas/motor combinations.
Biomass → Liquid Biofuel	✓✓✓	✓✓✓	✓✓✓	✓✓✓	✓✓?	✓✓x	✓✓x	Land use, dispersed resource, cost etc. of pre-processing and upgrading (latter not yet mature).	Mature	Mature depending on level of upgrading and nature of motor. Drop-in possible for ICEs.
Power & Biofuels → EV & ICE hybrid	✓✓?	✓✓?	✓✓?	✓✓✓	✓✓?	✓✓?		Power mature. Biofuel production as above, lower volumes needed.	Addresses battery energy density and specific energy in EVs	Cost of two technologies. Power density in aviation conversions.
Power & H_2 → EV & FC hybrid	✓✓?	✓✓?	✓✓?					Power mature. H_2 production as above, high cost has less impact.	H_2 as above but less acute	As above for Bio → Hybrid use.
Demand reduction										
Logistics	-✓✓	-✓✓		-✓✓	-✓✓	-✓✓	-✓✓	"Last mile", impact of ICT/AI/embedded intelligence, modal mix and vehicle efficiency, better sharing		
Telepresence etc	-✓✓	-✓✓				-✓✓	-✓✓	Human acceptability, technologies and local infrastructure, 3D printing		

Ticks etc. are a very initial and subjective assessment of respectively: feedstock availability relative to market; technology maturity by 2030; and approximate 2030 NZ price relative to a baseline of fossil fuel + CO_2-e @ $100/t. For demand reduction "feedstock" is not applicable. All fuels can achieve some degree of technology maturity at scale by 2030, the challenge is to then reduce the price, although markets will buy on more than price alone. Power → EV will be economic at the margin of many of the markets, defining the low duty cycle boundary, and is not shown.

Main sources: "Hydrogen in NZ" (2019) Concept Consulting; "NZ Biofuels Roadmap" (2018) Scion.

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[1] Limited to high duty cycle assuming battery technology will be used in applications not constrained by storage and recharge time limitations.
[2] A very high-level initial identification of where the research challenges lie
[3] Including various potential hydrogen carriers such as ammonia and synthetic fuels e.g. methanol.
[4] Biomass → Bio H_2 is an option but is less mature than (say) biomethane production; storage and distribution is more complex; and end use isn't a retrofit of existing engines.