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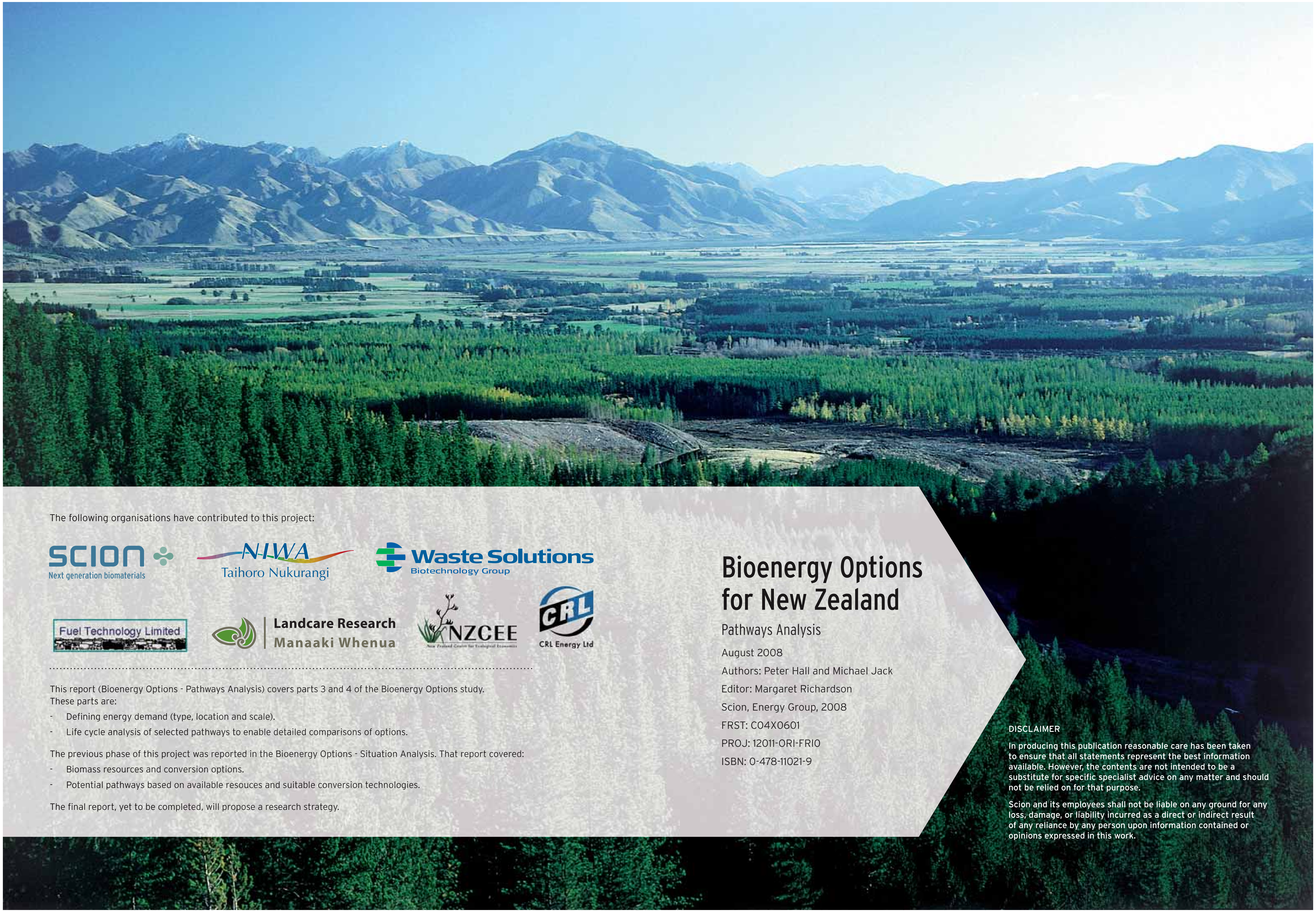
Next generation biomaterials

Bioenergy Options for New Zealand

PATHWAYS ANALYSIS

Energy demand | Pathways evaluation
Economics of purpose-grown energy forests
Life Cycle Analysis of biomass resource to consumer energy

New Zealand's EnergyScape



The following organisations have contributed to this project:

SCION Next generation biomaterials
NIWA Taihoro Nukurangi
Waste Solutions Biotechnology Group
Fuel Technology Limited
Landcare Research Manaaki Whenua
NZCEE New Zealand Centre for Ecological Economics
CRL Energy Ltd

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This report (Bioenergy Options - Pathways Analysis) covers parts 3 and 4 of the Bioenergy Options study. These parts are:

- Defining energy demand (type, location and scale).
- Life cycle analysis of selected pathways to enable detailed comparisons of options.

The previous phase of this project was reported in the Bioenergy Options - Situation Analysis. That report covered:

- Biomass resources and conversion options.
- Potential pathways based on available resouces and suitable conversion technologies.

The final report, yet to be completed, will propose a research strategy.

Bioenergy Options for New Zealand

Pathways Analysis

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EXECUTIVE SUMMARY

The Bioenergy Options for New Zealand project was initiated to consider the potential contribution of bioenergy to New Zealand's energy future. The Bioenergy Options work is a part of the larger EnergyScape project which integrates the findings from a range of studies with the aim of considering New Zealand's overall energy options.

This Pathways Analysis report is one of three reports from the Bioenergy Options project. The purpose of this report is to summarise information on:

- The potential role of geographically distributed biomass resources to meet regional energy demand now and in the future;
- The environmental sustainability of the biomass resource-to-consumer energy pathways identified in the *Bioenergy Options – Situation Analysis* report;
- The economic viability of these pathways now and in the future in light of rapidly rising energy prices.

A pathway is defined as a route from biomass resource through some conversion process to a consumer energy product.

A summary table presenting the potential scale, environmental sustainability and economic viability of a number of key biomass resource-to-consumer energy pathways is shown on page 7.

The final report of this study, *Bioenergy Options for New Zealand – Bioenergy Research and Development Strategy* will identify research priorities for realising the potential of bioenergy for New Zealand.

The challenge

The New Zealand Energy Strategy to 2050 was released at the end of 2007. It set out a vision for New Zealand's energy future in response to global climate change. The strategy contained a number of ambitious future targets for New Zealand including:

- A reliable and resilient system delivering New Zealand sustainable low emission energy services;
- 90% renewable electricity by 2030;
- Halving greenhouse gas emissions per capita from transport by 2040.

The New Zealand Energy Strategy to 2050 has played an important role in framing the scope and direction of the overall EnergyScape project. The EnergyScape project has concluded that:

- New Zealand has a number of options for more renewable electricity from hydro, geothermal, wind, solar and marine resources;
- New Zealand has a number of options for more renewable heat from geothermal, solar and residual biomass;
- Given our current reliance on fossil fuels for transportation and its current rate of growth, the transportation target for the New Zealand Energy Strategy is by far the biggest challenge, even with significant gains from efficiency and conservation.

Technologies exist for converting woody-biomass to a range of transport fuels (i.e. fossil petrol, diesel and jet fuel replacements).

The criteria

Renewable energy from biomass resources could play an important role in meeting this transportation challenge. To realise this potential, however, these resources must be:

- of sufficient scale to meet a significant percentage of demand;
- environmentally sustainable (e.g. not compete with food, not lead to deforestation, have a positive net energy balance, and reduce greenhouse gas emissions);
- economically viable.

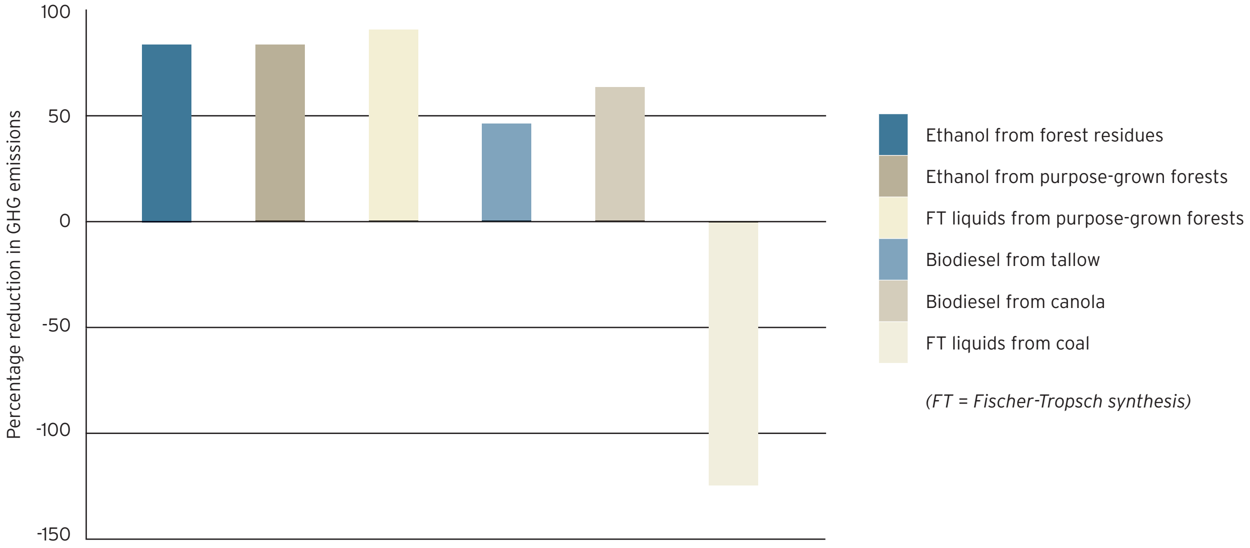
Central to all of the criteria is land use.

The large-scale opportunity

As described in the *Bioenergy Options – Situation Analysis* report, it is theoretically possible for New Zealand to be self-sufficient in transport fuel produced from sustainably managed forests. To meet the petrol and diesel fuel demand in 2040 (6.3 billion litres) would require 2.5 to 2.8 million ha of land - this is 34% of the available medium to low quality grazing land. The total liquid fuel demand, including jet fuel and fuel oil for air and sea transport, is expected to be around 8.1 billion litres. It would require approx. 3.7 million ha, or 42% of low to medium quality grazing land, to produce this volume of fuel from forests.

Technologies exist for converting biomass to liquid and gaseous transport fuels, or biofuels. Biofuels are considered one of the most rapidly deployable ways of reducing our reliance on fossil transport fuels. This assumption drives the focus on transport fuels in this report. Transport fuel production from purpose-grown forest provides significant greenhouse gas benefits (60-90% reduction) compared to fossil petrol and diesel (see Figure 1) and has an energy return on energy investment of approximately 4:1.

Figure 1: Greenhouse gas benefits of biofuels



(FT = Fischer-Tropsch synthesis)

Biofuel production from purpose-grown forests is currently not economically competitive. For example, for ethanol production from purpose-grown forest to be competitive, the price of oil will have to rise to US$185/bbl (exchange rate of $1NZ=$0.7US) assuming present-day technology. Based on oil price trends over the last six years this is likely to occur by 2020. Potential exists for improving the economics of producing biofuels from second-generation feedstocks such as woody biomass. Significant research and development effort is focused on second-generation technologies internationally, and there is large potential to optimise both feedstocks and the biomass supply chain for biofuel production.

The analysis carried out in this report does not take into account economic and environmental benefits to New Zealand as a whole from the creation of a biofuels industry based on purpose-grown forests. These potential benefits are:

- job creation;
- regional development;
- carbon sequestration;
- improved landuse management;
- erosion control;
- improved water quality;
- a significant long-term (~10 year) energy store;
- less exposure to international oil prices (New Zealand has the third highest oil consumption per GDP).

These benefits mean that this bioenergy option has implications for government policy in a number of areas, in addition to energy.

Niche opportunities

New Zealand has a number of biomass resources that are not of a nationally significant scale, but have significant environmental benefits or have the potential to make a contribution to regional energy demand. Some important pathways are:

- **Forest residues for heat** – reduces greenhouse gas (GHG) emissions (>95%) compared to coal; can make a significant contribution to regional heat demand in central North Island, Gisborne, southern North Island;
- **Agricultural straw residues for heat or combined heat and power (CHP)** – reduces GHG emissions (>95%) when compared to grid electricity and heat from coal; can make a significant contribution to regional heat demand in Canterbury;
- **Anaerobic digestion of municipal wastes and industrial effluents for CHP** – significant reductions in waste (80%) and GHG emissions (80%); currently economically viable at favourable sites;
- **Canola to biodiesel** - reduces GHG emissions (70%) compared to fossil diesel; currently economically viable in Canterbury when grown in rotation with other arable crops;
- **Algae to biodiesel or CHP** - Algae were not dealt with in this study as there were insufficient data to perform an accurate LCA. However algae have the potential to make a contribution to regional energy when grown on nutrient-rich effluents. Algae can be used in a variety of ways including biodiesel production and/or bio-gas via anaerobic digestion.

The Future

High levels of volatility in cost and supply in the energy market are likely to create ongoing uncertainty. During the course of this study (October 07 to July 08) the price of oil went from US$80/bbl to US$144/bbl, and is now (August 08) back to US$114/bbl. Further, there is significant investment in research and development globally in pursuit of renewable energy generally and liquid fuels from biomass in particular. New technological developments are likely to cause step changes in opportunities.

The viability of biofuels and renewable energy is not driven solely by price. Government policy with incentives and disincentives can have a major impact on the viability of different solutions or opportunities.

> "We need to leave oil before oil leaves us."
> – Fatih Birol, Chief Economist, International Energy Agency

Table 1: Summary of key biomass resource-to-consumer energy pathways

Pathway	Potential scale	GHG emissions and environmental sustainability	Economic viability
Straw to combined heat and power (CHP)	√ Significant contribution at the regional level.	√ Significant GHG reductions (>95%) when compared to grid electricity and heat from coal. The EROEI is 18:1.	X Currently not competitive. Carbon price will influence economics.
Canola crops to biodiesel	X Land use competition reduces potential scale.	√ Reduces GHG emissions (60%) compared to fossil diesel; EROEI is 2.2:1. Requires arable land.	√ Currently economically competitive.
Reject kiwifruit to biogas via anaerobic digestion	X Small resource (1.5 PJ) nationally.	√ Significant GHG reductions (>95%) compared to natural gas. EROEI is 27:1.	X Currently not competitive.
Industrial effluent to CHP via anaerobic digestion	X Resource is limited.	√ Significant reductions in waste (80%) and GHG emissions (200%), compared to land disposal and grid electricity.	√ Economic at favourable sites, increase in electricity prices 15 to 20% would make it viable at a greater range of sites.
Forest residues to heat via combustion	√ 20% of demand. Can meet demand in some regions.	√ Reduces GHG emissions by a factor of (90%) compared to coal. Energy return on energy investment (EROEI) is 6.4:1.	√ Future economics will be influenced by the price of carbon.
Forest residues to ethanol via enzymatic conversion	X 10% of demand.	√ Significant GHG reductions (~80%). Even low percentages blends provide environmental gains. EROEI is 3.5:1.	X Currently only 30% more costly than petrol.
Purpose-grown forest to ethanol	√ Sufficient low to moderate value land exists to make NZ self-sufficient in transport fuels.	√ Significant GHG reductions (60-90%). Even low percentage blends provide environmental gains. EROEI is 4.5:1.	X Currently not competitive.

Contents

1.0

INTRODUCTION

The Bioenergy Options for New Zealand project consists of three parts.

The first is a *Situation Analysis* (published January 2008) which reviewed residual biomass resources, conversion technologies and described a strategy to make New Zealand self sufficient in transport fuels from forests. It also outlined a number of resource-to-consumer energy pathways which were candidates for further investigation.

This *Pathways Analysis* is the second report, covering an analysis of the consumer economics and environmental benefits of the promising pathways identified in the Situation Analysis. The Pathways Analysis is summarised in the context of New Zealand's energy demand and current economics surrounding the production of consumer energy (heat, electricity and transport fuels) from biomass.

The combined results of these two reports will be synthesised into a third document that informs a bioenergy research strategy for New Zealand. This strategy will suggest research which enables bioenergy to make its most useful contribution to New Zealand's energy future. The ultimate goal is to accelerate the implementation of renewable energy, in line with government strategy.

Energy from biomass

Bioenergy is receiving significant political and social interest as well as large research and development investment. Globally much of this research is focussed on the production of liquid biofuels. This interest is driven by the rising cost of oil and increasing concern over the impact of peak oil, as well as climate/GHG concerns. This has been summarised by the Chief Economist of the International Energy Agency in his statement: "We need to leave oil before it leaves us".

New Zealand, along with the rest of the world, must find a way to produce renewable energy, including bioenergy and biofuels in a way that minimises its impacts on food production and our environment. New Zealand solutions must be tailored to our energy and resource profile, including our available land resources.

Fossil fuels are stored solar energy from plants that lived millions of years ago. As we mine this stored energy we need to consider what we will replace it with, and how we can most efficiently use that energy. One option is the use of plants to capture and store solar energy on a large scale (biomass), for a variety of future energy uses. In a New Zealand context this is made possible by large areas of suitable land and a relatively low population density.

The outputs of the EnergyScape asset review have been briefly summarised as:

" We can do electricity and heat, the problem is liquid fuels." (Don Elder, CEO Solid Energy, Chairman EnergyScape Steering committee).

In more detail this means we have sufficient natural resources (hydro, geothermal, wind, marine) to create enough renewable electricity to meet our demands.

We also have significant proven lignite, and coal resources, some gas, and a history of gas discoveries. Whilst they are not renewable or low GHG emitters, the resource exists in New Zealand and can be produced and used relatively cheaply.

Further it is apparent that for a resource to be worthy of development or research investment it must be both practical and able to deliver consumer energy on a significant scale. The order of this scale is driven by our current national energy demand (~740 PJ of primary energy, ~520 PJ of consumer energy).

There are many ways of making bioenergy, and the initial resources will inevitably be residues and wastes. These resources offer a double benefit as you can extract energy, and reduce the waste disposal cost and environmental impact at the same time. However, residuals are inevitably limited in scale and competition for wastes is growing as different uses are found for them. For this reason, a large scale bioenergy resource will be required in the future, preferably one that offers the possibility of large scale energy storage.

New Zealand is not alone in looking at bioenergy and potential biomass resources. There is a global trend to develop purpose-grown bioenergy resources, as residuals have typically proven to be limited in scale. The purpose-grown resources are in similar categories to those considered in New Zealand such as crops from arable land and the use of ligno-cellulosic material.

This analysis looks at a range of residual and potential purpose-grown bioenergy resources and some of the key conversion options available to utilise them. The information allows the preferred biomass to consumer energy routes to be identified and highlights areas where efficiency and environmental improvements can be made by research and development.

The research team consists of:

- Scion;
- Landcare Research;
- Waste Solutions;
- CRL Energy;
- Fuel Technology Ltd.

Structure of summary report

This document contains summaries of the contributing reports, and interpretation of the various results. The detailed reports (including references) on each topic are presented on the CD attached to this report.

This report follows on from the *Bioenergy Options for New Zealand Situation Analysis – Biomass Resources and Conversion Technologies*.

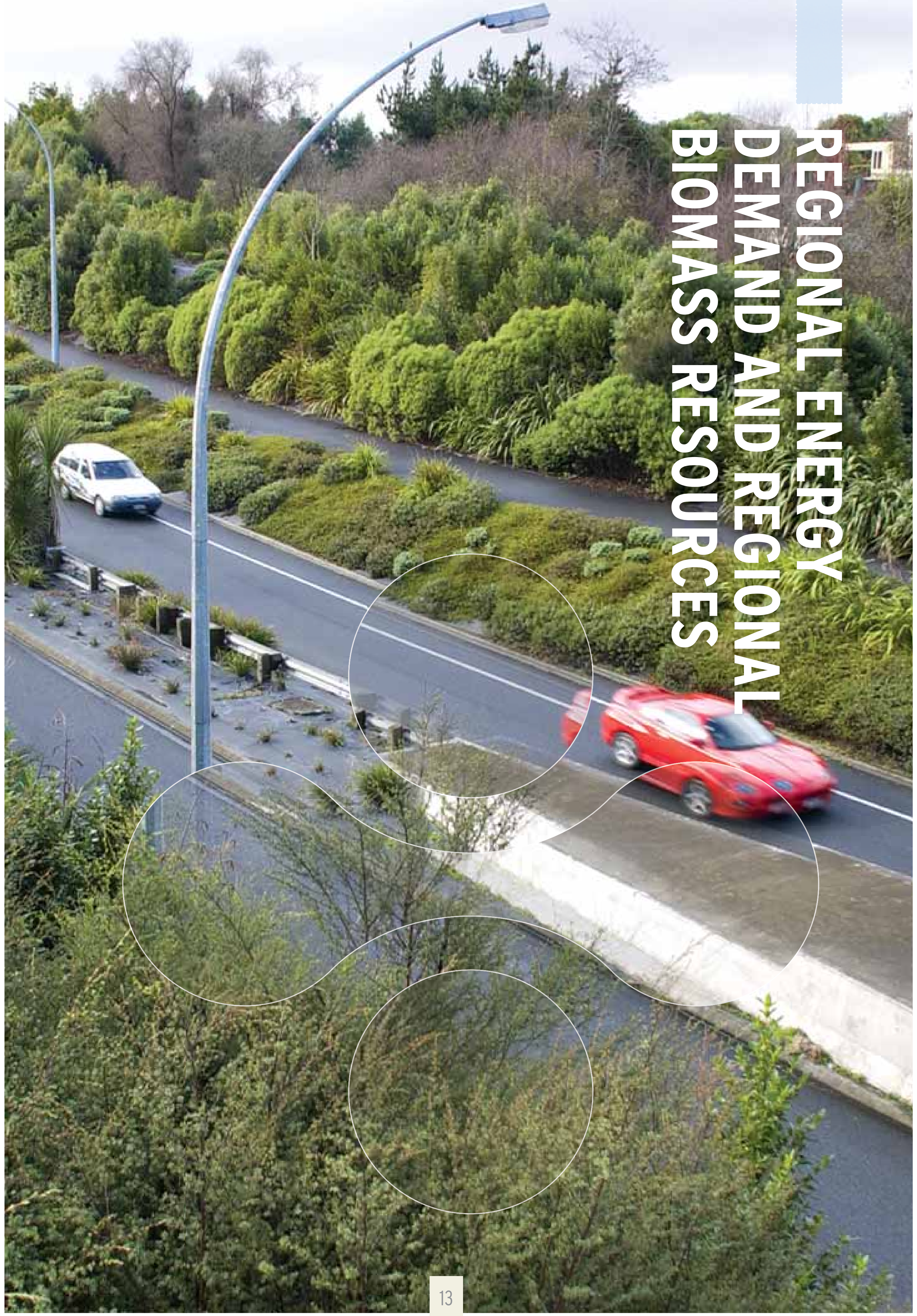
It provides:

1. A view of New Zealand's energy demand at a national and regional level by consumer energy type (heat, electricity and liquid fuels).
2. Detailed Life Cycle Assessments of the following case studies to identify environmental hotspots:
    - agricultural residue (straws);
    - horticultural residue (kiwifruit rejects);
    - effluent (meat works);
    - purpose-grown crop for production of biodiesel (first generation);
    - wood residues and purpose-grown forest wood for heat, electricity and liquid fuels (second generation).
3. A broad comparison of a wide range of bioenergy resource-to-consumer energy pathways.
4. The high level economic drivers of liquid fuel production from woody biomass.

Other opportunities

Beyond the conversion technologies presented here there are a number of emerging opportunities (e.g., algae to biodiesel or CHP, biomass to CO to ethanol, biomass and super critical water to liquid fuels, pyrolysis to liquid fuels). There was insufficient information on these technologies to complete LCA analyses.

REGIONAL ENERGY DEMAND AND REGIONAL BIOMASS RESOURCES



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REGIONAL ENERGY DEMAND AND REGIONAL BIOMASS RESOURCES

Biomass resources are inherently widely distributed. Their distribution is affected by a variety of local influences (geography, conservation areas, agriculture, forestry, population and industrial processing). In order to try and match these resources with energy demand it is useful to consider demand at a regional level.

Regional energy demand

Overall, current energy demand is dominated by Auckland (29% of total energy), with some regions having higher than average demands for certain types of energy. Energy demand is sometimes driven by industry rather than population. For example: Waikato and the Bay of Plenty have a high demand for industrial heat (dairy and wood processing) and Southland for electricity (aluminium smelting).

Regional demand for consumer-energy (heat, transport fuel and electricity) in 2007 is shown in Table 2. The figures for 2007 were extrapolated from publicly-available 2002 data assuming a 2% per annum annual growth in energy consumption.

Table 2: Regional heat, liquid fuel, electricity and total demand, PJ per annum, 2007

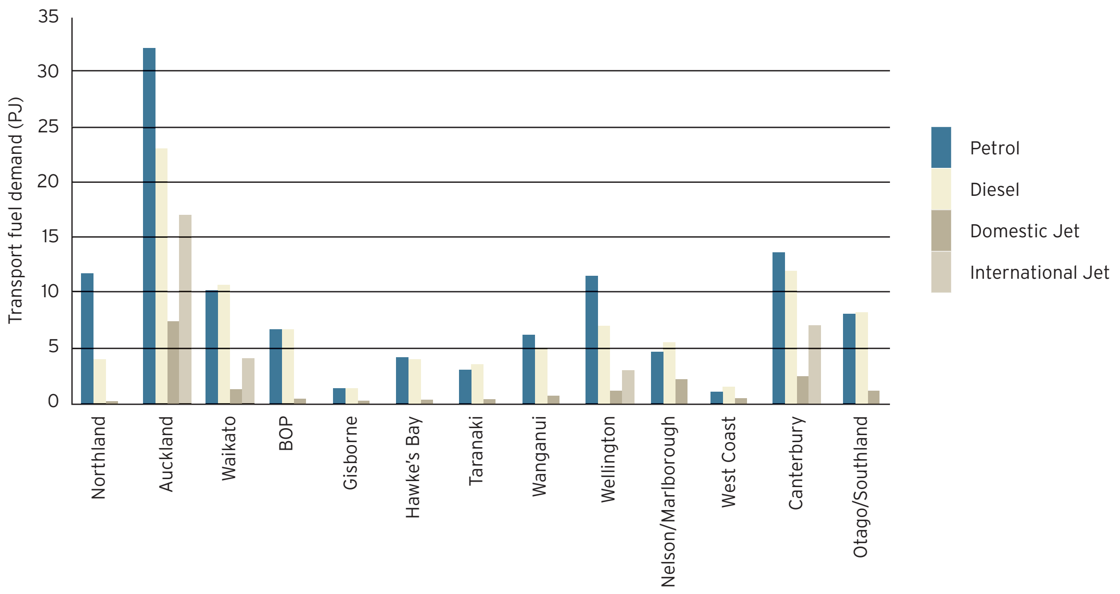
	Heat	Total transport fuel**	Electricity	Total energy
Northland	2.7	9.1	2.8	14.6
Auckland	47.5	78.0	32.1	158.0
Waikato	17.5	27.5	11.4	56.4
Bay of Plenty	16.3	13.4	7.3	37.1
Gisborne	0.9	2.8	1.0	4.8
Hawke's Bay	6.6	9.9	4.0	20.6
Taranaki	4.9	5.3	3.0	13.2
Manawatu/Wanganui	7.7	13.9	6.3	28.0
Wellington	12.9	22.9	13.2	49.1
Nelson/Marlborough	2.5	9.3	4.2	16.0
West Coast	1.1	2.2	1.1	4.4
Canterbury	10.4	32.8	17.2	60.6
Otago	4.6	10.7	7.5	22.9
Southland	4.2	7.0	23.6*	34.8
Total	**140.0**	**244.7**	**134.7**	**520.3**

* Assumes NZ Aluminium Smelters Ltd, Tiwai Point, at 18 PJ per annum

** Includes international shipping and air transport consumption.

Figure 2 shows the regional breakdown of transport fuel demand by petrol, diesel and jet fuel. In most regions petrol consumption exceeds diesel consumption, for example Auckland and Wellington. However, in some regions (Waikato, Bay of Plenty, Nelson/Marlborough and West Coast) diesel consumption meets or slightly exceeds petrol consumption. This is driven by the dominance of agricultural and forestry activity in the provincial areas versus the dominance of personal transport in large urban population centres.

Figure 2: Regional transport fuel demand by type, PJ per annum



Regional residual biomass resources

Biomass can potentially make a contribution to meeting some of the regional energy demand. The primary energy contained in all major residual biomass resources (forestry, agriculture, horticulture, municipal, meat industry and dairy industry), is presented in Figure 3. Typically these biomass resources total around 2 to 4 PJ per annum per region, with the exceptions being:

- Central North Island (14 PJ) – driven by forestry residues (wood);
- Canterbury (11 PJ) – driven by agricultural residues (straws);
- West Coast (<1 PJ) – from a variety of small sources.

Figure 3: Regional residual biomass, total primary energy, PJ per annum (Hall and Gifford 2008)

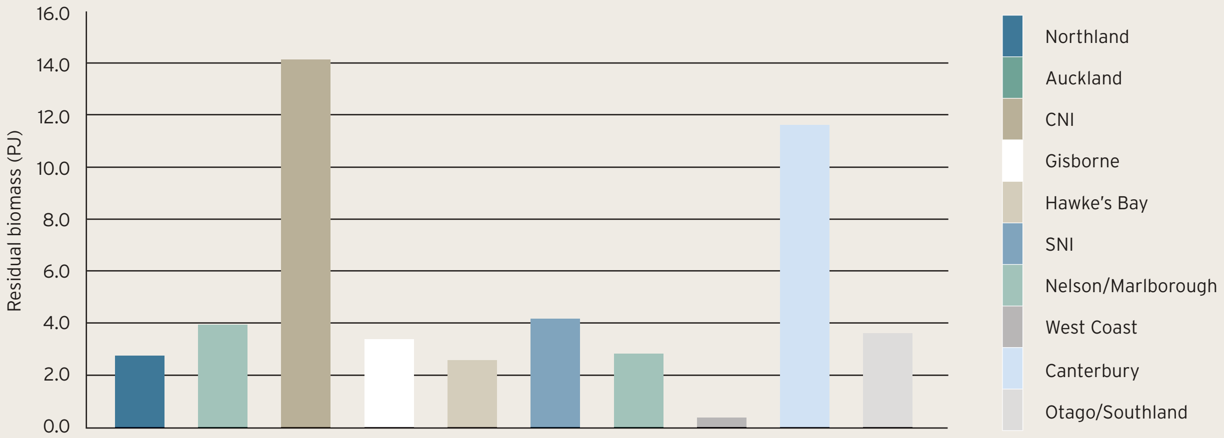
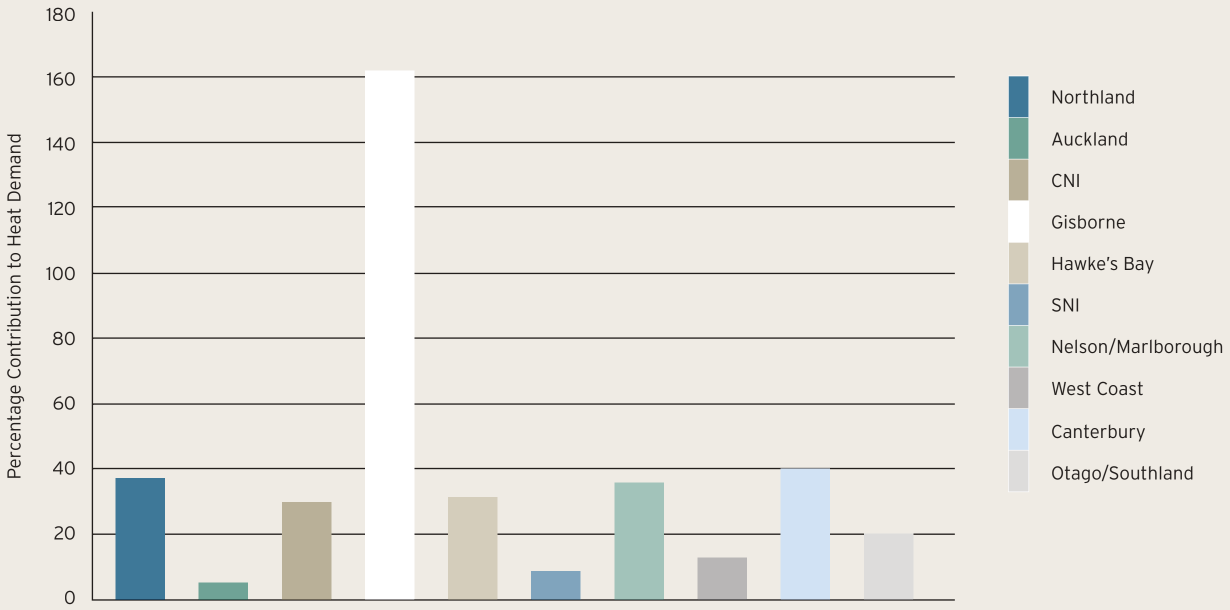


Figure 4 shows the contribution that current residual biomass could potentially make to regional heat demand. Residual biomass can make a significant contribution (>25%) at a regional level in Northland, Central North Island, Gisborne, Hawke's Bay, Southern North Island, Nelson/Marlborough and Canterbury.

Figure 4: Potential contribution of residual biomass to regional heat demand



Comparing the consumer energy that can be derived from residual biomass with the national demand for that type of energy (Table 3) it is clear that residual resources fall far short of current energy demands. The ability of biomass residues to meet heat demand is estimated to remain similar over time to 2050, with an overall increase in the long term.

Table 3: Residual biomass resources versus demand, national level

	Demand PJ per annum	All residual biomass resources converted to meet demand, PJ p.a.	Biomass as a % of demand
Heat	140	42	30
Liquid Fuels	245	15	6
Electricity	135	16	12

Future national demand

The New Zealand Energy Outlook to 2030 presents a scenario for future energy demand by fuel type to 2030. Further projections through to 2050 were made on a straight line basis from those of the Energy Outlook. These projections are shown in Table 4.

Table 4: New Zealand Energy Outlook: Future energy demand (PJ per annum)

	2010	2020	2030	2040	2050
Oil	250	290	320	340	390
Gas	50	52	61	66	70
Coal	41	42	44	46	48
Electricity	133	155	178	200	222
Renewables	28	30	33	36	39
Total	**502**	**560**	**636**	**628**	**769**

Under these assumptions, in 2050 total energy demand will be approximately 50% higher than it is now.

Peak oil and greenhouse gases

The New Zealand Energy Outlook projections were based on an assumed price of oil at US $60 per barrel. Already it is over US$120 (June 2008). These price increases are expected to continue, driven by the onset of peak oil (Figure 5) and increasing demand from China and India. It is predicted that there will be serious supply and cost issues with oil by 2030.

Figure 5: Peak oil supply prediction

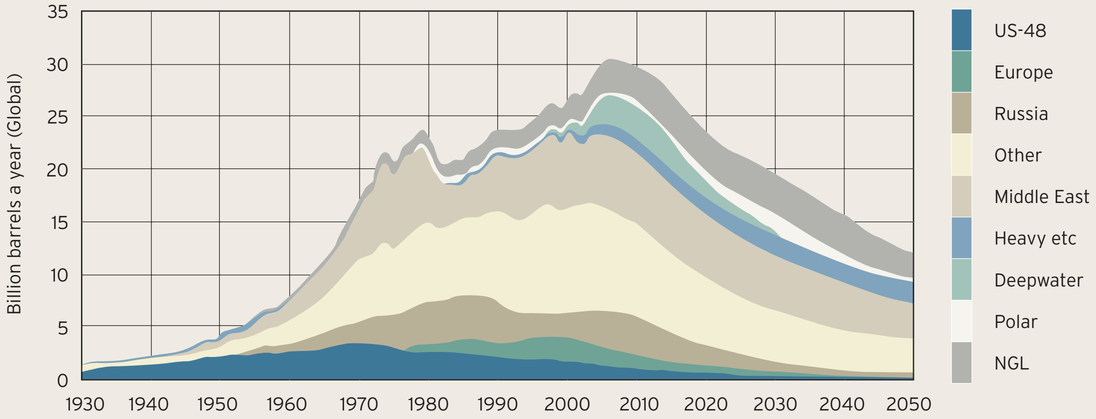


Image from, "The End of Oil" Professor Bob Lloyd, Physics Department, University of Otago July 2005: Colin Campbell's 2004 scenario for world oil and gas liquids.

It is illustrative to consider current fossil fuel usage broken down by consumer energy i.e. heat, electricity and transport fuels (Table 5). Virtually all transport fuels are derived from fossil sources, as is 27% of electricity, and 41% of heat. New Zealand is heavily dependant on fossil fuels with 509 PJ ie. of primary energy 509PJ (68%) being derived from fossil sources.

Table 5: New Zealand's consumer-energy derived from fossil sources (estimated from MED 2006)

	% from fossil sources	Amount of fossil energy, PJ	Comments
Liquid Fuels	100	287	87% imported
Electricity	27	38	Requires 132 PJ of fossil fuel to produce
Heat	41	80	Requires 90 PJ of fossil fuel to produce
Total	**65**	**405**	**77% of consumer energy**

The New Zealand Energy Strategy has made projections for New Zealand's energy demands in terms of consumer-energy (Table 6). This predicts a 50% increase in demand for transport fuels by 2050. Even under an ambitious scenario of electric cars replacing 40% of the fleet, the transport fuel demand will still increase 10% from current levels by 2050.

Table 6: New Zealand Energy Strategy: Future consumer-energy demands, PJ per annum

Year	Heat	Transport fuels	Electricity	Total
2025	200	325	192	717
2050	328	441	316	1085
2050 with electric cars at 40% of fleet	328	321(-120)	353(+37)	1002

Currently, transport fuels make up 20% of New Zealand's total greenhouse gas emissions (46% of CO_2). The combination of increasing oil prices and the need to reduce greenhouse gas emissions strongly suggest that New Zealand needs to reduce its dependence on oil as a source of transport fuels.

Purpose-grown forest

The *Bioenergy Options: Situation Analysis* report proposed a potential strategy to meet New Zealand's renewable energy needs with purpose grown forests; this strategy was driven by the limited nature of biomass residuals.

Land potentially available for afforestation (for energy forests) has been identified. Highly productive lands based on land use classes (LUC) and current land use and existing plantation forests were excluded. Also excluded were indigenous forest, Department of Conservation (DOC) estate and other areas such as wetlands, waterways and urban areas.

Three sets of analysis criteria based on slope, elevation and LUC were used to determine areas of land (low, medium and high) potentially suitable for conversion to forestry. The full set of regional figures, by criteria set (low, medium, high area of land) is presented in Table 7.

> "Currently, greenhouse gas emissions from transport fuels make up 20% of New Zealand's total greenhouse gas emissions."

Table 7 – Land area (ha), potentially available for forestry by region for each set of analysis criteria

	Low land area	Medium land area	High land area
Northland Region	6,658	67,759	258,010
Auckland Region	246	26,297	78,147
Waikato Region	5,541	266,872	462,849
Bay of Plenty Region	643	28,506	75,328
Gisborne Region	5,763	244,381	297,830
Hawke's Bay Region	11,578	392,044	505,106
Taranaki Region	12,765	87,483	119,888
Manawatu-Wanganui Region	34,747	641,184	755,415
Wellington Region	8,852	194,366	240,586
North Island	**86,793**	**1,948,892**	**2,793,159**
Nelson Region	35	1,758	2,667
Tasman Region	2,861	26,515	49,905
Marlborough Region	26,161	113,486	142,316
West Coast Region	4,497	18,773	54,362
Canterbury Region	342,023	572,459	928,048
Otago Region	318,146	521,179	850,602
Southland Region	50,644	169,292	348,017
South Island	**744,367**	**1,423,462**	**2,375,917**
New Zealand	**831,160**	**3,372,354**	**5,169,076**

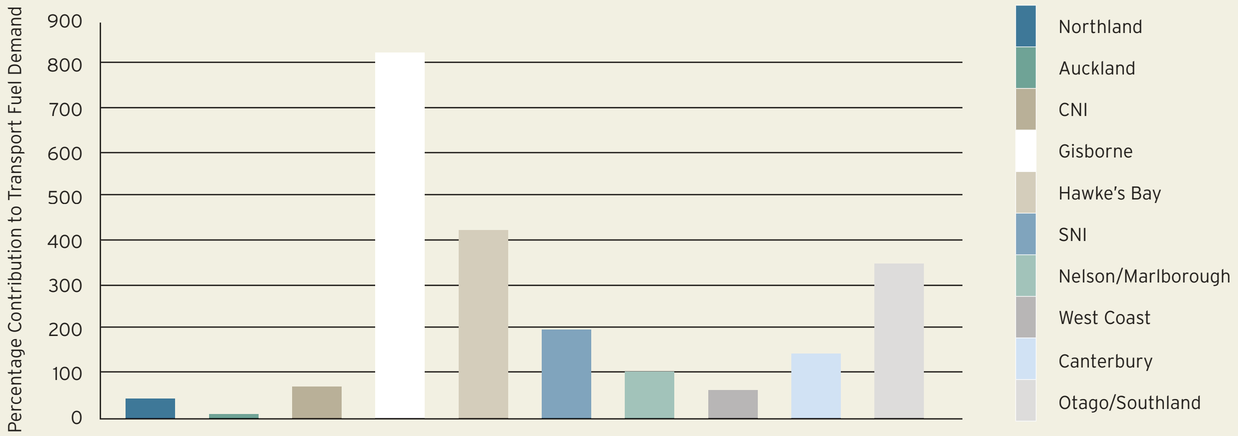
Assuming forest biomass productivity of 600m^3 of solid wood per ha (23-year rotation), a net calorific value of 7.1 GJ/m^3 for wood, and a conversion-efficiency to ethanol of 52% on an energy basis, we can estimate the potential contribution to liquid fuels supply. Table 8 shows the potential contribution from the medium land area scenario.

Table 8: Potential liquid fuel contribution from purpose grown forest (PGF) medium land area scenario

	Liquid fuel demand (PJ p.a.)	Fuel from residues (PJ p.a.)	Fuel from PGF (PJ p.a.)
Northland	17.4	1.3	6.5
Auckland	87.9	2.0	2.5
CNI	43.9	5.8	28.4
Gisborne	2.9	0.6	23.5
Hawke's Bay	9.0	0.9	37.8
SNI	45.1	1.9	88.9
Nelson/Marlborough	13.5	1.3	13.7
West Coast	2.9	0.1	0.6
Canterbury	38.7	1.3	50.9
Otago/Southland	19.1	1.3	66.5
New Zealand	**280.5**	**16.6**	**324.8**

Figure 6 shows the potential regional contribution of PGF (in the medium land area scenario) to liquid fuel demand. A number of regions (Gisborne, Hawke's Bay, Otago/Southland and Southern North Island) show potential that significantly exceeds their demand.

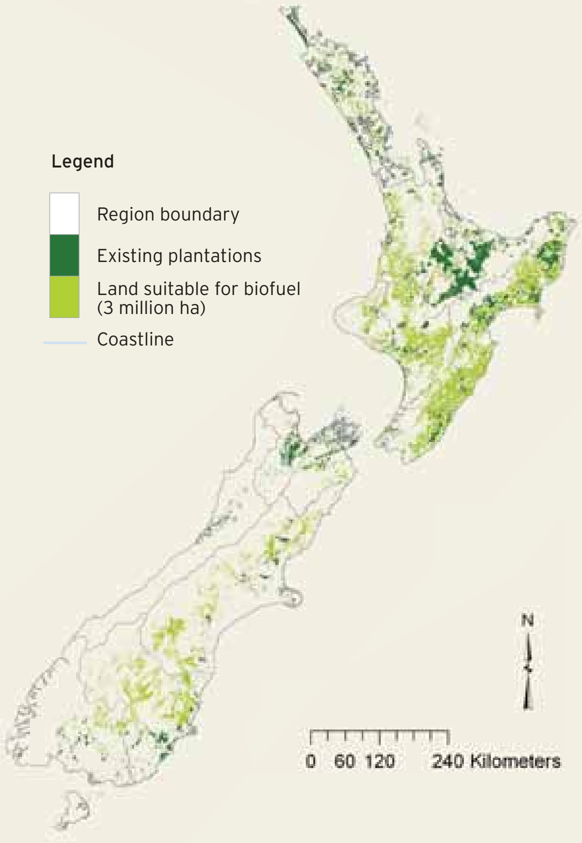
Figure 6: Potential contribution of PGF (medium land area scenario) to regional transport fuel demand



Conclusions

A number of conclusions can be drawn from this regional energy analysis:

- In comparison to energy demand, residual biomass is only significant in a few regions;
- Heat supply from biomass has potential in these regions;
- Due to growing national demand, future trends in international oil supply and the importance of producing environmentally sustainable fuels, transport fuels are likely to be the most significant energy issue in the foreseeable future;
- Purpose grown forests for energy are a potential large-scale energy resource that can be used to meet future energy demand, particularly, demand for transport fuels;
- A number of regions show significant potential for biofuel production.



Reference

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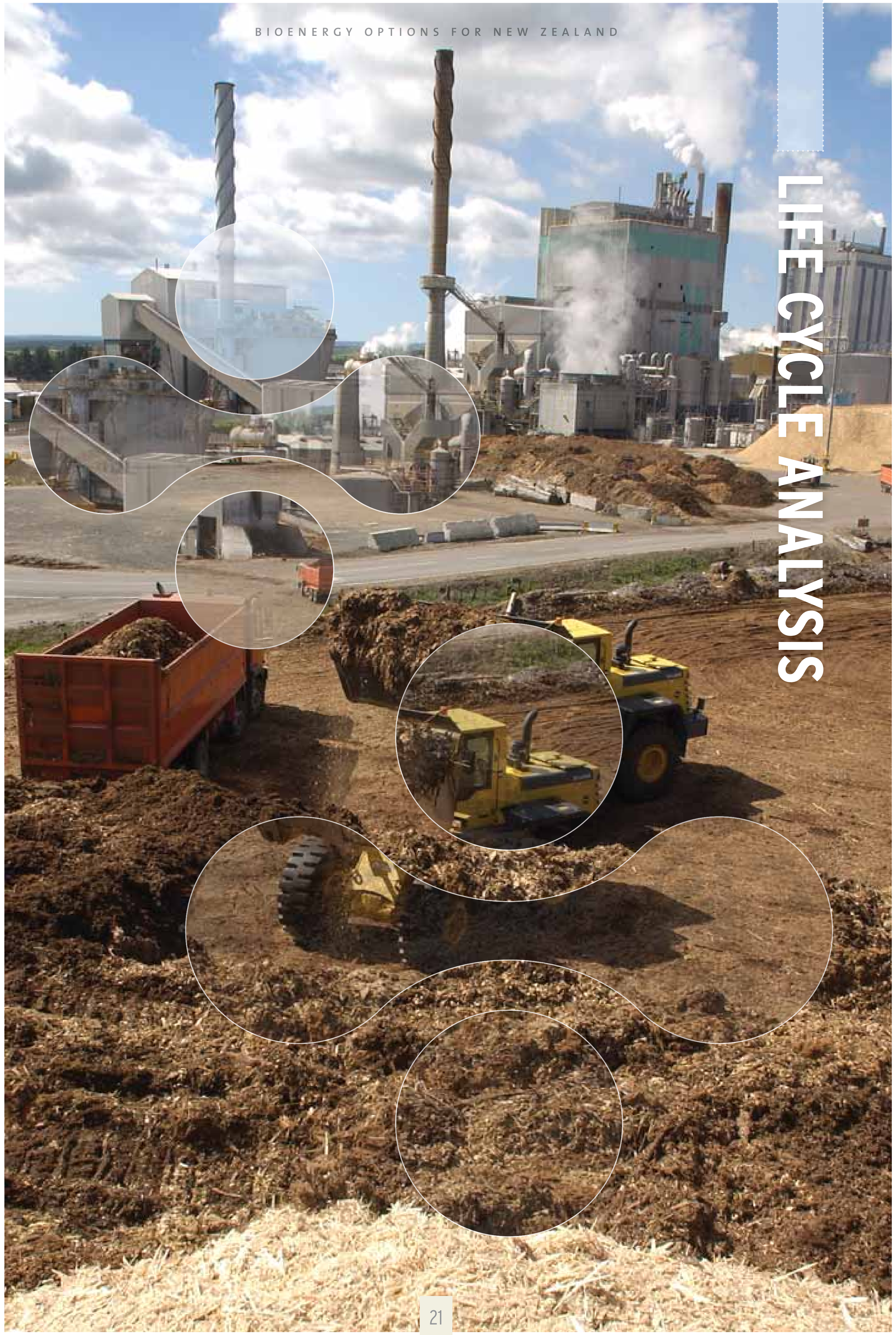


LIFE CYCLE ANALYSIS

3.0

LIFE CYCLE ANALYSES

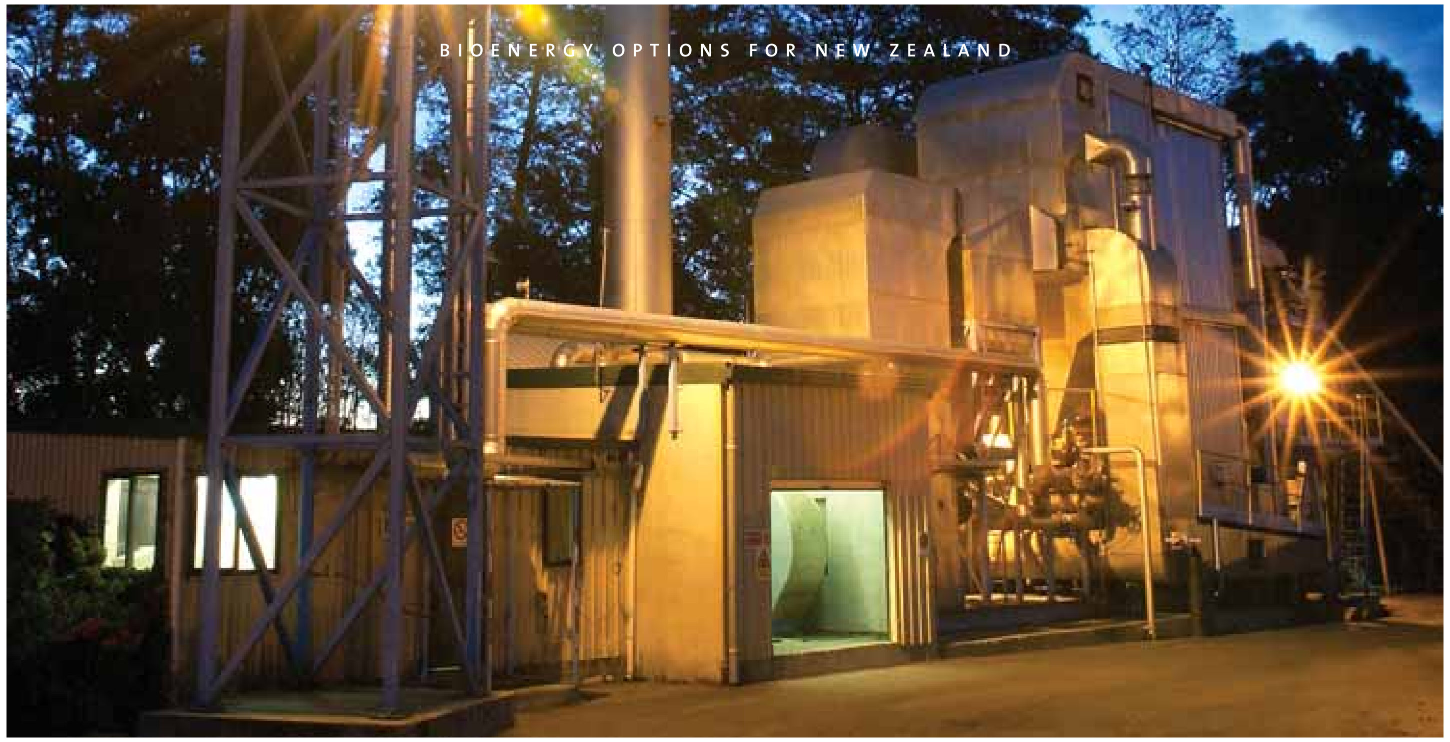
With the increasing use of biomass for energy, questions arise about the validity of using bioenergy as a means to reduce greenhouse gas (GHG) emissions and dependence on fossil-fuels. There are also questions about which of the many possible routes to take biomass from raw material to consumer energy offers the most effective use of the resource.

Life cycle assessment (LCA) is a systematic methodology for assessing the environmental impacts associated with a product, such as energy. The focus of this work is on greenhouse gas emissions (measured as CO_2 equivalents) and energy return on energy invested (EROEI).

This section presents detailed LCAs and Life cycle costings (LCC), to determine the economics of the following New Zealand biomass resource-to-consumer energy pathways:

1. Agricultural straw to combined heat and power via combustion (CHP);
2. Canola to biodiesel via transesterification;
3. Reject Kiwifruit to biogas via anaerobic digestion;
4. Industrial effluent to CHP via anaerobic digestion to biogas;
5. Forest residues to heat via combustion;
6. Forest residues to CHP via combustion;
7. Forest residues to heat via gasification;
8. Forest residues to CHP via gasification;
9. Forest residues to ethanol via enzymatic conversion;
10. Forest residues to Fisher-Tropsch (FT) liquids via gasification followed by a FT process;
11. Purpose-grown forest to heat via combustion;
12. Purpose-grown forest to CHP via combustion;
13. Purpose-grown forest to heat via gasification;
14. Purpose-grown forest to CHP via gasification;
15. Purpose-grown forest to ethanol via enzymatic conversion;
16. Purpose-grown forest to FT liquids via gasification followed by a FT process.

A key purpose of these detailed studies is to identify emissions and energy hot spots along the production chains. These hotspots can then undergo further investigation, to find ways of reducing their impact. This work complements the comparative pathway evaluation presented in Section 4.0.



In addition to data accuracy, the key factors that affect the results of an LCA are choice of:

- **System boundary** – This defines what is included in the study. For example, with a waste product (municipal effluent) the collection of the material is often not included in the modelling, as it would be gathered anyway.
- **Allocation method** - In systems where energy is produced together with non-energy commodities such as agricultural and timber products, the method by which the environmental impacts from production are allocated between the products strongly influence the results. Two common methods are allocation based on economic value or allocation based on mass.
- **Functional unit** - for energy systems, a unit such as 1 GJ of energy is often taken as the functional unit. However, not all consumer energies are equal (i.e. heat versus electricity versus liquid fuel) due to the unavoidable inefficiencies involved in interchanging some of these energies (e.g. converting heat to electricity).

When comparing the LCA results of different systems and/or comparing analyses carried out by different practitioners, it is important to take into consideration these factors.

While there are many advantages to using LCA and LCC to provide a holistic comparison of bioenergy forms considering the whole production chain, there are also limitations:

- The focus of the life cycle assessments done here has been material and energy flows relating to GHG production, fossil fuel use and economic costs.
- The assessment approach calculated only the primary environmental impacts of the process chain, (e.g., energy consumption and pollutant emission during the cultivation of energy canola. Secondary effects were not covered). For instance, if the demand for canola results in the conversion of forest land or wetlands, the environmental impact of this has not been included.
- Economic allocation is based on current prices (2008). The price of goods depends on market dynamics and will change over time.
- The process chains investigated represent only a subset of all production processes; many more production paths are conceivable. The paths chosen, however, are considered especially relevant for the current situation in New Zealand.
- The most recently available existing New Zealand data have been used where possible. Where these data are not available, overseas data have been used.
- Results may not apply to individual production plants, because the environmental impacts in individual cases may differ greatly from the average situation.

Reference

IEA Bioenergy Task 38 participants, 2008, *Comparing Greenhouse Gas Emissions and Energy Balances of Bioenergy* and *Other Energy Systems using a Life Cycle Assessment Approach: Strategic Position Paper*

Life cycle assessment of straw CHP in New Zealand

Summary Box

- **Potential scale of resource:** Significant regional resource, 0.6 PJ electricity and 1.8 PJ of heat from 210 000 tonnes of straw/year in Canterbury
- **Energy balance:** has an EROEI ratio of 17.6:1
- **GHG emissions:** greater than 90% reduction in comparison with coal for heat and grid electricity
- **Other environmental benefits:** avoids burning crop stubble
- **Economics:** currently not economically viable
- **Technology status:** mature

Background

Each season, arable cropping in New Zealand produces large volumes of excess straw that is not used. Unwanted straw is generally disposed of by cutting it up and leaving it on cropped fields to break down into organic matter. It can also be burnt to reduce the cost of establishing the next crop and vulnerability to pests. However, burning is becoming less common with tighter restrictions being imposed by local authorities.

Some of this material is not required for soil nutrition and could be utilised. For typical New Zealand cropped soils, an average of 50% of the crop residue can be removed.

This LCA analyses the feasibility of a CHP plant using straw as an alternative means of generating energy in New Zealand. CHP is the simultaneous generation of usable heat and electricity. This means of producing energy is already used in other countries and large volumes of surplus straw are used to fire CHP plants in Europe.

To make the process economic, and fully utilise the heat generated, a CHP plant in New Zealand would need to be located alongside an industrial plant that requires continual heat.

Canterbury is the principle region where arable crop residues are available in sufficient volumes to consider CHP using straw as a feedstock. The scenario assumed for this LCA is a CHP plant located in Timaru (which has industries that require heat), supplied with surplus straw from the surrounding arable farmland. Table 9 lists the surplus tonnage of residues from wheat and barley crops in Canterbury.

Table 9: Available residue production in Canterbury (tonnes)

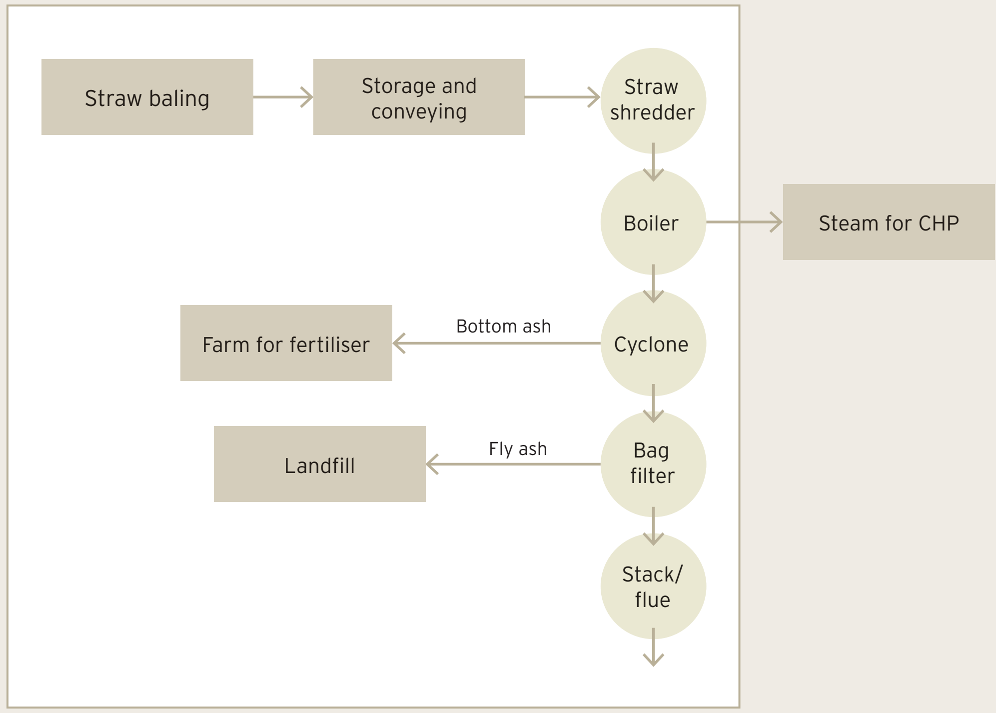
	Wheat	Barley	Total
Crop standard moisture content	292,678	204,149	496,827
Dry weight (less 13%)	254,630	166,101	420,731
Harvest index (50%)	0.5	0.5	
Residue (dry weight)	254,630	166,101	420,731
Surplus residue (dry weight)	127,315	83,050	210,365

Source: Saggar et al. (2007)

System boundary

Figure 7 shows the system boundaries used in this LCA. The cost of plant construction, operation, and maintenance is included in the life-cycle inventory.

Figure 7: Boundary of the straw LCA



Functional unit

The functional unit for this study is 1 GJ of energy.

Allocation method

Allocation of impacts between co-products is based on economic value. Since the crop residues are produced as an unwanted by-product of another farming activity and have no economic value to the farmer, no monetary value has been assigned to the straw. All energy inputs and costs of the growing and harvesting operation are allocated to the primary crop.

Key assumptions

Resource

- The cost of straw fuel for the CHP plant is determined by the cost of baling and storage and distance carted.
- Straw has a calorific value (at 15% moisture content) of 14.8MJ/kg.

Baling

- $22/tonne to bale.
- $1.465/litre for diesel, conversion rate 37.86 MJ/litre.

Transport

- 60 km supply radius to CHP plant in Timaru.
- Mean distance to farm 44km.

Plant

- A 33MW plant capable of generating 33GWh of electricity and 327 TJ of heat per year from 40,000 tonnes of straw.
- Inputs and outputs cover all processes related to heat and power production including administration and local wastewater treatment.
- Power and heat production is estimated based on an average straw-based CHP plant with a yearly net electricity efficiency of 25% and an overall net efficiency of 90%.

Electricity generation

- The cost of the turbines to generate electricity has been included in the LCA. Costs of connection to the grid have not been included.

Residue waste

- Slag by-products used as fertiliser. Average distance to distribute 44km.
- No additional cost or energy for spreading.

Capital

- $NZ1.65m per MW (based on plants in Spain and England).

Other assumptions are given in the full report.

Key impacts

1000kg of dry straw (i.e. with all moisture removed) produces 11760MJ of energy, comprised of 3060MJ of electricity and 8700MJ of heat.

Economics

The main costs associated with producing energy from straw are the capital costs ($67.61 per 11760MJ), and operating and maintenance costs ($33.81 per 11760MJ). Together, these costs account for $101.42 of the $164 cost of producing 11760MJ of heat and electricity.

Purchasing the equivalent amount of electricity from the grid and using coal to generate the heat would cost $119.8 (excluding capital cost of the existing boiler, wages, operating and maintenance, rates, and overheads).

Energy balance

From an energy perspective there are benefits; the amount of primary energy required to produce the above 11760 MJ is 670MJ. Table 10 shows the energy return on energy invested for the straw CHP plant, compared with electricity from the grid, and heat from coal. The energy return on investment is calculated as energy out/primary energy in.

Table 10: Energy return on investment for straw CHP plant

	Energy in[1] (MJ)	Energy out (MJ)	Energy out/ energy in
Straw CHP plant	670	11,760	17.6
Grid electricity and coal-fired heat	14,759	11,760	0.8

Greenhouse gas emissions

The greenhouse gas outputs from producing 3060MJ of electricity and 8700MJ of heat from straw are 40 kg CO_2-e, which compares favourably with those from electricity from the grid (174 kg CO_2-e) and heat from coal (828 kg CO_2-e).

Conclusions

Canterbury is the principle region where arable crop residues are available in sufficient quantities to consider CHP using straw. The total resource of surplus straws in Canterbury is 210,000 tonnes per annum. This resource is equivalent to 0.6 PJ electricity and 1.8 PJ heat under the present CHP scenario.

The plant modelled could produce 3060MJ of electricity and 8700MJ of heat at a cost of $164.

The greenhouse gas reductions of straw to heat and electricity via CHP are significant (>90%) when compared to electricity from the grid and heat from coal.

Energy return on energy invested is highly in favour of straw CHP with an EROEI of 17.6 to 1, where as the same energy from grid electricity and coal for heat is 0.8 to 1.

Reference

Forgie V. and Andrew R. Landcare Research May 2008. Lifecycle assessment of using straw to produce industrial energy in New Zealand. Report prepared for the Bioenergy Options for New Zealand - Pathways Analysis project.

> “Energy return on energy invested is highly in favour of straw CHP with an EROEI of 17.6 to 1, where as the same energy from grid electricity and coal for heat is 0.8 to 1.”

Life cycle assessment of Canola to Biodiesel in New Zealand

Summary Box

- **Potential scale of resource:** 39 PJ of liquid fuels (1.1 billion litres, assumes maximum crop area of 1 million ha)
- **Energy balance:** has an EROEI ratio of 2.2:1
- **GHG emissions:** 62% reduction in comparison with fossil diesel
- **Economics:** currently economically viable
- **Technology status:** mature

Background

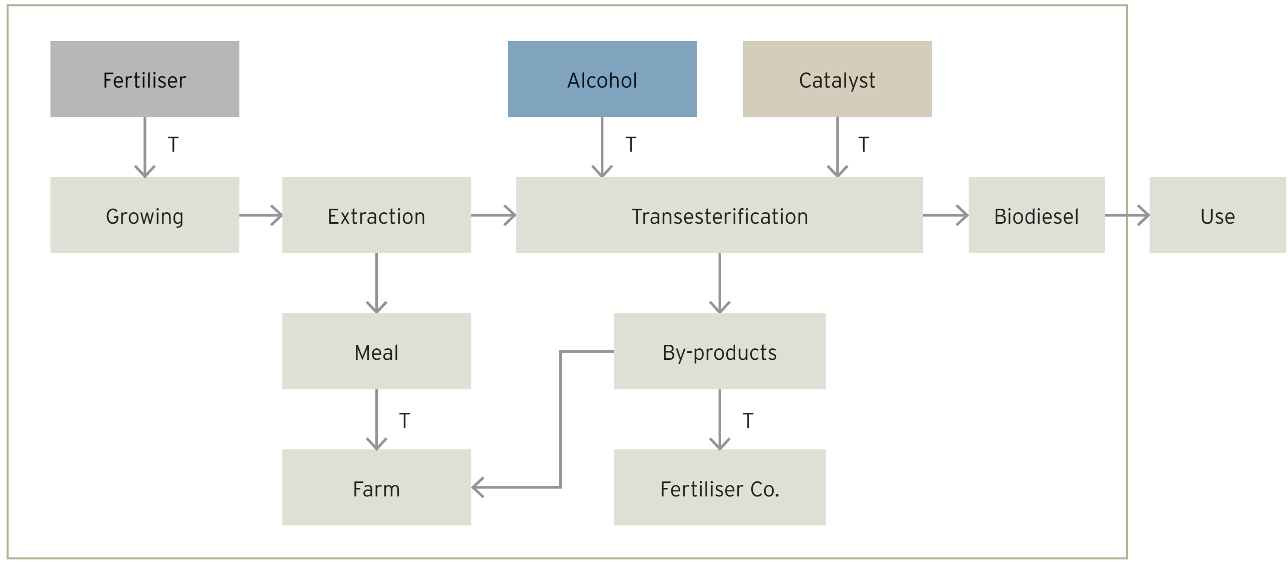
Biodiesel is a high-quality fuel that is widely accepted in Europe and North America. The creation of biodiesel from oily plant material (seeds and nuts) is a straightforward process based on common technologies that are well developed. Glycerol is a key co-product of biodiesel production that provides a cost offset.

The best potential source of biodiesel in New Zealand has been identified as canola crops. Canola is a brassica crop that produces seeds with oil content from about 40%-46%, at 8% moisture content. The area most suited to growing canola in New Zealand is on the Canterbury Plains of the South Island. Canola has previously been grown in New Zealand to produce cooking oil, and has been grown as a fodder crop for stock. The oil in canola seeds is most commonly extracted either mechanically in an oil press or chemically with a solvent. Normally 65%-80% of the oil can be extracted in an oil press. After the oil has been extracted the most valuable by-product is a protein-rich canola meal, which can be sold for stock food to dairy and beef farming operations.

System boundary

Figure 8 shows the system boundaries used in this LCA. The cost of plant construction, operation, and maintenance is included in the life-cycle inventory.

Figure 8: System boundary of the Canola Biodiesel LCA (T = transport)



Functional unit

The functional unit for this study is 1 GJ of energy.

Allocation method

Allocation of impacts between co-products is based on economic value.

Key assumptions

Crop Yield

- Dry canola seed yields of 3400 kg per hectare, which can produce 1130 kg of oil.
- Stock food co-product, canola meal, has a yield of 2240 kg/ha. Assumed to be sold by biodiesel plant at $500/tonne.

Growing

- Canola is grown on a 3-5-year rotation with other cereal crops, with a single canola rotation lasting about six months.
- Nitrogen fertiliser applied at 105 kg N/ha, minus 17.2 kg N/ha credit for canola straw returned to soil.

Transport

- Crops are grown in Canterbury a distance of 50 km (on average) from the processing plant.

Return to farmers

- Biodiesel plant pays farmers $49 per 75 kg of canola seed.

Glycerol co-product

- Glycerol is produced at a ratio of 1:10 with biodiesel, with the co-product credit in the order of $0.05–$0.10 per litre of biodiesel produced.

Plant capital and operational costs

- Capital costs of biodiesel plant are 4.89 c/l/yr based on a 20Ml/yr plant.
- Operational costs of biodiesel plant are 9.82 c/l/yr based on a 20 Ml/yr plant.

Other assumptions are given in full report.

Key impacts

It takes 75 kg of dried canola seed at 8% moisture content to produce 1000 MJ of biodiesel.

Economics

The main cost associated with production is the expense of obtaining the seed. It typically costs farmers approximately $20 to supply 75 kg of seed with the biggest cost inputs for the grower being nitrogen fertiliser, weed and pest control, and electricity for irrigation.

Given the assumed payout, this will provide farmers a gross margin of $1258/ha if they yield 3.5 tonnes of seed per hectare. In comparison, arable farmers were returning a gross margin of $965/ha for wheat and $708/ha for barley in 2005.

Under the study's assumptions, conversion of 75 kg of canola seed to 1000 MJ of energy and co-products will cost $37. Of this, $32.30 is allocated to canola biodiesel, $0.58 to potassium salts, and $4.00 to glycerin. In comparison, diesel fossil fuel retailed for $39 per 1000 MJ in April 2008.

Greenhouse gas emissions

The production and combustion of 1 GJ of canola biodiesel results in emissions of about 27 kgCO$_2$-e, which compares favourably with fossil diesel at around 83 kgCO$_2$-e. This is a reduction by 62%.

Energy balance

From an energy perspective there are benefits. The amount of primary energy required to grow 75 kg of seed is 408 MJ, which produces 25 kg of canola oil and 50 kg of meal. When the energy input into growing and pressing the canola seed is split on an economic allocation basis, the 25 kg of canola oil requires 231 MJ of energy to produce, and the meal 221 MJ of energy. The transesterification process requires an additional 282 MJ of energy.

With credits from sales of potassium salts and glycerol, it therefore takes 449 MJ of energy to produce biodiesel with 1000 MJ of energy from canola seed. The equivalent amount of fossil diesel requires 1193 MJ of energy. Fossil fuel energy makes up 70% of the energy required to produce the canola, mostly from diesel, electricity, and the production of nitrogen fertiliser and methanol.

Conclusions

At current prices, growing canola to create biodiesel is cost competitive with fossil diesel.

The GHG emissions from producing and using canola biodiesel are favourable compared to producing and using fossil diesel, with GHG emission reduced by 62%.

The energy balance (energy out:energy in) of the canola to biodiesel production chain is 2.22:1. This means the system is viable in the long term, fuelling itself, and producing an excess. This energy balance is better than that of fossil diesel.

The price of canola seed will be driven by the potential revenues from alternative arable crops (wheat oats).

Sensitivity analysis showed that:

- Economic viability depends critically on the price of canola seed. For example, a modest 20% increase in the price of canola seed results in production of canola biodiesel ($42/GJ) no longer being economically viable compared to fossil diesel.
- The use of residual meal from processing the oil seed for stock food , and its associated value, is critical to the cost competitiveness of biodiesel from canola.
- The price of glycerol has a small but significant effect on the cost competitiveness of producing biodiesel from canola.

Reference

Andrew R and Forgie V. Landcare Research 2008. Life cycle analysis of canola biodiesel in New Zealand. Report prepared for the Bioenergy Options for New Zealand - Pathways Analysis project.

> "The use of residual meal from processing the oil seed for stock food , and its associated value, is critical to the cost competitiveness of biodiesel from canola."

Life cycle analysis of reject kiwifruit to CHP via anaerobic digestion to biogas

Summary Box

- **Potential scale of resource:** Small, 0.06 PJ per annum nationally
- **Energy balance:** has an EROEI ratio of 11.3:1
- **GHG emissions:** greater than 90% reduction in comparison with gas for heat and grid electricity
- **Other environmental benefits:** waste reduction
- **Economics:** currently not economically viable
- **Technology status:** mature

Background

Kiwifruit orchards typically produce around 23 tonnes of kiwifruit per hectare and output volumes currently account for 30% of total horticultural exports from the country. It is estimated that nationally there are 60,000 tonnes of reject kiwifruit per year.

Kiwifruit are grown in three main regions of New Zealand – Bay of Plenty, Northland and Nelson. Because the Bay of Plenty region produces 86% of the kiwifruit crop, it is the region with most potential to use reject kiwifruit as a feedstock for biogas. The data used in the LCA for kiwifruit growing costs, energy use, and CO_2 emissions are based on the Bay of Plenty region.

Reject fruit from the horticultural industry is a potential feedstock for biogas production using anaerobic digestion (AD). This study tested the viability of this process using kiwifruit as an example, it being one of the biggest fruit waste resources in New Zealand.

Functional unit

The functional unit is 1 GJ of energy, of combined heat and power.

> “Reject fruit from the horticultural industry is a potential feedstock for biogas production using anaerobic digestion (AD).”

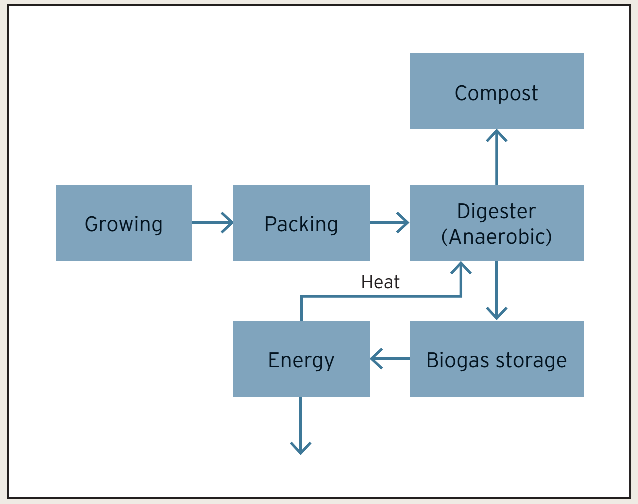
Allocation method

This study has used economic allocation as the method for analysis. The reject kiwifruit are assumed to have an economic value of $10/tonne. Based on economic value, impacts and costs associated with growing costs have an allocation of only 0.08% to the reject kiwifruit.

System boundary

The system boundary is shown in Figure 9.

Figure 9: System boundary of kiwifruit to biogas LCA



Key assumptions

Growing and packing

- 2420 MJ/tonne is embodied in kiwifruit on delivery to the packhouse. Using above allocation the embodied energy allocated to the waste kiwifruit is 9.9 MJ/tonne.
- Electricity use in packing is 263kWh per tonne and the electricity allocated to waste kiwifruit comes to 0.86 MJ/tonne.
- Packhouse size of 280m^2 (excluding the refrigerated area) and a lifetime of 35 years.
- Embodied energy of 590MJ/m^2.
- Costs based on construction costs of \$1000/m^2.

Transport

- Transport costs ($7.50 per tonne) were calculated on the basis of an average distance of 25km between the pack houses and orchards, and the processing plant.

Biogas plant

- Anaerobic digester assumed to be located at a meat processing plant. The digester is assumed to run on a 50/50 mixture of meat processing waste and reject kiwifruit for the six months of the year kiwifruit is available. When reject kiwifruit is not available, it is assumed that some other green waste stream is used. As kiwifruit accounts for 25% of the feedstock, 25% of the total plant costs and production were attributed to kiwifruit.
- Cogeneration plant at meat processing plant is capable of producing 500 kW of electricity and 400 kW of heat in the form of hot water.
- It is assumed the plant operates for 8000 hours per annum.

Economics

- Total economic inputs per tonne of kiwifruit processed are $38.57.

Key impacts

Approximately 1 tonne of kiwifruit rejects (979kg) is required to produce 1000MJ of energy (596 MJ electricity and 404 MJ heat).

Economics

The main economic costs associated with producing 1000 MJ of energy from waste kiwifruit is from producing the waste kiwifruit ($10 per 1000 MJ), capital costs ($10 per 1000 MJ), transport from the packhouse ($7 per 1000 MJ) and operating and maintenance costs ($5 per 1000 MJ). Together these costs account for $32 of the $38 cost of producing 1000 MJ of heat and electricity.

The revenue stream from generating 1000 MJ of energy from the biogas plant is $28. Electricity (valued at 10 cents/kWh) contributes $16.54, heat (valued at the cost of natural gas used to generate the same amount of heat) is worth $4.04, and the compost from the plant contributes $7.52.

Energy balance

From an energy perspective there are benefits. The amount of primary energy required to produce the 596 MJ of electricity (output from 979kg of kiwifruit

> “Kiwifruit orchards typically produce around 23 tonnes of kiwifruit per hectare and output volumes currently account for 30% of total horticultural exports from the country.”

waste) is 70 MJ. This primary energy input is almost all fossil fuel, attributed to inputs from capital, operating and maintenance, and transport, most of which use imported energy. This balance compares very favourably with the energy requirements to produce the same amount of electricity purchased from the national grid which is 1179 MJ, approximately 447 MJ of which is from fossil fuels.

Table 11 shows the energy return on investment for the anaerobic digester system, allocated between electricity and heat and for the system as a whole (which includes the energy allocated to compost production). The energy return on investment is calculated as energy out/primary energy in.

Table 11: Energy return on investment for anaerobic digester

	Energy in[2] (MJ)	Energy out (MJ)	Energy out/ energy in
Electricity (net)	71	596	8.4
Heat (net)	17	404	23.3
Whole system (excl. compost)	115	1000	8.7
Whole system (incl. compost)	88	1000	11.3

Greenhouse gas emissions

The greenhouse gas outputs are correspondingly higher for electricity from the grid (43 kgCO$_2$-e) compared to electricity from biogas (5 kgCO$_2$-e).

The energy required to generate 404 MJ of heat from the biogas operation (the output from 979kg of kiwifruit waste) requires just 17 MJ of primary energy compared to 463 MJ if natural gas is used. Most of the 17 MJ is in capital, operating and maintenance, and transport, and is imported. The CO$_2$-e emissions for the biogas are significantly lower than natural gas (1 kgCO$_2$-e compared to 25 kgCO$_2$-e).

Conclusions

Reject kiwifruit as a biomass resource for energy is small on a national scale.

The greenhouse gas benefits of converting reject kiwifruit to combined heat and power through anaerobic digestion are significant, with the emissions from fruit derived energy being significantly lower than those for the current conventional energy sources. Electricity from fruit digestion has emission reductions of 89% compared to grid electricity, and heat from fruit digestion has emission reductions of 96% compared to heat from natural gas.

While the economics are currently unattractive, this may change in the future as the cost of fossil fuels and grid electricity rise.

There is a competing use for reject fruit as stock food, which currently drives the price of obtaining the material. It also means that there are no credits from avoided disposal costs.

The environmental impacts and economic viability are most sensitive to the cost of the reject kiwifruit, which determines the how much of the growing impacts and costs are allocated to the reject kiwifruit.

Reference

Forgie, V., Giltrap, D., and Andrew, R. Landcare Research 2008. Life Cycle Assessment of Producing Biogas from Waste Kiwifruit. Report prepared For Bioenergy Options for New Zealand Pathways analysis programme. (Refer to CD).

> “The greenhouse gas benefits of converting reject kiwifruit to combined heat and power through anaerobic digestion are significant...”

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[2] *The energy input is allocated between electricity, heat and compost on an economic basis. For the “whole system” line all the energy (including that allocated to compost production) is included.*

Life cycle analysis for effluent to CHP via anaerobic digestion to biogas

Summary

- **Potential scale of resource:** Nationally 5-6 PJ/annum consumer energy from processing industry waste material and municipal biosolids/animal manure to biogas.
- **Energy balance:** has an EROEI ratio of 7.2:1
- **GHG emissions:** >200% reduction in comparison usual land disposal and grid electricity
- **Other environmental benefits:** 80% reduction in waste
- **Economics:** economic at favourable sites
- **Technology status:** mature

Background

Anaerobic digestion (AD) is a mature technology that can yield energy from a wide range of organic waste streams. This biogas can then be used to generate heat and power through a gas motor and genset. Using current anaerobic digestion technology, New Zealand has the potential to produce about 5-6 PJ/annum consumer energy from processing industry waste material and municipal biosolids/animal manure to biogas.

The specific case chosen for this LCA was the anaerobic treatment of dissolved air flotation (DAF) solids from a large sheep and beef slaughtering plant (10,000 stock units per day) in New Zealand. This plant is assumed to produce 5.7 tonnes per day of DAF sludge at 9% total solids (TS).

Functional unit

Functional unit is 1 TJ (1 million MJ) of electricity.

System boundary

The physical boundaries for the high level LCA and digester system costing in this report are based on a comparison with a business as usual (BAU) scenario; where:

- The DAF sludge from the end of a DAF pipe of an existing wastewater treatment system is conveyed to a sludge hopper of an existing belt-press for dewatering.
- Dewatered sludge is transported from the sludge hopper to a site 10 km away for land disposal.

The LCA for the digestor facility considered here has the system boundaries:

- From the end of a DAF float sludge pipe of the existing wastewater treatment to the hopper for dewatered DAF sludge at the relocated belt-press as part of the new digester facility.
- From a low pressure steam connection point at the meat processing plant.
- From a clean water connection point at the meat processing plant.
- To the end of the genset exhaust.
- To the end of a pipe delivering treated digester effluent into the factory wastewater stream upstream or downstream of the existing wastewater treatment DAF system.
- To a power connection point suitable for sale of electric power.
- To a hopper for dewatered digested DAF sludge to be transported off site.
- From the sludge hopper, to a site (10 km distance) suitable for land disposal of the dewatered DAF sludge.

Only material and energy flows that contribute more than 5% of the total material and energy flows were included in the life cycle inventory for this LCA and cost analysis.

Allocation method

There are no co-products in this system so all impacts are allocated to the electricity produced.

Key assumptions

DAF sludge composition

- The feedstock chemical composition assumed in this work, based on general industry experience, is presented in Table 12. This chemical composition implies good degradability of the DAF sludge.

Table 12: DAF sludge material composition

Component	Result	Unit
pH	4.9 - 5.5	-
Ammonia-N	70 - 130	mg/kg
Nitrate-N	<10	mg/kg
Total Kjeldahl Nitrogen	4400	mg/kg (wet)
Total Phosphorus	370	mg/kg
Total Solids	90	g/kg
Oil and Grease	27	g/L
Calcium	0.3	g/kg
Magnesium	0.05	g/kg
Potassium	0.05-0.09	g/kg
Sodium	0.3	g/kg
Sulphur	0.7	g/kg

Digestor facility

- Facility processes 5.7 tonnes per day of DAF sludge at 9 % total solids (TS).
- This produces 2,724 kg of methane per day.
- Biogas calorific value 50.7 MJ/kg.
- 8 month season.

Biogas genset

- Electrical conversion efficiency: 35%.
- Generator set (genset) cooling loop has a thermal heat output of 110% of electrical output (at 90°C).
- Heat output is fed back into digestor and is not available for export from the system.

Digester facility energy load

- The total electrical loads for the digester facilities are assumed to be 13% of the gross produced electricity.
- The maximum electrical load for digester, belt press and stripper is 150 kW.
- The thermal load of the digestor facility is assume to have a peak of 0.55 MW (which includes 0.4 MW for the thermal stripper and 0.15 MW for digestor heat).

Effluent discharge

- 80% of incoming Kjeldahl-N in DAF sludge becomes Ammonia-N.
- Thermal stripper is sized to remove up to 200 kg/day Ammonia-N from the digester effluent to meet a discharge limit of 50 g/m^3 Ammonia-N and a target of 30 g per m^3.

Additional energy savings compared to BAU

- The transport energy saving from avoided DAF sludge disposal is 0.51 TJ/annum.
- The dewatering energy saving through DAF sludge digestion is 0.037 TJ/annum.

Economics

- All economic costs are based on costs in 2006.
- Analysis based on an electricity price of 15 c/kWh.

Key impacts

Greenhouse gas emissions and other environmental impacts

The main air emissions from a DAF sludge digester facility are: Methane, CO_2, CO, NOx, N_2O and SO_2.

The emissions from land disposal of dewatered sludge are reduced by the dewatering. GHG emissions from disposal of DAF sludge materials from the digestor are estimated to be less than 1/5th of the emissions of the BAU scenario with DAF sludge materials at 9% TS.

For simplicity it is assumed that GHG emissions from dewatered digested DAF sludge are reduced pro-rata with the achieved TS destruction in the anaerobic digestion. This results in direct GHG emission reductions of at least 80%. Similarly, reduction in the volume of sludge after digestion is assumed to reduce the transport-related GHG emission by 80%.

Avoided GHG emissions credited from production of renewable electricity in New Zealand were estimated as 0.6 kg CO_2-e/kWh produced. After subtraction of parasitic electricity used for running the digester plant, the digester facility produces a net result of avoided GHG emissions of 2310 t CO_2-equivalent per annum. If all GHG reductions are attributed to the exported electricity, this corresponds to a greater than 200% reduction in greenhouse gasses compared to grid electricity and BAU.

Effluent nutrient content (BOD, TKN, ammonia-N) and flow are key regulatory parameters for the consenting of new industrial installations. Typically, treated discharge concentration of 10:10:10 (BOD, TKN, NH3-N) can be considered as an acceptable quality for discharge to river or marine outfall. The use of anaerobic digestion as described is expected to get the effluent nutrient concentrations down to these levels.

The second major environmental benefit of the digester plant is in the reduced daily volumes of dewatered sludge for final disposal from 35 tonnes per day to 7.4 tonnes per day (79%).

Economics

The technology presented here is already economically viable in New Zealand in selected favorable situations. Gross annual operating surplus figures between about 500,000 $/annum and 950,000 $/annum at power prices of 15 c/kWh (depending on local situation) are contrasted with construction costs of about 3-4 million NZ$/plant.

Energy Balance

The net electricity production from the digester facility is 6.26 TJ electricity/annum from a total of 13,000 t/annum of DAF sludge. There is no net thermal energy usage or production (see above) as all genset heat is considered as non-saleable, low grade, surplus waste heat. The EROEI is therefore 7.2:1.

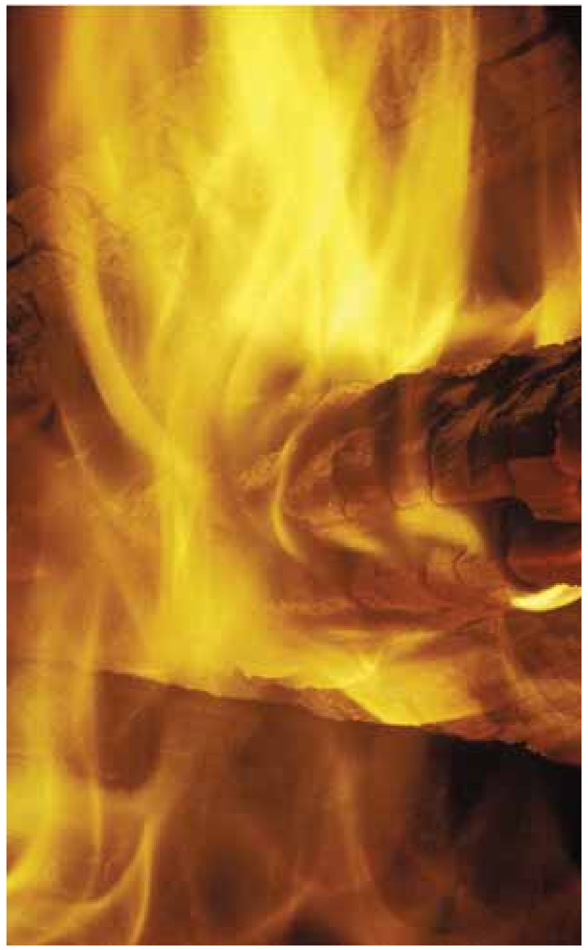
Conclusions

The total methane production potential from processing waste, municipal waste and manure in New Zealand of 5-6 PJ biogas/annum is capable of producing up to 630,000 MWh/annum of additional renewable electricity from waste. The DAF sludge digestion technology is directly transferable to the dairy processing sector. With both meat and dairy sectors combined this technology could supply 1 PJ of methane biofuel sufficient to replace 2% of the current national power production from natural gas.

Anaerobic digestion presents significant environmental benefits from avoided emissions from decomposing effluent and reduced waste.

Significant technical knowledge gaps do not exist and the technology is sufficiently mature to proceed to implementation in the New Zealand primary processing sector.

Uptake could be accelerated by an attempt to identify early implementation sites and by the creation of demonstration facilities.



The anaerobic digestion of effluents presented here is already economically viable in New Zealand in selected favorable situations.

Extending operation to 12 months would make this system more economically attractive. The economic feasibility of a digester facility design can be improved with effluent irrigation to land instead of "ammonia stripping and discharge to water course" (subject to land availability).

Reference

Thiele J 2008. High level Life cycle analysis Report for Anaerobic Digestion of DAF sludge from a meat processing plant. Report prepared For Bioenergy Options programme. (Refer to CD).

Thiele J 2008. Potential Assessment from Anaerobic Digestion (AD) of Municipal Biosolids and Effluent and Dairy Factory, Meat Processing and Wool Processing Waste. Report prepared for Bioenergy Options for New Zealand–Situation analysis.

Life cycle analysis of woody residues to consumer energy

Potential scale: up to 3.372 million ha of forest producing up to 600 PJ p.a. of primary energy.

Energy balance, GHG emissions, other environmental benefits, economics, technology status:

Summary

	Combustion Heat	Combustion CHP	Ethanol	Gasification Heat	Gasification CHP	Gasification Biodiesel
EROEI	7.5:1	4.9:1	3.5:1	5.6:1	4.0:1	3.9:1
Greenhouse gas reductions*	92%	94%	75%	90%	83%	83%
Cost ($/GJ)	$15.60	$27.60	$59.40	$31.20	$42.00	$34.50
Technology status	Mature	Mature	Developing	Developing	Developing	Developing

* Compared to heat from coal, electricity form the grid and fossil transport fuels

Background

The use of forest residues as a source of energy products is attractive because, as a by-product of forestry operations, forest residues do not use additional land. This is important where land competition is present between (for example) dairy, forestry, food crops or energy crops. It is estimated that a forest residue resource of 26PJ/annum is currently available in New Zealand.

Life Cycle Assessments (LCA) of six possible pathways to energy-related products from wood residues. The six pathways analysed are listed in Table 13.

Table 13: Pathways to energy product production from forest residues

Pathway name	Conversion technology	End product(s)
Combustion	Combustion	Heat
Cogeneration	Combustion	Heat and electricity
Ethanol	Enzymatic hydrolysis	Ethanol
Gasification - combustion	Gasification	Heat
Gasification - cogeneration	Gasification	Heat and electricity
Gasification - Fischer Tropsch	Gasification + Fischer Tropsch	Biodiesel

System boundary

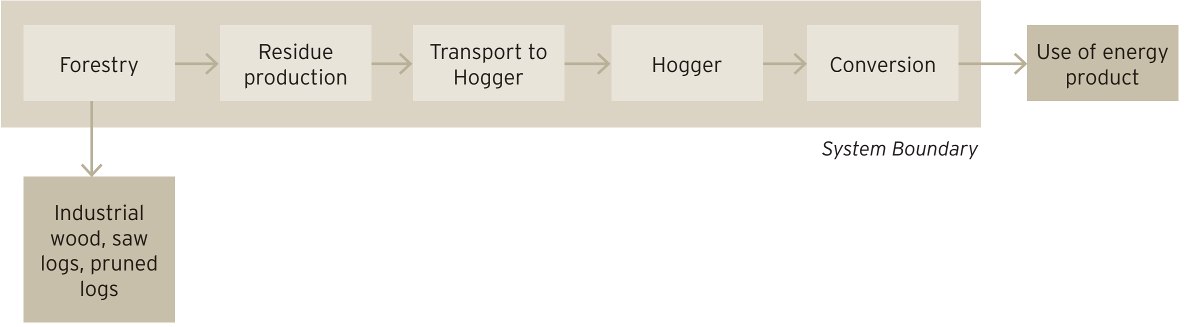
The analysis took into account all life cycle stages of the energy product life cycle, including forestry and forest residue processing, transport to hogger, hogging, and conversion to an energy product. The life cycle of the energy products is displayed in Figure 10. The processes in blue are all included in the system boundary. In this figure, 'conversion' represents the conversion of the forest residues into an energy product for each of the six pathways.

Included in the forestry life cycle stage are the processes for nursery production, site preparation, forest establishment, forest management and harvesting.

Emissions and impacts associated with the use of the energy product have not been considered, except that the future combustion of ethanol and biodiesel is assumed to release all carbon stored in the fuel.

Outputs of forestry that do not contribute to the production of the energy products (i.e. industrial wood, saw logs and pruned logs) are excluded from the analysis.

Figure 10: System boundary of forest residue conversion



Functional unit

The functional unit of each pathway is 1 gigajoule (GJ) of energy in the energy product. As each pathway produces a different energy product or products, the functional unit for each pathway is different. The energy product for each pathway is listed in Table 14.

Table 14: Form of energy for each forest residue pathway

Pathway name	Energy product(s)	Notes
Combustion	Heat	Combustion has efficiency of 60%
Cogeneration	Heat and electricity	Combustion has efficiency of 60% steam production
Ethanol	Ethanol	Efficiency of ethanol production is 42%
Gasification - combustion	Heat	Gas Combustion has efficiency of 85%
Gasification - cogeneration	Heat and electricity	Combustion has efficiency of 60%
Gasification - Fischer Tropsch	Biodiesel	Fischer-Tropsch has efficiency of 59%

Allocation method

Allocation has been done on a mass basis for the outputs of forestry. All outputs therefore have a share of the total impacts of the process proportional to their contribution by mass.

Key assumptions

Resource

- Forest residues from pine are produced as a by-product of forestry operations.
- Landing residues are gathered, loaded onto a truck and taken to a diesel hogger. The comminuted residues are then reloaded onto a truck and taken to an energy conversion facility.
- Cutover residues are baled, loaded onto a truck and taken to an electric chipper/hogger located at the energy conversion facility. The residues are chipped/hogged and are then ready for conversion.
- Moisture content of the forest residues was assumed to be 53% (wet basis), and the wood was assumed to have a net calorific value of 7.6 MJ/kg. The modelling is sensitive to this assumption.
- The embodied energy and greenhouse gas emissions of infrastructure has not been included.
- The quantities and assumptions used for forest residue processing are shown in Tables 15 and 16.

Table 15: Forest residue inventory data, per tonne of forest residues

Forest residue processing	Input	Quantity	Comment
	Residue wood	1000kg	
Gathering	Diesel	9.8E-2kg	For landing residues
Baling	Diesel	1.10kg	For cutover residues
Residue Extraction	Diesel	0.81kg	For cutover residues

Transport

- After hogging, the landing residues are loaded onto a truck, and then transported an assumed distance of 75km to the conversion facility.
- Loading of residues onto the truck requires 0.27litres of diesel per tonne of residues, for both landing and cutover residues.
- The transport of the residues 75km to the conversion facility requires 3.92litres of diesel per tonne of residues (21 tonne payload).

Table 16: Hogger inventory data, per tonne of forest residues

Hogger	Input	Quantity	Comment
Diesel Hogger	Wood	250kg	Landing residues
	Diesel	0.054kg	Loading
	Diesel	0.37kg	Hogging
Electric Hogger	Wood	750kg	Cutover residues
	Diesel	0.027 kg	Loading
	Electricity	10.5MJ	

Source: Hogging data provided by Scion. Emissions data based on 'universal tractor' in GaBi 4.2

Pathway of conversion

Plant – combustion and ethanol

- Reliable infrastructure data was not available for some of the energy conversion processes and has hence been excluded from all conversion pathways in order to retain consistency.
- The combustion plant is assumed to have a combustion efficiency of 60%. In CHP applications an additional loss occurs in converting the steam to electricity, resulting in a net efficiency of 42%.
- The quantities of wood, water and electricity used to produce 1GJ of heat were:
    - Wood 219kg
    - Electricity 12.6MJ
    - Water 105kg
- The cogeneration analysis assumed a fluidised bed biomass combustion plant used to produce 40MW of steam which is converted into 20MW process heat and 7.5MW of electricity.
- The quantities of wood, water and electricity used to produce 1GJ of heat and electricity were:
    - Wood 315.6kg
    - Electricity 23.6MJ
    - Water 404kg
- The ethanol production plant produces 1kg of ethanol for every 8.4kg of forest residues. This equates to an efficiency of ethanol production on an energy basis of 42%.
- Ethanol production has a by-product of lignin from the wood. This lignin is burned to provide energy for the ethanol distilation process.

Plant-gasification

- The following three pathways involve gasification of wood residues to produce syn-gas, followed by the production of an energy product(s) from the syn-gas (heat, heat and electricity, and biodiesel).
- All three pathways involve the drying of forest residues, and the gasification of the dried wood. The drying takes the wood residues from a moisture content of 53% (wet basis) to 11%.
- The dryer heat is fuelled by undried forest residues and requires 2.4GJ of energy from the residues to produce one dried cubic metre of residues. The dried residues have a net calorific value of 16.7MJ. The dryer also requires 18 MJ of electricity to produce 1000kg of dried residues.
- The gasifier is assumed to be a bubbling fluidised bed gasifier operating at atmospheric pressure, with a 60% efficiency of syn-gas production.
- The quantities used to model the furnace and gasification are shown in Table 17.
- The gas combustor has an assumed efficiency of 85% and is carbon neutral.

Table 17: Furnace and gasification inventory data per 1GJ of syn-gas produced

Scenario	Input	Quantity
Furnace	Forest residues to be dried	180kg
	Forest residues as fuel	31kg
	Electricity	1.8MJ
Gasification	Dried forest residues	100kg
	Electricity	16MJ

- Cogeneration is assumed to be carbon neutral and has an electricity production efficiency of 33%.
- The gasifier is assumed to be a bubbling fluidised bed gasifier operating at atmospheric pressure. The Fischer-Tropsch biodiesel production is assumed to be carbon neutral, with an efficiency of 59%. 1695 MJ of syn-gas are required to produce 1GJ of bio-diesel.

Table 18: Costs of forest residue life cycle stages

Life cycle stage	Cost	Explanation
Forestry	Free	Forest residues are assumed to be a waste product of forestry operations
Residue production	$24/tonne	Includes baling, transport to roadside, and loading on to transport
Hogger	$9/tonne	Comminutes large pieces of biomass into a feedstock suitable for processing
Transport	$0.27 / t/km	Per Tonne kilometre rate is multiplied by transport distance (75km)

> "Ethanol production has a by-product of lignin from the wood. This lignin is burned to provide energy for the ethanol distilation process."

Table 19: Costs of conversion processes

Conversion process	Cost	Explanation
Combustion	$3.94/GJ	Includes capital expenditure, operation and maintenance
Cogeneration	$10.76/GJ	Includes capital expenditure, operation and maintenance
Ethanol	$42.8/GJ	Includes capital expenditure, operation and maintenance
Gasification	$14.08/GJ	Includes capital expenditure and operating costs
Combustion from gasification	$3.87/GJ *	Includes capital expenditure, operation and maintenance
Cogeneration from gasification	$9.13/GJ *	Includes capital expenditure, operation and maintenance
Fischer-Tropsch from gasification	$1.3/GJ *	Includes capital expenditure, operation and maintenance

* Additional to the $14.08 of the initial gasification process.

Costs

The cost assumptions used in these LCAs are presented in Table 18 (residue production and delivery) and Table 19 (conversion processes).

Key impacts

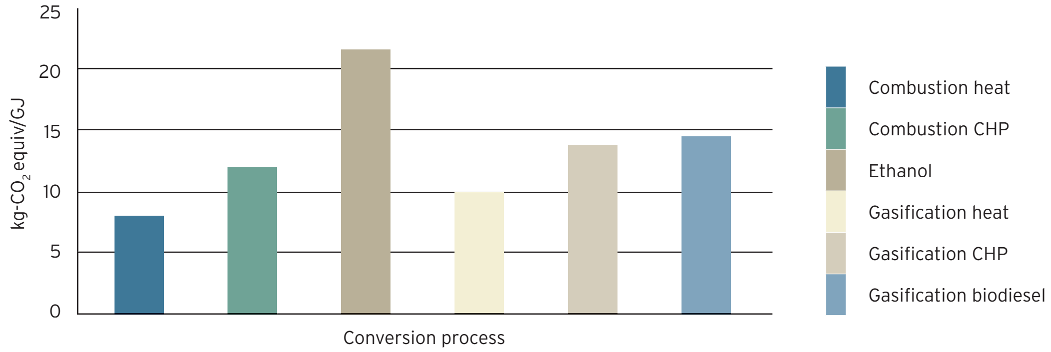
Greenhouse gas emissions

In Figure 11 we can see that combustion to heat has the lowest greenhouse gas emissions and that ethanol has the highest.

These results compare with the equivalent fossil fuel values as follows:

95 kg-CO2-e from 1GJ of coal; 85 kg-CO2-e for 1GJ of petrol; 83 kg-CO2-e for 1GJ of diesel and; 43 kg-CO2-e for 1GJ of grid electricity. All pathways show significant reductions in greenhouse gases.

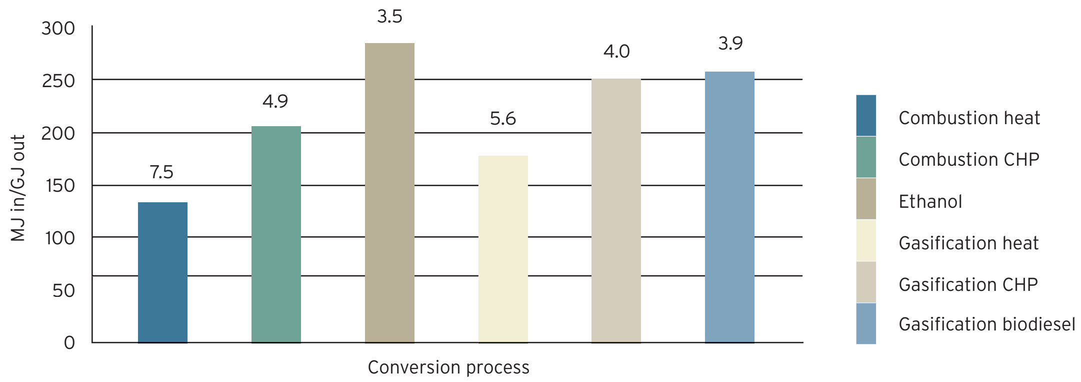
Figure 11 - GHG emissions by conversion process



Energy balance

The energy return on energy invested (EROEI) is best for combustion (Figure 12) and worst for ethanol production. Whilst the efficiency of the wood to energy conversion efficiency of the ethanol route is slightly higher than for gasification to biodiesel (Fischer-Tropsch), it requires more external energy to get to the end product.

Figure 12 - Energy Balance by conversion process



The EROEI figures are presented at the top of each column.

Economics

The higher inputs of the wood to ethanol conversion route are reflected in the higher cost per GJ of the ethanol (Figure 13)

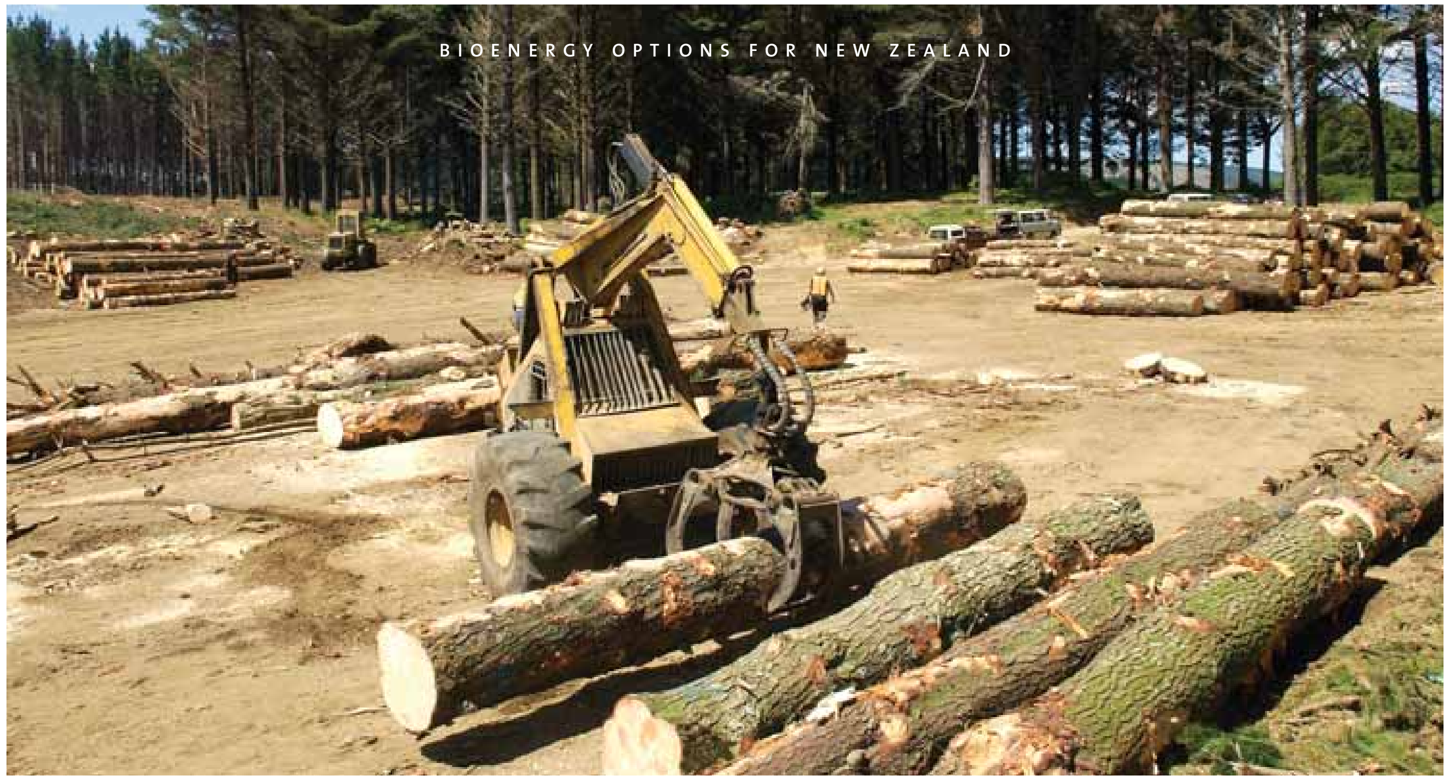
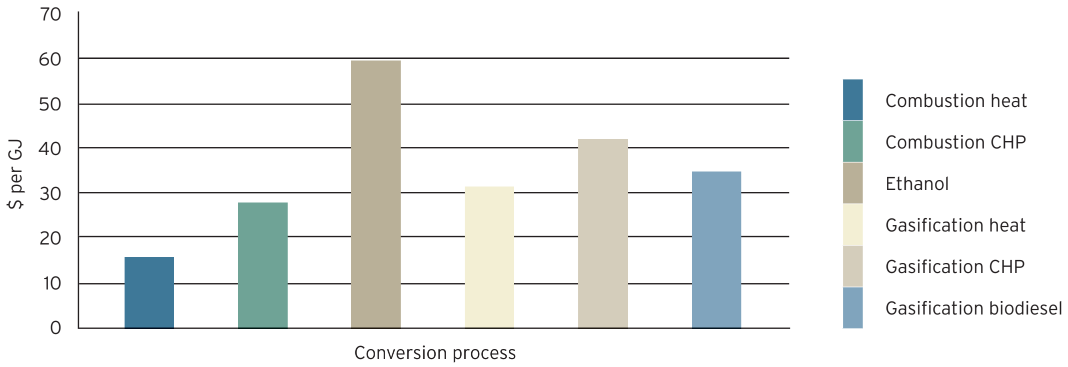


Figure 13 - Economics by conversion process



Conclusions

The six Life Cycle Assessments presented follow the production of 1 GJ of energy product from forest residues. As each pathway produces a different type of energy product, the results of the Life Cycle Assessments are not directly comparable. However, inferences have been made in this section for the purpose of interpreting the results and aiding decision making.

The combustion of forest residues to produce heat is the most economic pathway to produce 1 GJ of energy product. Combustion also requires the least amount of non-biomass embodied energy, and has the lowest greenhouse gas emissions. Conversely, the production of ethanol from forest residues has the highest embodied energy, and greenhouse gas emissions.

Transportation and the conversion process have the highest contribution to the greenhouse gas emissions and to the embodied energy of all energy pathways.

The efficiency of energy production significantly affects the relative performance of each energy pathway. The energy required in the conversion process also affects the performance of each pathway, but to a lesser extent. The upstream processes that occur before the forest residues are converted into energy have a greater embodied energy and greenhouse gas emissions than the energy conversion processes themselves. Therefore, a reduction in the amount of forest residues required to produce 1 GJ of energy product would reduce the larger part of the embodied energy and greenhouse gas emissions of the pathways.

Life cycle analysis of purpose-grown forest to consumer energy

Potential scale: current 26 PJ p.a. of primary energy, rising to 46 PJ p.a. by 2030

Energy balance, GHG emissions, other environmental benefits, economics, technology status:

Summary

	Combustion Heat	Combustion CHP	Ethanol	Gasification Heat	Gasification CHP	Gasification Biodiesel
EROEI	10.9:1	6.9:1	4.5:1	7.7:1	5.5:1	5.4:1
Greenhouse gas reductions*	95%	91%	80%	93%	89%	89%
Cost ($/GJ)	$34.50	$54.80	$86.60	$53.20	$72.60	$65.40
Technology status	Mature	Mature	Developing	Developing	Developing	Developing

* Compared to heat from coal, electricity form the grid and fossil transport fuels

Table 13a: Pathways to energy product production from purpose-grown forests

Pathway name	Conversion technology	End product(s)
Combustion	Combustion	Heat
Cogeneration	Combustion	Heat and electricity
Ethanol	Enzymatic hydrolysis	Ethanol
Gasification – combustion	Gasification	Heat
Gasification – cogeneration	Gasification	Heat and electricity
Gasification – Fischer Tropsch	Gasification + Fischer Tropsch	Biodiesel

Background

This section considers the products of the six energy product pathways, where the wood is sourced from a forest grown specifically for energy product production (see Table 13a above). Purpose-grown forest would allow for large scale energy production.

In this scenario, all the costs and environmental burdens of forestry are attributed to the wood used to make bioenergy, and all wood is hogged in an electric hogger/chipper located at the conversion facility.

The goal of this section of the study is to develop a Life Cycle Assessment profile of the greenhouse gas emissions, embodied energy, and costs associated with the generation of energy product from purpose-grown forest. It also allows the comparison of costs and impacts of energy product production from purpose-grown forest with energy products from forest residues.

System boundary

The analysis took into account all life cycle stages of the energy product life cycle, including forestry, transport to hogger, hogging, and conversion to an energy product.

The life cycle of the energy products is displayed in Figure 14. The processes in blue are all included in the system boundary. In this figure, 'conversion' represents the conversion of the wood into an energy product for each of the six pathways.

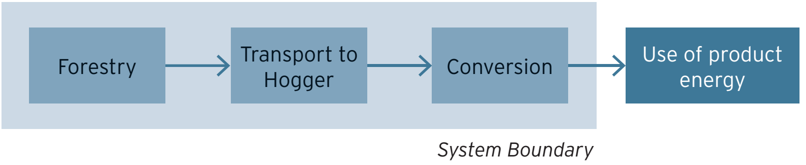
Included in the forestry life cycle stage are the nursery, site preparation, forest establishment, forest management and harvesting. Also included are material inputs, energy inputs, transport; and outputs as well as the emissions related to energy use and production.

Embodied energy in capital equipment and infrastructure are excluded from energy and emissions calculations.

Fuel and electricity consumption, together with their upstream process, were taken into account.

The forest residues were given a share of the environmental impact from forestry based on the mass of the residues. Outputs of forestry that do not contribute to the production of the energy products (i.e. industrial wood, saw logs and pruned logs) are excluded from the analysis.

Figure 14: System boundary of wood from purpose-grown forest conversion



Functional unit

The results of the Life Cycle Assessments are presented for each energy product pathway in terms of 1 gigajoule (GJ) of energy in the energy product (the 'functional unit'). As each pathway produces a different energy product, the functional unit for each pathway is different. The energy product for each pathway is the same as for the forest residues, and these are listed in Table 13a.

Allocation method

No other wood products are produced in these pathways so all impacts are allocated to the energy products.

Key assumptions

Resource

- Harvested wood from forestry is loaded onto a truck and transported to an electric chipper/hogger located at the energy conversion facility. The wood is chipped/hogged and is then ready for conversion.
- Unlike forest residues, the wood from purpose-grown forest does not need to be gathered or baled. In addition, all wood is hogged in an electric hogger, which is more efficient than the diesel hogger used to hog landing forest residues.
- Moisture content of the wood from purpose-grown forest was assumed to be 53% (wet basis), and the wood was assumed to have a net calorific value of 7.6 MJ/kg. The modelling is sensitive to this assumption.
- Forestry includes the processes: nursery production, site preparation, forest establishment, road construction, forest management, and harvesting. Harvesting and road construction contribute the majority of the energy inputs and greenhouse gas emissions.

Transport

- Harvested wood from forestry is loaded onto a truck and transported an assumed distance of 75km to an energy conversion facility.
- Loading of wood onto the truck requires 0.26 litres of diesel per tonne of wood.
- The transport of the wood 75km to the conversion facility requires 2.9 litres of diesel per tonne of wood. The wood is assumed to be transported by a truck with a 27 tonne payload capacity.

Conversion

- The wood is comminuted in an electric chipper/hogger located at the conversion plant that requires 14 MJ of electricity per tonne of wood produced.
- The conversion processes were the same as those used for the forest residues analysis and are presented in Table 13; previous section.
- All the carbon stored in the wood is assumed to be released during energy production and use. The net carbon output of carbon storage and production/use is zero, as one process absorbs carbon from the environment and the others release it. The greenhouse gas emissions for the production/use of each conversion pathway has therefore been set to zero. The greenhouse gas emissions for forestry observable in the results is caused by other processes occurring during the forestry life cycle.

Plant

- All plant assumptions are the same as for the previous section – forest residues.

Costs

- The assumed cost of each stage in the purpose-grown-forest energy production life cycle is detailed below (Table 20).

Table 20: Costs of purpose-grown forest life cycle stages

Life cycle stage	Cost	Explanation
Forestry	$134.7/ tonne	Includes all land, establishment, silviculture, roading and logging costs
Hogger	$5/tonne	The electric hogger is more cost efficient than the diesel hogger
Transport	$0.27 t/km	Transport distance of 75 km is assumed

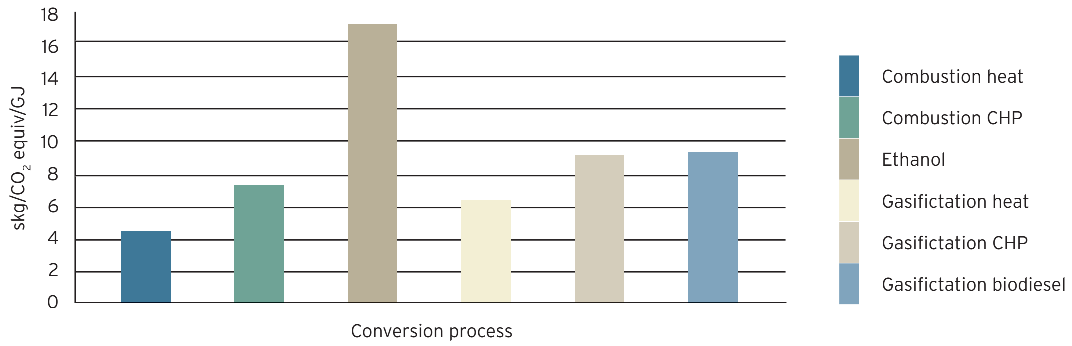
- The costs and efficiencies of the conversion processes are the same as for forest residues (Table 19).

Key impacts

Greenhouse gas emissions

In Figure 15 we can see that combustion to heat has the lowest greenhouse gas emissions and that ethanol has the highest, similar to the impact of residue conversion in the previous section.

Figure 15 – GHG emissions by conversion process



Combustion of wood from purpose-grown forest is over twice as expensive as combustion of wood from forest residues, over the life cycle from forestry to combustion. However, the embodied energy and greenhouse gas emissions of combustion from purpose-grown forest is reduced, due to the elimination of the forest residue production process, and the more efficient hogger.

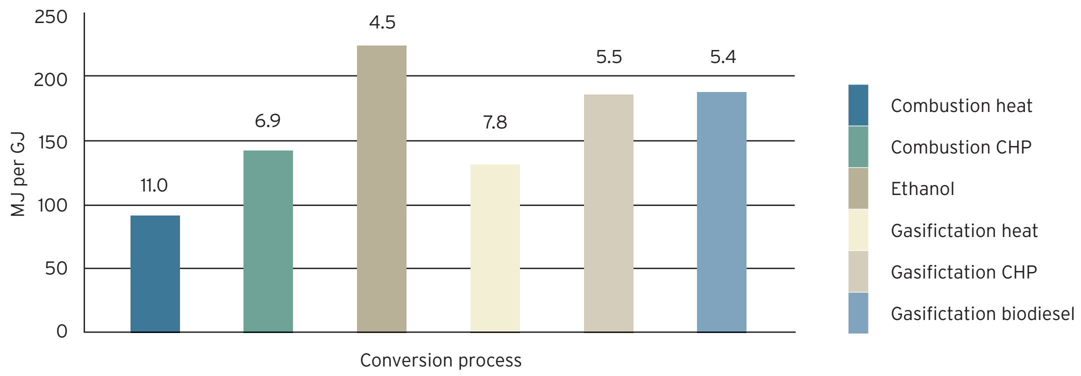
Ethanol from purpose-grown forest has a lower embodied energy and greenhouse gas emissions than ethanol from forest residues, but a higher cost due to the value of the wood from forestry.

In all purpose-grown forest pathways, transport and forestry production make a significant contribution to the cost, embodied energy and greenhouse gas emissions of the pathway.

Energy balance

The energy return on energy invested (EROEI) is best for combustion (Figure 16) and worst for ethanol production, as in the previous section with forest residues. Whilst the wood to energy conversion efficiency of the ethanol route is slightly higher than for gasification to biodiesel (Fischer-Tropsch), it requires more external energy to get to the end product.

Figure 16 – Energy balance by conversion process

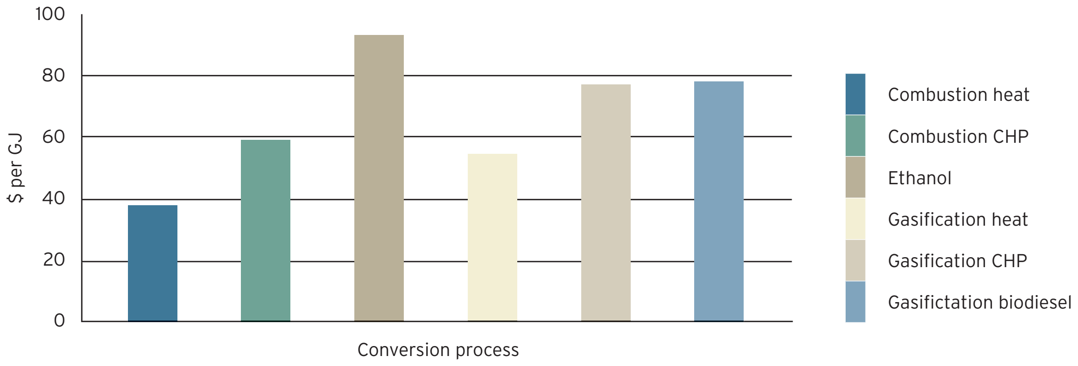


The EROEI figures are presented at the top of each column.

Economics

As with forest residues, the higher inputs of the wood to ethanol conversion route are reflected in the higher cost per GJ of the ethanol (Figure 17)

Figure 17 – Economics by conversion process



The pattern of results is the same for purpose grown forests as it is for forest residues (Figures 15 to 17), although the numbers differ. The costs are higher reflecting the additional cost of growing the resource.

Conclusions

Overall, the cost of producing energy from a purpose-grown forest is greater than for forest residues, but the embodied energy, (not including stored solar energy) and greenhouse gas emissions are smaller.

The greenhouse gas emissions and MJ per GJ are lower because the energy inputs to creating the resource are also lower, due to a more efficient supply chain being enabled with a large scale process. The production of energy from a purpose-grown forest is more expensive than from forest residues, as the cost of all forestry operations are now attributed to the wood, whereas in the case of forest residues there was no economic value given to the residues.

As the energy and greenhouse gas emissions of forestry was allocated to the forest residues on a mass basis, there is no difference in the burdens of forestry in forest residues and the purpose-grown forest.

In addition, no transport of wood within the forest is required for purpose-grown forest, whereas landing residues must be transported to the diesel hogger located within the forest in the forest residue pathways.

Conclusions from detailed life cycle assessments

A number of general observations can be deduced from the LCA studies presented in this report:

Pathways with large EROEI generally correspond to large reductions in greenhouse gas emissions, demonstrating the significant role of fossil fuels.

The greenhouse gas emissions from intensive farming of energy crops are significantly higher than from plantation forestry, which limits their ability to reduce greenhouse gas emissions. For example the greenhouse gas emissions from growing canola to produce 1GJ of fuel are 19 kg CO_2-e, whereas to produce the equivalent from forestry produces 6 kg CO_2-e.

Greenhouse gas reductions from utilising waste material such as effluent and agricultural waste are very significant. This is due to the fact that little of the farming emissions are attributed to the waste. There are also additional benefits from avoided methane emissions from decomposing waste.

In the case of the straw and wood pathways, the biomass supply chain, including harvesting, transportation and pre-processing makes a significant contribution to the GHG emissions.

Six energy production pathways from forestry-derived biomass (residues and purpose-grown) were analysed which used different energy conversion methods to produce different types of energy product (heat, electricity, ethanol and biodiesel).

Of the six pathways analysed, combustion to produce heat (of forest residues and/or wood from purpose-grown forests) is the most economical, requires the least amount of energy input, and has the lowest greenhouse gas emissions. Conversely, production of ethanol has the largest embodied energy and greenhouse gas emissions.

A key factor in the embodied energy and greenhouse gas emissions is the efficiency of the pathway. Thus, combustion is the most efficient pathway (60% efficiency), and gasification – Fischer-Tropsch to liquid fuels is the least efficient (35% efficiency).

The efficiency of the pathway determines the amount of wood required as an input. If less wood is required, then the embodied energy and greenhouse gas emissions associated with forestry, transportation, forest residue production and hogging are reduced. Research focussed on improving these efficiencies is therefore a priority.

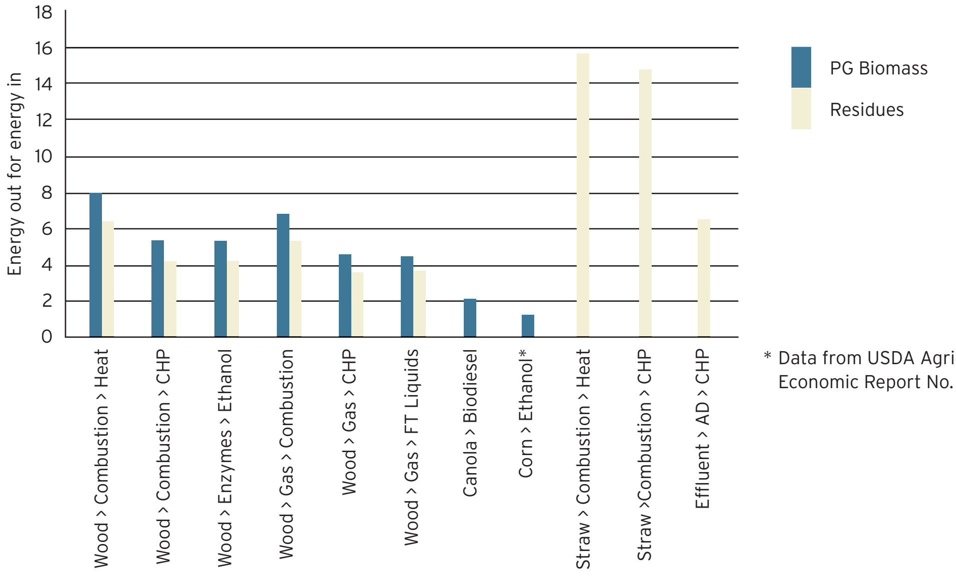
The comparison made in Figure 18 can be used to look at energy-used versus energy produced (Energy return on energy invested or EROEI). This is important for liquid fuels in particular as they have lower efficiencies than combustion but their production can be driven by a high value end product. However, it is critical that the process is sustainable in terms of energy. For example, a process can produce liquid fuels at a ratio of four units out for every unit in. Then of the four produced, one can be used in the system and three are available for export to the wider community.

The key cost difference between residues and purpose-grown forestry is that the costs of forestry are allocated entirely to the wood used for energy production in the purpose-grown forest. Forestry in the forest residues scenario has no cost, as the forest residues are considered a waste product of forestry.

The choice of pathway from resource to consumer energy needs to be made considering cost, scale, demand, energy return and environmental impact. Biomass-based renewables are all superior to fossil fuels in terms of greenhouse gas emissions. Deciding which route to take will be a complex decision based on the most efficient means (least cost) of meeting demand, whilst maximising environmental benefits.

A focus on the productivity of the raw material would reduce the cost, as the primary productivity of the forest system greatly affects the cost of the raw material going into the conversion process.

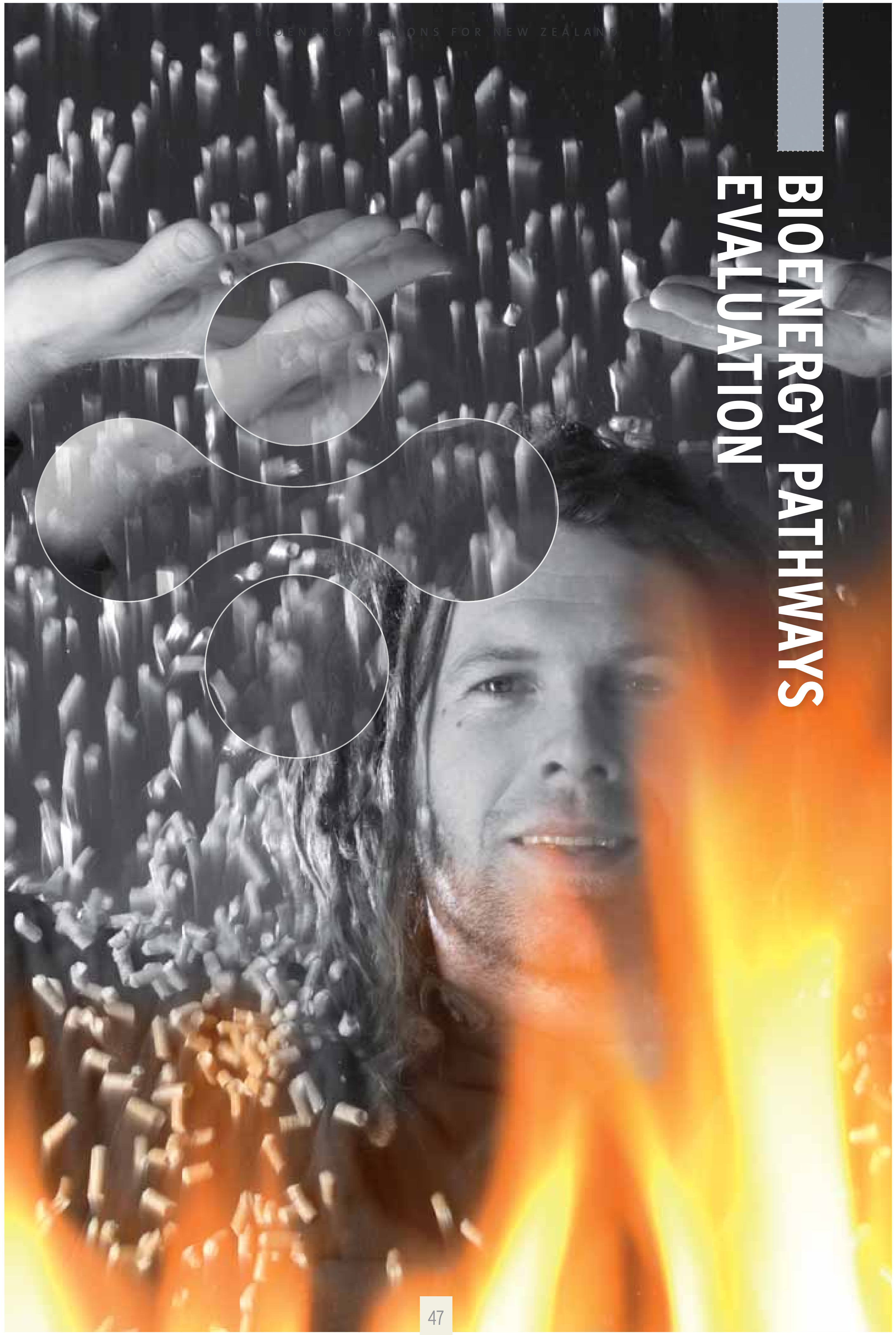
Figure 17a: EROEI



* Data from USDA Agricultural Economic Report No. 813

For the LCA on any given pathway, the system boundaries used can have a significant effect on the environmental impacts and greenhouse gas emissions. A standardised approach for New Zealand would assist in comparison of results.

BIOENERGY PATHWAYS EVALUATION



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BIOENERGY PATHWAYS EVALUATION - A COMPARATIVE ANALYSIS

In a separate analysis by different authors, 22 biomass resource-to-consumer energy pathways were compared on the basis of economics; energy efficiency; greenhouse gas emissions; technology status; and risks and benefits. Energy efficiency is defined as the amount of energy retrieved from the amount of the raw biomass that was put into a process. Energy return on energy invested (EROEI) is the total amount of energy that goes into the pathway versus that which is generated from it.

Pathway selection was based upon numerous criteria including stakeholder engagement feedback, resource size, conversion technologies applicable to the resources of significance, and ability to provide liquids for engine use. For the latter, New Zealand is perceived to have sufficient energy resources such as renewable electricity, lignite, coal and gas, to provide its electricity and heat needs for the foreseeable future, but does not have ready options to contribute significantly to reducing transport fuel imports. Hence it was deemed important to include biomass-to-liquid pathways. Biomass from residues and purpose-grown forest could also make contributions to electricity and heat demands.

Two coal-based reference chains, based on the use of lignite, have also been provided for comparison with the biomass energy pathways.

Some of the biomass energy pathways compared had components in them for which the technology involved is still at a developmental stage. As such, there is some uncertainty with regard to future economics and process efficiencies for these pathways. This variance was considered when making comparisons, and means that economic and other comparisons were made at a higher, more holistic level.

Pathways description

Table 21 provides a description of the selected pathways. Pathways 1 to 7 and 8 to 14 effectively repeat the same conversion technology, but the latter set of conversions (8 to 14) are applied to wood from a purpose-grown forest resource (PGF), as opposed to wood from residues streams (1 to 7).

Table 21: Pathway descriptions

Pathway	Input (Resource)	Process	Outputs
1	Wood (Landing Residue)	Wood is gathered from the landing site, hogged onsite and transported by truck a distance of 50km to a fluidised bed biomass combustion plant and used to produce of process heat.	Process Heat
2	Wood (Landing Residue)	As above but the wood is supplied to a combined heat and power plant and used to produce 20MW of process heat and additional electricity.	Process Heat Electricity
3	Wood (Landing Residue)	Wood is gathered and transported the same as chains 1 and 2 but is then subject to enzymatic hydrolysis and fermentation to produce ethanol with electricity also produced as a by-product.	Ethanol Electricity
4	Wood (Landing Residue)	Wood gathered and transported as above but the wood is then gasified to generate a synthesis gas which is subsequently burned to produce process heat. The gasifier is retro-fitted to an existing gas fired heat plant	Process Heat
5	Wood (Landing Residue)	As for chain 4 but the syngas is burned in a gas turbine to produce electricity with process heat produced as a by-product.	Electricity Process Heat
6	Wood (Landing Residue)	As for chain 4 and 5 but the syngas is converted into diesel using a Fischer Tropsch process with electricity as a by-product.	FT Diesel Electricity
7	Wood (Landing Residue)	Wood is gathered and transported the same as chain 1 but is then converted into a bio-oil by pyrolysis and the bio-oil is upgraded to hydrocarbon fuels by hydro-treatment.	Petrol Diesel
8	Wood (Purpose Grown Forests, (PGF))	Same as 1 but using PGF as feedstock.	Process Heat
9	Wood (PGF)	Same as 2 but using PGF as feedstock.	Process Heat Electricity
10a	Wood (PGF)	Same as 3 but using PGF as feedstock.	Ethanol Electricity
10b	Wood (PGF)	Same as 10a but conversion to diesel, not ethanol.	Diesel Electricity
11	Wood (PGF)	Same as 4 but using PGF as feedstock.	Process Heat
12	Wood (PGF)	Same as 5 but using PGF as feedstock.	Electricity Process Heat
13	Wood (PGF)	Same as 6 but using PGF as feedstock.	FT Diesel Electricity
14	Wood (PGF)	Same as 7 but using PGF as feedstock.	Petrol Diesel
15	Straw (Agricultural Residue)	Same as 1 but using straw as a feedstock.	Process Heat
16	Straw (Agricultural Residue)	Same as 2 but using straw as a feedstock.	Process Heat Electricity
17	Waste Vegetable Oil	Waste vegetable oil is converted into biodiesel by transesterification.	Biodiesel
18	Tallow	Render material from beef and lamb processing is rendered into tallow and then converted into biodiesel by transesterification.	Biodiesel
19	Rapeseed Oil	As for 17 but using rapeseed oil from a purpose grown energy crop.	Biodiesel
20	Coal (Lignite)	Same as 1 but using lignite as a feedstock.	Process Heat
21	Coal (Lignite)	Same as 6 but using lignite as a feedstock.	FT Diesel

Results

Energy efficiency

Table 22: Energy conversion efficiency and outputs per 1 GJ of energy output.

Pathway	Description	Energy efficiency	Heat (GJ)	Electricity (GJ)	Diesel (GJ)	Ethanol (GJ)
1	Wood to Heat	67%	0.7			
2	Wood to CHP	46%	0.35	0.13		
3	Wood to EtOH	41%		0.12		0.325
4	Wood-Gas-Heat	57%	0.60			
5	Wood-Gas-CHP	47%	0.26	0.231		
6	Wood to gas to FT** liquids	52%		0.186	0.41	
7	Wood to Pyrolysis to LF***	56%			0.013	0.46*
8	PGF to Heat	63%	0.7			
9	PGF to CHP	43%	0.35	0.13		
10a	PGF to EtOH	43%		0.12		0.325
10b	PGF to Biodiesel	43%		0.12	0.325	
11	PGF-gas-heat	60%	0.60			
12	PGF-gas-CHP	49%	0.26	0.23		
13	PGF to gas to FT liquids	54%		0.186	0.413	
14	PGF to Pyrolysis to LF	58%			0.13	0.46*
15	Straw to Heat	88%	0.9			
16	Straw to CHP	61%	0.45	0.17		
17	WVO to Biodiesel	84%			0.99	
18	Tallow to Biodiesel	64%			0.73	
19	Rapeseed to Biodiesel	69%			0.81	
20	Coal to Heat	74%	0.75			
21	Coal to gas to FT liquids	53%		0.186	0.43	

* The output from pyrolysis is petrol but petrol and ethanol are valued the same in this analysis.

**FT = Fischer Tropsch

***Liquid Fuels

PGF = Purpose-grown forests

- The energy efficiency of the pathway, defined as total energy outputs divided by total energy inputs, is shown in Table 22.
- Total energy inputs encompass: biomass resource inputs, transport fuels and additional energy inputs in the conversion process.
- The energy efficiency of the pathways varies from a high of 88% for straw to heat through to a low of 41% for wood residues to ethanol.
- Energy efficiency is an important indicator of efficient resource use. However, efficiency should not be viewed in isolation as there are many other drivers to the viability of a pathway. These drivers include the scale of the resource, its physical location, local and national demand for different types of consumer energy, environmental impact and economics.

If the focus is less on electricity and more on liquid fuels, with niche opportunities for heat and distributed combined heat and power (CHP) also being of interest, there is a good argument for more detailed investigation of the pyrolysis to transport fuels pathway. Due to its efficiency, pyrolysis appears to have some benefits in terms of producing liquid fuels in a New Zealand context. It is also an area where detailed information is scarce or emerging due to its relative immaturity of development.

Greenhouse gas emissions

Table 23: Climate change emissions in CO$_2$equivalence, kg per 1GJ of energy output.

Pathway	Description	CO$_2$ equiv emissions kg/GJ out
1	Wood to Heat	4.0
2	Wood to CHP	5.9
3	Wood to EtOH	8.5
4	Wood-Gas-Heat	4.7
5	Wood-Gas-CHP	5.7
6	Wood to FT	5.2
7	Wood to Pyrolysis	4.8
8	PGF to Heat	4.3
9	PGF to CHP	6.3
10a	PGF to EtOH	8.1
10b	PGF to Biodiesel	8.1
11	PGF-gas-heat	4.5
12	PGF-gas-CHP	5.5
13	PGF to FT	5.0
14	PGF to Pyrolysis	4.6
15	Straw to Heat	4.5
16	Straw to CHP	6.5
17	WVO to Biodiesel	7.4
18	Tallow to Biodiesel	42.8*
19	Rapeseed to Biodiesel	32.7**
20	Coal to Heat	128.1
21	Coal to FT	178.8

* This figure can vary substantially (12.8-55.8) depending on the system boudary used.

** Variation due to LCA boundaries (27-51)

- Table 23 shows the greenhouse gas (GHG) emissions from the various pathways.
- GHG emissions are very similar for many of the biomass-to-consumer energy pathways.
- The combustion options have lower GHG emissions due to their greater efficiency.

- Due to differences in demand, it is more appropriate to compare pathways that produce the same final product.
    - For the heat pathways the biomass is superior to coal-to-heat pathway in GHG emissions by a factor of 35.
    - In the case of liquid fuels, biomass chains are superior to the coal-to-FT liquids pathway (21). The biomass chains are superior by a factor 27. The greenhouse gas reductions for the liquid fuel pathways when used to replace petrol or diesel are shown in Figure 18.

The GHG profile of the biomass chains, whilst superior to that of the coal pathways, is dependant on their own efficiencies, and these profiles could be improved by optimising the biomass pathways for GHG emissions.

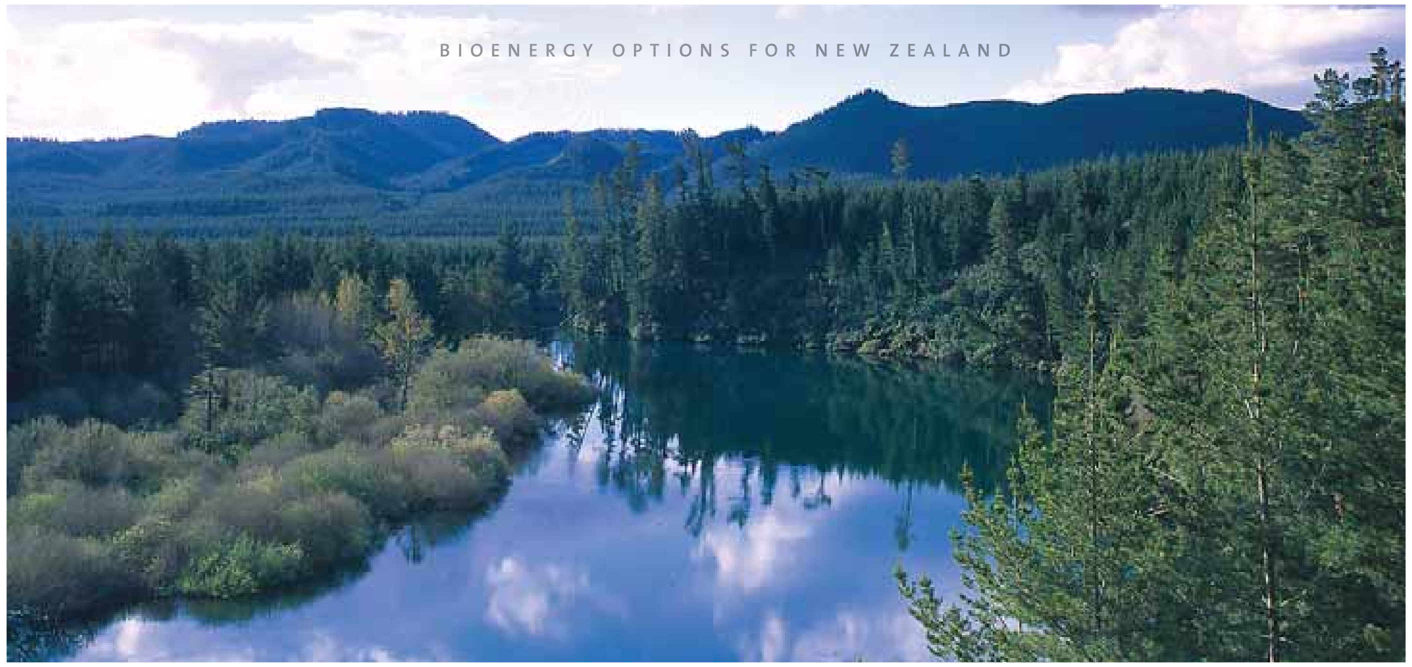
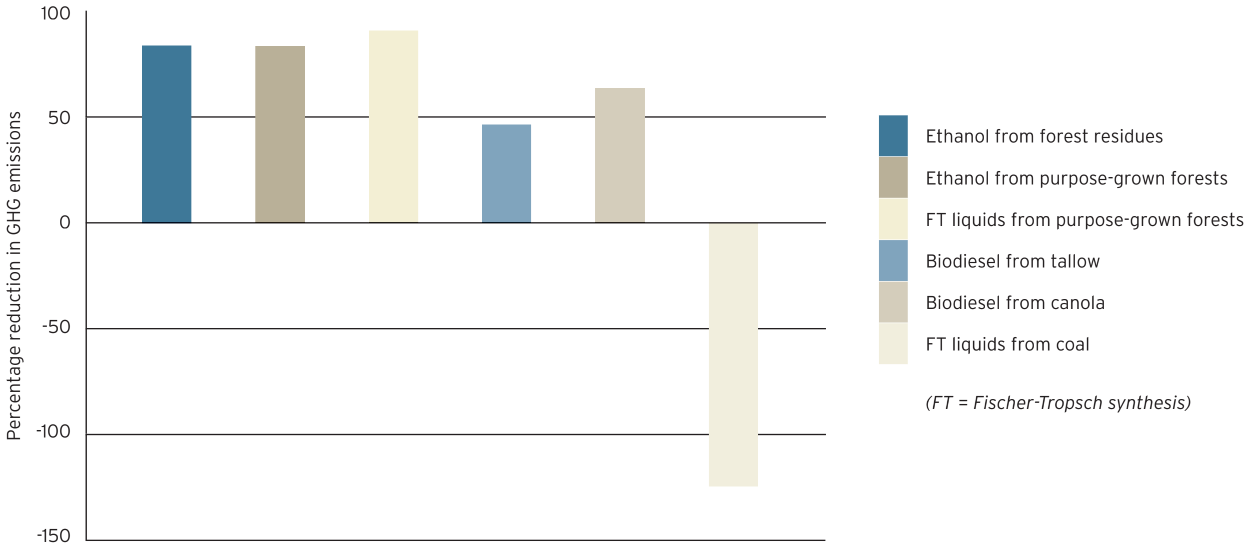


Figure 18: Liquid fuel options - percentage reduction in GHG emissions when used to replace petrol or diesel



Fischer Tropsch (FT) liquids from coal show an increase in emissions when compared to current use of fossil fuels (Figure 18).

Economics

Table 24 shows a summary of the potential profit for each of the chains based on current knowledge. These results should not be viewed in isolation. The waste vegetable oil chain is high value, but it is a small and limited resource. The chains which show high value are typically those that are associated with liquid fuels. The exceptions to this are the straw chains, but again this resource is limited both in scale and location, indicating that it has niche relevance, but not national significance.

A more detailed treatment of economic of the Purpose-Grown Forest (PGF)-to-ethanol pathway is carried out in a later section.

Table 24: Cost, value and resulting profit per 1GJ of energy output.

Pathway	Description	Cost	Value per GJ Out	Profit (loss) per GJ Out
1	Wood to Heat	$6.76	$6.78	$0.33
2	Wood to CHP	$11.74	$12.58	$ 1.39
3	Wood to EtOH	$20.56	$31.66	$13.80
4	Wood-Gas-Heat	$25.14	$6.73	-$18.05
5	Wood-Gas-CHP	$30.06	$16.79	-$12.55
6	Wood to gas to FT	$24.15	$21.05	$5.71
7	Wood to Pyrolysis to LF	$13.09	$14.11	$1.79
8	PGF to Heat	$32.40	$6.78	-$24.86
9	PGF to CHP	$42.67	$12.58	-$28.63
10a	PGF to EtOH	$56.53	$31.66	-$23.79
10b	PGF to Biodiesel	$56.53	$31.66	-$23.79
11	PGF-gas-heat	$50.35	$6.73	-$43.62
12	PGF-gas-CHP	$61.24	$16.80	-$44.45
13	PGF to gas to FT	$52.67	$26.06	-$23.91
14	PGF to Pyrolysis to LF	$40.02	$14.11	-$25.66
15	Straw to Heat	$5.77	$6.79	$1.17
16	Straw to CHP	$9.75	$12.56	$3.02
17	WVO to Biodiesel	$18.99	$24.95	$23.76
18	Tallow to Biodiesel	$24.92	$24.97	$3.56
19	Rapeseed to Biodiesel	$47.15	$25.00	-$16.93
20	Coal to Heat	$6.88	$6.79	-
21	Coal to FT	$23.62	$26.06	$5.68

Results indicate that the value of the fuels must be considered when deciding on which pathways to develop, as the value of the end product may not be directly influenced by the efficiency of the process but by the willingness of society to pay more for energy in a particular form. This value is related to convenience of the product (electricity and switch on/off) and its ability to provide a service we desire (liquid fuels and relatively unconstrained personal mobility).

Energy pathway comparison and recommendations for the future

There are many factors to consider when comparing energy pathways with an aim of identifying preferred options. Focus to this point has been on what are expected to be the most significant defining parameters of energy pathways in the future (and assuming, given time, that the practicalities or technical unknowns can be resolved), namely:

- energy efficiency - as we expect to be resource-limited and require efficient utilisation of resources on offer;
- low emission of climate change-related gases - currently driven by social responsibility and likely to be supported in the future by the way of emissions trading schemes or other tax regimes;
- economics - the pathways are required to be affordable compared to alternatives.

The comparison includes other factors such as:

- potential showstoppers - mainly concerning the status of the technology and availability of feedstock;
- other risks – such as land and water use competition, scale of operation, etc;
- potential benefits.

The conclusions derived from the pathways evaluation are now considered together, across all the selected pathways, with discussion collated under a number of subject headings.

The role of purpose-grown forests (PGF)

Of the selected bioenergy pathway options, only purpose-grown forests can provide a significant change to New Zealand's current primary energy profile.

However, this resource is not currently available and to be a significant resource in the future will require considerable effort to: develop a national plan; identify or develop appropriate plant species and hybrids; establish the plantations, and manage them. Because of the potential significance of purpose-grown forests in light of the apparent need for a large scale biomass resource, we feel this is priority research.

In contrast, residual woody biomass resources are limited in scale to around 8 to 10% of primary energy or 23% of heat demand, or 8 to 10% of liquid fuel demand, or a mix of both. On the other hand, residual material is available now and it is often very cheap to obtain. Its utilisation has environmental benefits (reduce green house gas emissions, reduced landfill volumes, reduced effluent etc) and so the use of residual material should be a priority. The cost of the residuals could rise as utilisation and competition for the resource occurs.

Utilisation of purpose-grown forests (PGF)

Wood from PGF is a reasonably costly energy feedstock and consequently the economics for use rely on taking PGF resources through to a high-value energy product such as liquid fuels for transport. When considering expected economics alone, there are four pathways considered here that appear reasonably attractive for the future, all with similar-order economics. These pathways are:

- enzymic hydrolysis and conversion through to ethanol (a pathway referred to here as the "enzymic pathway");
- enzymic conversion through to biodiesel (another form of an "enzymic pathway);
- Fisher Tropsch conversion of PGF-derived syngas to liquid fuels (referred to here as the "FT pathway");
- hydro-treating pyrolysis-derived bio-oils (referred to here as the "pyrolysis pathway").

Note that this list is not intended to be exclusive; there are a broad range of other conversion technologies that were not considered in this study. A close watch on international trends and advances is critical in the liquid fuels area.

Conversion technologies

The technology supporting these options is currently in various forms of development. It is therefore difficult to identify which will become the preferred option in the future. There is significant work being done overseas on a variety of conversion technologies, with an emphasis on ligno-cellulosics to liquid fuels.

The gasification pathway is the most advanced of these in that commercial coal- or natural gas-to-liquids plants do currently exist (although only four in the world). Large-scale gasification of biomass and the logistics surrounding this has not been proven.

The enzymic pathway has characteristics that suggest it would offer improved economics over the gasification pathway, but the technology is still in its infancy and therefore this is far from certain in practice. The development of the enzymic pathway is expected to be extremely capital-intensive.

The pyrolysis pathway is in its infancy. Whilst the pathway chosen for the comparison analysis was specific, it represents a number of possible options that are being considered, including plantation-localised bio-crude production and stabilisation (through simple hydrotreating) to make a bio-crude suitable for use as a feedstock for petrochemical refineries. The pyrolysation and hydrotreating steps are expected to be moderately capital intensive and reliant on research from overseas.

Note that having a supply of low cost hydrogen will be a key to the hydrotreating component of the pyrolysation pathway. The Energyscape Hydrogen Options work (led by CRL Energy) has found that one of the preferred hydrogen production pathways uses biomass as the primary energy resource. There is opportunity to integrate the two pathways, pyrolysis and hydrogen production, which has the potential to decrease the cost of supplying the hydrogen.

These normally large-scale pathways might be more attractive if downscaling were an option. There is certainly an opportunity for downscaling in the case of pyrolysis and simple hydrotreating to make biocrude for further refining. Research is required to understand what future plant sizes may be so that this understanding can be used in the design of a national PGF model.

CHP offers a known-technology fallback option for utilising PGF feedstock, and also provides a small-scale option for use in transition periods when plantations are being established or before major fuel plants come on stream (although care would be required to avoid stranding CHP plant in the case of the latter).

Use of wood residue

The use of wood residue offers a low-cost feedstock, but is expected to be limited to small scale operations due to the significant increases in transport costs and logistics required as plant size increases. Better economics could be gained through the use of improved collection and transport mechanisms and logistics.

Use of wood residues in boilers and in CHP offers simple, small-scale utilisation of wood residue at similar economics to the use of lignite (which is generally a lower-cost coal option, compared with sub-bituminous coals). Specific local conditions could see improved economics for the use of wood residue, for example, where the transport costs for the wood residue are particularly low and where wood waste is required to be disposed of.

Including a gasification step in the simple boiler or CHP plant pathway adds a cost that results in poor economics, even when using the syngas in existing gas fired boilers. These gasification options therefore do not appear economically viable.

The Fisher Tropsch, enzymic and pyrolysis pathways all exhibit attractive economics for the use of wood residue. However, these types of technology are expected to require large plant to be economic, at least in the short to medium term. The use of wood residues alone is not expected to meet the demand required for large plant (or otherwise requires transport of feedstock from a very wide area, which is unlikely to be economic in all but a few locations in the Central North Island). Hence these pathways are not believed to be options for the use of wood residues unless wood residues are used for co-firing.

Straw

The results suggest that the use of straw provides slightly improved economics over the use of wood residue in simple boiler and CHP applications, and hence is an attractive option should the resource be available locally (to keep transportation costs low) and in sufficient quantity. One of the reasons for the improved economics stems from the improved efficiency of the combustion of straw over that for wood waste, due mainly to the lower moisture content of straw.

Biodiesel options

The production of biodiesel from used cooking oil and tallow appears economic on small scale. Although the resource is limited, demand for feedstock from other sectors high, and price for the feedstock is increasing.

Based upon the results of the analysis, the production of biodiesel from oil rapeseed (canola) currently appears economic, with economic breakeven with fossil diesel achieved at a price of around US$135/bbl. There are currently plans to begin production of biodiesel from oil rapeseed grown in New Zealand.

The planned development involves production of around 70 million litres of biodiesel per year. This is around 20-times the production we expect to be obtained nationally from used cooking oil and tallow-based biodiesel manufacture, and hence represents a significant increase in volume (although still small compared to the current national consumption of fossil diesel at around 3,000 million litres per year). It is uncertain how land-use and water-use issues might restrict further biodiesel production from oil rapeseed cropped in New Zealand and this could be an area of research. However, it is clear that large scale production of vegetable oil from crops will lead to land use competition with food crops as the same land is required for both, and it is in limited supply.

Sensitivity to a carbon-based charge

All bioenergy pathways exhibit improvements in economics relative to their fossil fuel alternatives with increasing carbon charge. The options exhibiting particular improvement are those involving the production of heat, in comparison to coal.

Conclusions

The wider EnergyScape project has identified a need to focus on developing renewable alternatives to imported fossil-derived transportation fuels as an important component of New Zealand's future.

Large scale resources

Of the pathways considered, only those based on the purpose-grown forest resource have sufficient scale to impact New Zealand's current primary energy profile. Analysis has shown that production of liquid fuels from this resource can have a significant impact on reducing GHG emissions compared to petrol and diesel, and in particular to the coal-to-FT liquids option. This option is currently not yet viable economically, but should be viewed in light of rapidly increasing oil prices and broader economic implications of developing a national biofuels industry.

A purpose grown forest resource does not presently exist. Priority for research should be the development of an implementation programme for early establishment of plantations leading to:

- detailed analysis on land availability, its productivity, species options (current and future), current use, land use change impacts, water yield and water quality, erosion etc.;
- downscaling conversion technologies without significant increase in cost. This represents an important opportunity as biomass resources are geographically distributed, e.g. making biocrude through pyrolysis.

Currently available resources

Residual woody biomass resources, although of limited scale, are the next largest biomass opportunity. This material is available now and it is often cheap to obtain. Its utilisation has environmental benefits (reduced greenhouse gas emissions, reduced landfill volumes, reduced effluent etc).

Biodiesel derived from canola offers the next-most significant potential resource. With the recent increase in oil price, it is believed that the economics for this pathway are now becoming viable.

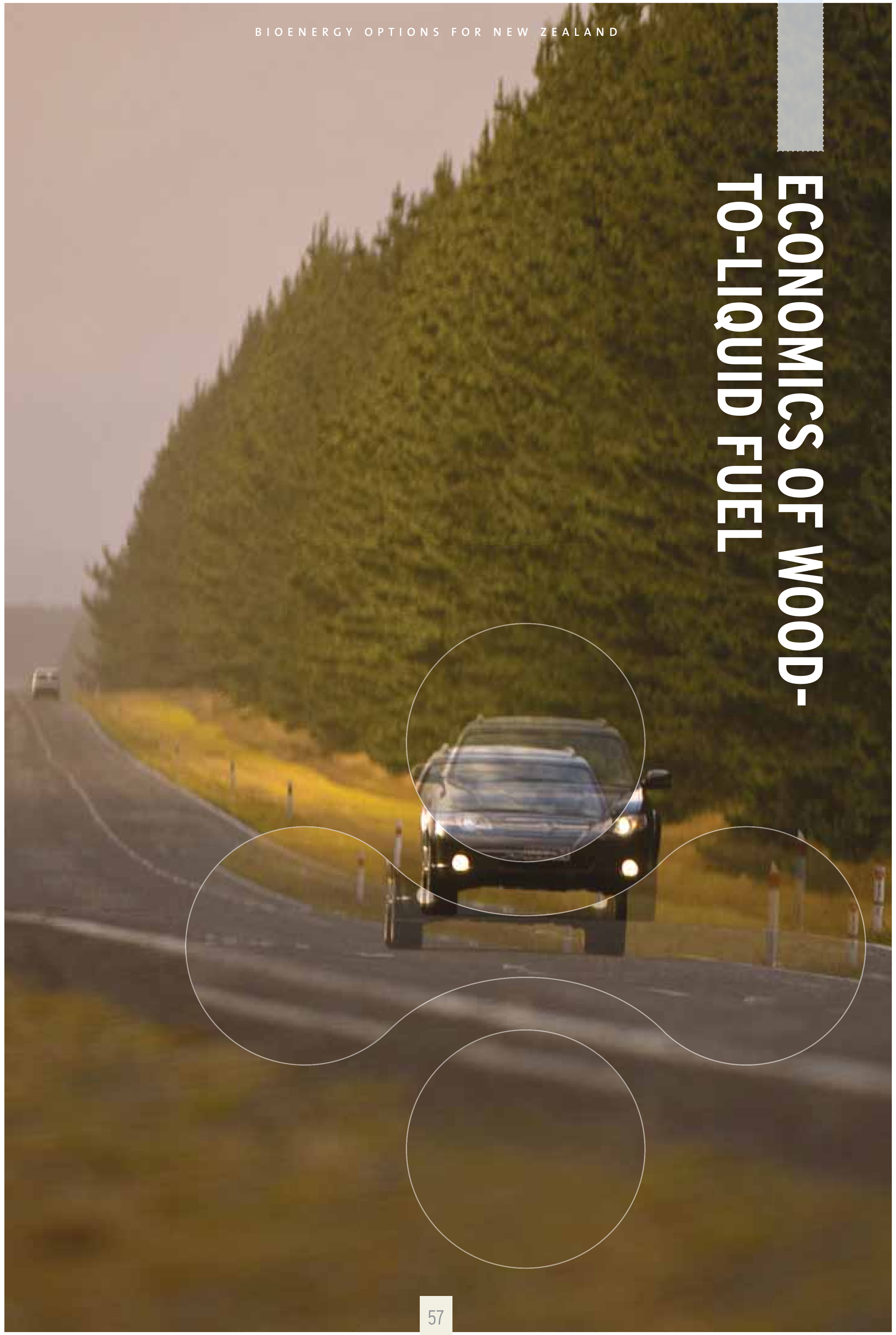
The remaining bioenergy pathway options analysed concern feedstocks of relatively small annual quantities, which limited their application. The most economic options were the simple, small scale heat and CHP applications. These were attractive options today, compared to the use of coal, with the likelihood that the economics could be improved upon further by local niche opportunities.

> “Residual woody biomass resources, although of limited in scale, are the next largest biomass opportunity. This material is available now and it is often very cheap to obtain.”

Reference

Andrew Campbell[1], Murray McCurdy[2] and Garth Williamson[2]. CRL Energy 2008: Bioenergy Pathway Analysis: Comparison of Cost, Energy Balance and GHG Emissions of Selected Biomass to Energy Production chains. [1]Fuel Technology Limited, [2]CRL Energy Limited. Report prepared for the Bioenergy Options for New Zealand – Pathways Analysis Project.

ECONOMICS OF WOOD-TO-LIQUID FUEL



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ECONOMICS OF WOOD-TO-LIQUID FUEL

For New Zealand, plantation forests, purpose-grown for energy, or a mix of timber and energy, may offer solutions for energy security and environmental benefits.

Wood can be used for low and high grade heat, and to some extent to make electricity in co-generation facilities. Currently wood is mainly used to make heat (8 PJ per annum of domestic heat, 45 PJ per annum of industrial heat and about 75 MW or 2.3 PJ of electricity).

Wood can also be used to make liquid fuels through a variety of conversion processes. In addition, it is physically and technically possible for New Zealand to grow large quantities of energy in forests on steep terrain and for this material to make a significant contribution to our liquid fuel demand (Bioenergy Options for New Zealand – Situation analysis). Due to this potential, it is important to investigate the economics of this opportunity in detail.

At the time of writing (July 2008) the following parameters were used to evaluate the economics of the price of petrol versus liquid fuels from biomass sources: US exchange rate = ~0.77; oil at US $130+ a barrel (bbl); pump price of petrol $2.18, Carbon price $21/t of CO_2-equivalent; ethanol ~$1.40 litre (NZ manufacture from residual softwoods, 2007 estimate), and; biofuels (ethanol) are not subject to excise tax.

Producing ethanol only

Feasibility studies have determined that a 90 Ml per annum bioethanol plant located in the Central North Island could produce ethanol at approximately ~$1.40 per litre utilising available woody biomass residues. Given the differences in calorific value (petrol is 33.2 MJ/l, ethanol is 22.4 MJ/l) this equates to $1.98 per litre petrol equivalent or $2.25 per litre including GST. These estimates assumed currently available technology, growing practices and efficiencies, and do not include a return from co-products.

The biomass residue feedstocks for this plant were assumed to have a delivered cost of $37 per tonne. Wood from purpose-grown forest will cost more than residues, and the delivered raw material cost would likely be in the order of $100 per tonne (increase of $63 per tonne). This could add at least $0.45 per litre to the cost of the ethanol, or $0.67 per litre of petrol equivalent.

Ethanol made from purpose-grown forest is estimated to be $2.08, or $2.97 per litre of petrol equivalent. In comparison, at time of writing (July 2008) the cost of petrol was ~$2.18 per litre at the pump. The petrol price less excise tax of $0.45 (plus GST on excise) is $1.62.

For ethanol from purpose-grown forests to be competitive with petrol, petrol prices would have to rise to ~$3/litre at the pump. Alternatively production costs would need to decrease.

Table 25 – Price of oil (US$/bbl) that would make liquid biofuels viable, by carbon price and exchange rate (NZ$: US$)

		Foreign exchange rate, NZ to US dollars		
		0.8	0.7	0.6
Carbon tax $20 tCO_2eq	Residual	US$145/bbl	US$127/bbl	US$109/bbl
Carbon tax $20 tCO_2eq	Purpose-grown	US$211/bbl	US$185/bbl	US$159/bbl
Carbon tax $30 tCO_2eq	Residual	US$143/bbl	US$125/bbl	US$107/bbl
Carbon tax $30 tCO_2eq	Purpose-grown	US$208/bbl	US$183/bbl	US$157/bbl

Future petrol prices

Key influences on future petrol prices were considered: cost of carbon ($$tCO_2$ equivalent); cost of oil ($US barrel); and NZ$ versus US$ exchange rate. A summary of these influences is shown in Table 25, which shows the price of oil that would enable ethanol from wood (from both residual or purpose-grown sources) to compete directly on a $ per unit of energy basis.

The cost of oil is likely to rise and an estimate of the trend for the future price of oil was made based on the prices from 2002 to 2008. The rationale for using 2002 as the start point is that that was the nearest historic low, from which point prices have trended up. A straight line trend was used. Using this trend prices would be: 2030 = US $348 bbl, 2050 = US $586 bbl.

If prices rise even close to these predictions, then fuel from purpose-grown forests would be economically viable by 2020. These prices should be considered bearing in mind that oil has increased five-fold in cost in the past six years, from US$21 barrel in 2002 to $US $130+ in 2008, a rise of around US$110 per barrel.

Carbon tax/coal and gas cost

A driver for the use of forestry, or any, biomass for fuel will be the cost of carbon emissions. If and when a carbon tax is initiated, the cost of CO_2 emissions will be added to the cost of fossil fuels, but not to renewable biomass fuels (which are deemed carbon neutral).

The cost of carbon is likely to be in the order of $15 to $30 per tonne of$CO_2$-equivalent. This would increase the cost of petrol by 3.5 to 7.0 cents per litre, depending on the level of carbon cost applied. This will not be sufficient on its own to have a major influence on the price of petrol, the impact being just a few percent (2 to 4). However, the impact on the price of coal could be substantial, with even a low cost of carbon ($15) having the effect of driving up coal prices to industrial users by 20 to 45%. Higher carbon costs will have an even more dramatic effect. It is highly likely that this will drive increased use of woody residues from all sources as fuel for industrial heat.

Forest residues

At today's prices, purpose-grown biomass for energy cannot compete economically with fossil fuels for heat or transport fuels. However, residual biomass can, and does, compete with coal and gas for heat. Large volumes of residual woody biomass are used for heat on both a large and small scale with around 4.0 million tonnes per annum (53 PJ) of woody biomass used in domestic, commercial and industrial sites.

The majority of this is wood processing residues used as industrial heat fuels at wood processing sites. This material is derived from a log harvest of 19.3 million tonnes, and the volume will increase over the next 20 years as the harvestable volume rises.

Emerging trends

The future is hard to predict but the assumptions behind the strategy presented in the Bioenergy Options – Situation Analysis report are:

- oil supply will be constrained and the price will rise (peak oil, increasing international and domestic demand for liquid fuels, possible international crises);
- the cost of coal will rise substantially, by at least 23% or more, the cost of gas will rise (at least 6%), the cost of liquid fuels will rise (by at least 4 to 5 cents per litre, around 2 to 3%) driven by the cost of carbon at $15 per tonne (ETS)

Future scenarios for technological advances

In the future it is likely that:

- forest growth will be more productive due to improved genetics, forest management and regime changes;
- log harvest and log transport will be more efficient through innovation and improved transport infrastructure;
- biomass-to-liquid fuel conversion will be more productive and efficient due to technological advances.

Table 26 presents some scenarios of improved growth and harvest efficiency, and the impact of these on the cost of liquid fuels from purpose-grown forest.

Table 26 - Cost of producing liquid fuel (ethanol) from purpose-grown forest with different growth rates and regimes (includes conversion costs – wood to ethanol)

	Rotation (years)					
	23	23+	23++	18	18+	18++
Volume m³	600	950	950	400	730	730
Grow $/m³	$49.50	$31.25	$31.25	$58.90	$32.25	$32.25
Log $m³	$36.00	$36.00	$30.00	$36.00	$36.00	$30.00
Transport $m³	$10.50	$10.50	$8.50	$10.50	$10.50	$8.50
Total $m³	$96.00	$77.75	$69.75	$105.40	$78.75	$68.75
$ l-peqv	$3.00	$2.81	$2.73	$3.13	$2.84	$2.74

Notes: + = large future gains in growth and yield volumes from genetics and regime changes
++ = 20% future gain in logging and transport efficiency

The table above shows that growth gains combined with a 20% reduction in logging and harvesting costs can reduce the cost in $ per litre of petrol equivalent (l-peqv) to approximately $2.75. At current foreign exchange rates this is the equivalent to oil at US$190 a barrel. If the exchange rate moved back to US$0.60, it would be the equivalent of US$150 a barrel.

Production of both solid wood and ethanol

An alternative scenario to consider is the situation where some of the forest harvest is used for energy and some goes to high value timber uses (Appendix III). This is similar to the current situation where a proportion of the crop is sold at low prices to pulp and panel mills.

If we assumed that 50% of the crop sold for an average of $130/m³ as saw logs and 50% of the crop went as energy feed stock at $65 per m³, then the forest grower would get $97.50 on average per m³. The cost of the energy feedstock would subsequently be reduced. In this case the ethanol could be produced for an estimated $2.67 per l-pqev (equivalent to oil at $180 to $140 US per barrel, depending on exchange rate).

Production of multiple products

In addition, research and development on the concept of a biorefinery is receiving considerable interest internationally. A biorefinery co-produces fuels and high-value products in the same production facility (similar to an oil refinery). Revenue streams from the co-products are anticipated to have a significant impact on the economic viability of producing fuels from forests.

Key points

Assuming current forest productivity and conversion efficiencies, oil prices would have to approach US$210 a barrel (currently US$130+ a barrel, July 2008) for ethanol from purpose-grown forests to be feasible. Given the current trends in oil price this is likely to occur before 2020. Carbon taxes are likely to have only a small effect on these prices.

Realistic future improvements in forest yields and harvesting and transport efficiency could reduce the breakeven cost of oil. This does not include improvements in the cost of conversion per litre of ethanol due to improved conversion efficiencies. Given the intense international research in this area, this is likely to be an area of significant improvement.

A more promising (and therefore more likely) scenario is for forests to produce timber as well as energy feedstocks. Under this scenario, the breakeven cost of oil would be US$180 per barrel. In addition, the co-production of high-value chemicals in the conversion of wood to biofuels is likely to have a significant impact on the economics in the future.

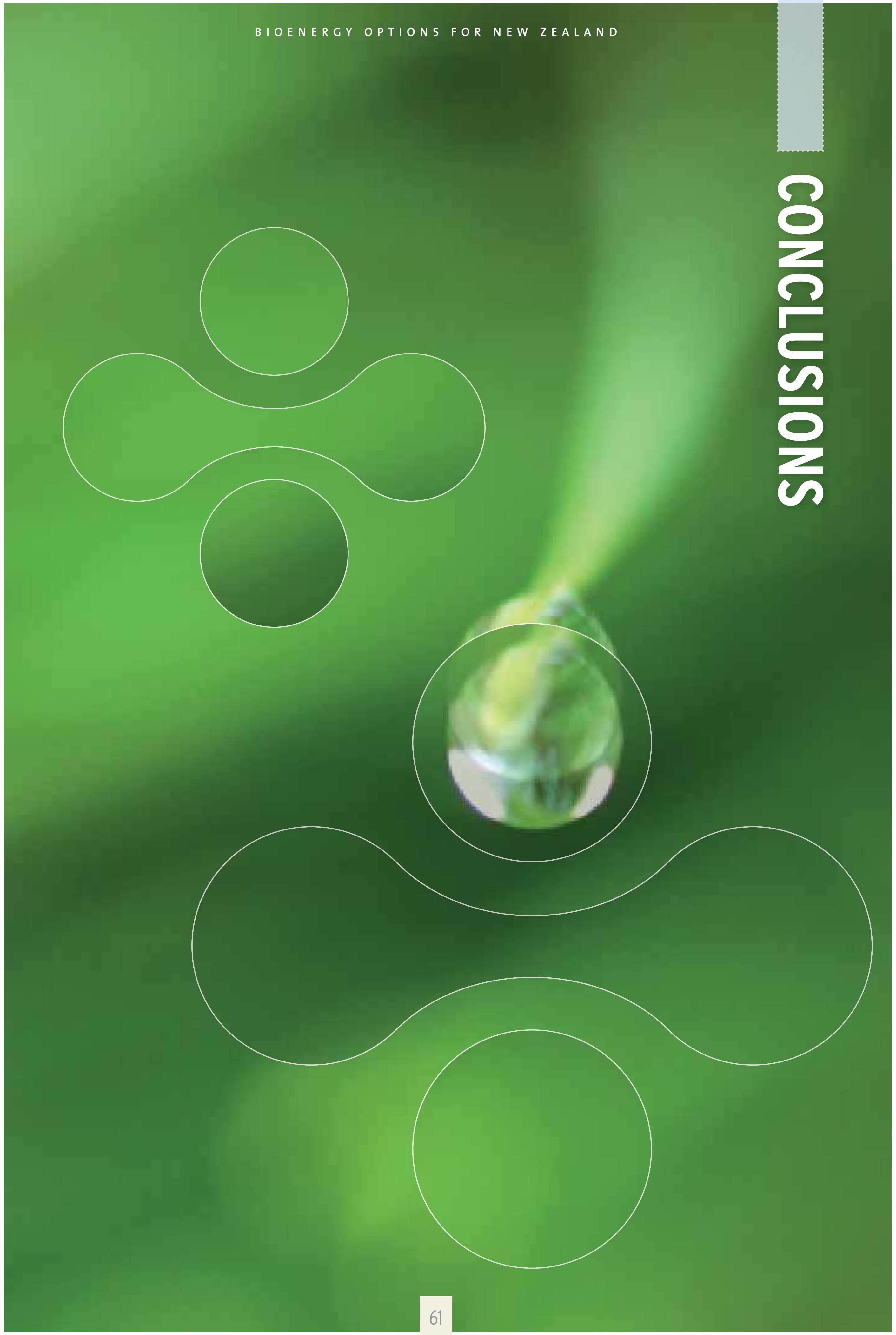
The above costs assume a US$0.8=NZ$1 exchange rate and the removal of the excise tax from biofuels. These assumptions have a significant impact on costs. If the New Zealand dollar falls against the US dollar the effective cost of oil rises, and the breakeven price for ethanol production drops.

During the course of the study the price of oil varied substantially. In October 2007 oil was as low as US$77 per barrel and peaked at US$147 in July 2008. It has since dropped back to US$114 (August 2008). Such volatility in the price and demand for oil is likely to remain over the long term and will always affect the economic viability of biofuels, but is by no means the sole reason for its implementation. In New Zealand, sustainability drivers remain a key reason for developing a national solution for biofuel production.

Reference

Hall P and Turner J. Scion 2008. Economics of purpose grown forests for liquid biofuels. Report prepared for the Bioenergy Options form New Zealand - Pathways Analysis Project.

CONCLUSIONS



6.0

BIOENERGY PATHWAYS EVALUATION - CONCLUSION

The potential benefits from bioenergy extend well beyond the energy sector, crossing into areas of sustainable land use management, regional development and national economic development. A bioenergy vision may be the national sustainable development opportunity that could enable New Zealand to reach carbon neutrality, without sacrificing economic well-being.

The economic well-being of the developed world has been derived from cheap and plentiful fossil fuels. Many key industries including agriculture and manufacturing are dependent on these fuels. New Zealand's relative dependence on fossil fuels is illustrated by our third placing in oil consumption per GDP. Modern society's reliance on fossil fuels for energy is being threatened by the twin pressures of resource depletion (such as peak oil), and climate change.

How individual countries respond to these global challenges is likely to define their future over the next few decades and probably throughout the rest of this century.

In response to the 1973 oil crisis, the Brazilian government initiated a nationwide programme of biofuel substitution of oil in order to promote self-sufficiency. They chose the bioenergy pathway based on an existing industry and a source that most suited their climatic conditions: sugar cane to ethanol. Now bioethanol makes up 17% (17 billon litres) of Brazil's transportation fuel usage. Nearly every fuelling station in Brazil offers a choice of either a 25% ethanol/petrol blend or pure ethanol. Sales of flexi-fuel vehicles that can run on any blend of ethanol make up two-thirds of new vehicle sales. Most of Brazil's flexi-fuel cars can now run up to 100% ethanol, with a small gasoline tank used to start the car during cold mornings.

It is not Brazil's past achievements that are significant here, it is the way in which this initiative has positioned them for the future. The lesson for New Zealand is how the shift can be achieved through foresight, long-term Government commitment, appropriate regulation and targeted research.

Bioenergy's Role

Bioenergy has the potential to play an important role in meeting New Zealand's challenges. Biomass resources are more under human control than other renewables, which are predominantly weather-dependent. In the short-term, biomass resources can be increased at will, limited only by land availability and growth rates. Due to this flexibility, bioenergy can be used to fill areas of demand not met by other renewable sources. Bioenergy also provides energy storage (Appendix II).

Based on New Zealand's land availability and other renewable resources, two areas have been identified where bioenergy could play an important role in New Zealand's energy mix:

- Supply of industrial and community heat and power on a regional level from heat only and; CHP plants fuelled by biomass residuals;
- Supply of transport fuels on a national level from purpose-grown energy biomass.

Technologies for combined heat and power have already reached commercial maturity, and are widely deployed in many countries. A number of technologies for woody biomass to liquid biofuel production have reached scale-up and demonstration stage. However, significant research is still required before they are deployed commercially. For New Zealand, the research focus needs to be on locally-produced feedstocks and integrated production systems for New Zealand conditions. A detailed research strategy will be published in a separate document.

Using biomass residuals

Three bioenergy pathways that have sufficient scale to play an important role on regional level and also have large environmental benefits (such as greenhouse gas reductions) are:

- Industrial and municipal organic waste to heat and power via anaerobic digestion;
- Woody biomass residuals (including forest residues and municipal green waste) to heat and power via combustion;
- Straw to heat and power in the Canterbury region.

These pathways have potential to make a significant contribution to rural and regional energy security and the greenhouse gas footprint of industrial product manufacture.

Growing biomass for energy

To tackle transport fuel problems of national scale it is necessary to go beyond residuals and consider purpose-grown biomass. The possible purpose-grown biomass resources are:

- Oil (e.g. canola) and carbohydrate (e.g. corn, or sugar beet) crops;
- Algae;
- Woody biomass;
- Other lignocellulosic crops (grasses).

Transport biofuels from oil, carbohydrate and grass-like crops suffer from restricted land availability, competition with food production and high value export products, and limited environmental benefits (see Appendix I for a detailed comparison with woody-biomass).

Transport biofuels from algae suffer from risks due to technology immaturity and infrustructural requirements. For example, the cheapest proposed approach grows algae on ponds. To meet New Zealand's current transport fuel demand would require around 330,000 ha (5.5 times Lake Taupo) of man-made ponds.

In contrast, transport biofuels from woody biomass do not have the same land availability restrictions. All of New Zealand's current fuel consumption of 8 billion litres - including petrol, diesel, jet fuel and fuel oil for ships - can be produced from 42% of New Zealand's medium to low productivity land, while providing significant environmental benefits. The greatest drawback of this option is that it is not currently economically viable. Technology improvements and rising oil prices are likely to see this change in the future.

Establishment of a large-scale woody biomass resource, made up of various short- to long- rotation tree species, could mitigate a number of the risks associated with other options by:

- Acting as significant long term energy store;
- Carbon sequestration during the establishment phase;
- Acting as a sustainable land management option: stabilising erosion prone land, low input (e.g. fertiliser, pesticides) land use, improving water quality;
- Producing sustainable co-products such as traditional timber products; high-value biomaterials and chemicals through biorefinery operations, and; providing the forest industry with a significant alternative market for low value crops (see Appendix III for more details of multi-product forests);
- Stimulating regional development.

Due to the scale of the energy problem and the inherent limitations of all the bioenergy options it is possible that all four purpose-grown biomass options should be pursued. However, there are advantages for a small country to focus resources on one possibility, especially since it significantly surpasses the others in terms of potential benefit for New Zealand. A study is presently under way to quantify the environmental, macroeconomic, and land use impacts and benefits of the woody-biomass option on a national scale.

New technologies will have a major impact in the future for both niche opportunities and large scale options. For example, the use of algae to make biodiesel from effluents shows promise as a significant niche opportunity. Around 9,000 ha of ponds would potentially create 250 million litres of biodiesel spread over a large number of regional sites.

> “New technologies will have a major impact in the future for both niche opportunities and large scale options.”

A bioenergy vision for New Zealand

Any shift from fossil energy to bioenergy will require much more than research. Technology demonstration, infrastructure, industry partnership, the right policy environment and consumer perceptions must all be addressed (see Appendix IV for more transition issues).

The potential benefits from this bioenergy vision extend well beyond the energy sector, crossing into areas of sustainable land use management, regional development and national economic development. Given full government backing and careful management, this bioenergy vision may be the national sustainable development opportunity that could enable New Zealand to reach carbon neutrality, without sacrificing economic well-being.

A glimpse of New Zealand’s possible energy future?

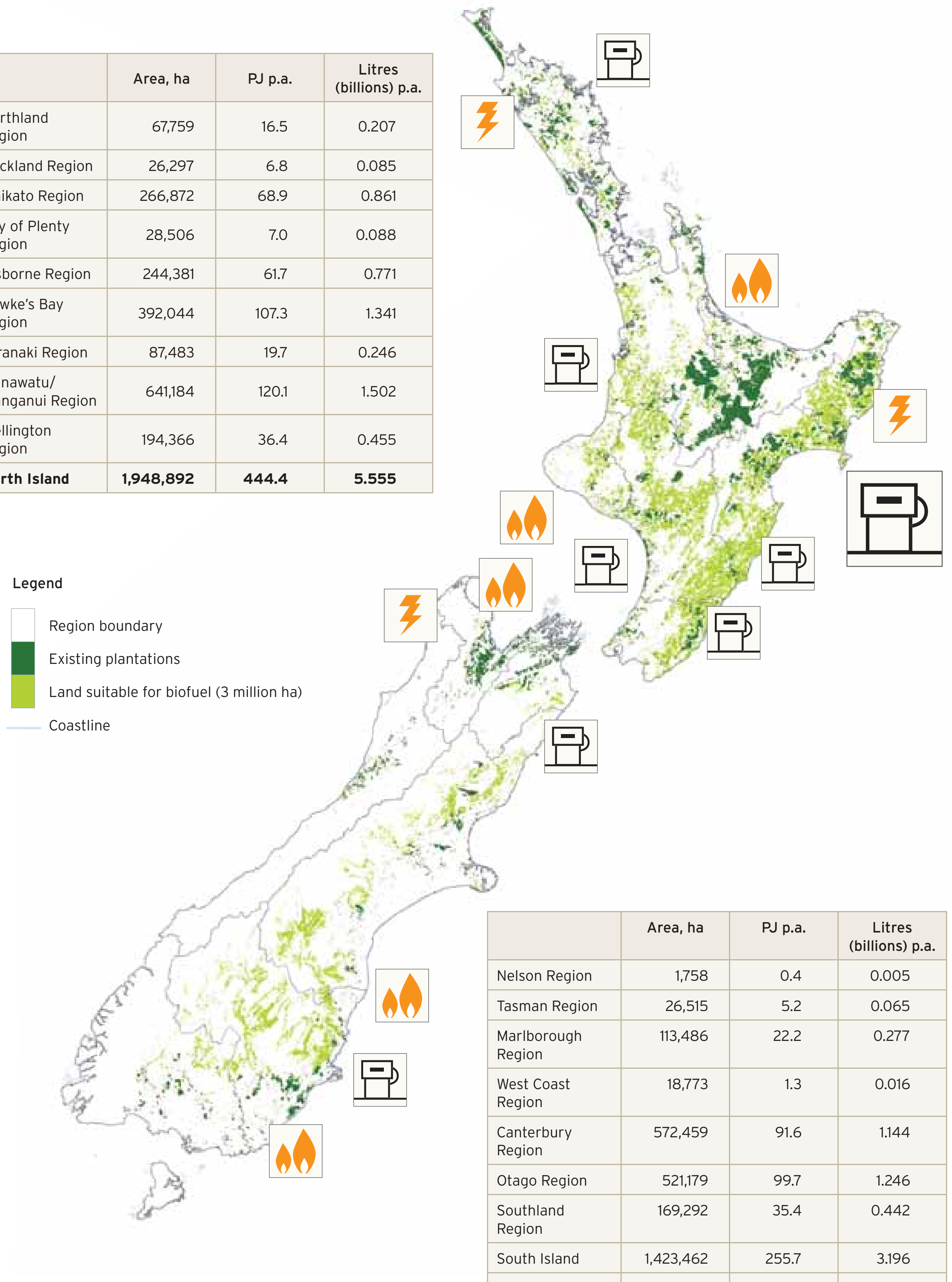
The map on the opposite page represents a possible future energy scenario, based on large scale bioenergy from forestry.

The map shows the current forest estate (dark green); and the area of new forested land (light green) that would be needed to create up to 8.7 billion litres of liquid fuels. The selection of this land areas was by GIS analysis, using a variety of criteria (slope, altitude, land use class) to select land that was of low agricultural value but viable for forestry use.

The tables show the regional areas of land suitable for afforestation. They also show estimates of what these areas could be converted to in terms of energy (PJ) and liquid fuels (litres of petrol equivalent) on an annual basis, assuming a sustainable yield approach and a rotation of 23 years.

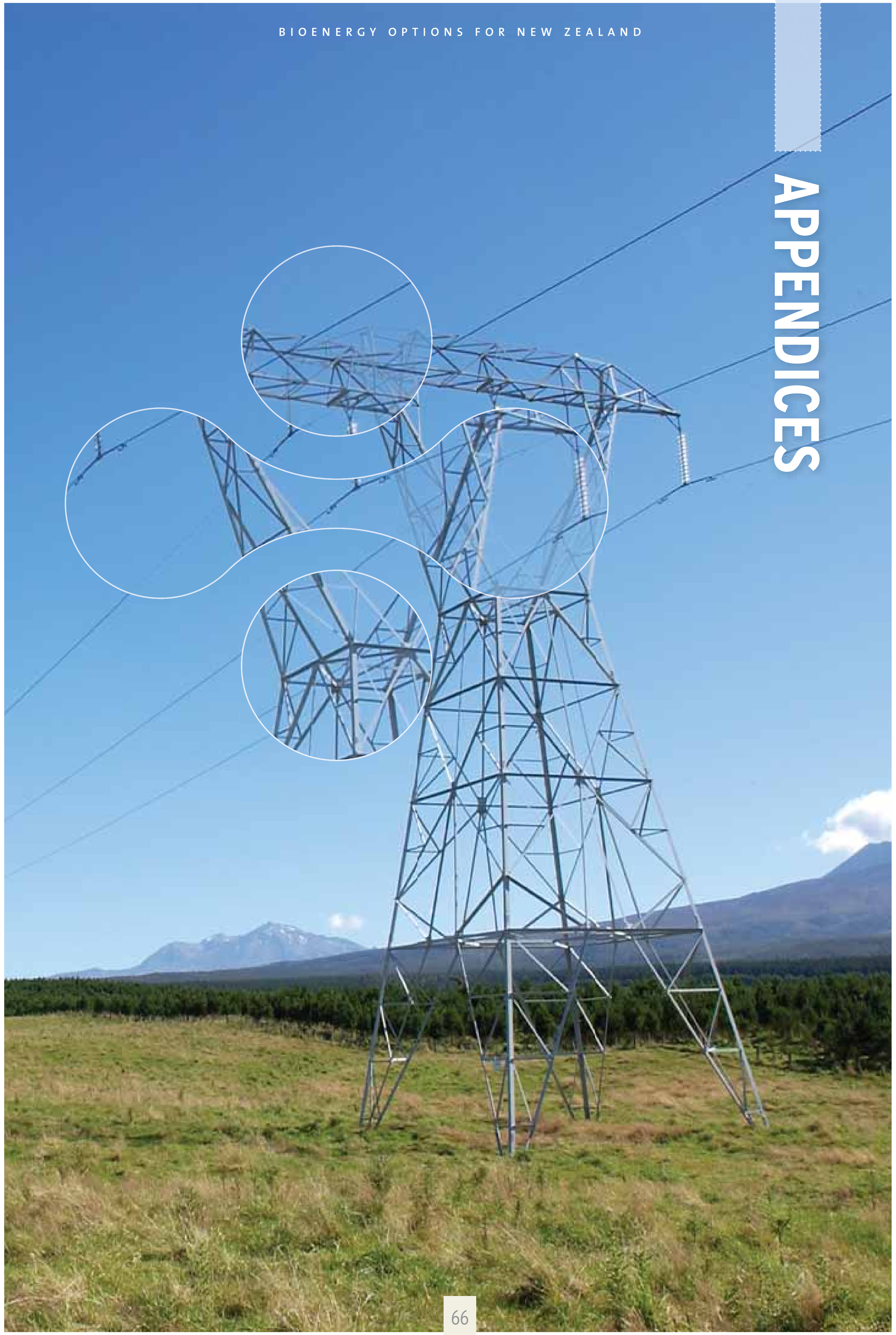
The icons are used to indicate the size and general location of biomass to consumer energy conversion plant. It is possible that not all the wood is used for liquid fuels and that some is used for the creation of carbon-neutral heat. Some electricity generation is also viable: as cogeneration at large heat plant; or as small scale distributed generation in areas with limited generation capacity.

Figure 19 – Potential forested area (3.372 million ha) by region, potential energy (PJ) and equivalent in biofuels, potential for heat and transport fuel processing



	Area, ha	PJ p.a.	Litres (billions) p.a.
Northland Region	67,759	16.5	0.207
Auckland Region	26,297	6.8	0.085
Waikato Region	266,872	68.9	0.861
Bay of Plenty Region	28,506	7.0	0.088
Gisborne Region	244,381	61.7	0.771
Hawke’s Bay Region	392,044	107.3	1.341
Taranaki Region	87,483	19.7	0.246
Manawatu/ Wanganui Region	641,184	120.1	1.502
Wellington Region	194,366	36.4	0.455
North Island	**1,948,892**	**444.4**	**5.555**

	Area, ha	PJ p.a.	Litres (billions) p.a.
Nelson Region	1,758	0.4	0.005
Tasman Region	26,515	5.2	0.065
Marlborough Region	113,486	22.2	0.277
West Coast Region	18,773	1.3	0.016
Canterbury Region	572,459	91.6	1.144
Otago Region	521,179	99.7	1.246
Southland Region	169,292	35.4	0.442
South Island	1,423,462	255.7	3.196
New Zealand	**3,372,354**	**700.1**	**8.751**



APPENDICES

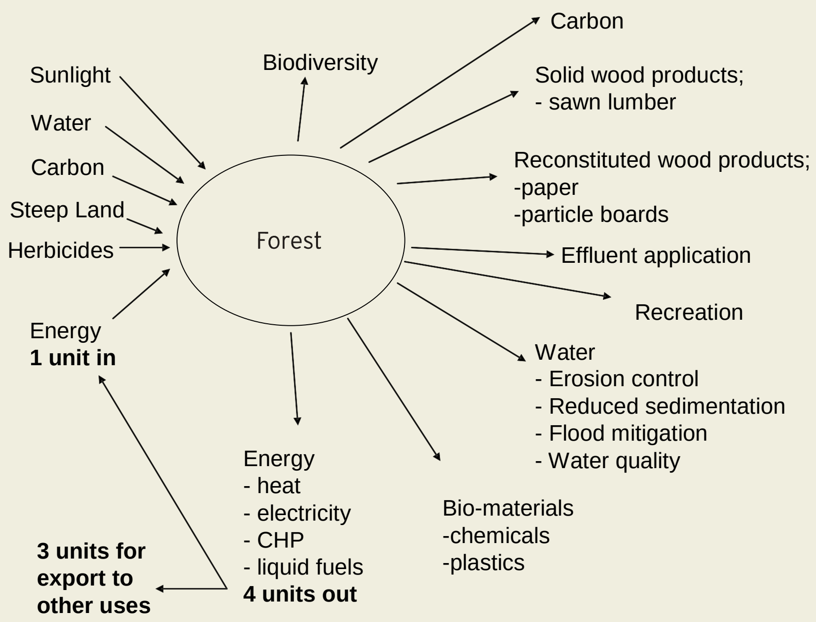
7.0

APPENDIX I: FOREST SCENARIO VERSUS CROP SCENARIO – OPTIONS AND BENEFITS

Purpose grown forests - benefits and options

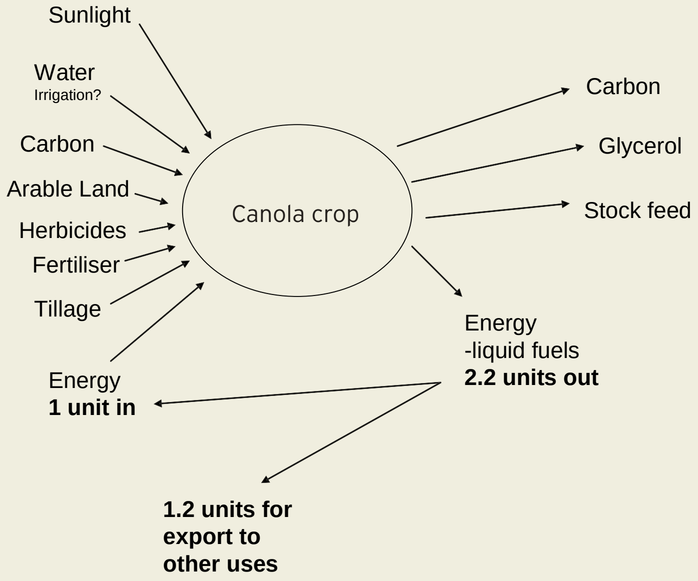
Forests that are purpose-grown for energy have a significant number of favourable characteristics. They can be planted on comparatively low value land and, after establishment, require only sunlight and water in order to absorb carbon from the atmosphere and create stored energy. In this process they provide erosion control, sediment reduction, improved water quality and some flood mitigation. The mature forest then has a number of utilisation routes. If used for energy then the wood can be converted to heat, power or liquid fuels. If the energy option is not required or economic the wood can be used for traditional solid wood products, reconstituted wood products or exported as logs. In future, the creation of biomaterials and chemicals from wood is also likely to be an option. Forests compare favourably in terms of their environmental performance and flexibility of use when compared to canola-to-biodiesel or other arable crops.

Figure 20 - Wood is a renewable, environmentally benign multipurpose product.



* Energy in – out. It is currently possible to get 4 out for 1 in. This could improve as technology develops, to 5 to 1 in the near term and possibly as high as 8 to 1 post 2030

Figure 21 - Canola is renewable, requires greater inputs and has less options



* Energy in - fuel out. It is currently possible to get just over 2 units out for 1 in. There is little room to improve the conversion technology and crop yield will only increase with greater inputs (irrigation, fertiliser).

APPENDIX II

Energy storage

The world today functions on the extraction and use of stored energy (coal, oil and gas). These materials are typically referred to as fossil fuels, but in fact they are stored solar energy, captured by biomass and geologically processed (heat and pressure over millennia). We are using this store up, and it will run out. Once it is gone our energy options become limited. We will be reliant on sources of energy which are to a large extent intermittent or cyclical, with the exception of geothermal. All other forms of energy are solar driven (including wind) or lunar driven (tidal) or weather reliant (hydro). Storage of energy from these sources is a challenge, especially on large scale.

The value of being able to mine an energy resource at will, often at short notice should not be underestimated. Until now, our store of energy (as fossil fuels) has been sufficiently large that we can all draw on it to meet our needs as and when we need to. This will not be the case in the future (long term, post 2050).

In the case of bioenergy, many of the resources that are being considered are small scale and dependant on other processes continuing (residuals) or seasonal (crops). In order to have large scale energy on demand, we need to have a large energy store to replace the declining reserves of fossil energy.

Forests are a natural choice for ths. This is due to the fact that trees are long lived, compared to arable crops. They do not have a critical, must-harvest-by, window limited to a few days or weeks. A forest of radiata pine can be harvested as early as 18 years or as late as 60. The difference between the two options being the volume harvested, the size of the trees and the cost of time. During this 40-year window the trees simply store more energy (grow). After 60 years the forest may begin to decline in health and lose volume, but other species (Douglas fir, Redwoods) have greater longevity and may be healthy and growing for a century or more.

Once harvested, the wood (in log form) can be stored for periods of weeks or months with limited dry matter loss at minimal cost (inventory and land area). The logs will dry during storage, raising the efficiency of subsequent conversion processes.

The question that needs to be investigated further is: what is the value of a large scale source of stored energy, available on demand - like a coal mine but carbon neutral.

If it does have a value, then this further reinforces the concept of large scale energy forests.

A way of viewing energy storage/resilience and renewability is presented in Figure 22, the scales are logarithmic.

Figure 22 – Storability of energy

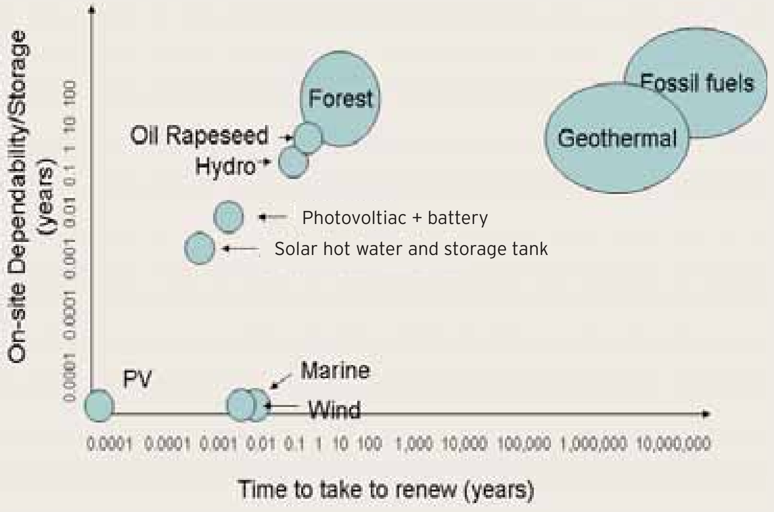


Image courtesy of Andrew Campbell, Fuel Technology Limited

APPENDIX III

Forest energy from multiple log product scenario

The original scenario strategy (Bioenergy Options for New Zealand – Situation Analysis) for a forest energy future had an outline of New Zealand developing a large scale forest resource, to create biofuels from wood, potentially enough to provide all of New Zealand's liquid fuels demand. All of the logs from these forests were dedicated to energy.

Obviously this takes time; to establish, and then grow the forest. Upper limits on the rate of new forest establishment are set at 100,000 ha per annum, with much of this not producing any harvest for over 20 years. The question then becomes what could we do in the short term? Part of the Situation Analysis Strategy covered the use of short and medium rotation forests to get a harvestable resource developing quickly (5 to 15 years). It also assumed that we would use none of the existing forest estate. These assumptions were used in order to gain a sense of the scale of the forest estate that might be required to fuel our future and to determine if it was physically and reasonably possible.

In reality forests produce a range of log products and plantation forests could contribute energy logs as well as logs for other purposes as markets demand (FAO 2008). The integration of energy production into plantation forest operations is a means of strengthening energy diversity and security, contributing to climate change mitigation and increasing forest profitability. Further; not all logs are equal; some are high value ($100 - $140) pruned logs suitable for engineering and appearance uses. Some are medium value ($70 - $90) for construction use and some are low value ($30 - $45) industrial logs used in reconstituted products such as paper and particle boards. It is highly likely that a forest planted with energy in mind would end up having some of the logs used for creation of products other than energy. These products would typically be high value solid wood, which can provide high returns to the forest grower.

If there was real pressure to do something quickly, what could we do now? The solution entails looking at the existing forest harvest residue resource and the existing forest harvest end-use. This could be described as:

- the present resource – unused residues;
- the possible present resource – logs that are exported and potentially some of the industrial logs;
- the future potential resource – the new energy focussed forest estate, with a range of options around what percentage of the crop would be used for energy.

How much wood do we need? Our current liquid fuel demand is 8.1 billion litres. If we assume that we will have efficiency, conservation, some biofuels produced from various residuals, some canola crop based biodiesel, some fuel from algae and some displaced by the introduction of light electric vehicles, we could require in excess of 5 billion litres of fuel to be created from woody biomass in 2050 assuming that oil is either expensive or unavailable.

It should be technically possible to make around 90 to 100 litres of diesel equivalent from every cubic metre of wood. Using this as a base for estimates of fuel from wood production we get the figures outlined below: progressing from what we could make now out of residues; through to what we could derive from exported logs; adding some industrial wood; and then utilising the new energy focussed forest estate we could develop now, which would be available for harvest from 2030 onwards. This is still a simple estimate of what is possible, as there are many variables and options, including the use of short and medium rotation species. The impact of the options should be examined in more detail than presented here.

Table 29 - Forest residues – volumes available, millions of cubic metres per annum

	2010	2030	2050
Landings	0.92	2.41	2.54
Ground based	1.22	2.46	1.8
Steep	1.44	3.37	2.14
Total	**3.58**	**8.24**	**6.48**

Table 30 - Existing plantation harvest – volumes potentially available from existing harvest, millions of cubic metres per annum

	2010	2030	2050
Export Logs	5.8	14.4	15.2
Chip export	0.2	0.5	0.5
50% of Industrial	4.0	9.8	10.4
Total	**10.0**	**24.7**	**26.1**

Note - for 2030 and 2050 the amount of export chip and industrial logs were assumed to be the same proportion of harvest as they are now.

Table 31 - Purpose Grown Energy Forest (PGEF) – multi product forest, with varying % of harvest to energy or other uses, based on varying new estate size (Millions of cubic metres per annum).

PGEF hectares	% to energy	2010	2030	2050
1.0 million	25	-	5.9	5.9
	50	-	11.9	11.9
	100	-	23.9	23.9
2.0 million	25	-	-	11.9
	50	-	-	23.9
	100	-	-	47.8
3.0 million	25	-	-	17.9
	50	-	-	35.8
	100	-	-	71.7

Note - assumes 550 m^3 / ha of recoverable wood and a 23 year rotation

Table 32 - Total wood volume, millions of cubic metres per annum (residues, export logs and 50% of industrial wood, and PGEF at varying percentages)

PGEF hectares	% to energy	2010	2030	2050
1.0 million	25	13.43	38.61	32.31
	50		44.61	44.21
	100		56.61	56.21
2.0 million	25			44.21
	50			56.21
	100			80.11
3.0 million	25			50.21
	50			68.11
	100			104.01

Table 33 - Total liquid fuel, litres of diesel equivalent which could be generated, using the residues, export logs, 50% of industrial wood and PGEF at varying %'s

PGEF hectares	Crop % to energy	2010	2030	2050
1.0 million	25	1,316,140,000	3,791,620,000	3,172,260,000
	50	-	4,379,620,000	4,338,460,000
	100	-	5,555,620,000	5,514,460,000
2.0 million	25	-	-	4,338,460,000
	50	-	-	5,514,460,000
	100	-	-	7,856,660,000
3.0 million	25	-	-	4,926,460,000
	50	-	-	6,680,660,000
	100	-	-	10,198,860,000

From Table 33 it can be seen that with the use of all residues, all export logs and substantial part of the industrial log volume (50%) as well as 1.0 million hectares of purpose grown energy forest we could make 5.5 billion litres of liquid biofuels by 2030.

Without the PGEF we can get to about 1.3 billion litres and would need to divert some of the industrial wood production to fuel to production to achieve this.

This further highlights the need for a large scale purpose grown energy crop.

APPENDIX IV

Transition Issues

If the high oil price/peak oil scenario is a reality there will have to be a transition from fossil oil energy for transport to an alternative energy supply/system.

At this stage it is not clear what the future dominant transport fuel supply will be. There are many options, with most still in development and demonstration phases. Which will be the dominant pathway (and there may be more than one) will to some extent be driven by national level resources. Oil is effectively a global resource; there are few other energy resources that have the ability to reach from source to user so effectively due to more complex and demanding transmission and distribution issues. This would suggest that we will have a more diverse range of energy options both globally and nationally.

We have significant potential for forests, crops and algae to make a contribution to the primary energy supply for transport fuels, but it will require a lot of effort and some time to create the resources. There are a number of options to build up a supply incrementally over time, they are:

- waste oils (already functioning);
- effluents (algae and anaerobic digestion);
- municipal wastes (including wood);
- wood process residues (wood);
- forest harvest residues (wood);
- crops from arable land (canola [oil] / miscanthus [ligno-cellulose]);
- short rotation coppice (woody biomass);
- medium and long rotation forests.

Two future scenarios were considered where a range of biomass and other energy sources made a contribution to transport fuel supply in 2050 (see Table 34). Key differences in the scenarios were the contributions from fossil fuels (30% in scenario 1 and 10% in scenario 2) with arable energy crops, algae and electric vehicles making larger contributions in scenario 2. In both scenarios, significant contributions from energy forests are required to meet demand.

Table 34 - Future scenarios (2050); demand is 8.1 billion litres (~277 PJ) of liquid fuels per annum

Source	Contribution Scenario 1	Contribution Scenario 2
Crops (canola) for biodiesel	5% 405 M/l 13.9PJ	10% 810 M/l 27.7 PJ
Residual biomass	5% 405 M/l 13.9PJ	5% 405 M/l 13.9PJ
Algae	5% 405 M/l 13.9PJ	10% 810 M/l 27.7 PJ
Yet to be developed resource	5% 405 M/l 13.9PJ	10% 810 M/l 27.7 PJ
Electric vehicles (~40% of the light vehicles)	20%* Substitutes for 1620 M/l 55PJ	30%* Substitutes for 2430 M/l 83PJ
Fossil	30% 2430 M/l 83PJ	10% 810 M/l 27.7 PJ
Energy Forest	30% 2430 m/l 83PJ	25% 2025 M/l 69PJ

* Note: % of total transport fuel.

The options presented in Table 34 are both based on the assumption that our future fuel supply will be more diverse, more distributed and more sustainable. However, given the limits on supply from wastes, and purpose grown biomass from agricultural and algal resources and taking into account the uncertainty about future oil supply and cost, the option of growing large scale forests for energy seems to be an inevitable choice.

New Zealand is not unique in the energy challenges it faces, and many countries are developing research and implementation strategies and policies to reduce reliance on fossil fuels and to improve their sustainability. A key to sustainability of renewables is the sustainability of the land use. One of the options for New Zealand to follow is the fast adaptation of ligno-cellulosic conversion technologies developed overseas. However for this strategy to be viable in the medium term we need to consider the resource to which the conversion technology is to be applied, what it is, where it is and how much there is. Given the information gathered and summarised in the Bioenergy Options project to date it seems clear that one of the most significant opportunities available is based on forests from marginal lands.

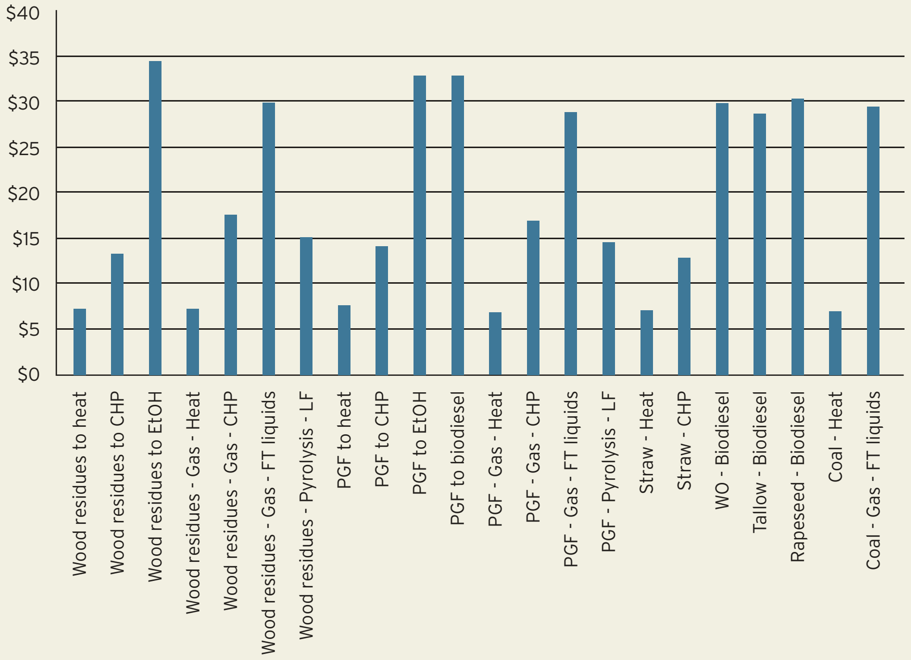
APPENDIX V

Table 35 - Pathways evaluation summary energy efficiency and outputs per 1GJ of resource output.

Pathway	Description	Scale	Energy efficiency	CO_2 equiv emissions	Cost	Value per GJ out	Profit (loss) per GJ out
1	Wood Residues to Heat	Medium	67%	0.0040	$ 6.76	$6.78	$0.33
2	Wood Residues to CHP	Small	46%	0.0059	$11.74	$12.58	$1.39
3	Wood Residues to EtOH	Medium	41%	0.0085	$20.56	$31.66	$13.80
4	Wood Residues -Gas-Heat	Medium	57%	0.0047	$25.14	$6.73	-$18.05
5	Wood Residues -Gas-CHP	Medium	47%	0.0057	$30.06	$16.79	-$12.55
6	Wood Residues - Gas - FT liquids	Small	52%	0.0052	$24.15	$21.05	$5.71
7	Wood Residues - Pyrolysis - LF	Small	56%	0.0048	$13.09	$14.11	$1.79
8	PGF to Heat	Large	63%	0.0043	$32.40	$6.78	-$24.86
9	PGF to CHP	Large	43%	0.0063	$42.67	$12.58	-$28.63
10a	PGF to EtOH	Large	43%	0.0081	$56.53	$31.66	-$23.79
10b	PGF to Biodiesel	Large	43%	0.0081	$56.53	$31.66	-$23.79
11	PGF-gas-heat	Large	60%	0.0045	$50.35	$6.73	-$43.62
12	PGF-gas-CHP	Large	49%	0.0055	$61.24	$16.80	-$44.45
13	PGF to gas to FT liquids	Large	54%	0.0050	$52.67	$26.06	-$23.91
14	PGF to Pyrolysis to LF	Large	58%	0.0046	$40.02	$14.11	-$25.66
15	Straw to Heat	Small	88%	0.0045	$ 5.77	$6.79	$1.17
16	Straw to CHP	Small	61%	0.0065	$ 9.75	$12.56	$3.02
17	WVO to Biodiesel	Very Small	84%	0.0074	$18.99	$24.95	$23.76
18	Tallow to Biodiesel	Small	64%	0.0558	$24.92	$24.97	$3.56
19	Rapeseed to Biodiesel	Medium	69%	0.0327	$47.15	$25.00	-$16.93
20*	Coal to Heat *	Very Large	74%	0.1281	$ 6.88	$6.79	-
21	Coal to gas to FT liquids	Large	53%	0.1788	$23.62	$26.06	$5.68

* Base case

Figure 23 – Value per GJ out



Glossary of abbreviations

BTL – Biomass to liquid

C – Carbon

CHP – Combined heat and power

CO – Carbon monoxide

CO_2-e - CO_2 equivalent

DM – Dry matter

DME – Dimethyl ether

DW – Dry weight

EJ – Exajoule (1 x 1018)

F-T – Fischer Tropsch

FRST – Foundation for Research, Science and Technology

GHG – Green-house gas

GJ – Gigajoule (1 x 109)

GTL – Gas to liquid

ha – Hectares

kW – Kilowatt

kWh – Kilowatt hour

l = Litre

MRF – Medium rotation forest

MW – Mega watt

NOx – Nitrous oxide

ODT – Oven dry tonnes

p.a. – Per annum

PGF - Purpose-grown forest

PJ – Petajoule (1 x 1015)

SCWO – Super critical water oxidation

SOx – Sulphur oxide gases

SRC – Short rotation coppice

SRF – Short rotation forest

t – Tonne

Definitions

Primary energy = gross fuel/energy consumption

Consumer energy = energy delivered to consumers

User and consumer energy are interchangeable terms, and are always less than primary energy due to conversion efficiency and distribution losses.

Example;

Primary energy going to heat = 1 GJ for Consumer energy of heat = 0.7 GJ

More information

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