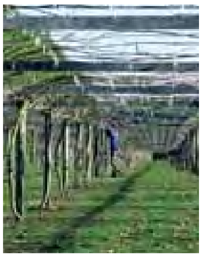
Next generation biomaterials

Bioenergy Options for New Zealand

SITUATION ANALYSIS

Biomass Resources and Conversion Technologies



The following organisations have contributed to this project:

Landcare Research Manaaki Whenua

CRL Energy Ltd

Crop & Food Research

NIWA Taihoro Nukurangi

Waste Solutions Biotechnology Group

This report (Bioenergy Options – Situation Analysis) covers parts 1 and 2 of the bioenergy options study, these are:

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

The subsequent phases of this project, which will be reported separately, are:

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

New Zealand has a range of bioenergy options that could provide a meaningful contribution to the nation's energy future. The role of this Situation Analysis is to identify options for realising this potential and to determine the most appropriate areas of research for New Zealand to pursue.

Bioenergy Options for New Zealand

A situation analysis of biomass resources and conversion technologies

November 2007

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Editor: Margaret Richardson

Scion, Energy Group, 2008

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EXECUTIVE SUMMARY

New Zealand has a range of bioenergy options available that could provide a meaningful contribution to the nation's energy future. The role of this Situation Analysis is to identify options for realising the potential of bioenergy and to determine the most appropriate areas of research for New Zealand to pursue.

This study shows that New Zealand has the potential to fuel itself from renewable resources. This ability is due to a low population density and large areas of land suitable for agriculture and forestry.

It is theoretically possible for New Zealand to be self-sufficient in terms of liquid fuels by using sustainably managed forests, while having low impact on domestic and export food production. Along with the energy will come ancillary benefits of forests including flood mitigation, improved water quality, erosion control and carbon sequestration.

The diagram on the following page illustrates a concept strategy to achieve carbon neutral energy and a sustainable economy by 2050.

The resource

Locally-available biomass resources, in descending order of volume, include woody resources, agricultural plants, and municipal and industrial wastes from various sources. In addition, algal production shows promise as a biomass resource that can be grown using nutrient-rich waste streams.

New Zealand's current energy demand is:

- Heat - 190 Peta Joules (PJ) per annum.
- Electricity - 39 Terra Watt hours (141 PJ) per annum.
- Liquid fuels, road transport - 6.3 billion litres (212 PJ) per annum.

Current energy production from biomass resources is in the order of 45PJ per annum.

Biomass residues could further contribute another 60PJ per annum. This contribution could theoretically rise to 90PJ in 2050, based on increasing residues from increasing volumes of forest harvesting and wood processing.

The potential exists to substantially increase the nation's woody resource by using purpose-grown forest crops to meet future energy demands.

The goal

The Government has set targets for increased use of renewable energy which will see New Zealand being carbon neutral in:

- electricity by 2025.
- industrial energy by 2030.
- transport fuels by 2040.

In order for New Zealand to be sustainable it must not only be carbon neutral, it must also be economically competitive and have economic growth. Such growth has to occur in an increasingly resource constrained world, therefore it is necessary to:

- meet energy demand from renewables.
- manage land sustainably.
- maintain a robust export sector whose sustainability can be verified and defended.

The generally accepted view of climate change is that it is real, and requires large scale, rapid change to reduce greenhouse gas emissions.

The solution

New Zealand can reduce emissions from industrial heat and transport, through efficiency gains and by substituting bioenergy for fossil energy. The use of residual biomass is a logical start point, and a step in the direction of renewables. However the total amount of energy available from residual biomass is relatively small (around 10%) in comparison to total energy demand.

The use of wastes for energy will have large impacts on greenhouse gas emissions because biomass resources tend to produce methane when dumped. If fossil energy is displaced by the use of energy from such waste, there will be a double gain in reduced emissions, along with other environmental benefits. This is particularly relevant to materials such as municipal effluents, biosolids and solid waste.

The next logical step is to grow biomass for energy, wherein the limiting resource becomes land. If New Zealand is to achieve bioenergy goals without competing for land with food crops, it is necessary to consider growing medium- to long-rotation forests on marginal lands. These forests would have to be significantly greater in area than the existing planted estate (1.7 million ha). To meet the country's total heat demand, an estate of 700,000 ha would be required. To meet the liquid fuels demand a further 2.5 to 2.8 million ha would be needed.

Use of biomass from forests (including purpose grown forests) to produce biofuels has fewer environmental concerns than intensive cropping of arable land because forests:

- do not require intensive fertilisation.
- do not require irrigation.
- do not cause nutrient rich run-off.
- do not compete for high value land used for production of food crops such as corn, wheat and vegetables.

Forests also provide an energy store that can be used when required or processed into other valuable products.

New Zealand has at least 830,000 ha that could be cost-effectively used for forestry. Some estimates indicate that there could be as much as 3.0 million ha. A combined energy forest estate of approximately 3.2 million ha could provide most of New Zealand's heat and liquid fuel demand. This is achievable based on the amount of marginal and lower quality grazing land available.

Converting biomass into energy

Biomass can be used to produce heat, power and liquid fuels, along with other products. Energy products from biomass can be produced in a range of forms (solid, gas, liquid) which can be handled by existing infrastructure in many cases.

Biomass has advantages over fossil fuels because it:

- is renewable.
- produces less greenhouse gas.
- is widely distributed.
- utilises and/or mitigates wastes.

The logical route for biomass resources is largely for heat and liquid fuels, with some ancillary electricity.

Energy outputs can be derived from biomass using a range of existing or developing technologies. Conversion technologies commonly used in New Zealand to produce heat, biogas and biodiesel include combustion, anaerobic digestion and chemical/mechanical methods. Emerging technologies for the production of liquid biofuels include gasification (+ Fischer Tropsch), enzyme technology and pyrolysis.

The use of biomass resources, which are diverse and widely distributed, is technically feasible, but costs are highly variable.

Significant barriers are:

- guaranteeing quantity and quality of biomass feedstock supply to conversion plant.
- achieving economic scale.

Research directions

To realise the potential of using these technologies to convert biomass into energy, the following research needs have been identified:

- Woody biomass: All facets of growth, harvest, delivery, processing and conversion, driven by the relative importance of residual resource and potential to develop a purpose grown resource. Technology areas would be gasification with combined heat and power, gasification to liquid fuels and enzyme technology. Improvement of data in some areas is required.
- Life cycle analysis (LCA) and costings and the development of New Zealand centric LCA databases.
- Anaerobic digestion of effluents and wastes including gas productivity, catalysts, scale and environmental benefits.
- Algae: The potential to utilise nutrient rich waste waters from anaerobic digestion and the production of both biogas via digestion and production of biodiesel.
- Pyrolysis technology and the potential of biochar as a carbon store.
- Social, environmental and economic impacts of bioenergy.
- Policy mechanisms and effects.
- Carbon capture and storage.

The full set of reports underpinning this summary is available on CD along with maps and tables of resource distribution. This document represents the first stage of an ongoing project. The next report arising from the Bioenergy Options study will further explore the concepts raised herein.

Key Conclusions:

- All available biomass residues combined would meet only 10% +/- of New Zealand's current energy demand.
- Woody biomass is the bulk of this material.
- Purpose grown crops will be required to meet a larger proportion of New Zealand's energy demand.
- Steep hill country will need to be used for growing this extra biomass to avoid conflict with agricultural production.
- The only viable biomass crop for steep lands is forests, which have additional uses, environmental benefits and can act as a significant energy store.
- Research is required on a range of conversion technologies to improve their economic viability, as well as forest and agricultural crops and algal systems.

NEW ZEALAND CONCEPT STRATEGY TO SUSTAINABLE ENERGY

CURRENT SITUATION

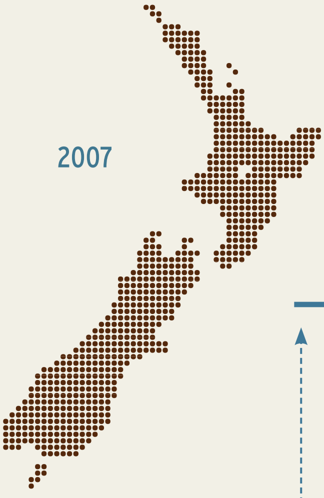
Fossil Dependant

- 12th highest per capita CO_2 emissions in the world
- Expecting 40% increase in transport energy use by 2030

Developments

- Conversion technologies mature
- Gasification to biofuels
- Enzymes to biofuels
- Combined heat and power – small-scale
- Bio refineries

2007



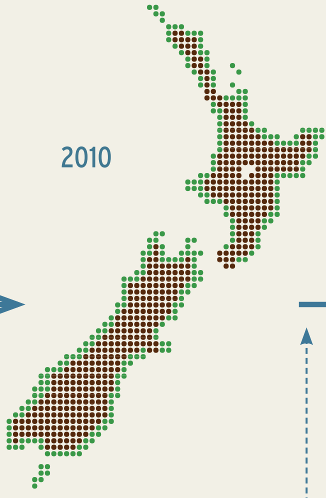
Actions

- Plant 70,000 ha short rotation forests
- Plant 20,000 ha/year medium rotation forests
- Plant 80,000 ha/year pine forest (or equivalent)

Outcomes

- Future resource under development
- Mixed land use, nutrient and erosion control

2010



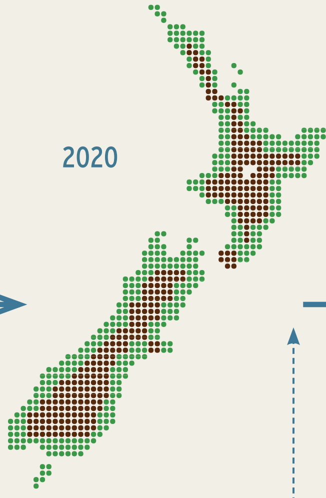
Actions

- Begin to harvest short rotation forests
- Plant 30,000 ha/year in medium rotation forest
- Plant 100,000 ha/year pine forest (or equivalent)
- Convert all effluents using anaerobic digestion

Outcomes

- Biofuels from short rotation forests
- Biomass heat
- Biogas (combined heat and power)

2020

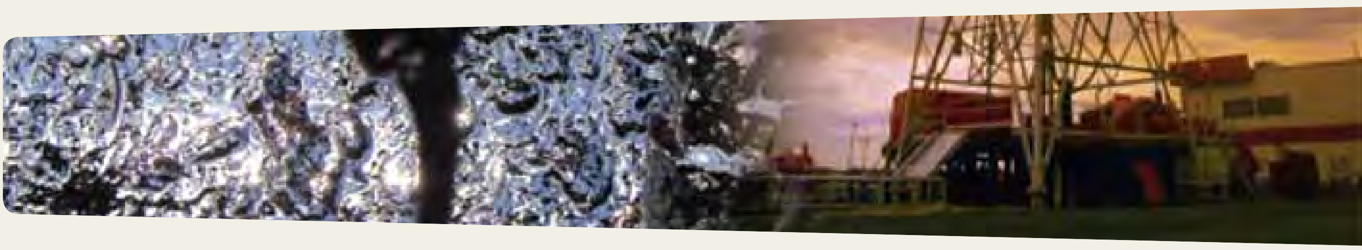


Actions

- Plant 130,000 ha of forest
- Reduce fuel use via efficiency (freight and urban)

Outcomes

- Wood to gas for industrial heat and power
- Biofuels from short and medium rotation forests
- Erosion and flooding control
- Greenhouse gas reduction



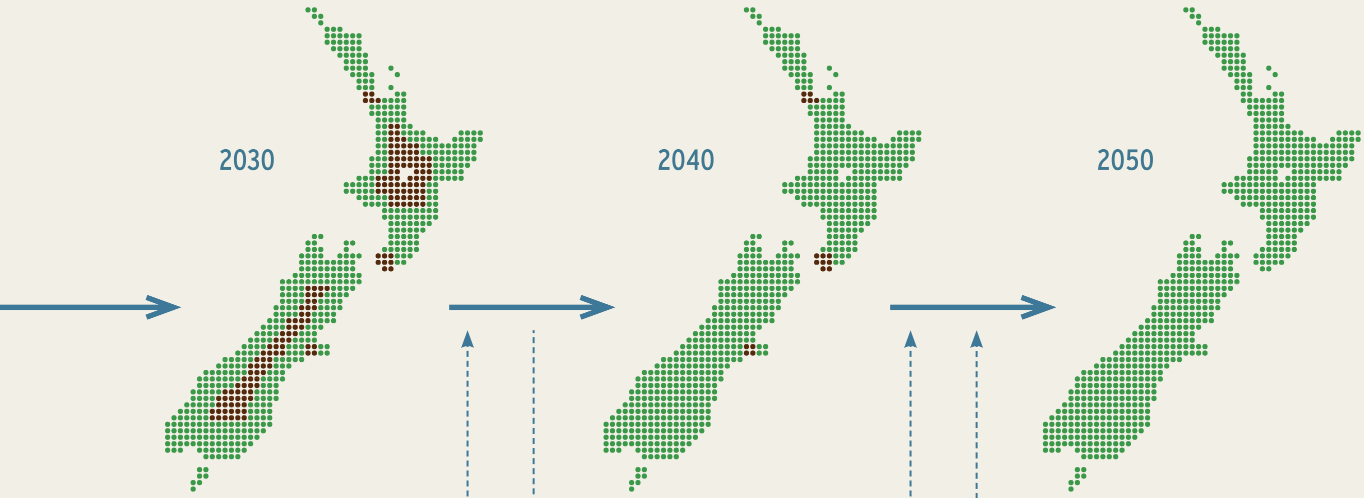
Focus

- Biofuel (liquids from biomass)
- Heat (with some electricity from CHP – combined heat and power)

Note: Electricity provided by renewables from hydro, geothermal, wind, marine and solar.

GOALS

- NZ sustainable in heat and transport fuels derived from biomass (carbon neutral energy)
- Optimised land use
- Improved water quality



Actions

- Plant 100,000ha/year
- Develop distributed biofuel refineries based on forest resource

Outcomes

- Biofuels for transport meeting a significant % of demand
- Biomass for combined heat and power to meet a large % of heat demand

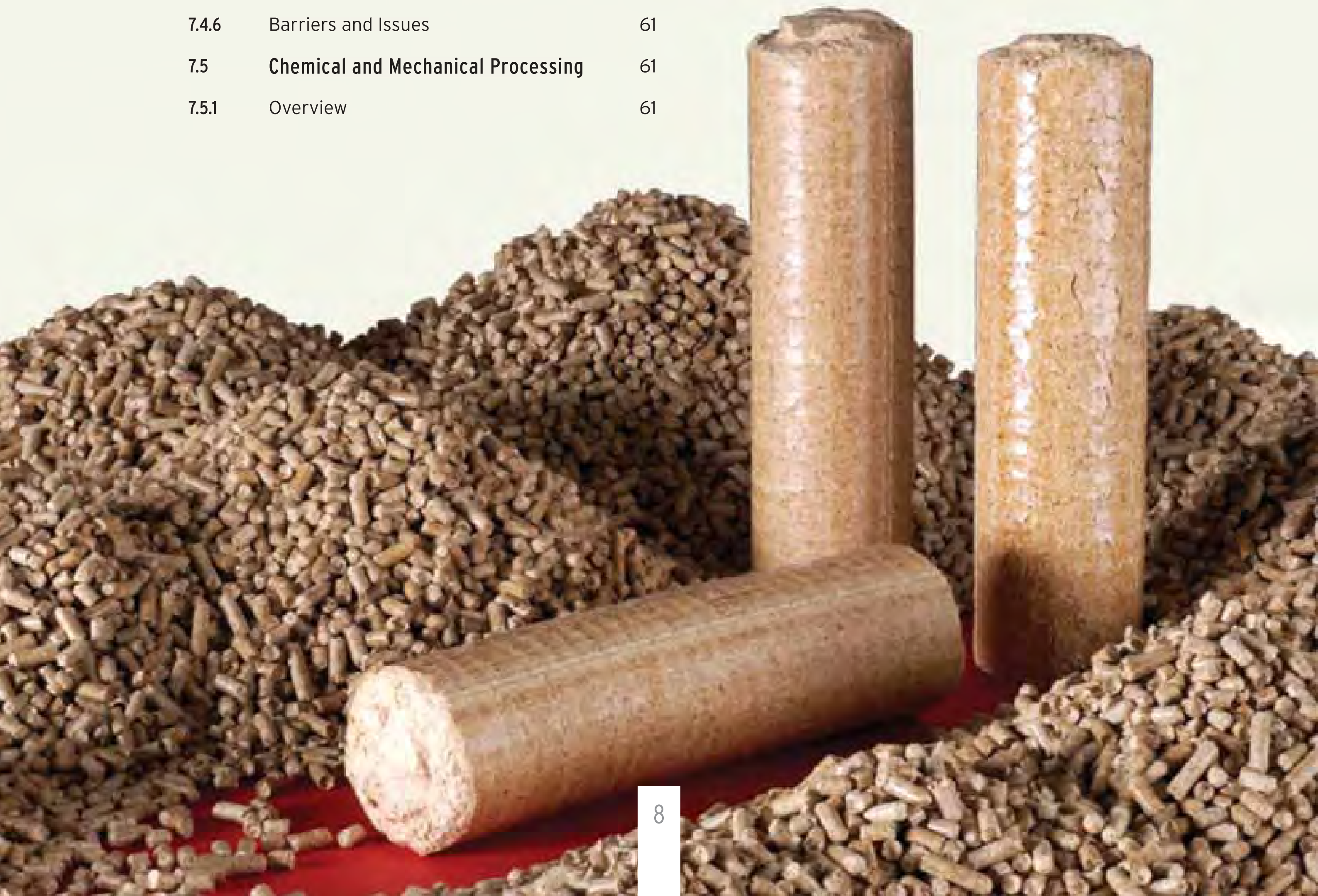
Actions

- Manage sustainable harvest 130,000 ha/year from 3.2 million ha energy forest estate

Outcomes

- 100% of liquid fuels and heat from wood and effluents

CONTENTS



1.0 INTRODUCTION

This project, Bioenergy Options for New Zealand, provides an overview of the biomass resources currently and potentially available for energy production. It also outlines appropriate conversion technologies to produce heat, electricity and liquid transport fuels from these resources.

The project is funded by FRST contract C04X0601 and is part of the Energyscape Project being conducted by NIWA, Scion and CRL Energy. The full Energyscape project scope covers Indigenous energy, Bioenergy and Hydrogen respectively.

The bioenergy project focuses on assessing New Zealand's bioenergy options, identifying the contribution that bioenergy can make to the nation's energy future, and identifying research priorities to fill information and technology gaps. The purpose of this information is to accelerate New Zealand's implementation of renewable energy.

This document summarises a series of comprehensive reports covering biomass resources and conversion technologies. These reports include maps of biomass resources and areas where further resources could be developed. Full copies of these individual reports are available on the attached CD.

1.1 Bioenergy in the Global Context

Current global energy demand is around 467 exa Joules (EJ), with 388 EJ being met by fossil fuels. This energy demand is expected to at least double or triple during the current century. Other major energy sources are nuclear power (26 EJ) and hydropower (28 EJ). Biomass provides 45 $\pm$ 10 EJ, making it by far the most important renewable energy source used today. Much of this energy is used for cooking and heating in developing countries. Modern bioenergy (commercial energy production for industry, power generation or transport) is around 7 EJ (IEA Bioenergy 2007).

Projections of the biomass resource potentials are around 100-300 EJ annually, based on energy farming on available agricultural land and some technology advancement. This level of growth in biomass-derived energy can be achieved without jeopardising the world's future food supplies. In terms of the current and projected role of bioenergy, there is need for both significant investment into R&D and expansion of its role in today's energy marketplace.

New Zealand's total primary energy demand is 540 PJ. Bioenergy currently contributes approximately 45 PJs, or 8.3%.

1.2 Bioenergy and the New Zealand Energy Strategy

The recently released New Zealand Energy Strategy (NZES) and New Zealand Energy Efficiency and Conservation Strategy (NZEECS) support the direct use of biomass through the following actions and targets.

- 90% of electricity to be generated from renewable sources by 2025.
- A biofuels sales obligation to be introduced.
- Use of electric vehicles to be encouraged.
- Clean and efficient use of bioenergy.
- The use of an additional 10.5 PJ per year of bioenergy, based on woody residue.

Underpinning these policy objectives is a range of actions such as: a capital grants scheme; a pilot scheme to convert school coal-fired boilers to woody biomass, and; additional funding support for projects through the Low Carbon Energy Technology Fund.

1.3 Research Team

The Research Team that has been involved in providing this Situation Analysis has included:

Scion	Forest Resources Logging Residues Municipal wood waste Wood Processing Waste Short-rotation Forestry Pyrolysis Enzymes Chemical and Mechanical processing
Landcare and Crop & Food	Agricultural and Horticultural crops and residues
Waste Solutions	Industrial Effluents Municipal Biosolids Anaerobic Digestion
NIWA	Algae
CRL Energy and Process Developments*	Combustion Gasification

* Process Developments has now merged with Connell Wagner

1.4 Structure of Summary Report

This summary is targeted at a wide readership to assist the process of expanding knowledge of bioenergy options to many stakeholders.

It provides an overview of the following:

- The key biomass resources that can be converted into energy products.
- The nature and issues associated with different conversion technologies.
- Consideration of the different types of energy products that can be produced.
- Indicative cost information relevant to the supply of resources and different conversion systems.
- An indication of relevance and scale applicable to New Zealand situations.
- Identification and discussion of key barriers and issues constraining implementation of bioenergy.

This summary is supported by a series of specific, more detailed reports, which are supplied on CD at the back of the document.

The overall objective of this summary is to provide a reference document and facilitate broad stakeholder engagement in the subsequent stages of the Bioenergy Options Programmes, which include:

- Definition and selection of specific bioenergy options for New Zealand.
- Detailed assessment of these options (i.e., fully costed and evaluated from a broader social, economic, and environmental perspective.
- Identification of the research gaps required to "make real" the options.
- Development of a research pathway.

This report (Bioenergy Options – Situation Analysis: Summary and CD with contributing reports) covers parts 1 and 2 of the bioenergy options study. These are:

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

The subsequent phases of this project, which will be reported separately are:

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

2.0 BIOENERGY

The terms bioenergy and biofuels cover any energy products derived from plant or animal materials. Where these materials are sourced from renewable, process or waste sources, the energy produced can be considered renewable. Interest in bioenergy and biofuels has increased recently due to their:

- Potential to reduce GHG emissions.
- Energy security benefits.
- Substitution for diminishing global oil supplies.
- Potential impacts on agricultural policy and the possibility to utilise surplus crops or crop waste to reduce environmental impacts.

2.1 Biomass resources

In principle, any biomass contains energy which can be extracted and converted to a user energy, at a cost.

The sources that provide suitable feedstocks to produce bioenergy and biofuels in a New Zealand context include: herbaceous and woody plants; sugar crops (beets); oil crops (canola); agricultural and forestry residues and municipal and industrial wastes.

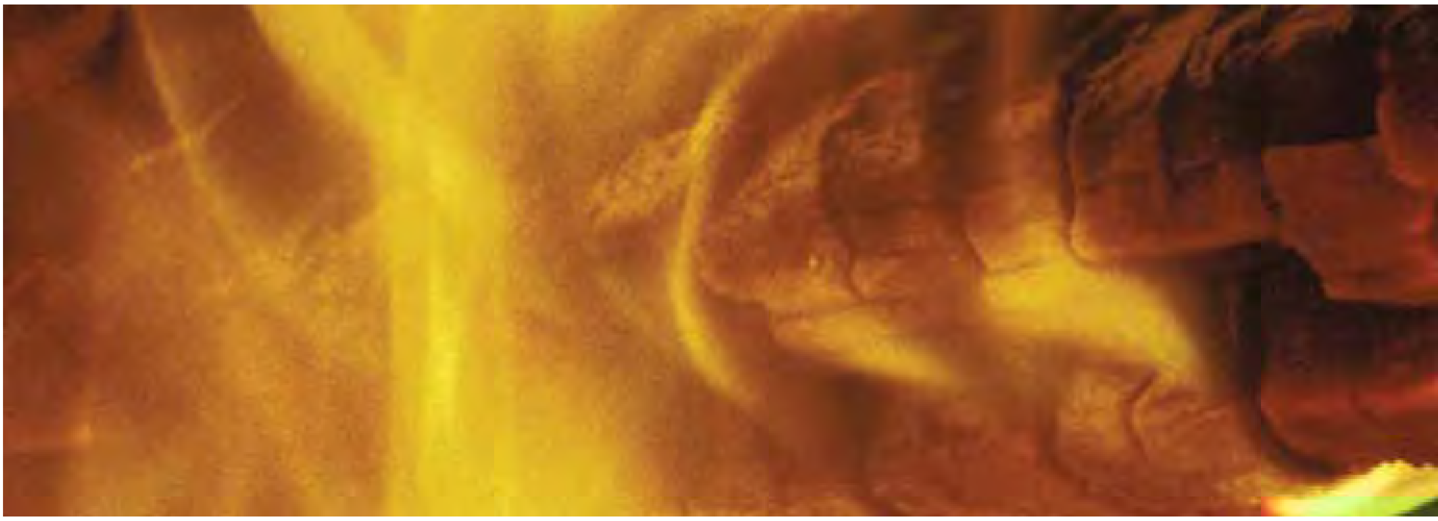
The following biomass resources are examined in this project:

- Woody biomass including: wood residues from forests; wood processing residues; municipal wood waste; horticultural prunings, and; short rotation forestry.
- Agricultural plants including energy crops, crop residues and horticultural wastes.
- Municipal and industrial wastes including: sewage bio-solid effluents; solid waste; farm manures, and; industrial wastes from dairy, and fruit, vegetable and meat processing.
- Algae.

2.2 Conversion technologies

There are a number of conversion technologies to produce energy from biomass such as: direct combustion for heat; fermentation for ethanol production; gasification/pyrolysis for the production of liquid or gaseous fuels, and; anaerobic digestion to produce methane gas. Not all feedstocks will be suited to all conversion systems.

The conversion of biomass resources to different forms of energy relies on a range of different technologies,



some of which are still unproven. This report summarises these processes and the fuels they are applicable to. The technologies covered are:

- Combustion - burning biomass to generate heat.
- Gasification - using partial combustion to produce gas from biomass.
- Pyrolysis - using heat in the absence of oxygen to break organic matter down to its chemical components.
- Anaerobic Digestion - naturally degrading organic material in the absence of oxygen.
- Chemical and Mechanical processing – converting canola, waste oil, and tallow to biodiesel by pressing and/or trans-esterifcation.
- Biochemical and enzyme technology - biological catalysts that can be used at critical stages of the bioconversion process to replace more energy-intensive methods.

Combustion is a well-developed technology that is commonly used in New Zealand. Equally, anaerobic digestion is a mature technology with a wide range of biofuel end use options which have been practiced globally for many years, especially in Europe, Asia and the Americas. These technologies provide value not only for generating energy, but also for disposing of residues and wastes.

Gasification and pyrolysis are existing technologies not yet fully commercial.

Chemical/mechanical processing is used in New Zealand to produce biodiesel in relatively small quantities from waste cooking oil. Interest is developing in the use of tallow and growing canola to produce biodiesel at larger scales, while applications for enzyme technology and pyrolysis in New Zealand are still being researched.

Methods for producing biofuels are often classified as "first generation" (well-proven technologies based on easily converted feedstocks) or "second generation" (methods using new technologies and/or feedstocks). First generation technologies include ethanol production from whey, grains or sugar cane and biodiesel production from vegetable or animal oils. Second generation technologies include ethanol production from cellulose or gasification followed by a "gas to liquid" process and biodiesel production from algae.

2.3 Energy products

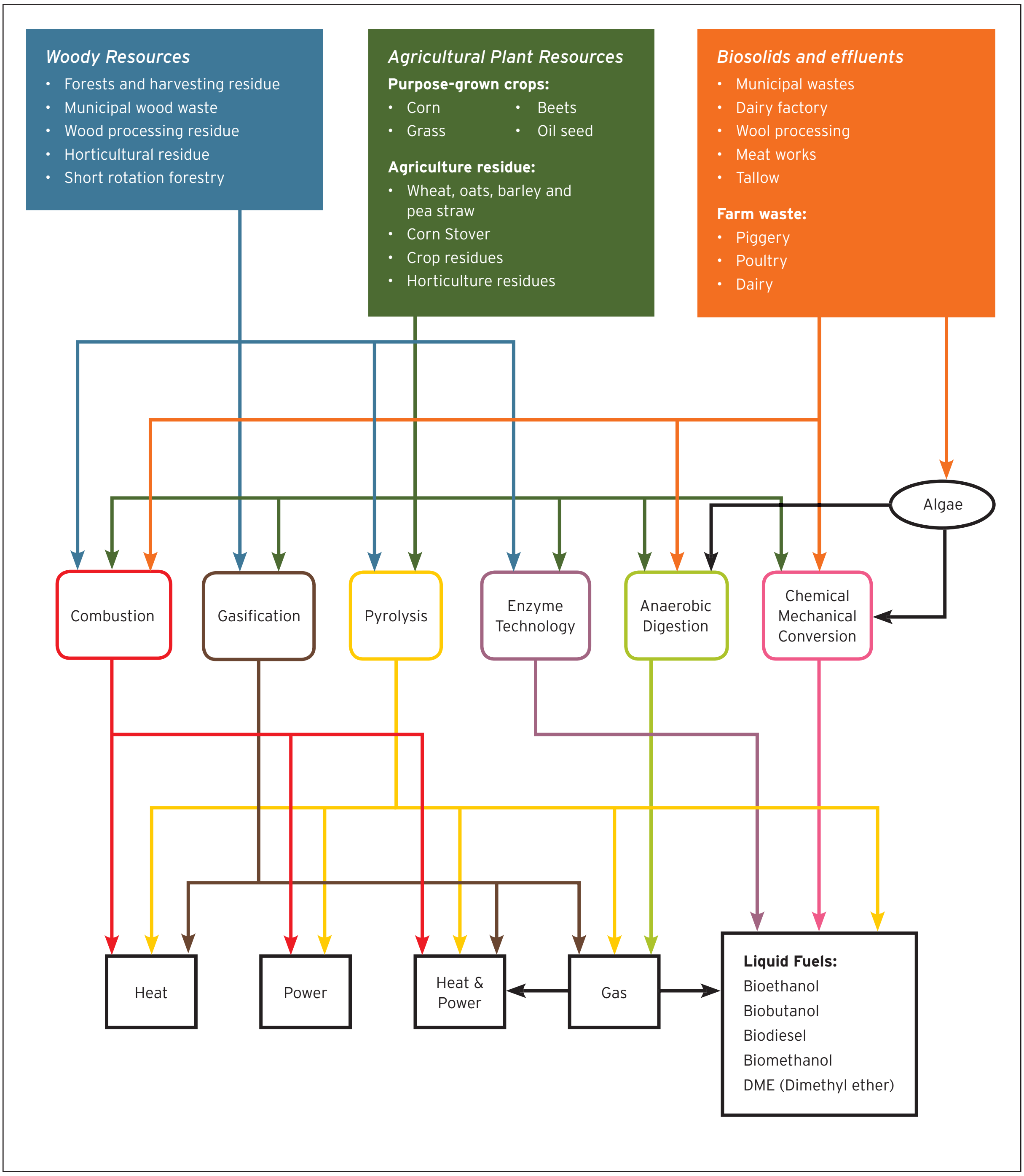
The energy products available from biomass range from industrial heat to liquid biofuels. The main conversion processes considered in this report generate the following energy products:

- Heat via combustion (direct or indirect).
- Combined heat and power – (cogeneration of heat and electricity via combustion).
- Ethanol from the biochemical conversion of sugars, starch, and lignocellulosics.
- Biodiesel from the chemical and mechanical processing of animal, plant and algae fats and oils.
- Bio-oil from pyrolysis.
- Biogas from anaerobic digestion.

The relationships between resources, conversion technologies and energy products are shown in Figure 1 on the following page.

2.4 Resource, Conversion and Product Pathways

Figure 1: Possible resource, conversion and user energy pathways.



2.5 Barriers

Issues constraining bioenergy use are supply, demand, cost, competition, infrastructure and land use.

Woody resources

3.0 WOODY RESOURCES

Wood materials arising from various sources provide an important bioenergy resource for producing heat, electricity and, potentially, fuel for transportation.

Currently in New Zealand, the most common and cost efficient way of using woody biomass is to burn the wood material to generate heat and, in a few situations, electricity. Common fuel options include wood chips for industrial heat, or converting chips into wood pellets for feeding home fires or commercial boilers. Many wood processing plants use wood processing residues as boiler feedstock.

While not yet economic, gasification processes are also technically viable to convert woody residues into biogas fuels for heat, power and transport.

It is increasingly recognised that liquid biofuels arising from woody biomass could contribute to meeting future global demand for sustainable energy due to the large volume of the forestry resource.

"First generation" biofuels are currently being produced using biological feedstocks that are readily processed, such as sugarcane sugars, milk sugars, starch and tallow.

In future, "second generation" biofuels may be economically produced using woody biomass (lignocellulosics), which are more difficult to break down. Technologies are currently under development worldwide to convert woody biomass into liquid fuels.

This section includes consideration of the following feedstocks that can be used for bioenergy production in New Zealand:

- Wood resides from forests.
- Wood processing residues.
- Municipal wood waste.
- Horticultural prunings.
- Short rotation forestry.

Bioenergy is considered renewable if the biomass comes from sustainably-managed resources, such as plantation forests, agriculture, or production residues that would otherwise be wasted.

Wood materials arising from various sources provide an important bioenergy resource for producing heat, electricity and, potentially, fuel for transportation.

3.1 Wood residues from forests

3.1.1 Background

New Zealand forests contain a large resource of woody biomass that has potential to be used for bioenergy. Most of this biomass will arise from the 1.7 million hectares of pine plantation forests currently spread throughout New Zealand.

Residues from routine harvesting operations offer a significant resource that is already available, with no need to plant new areas or use any additional land. The use of these harvesting residues potentially creates a new value stream for forest growers.

Residual materials that result from logging are created from sustainably managed pine forests at two general locations:

1. In the forest (cutover) large trees frequently break when they are felled, typically at around two-thirds to three-quarters of the tree height. Often these broken sections are small and of low value so they are not extracted to the landings, but left on the cutover, along with the branches, to rot away.
2. On central landings (skid sites) tree-length material is cut into logs. Off-cuts from the base, tip and midsections of trees become waste material that averages 4 to 6% of the extracted volume. A variable amount of branch material is also produced. Because these landings are centralised processing sites, they make it relatively easy to recover significant volumes of wood residues.

What recovery systems are available?

Systems are already in place to utilise logging residues from landings for energy. Such systems consist of either processing at landings or at centralised processing facilities where it is necessary to use two-stage processing. When using centralised processing, 10% to 15% may be added to the delivered cost due to extra transport and handling requirements.

How can the resource be used?

Currently in New Zealand there are only a few industrial sites where the use of forest residues as fuel occurs. These industries are generally associated with forestry and forest products processing and have existing plant for burning wood processing residues to produce heat. These users are commonly large scale operations (both forest production and energy use), who have access to off-highway transport networks with low transport distances. Their use of forest residues is driven primarily by environmental or economic pressures to remove residues from the site where it is originally produced and/or address fuel shortages.

Systems already in place to harvest logging residues currently yield about 250,000 tonnes of residue per annum, which is largely used to fuel energy plant for wood processing facilities.

3.1.2 Quantities

Systems already in place to harvest logging residues currently yield about 250,000 tonnes of residue per annum, which is largely used to fuel energy plant for wood processing facilities. This is approximately 27% of the existing landing residue resource, or 7% of the total forest harvest residue resource. The bulk of this material is being used at large wood processing sites in the Central North Island and some in Nelson and Hawke's Bay. The economics are driven by the fact that these sites have wood-burning heat and power plants on site to utilise processing residues, and have a demand for additional fuel.

Volumes of residues potentially available from forest harvesting are significant, and will increase over time to 2030 (see Table 1). The maximum quantity of residues is expected to be over 5 million tonnes in 2026-2030. Five million tonnes equates to 200,000 truck loads, or sufficient feedstock for two large pulp mills.

Table 1: Logging residues

	2005-2010	2016-2020	2026-2030	2036-2040	2046-2050
COR* hauler 1	1,449,187	1,656,354	3,379,861	2,142,183	1,637,158
COR ground based 2	1,225,926	1,429,470	2,647,984	1,802,141	2,203,866
Landing residues	923,767	1,223,671	2,410,040	1,519,131	2,540,333
Total	3,598,880	4,309,495	8,437,885	5,463,454	6,381,357
Landing + COR ground based	2,149,693	2,653,141	5,058,024	3,321,271	4,744,199

* COR = Cutover residues

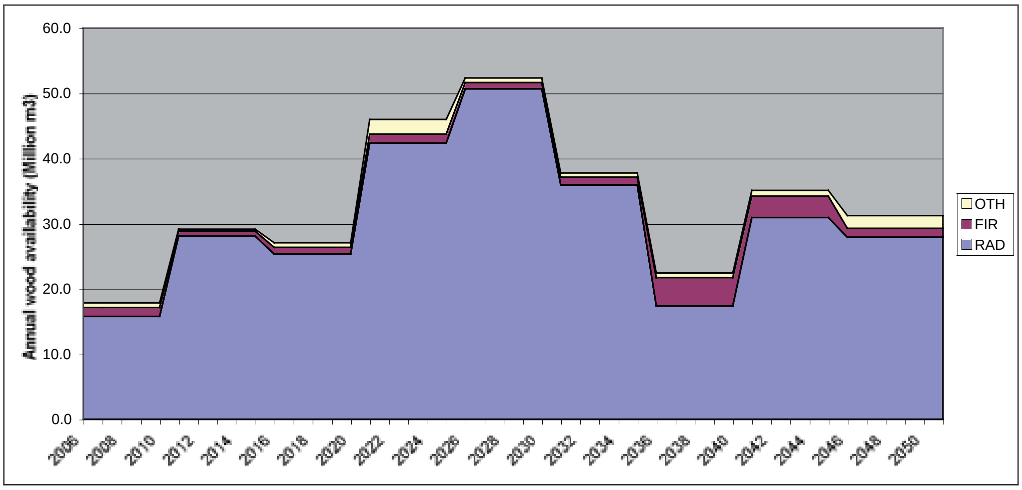
[1] Hauler = steep terrain logged by cable hauler systems

[2] Ground based = flat to rolling terrain logged by wheeled or tracked machines

The availability of forest residues over the next 30 years will be largely determined by the current extent and age of plantations together with the rotation length. The volume of biomass available for energy uses can be estimated by calculating residues as a proportion of total recoverable volume from the forests.

3.1.3 Forecasting wood availability

Figure 2: Annual wood supply (million m3/year)



Existing forecasts of wood availability from New Zealand plantations are outdated, so new estimates have been developed for this study using estimates of area and interim yield tables developed for the Ministry of Agriculture and Forestry's (MAF) latest regional wood availability forecasts. While these yield tables are yet to be finalised, they were regarded as more reliable than the previous tables published in 1995. Forest area and harvest volume estimates could be improved if detailed company data was used, rather than the more aggregated data contained in MAF's National Exotic Forest Description (NEFD).

The areas used were averages over five-year age classes within Territorial Authority boundaries. Harvesting was assumed to take place at age 30 for radiata pine, 40 for Douglas fir, cypress, and other softwoods, and 25 for all hardwood species. All area was assumed to be replanted back to the same species after harvesting, with no net deforestation or afforestation.

At the aggregated national level, the dominance of radiata pine is evident. Harvesting increases to a peak as stands mature which were established in the mid-1990s planting boom.

Land-use changes and afforestation will strongly affect future residue availability. Forecasts beyond 2036 are influenced by restocking and afforestation decisions. Sufficient land (at least 830,000 ha in low intensity use, and as much as 3.0 million ha) is potentially available to support a significant planting programme, which would result in higher rates of harvesting than used for the above volume assessments.

In the shorter term, increased availability of residues could be achieved by:

- Shorter rotation ages than those modelled, including utilising material from deforestation of immature plantations.
- Establishment of short-rotation forestry crops specifically for energy supply. This is considered further in section 3.5.

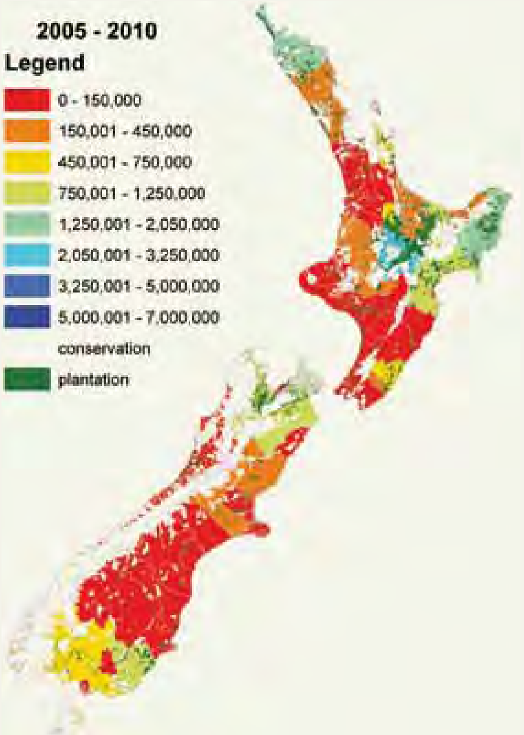
The introduction of a Permanent Forest Sinks Initiative by the Government could also contribute forest area in the future, as these areas allow thinning of the crop, although not clearfelling.

3.1.4 Distribution of the Forest Resource

The Central North Island region dominates current and future wood supply. At present it provides over 30% of the national cut. This dominance will continue, peaking in 2026 to 2030 when more than 70% of the national cut will possibly be from this region alone. In the next 5-10 years Northland will see a significant rise in harvest, and in the next 10 to 15 years East Coast will have a major increase in cut.

Influences on future harvest are happening now that will not be reflected in current plantation figures, including deforestation of mixed age class associated with dairy farm conversions. Actual forest areas that will be lost are hard to predict precisely, but as much as 50,000 ha could be cleared during the period 2005 to 2010.

Figure 3: Regional distribution of forest and annual harvest volume



3.1.5 Contribution to New Zealand's energy supply

Woody residues from forests represent a potentially major energy feedstock, with an estimated 5 million tonnes of wood fuel available. The wide distribution of forests throughout New Zealand means that some of the resource is available in many regions. Woody resources can cater to a range of demands from small- to large-scale plants.

Woody biomass from all logging residues could contribute up to 32 PJ of a national demand of 190 PJ of heat. This amounts to 17% of the national demand and 58% of the potential biomass contribution to heat.

Figure 4a: Potential heat from residual biomass by type, volume, approximate cost and perceived risk

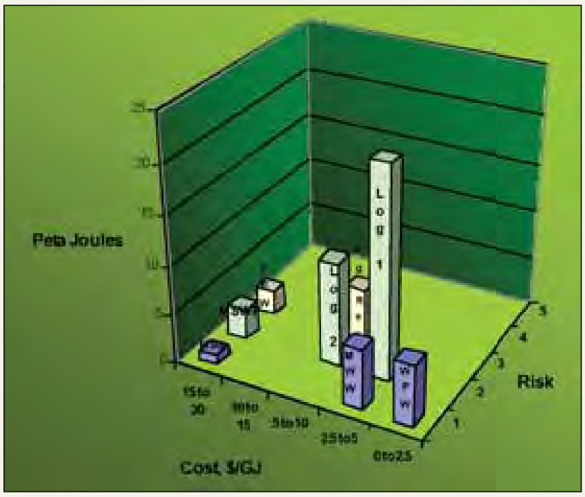


Figure 4b: Potential heat from residual biomass by type, volume, approximate cost and perceived risk with demand to give scale

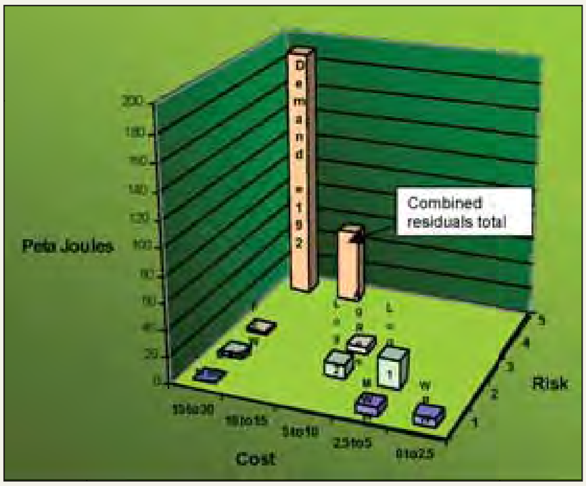


Figure 4c: Contribution of forest residues relative to other biomass resources.

Key to abbreviations in graphs 4a and 4b

MBS = Municipal Biosolids

MSWP = Municipal Solid Waste, Putrescible

MWW = Municipal Wood Waste

WPW = Wood Processing Waste

Ag Res = Agricultural Residues

Log Res = Logging Residues

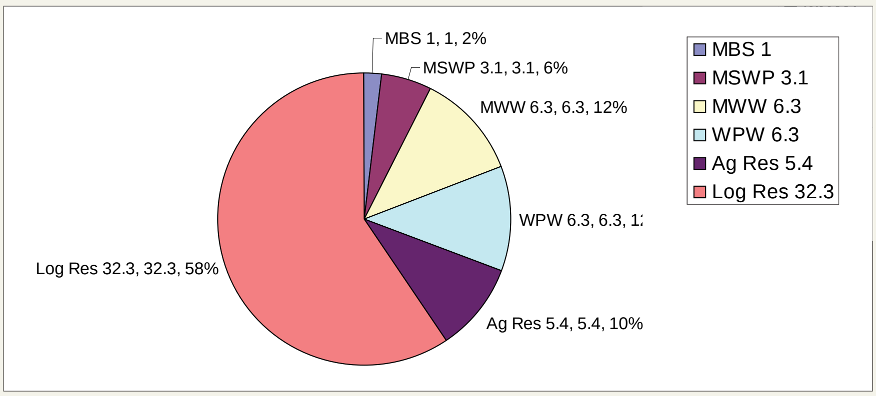


Figure 4d: Potential liquid fuels from residual biomass by type, volume, approximate cost and perceived risk

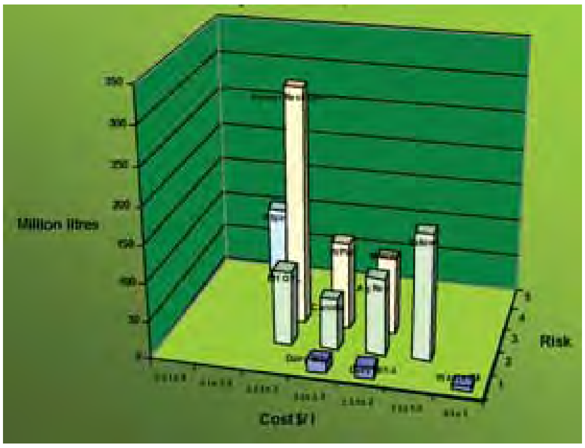
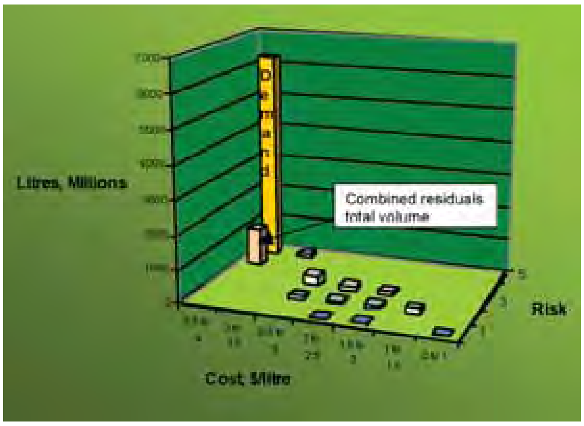


Figure 4e: Potential liquid fuels from residual biomass by type, volume, approximate cost and perceived risk with demand to give scale



3.1.6 Cost of recovering forest residues

The delivered costs of forest residue-derived biofuels varies significantly from site to site and by region. However, likely costs (2007) range between \$24/m3 and \$91/m^3 for solid wood (not a cubic metre of chipped wood, which is approximately 60% void space) delivered from forests to points of use between 25 and 100 kilometres.

Table 2: Delivered costs of forest residues to a user (\$/m^3, 2007)

Transport distance (one way)	Landing residues		Rolling cutover Ground based harvest		Steep terrain Hauler harvest	
	Low	High	Low	High	Low	High
25 km	\$24	\$34	\$36	\$50	\$63	\$78
50 km	\$27	\$39	\$39	\$55	\$67	\$83
75 km	\$30	\$43	\$42	\$59	\$70	\$87
100 km	\$33	\$47	\$45	\$63	\$72	\$91

Table 3: Cost per GJ of delivered fuel (assumes 8 GJ per m^3)

Transport distance (one way)	Landing residues		Rolling cutover ground based harvest		Steep terrain hauler harvest	
	Low	High	Low	High	Low	High
25 km	\$3.00	\$4.25	\$4.50	\$6.25	\$7.90	\$9.75
50 km	\$3.40	\$4.90	\$4.90	\$6.90	\$8.40	\$10.40
75 km	\$3.75	\$5.35	\$5.25	\$7.40	\$8.75	\$10.90
100 km	\$4.10	\$5.90	\$5.65	\$7.90	\$9.00	\$11.40

The cost of supplying forest residues delivered to users compares to October 2007 costs of \$5.50 per GJ for coal delivered to a Central North Island site and \$13.00 per GJ for commercial supply of gas.

Transport distances can have a substantial impact on the delivered cost of fuel. The cost increase from short- to long-haul is 37%. When this cost is carried through the conversion to consumer heat it reduces to a 14% increase in the cost of the heat provided (assumes a large industrial heat plant).

Processing and transport (including loading) make up the bulk (60 to 70%) of the costs to recover and deliver forest residues. However, it should be noted that changes to current handling and storage practices could substantially reduce material losses associated with handling and storage as well as reducing costs. These changes are:

- Direct hogging into trucks.
- Reduced handling.
- Air drying prior to comminuting.

At longer distances, transport efficiency is critical. These transport costs are affected not only by distance, but by truck configuration, loading efficiency and the nature of the road network on a site-specific basis. Transport costs (2007) are likely to be $0.18 to $0.25/ tonne per kilometre.

A delivered cost of $2.50 per GJ would make biomass cost competitive with coal at a new heat plant installation that has no drivers for use of on-site wood residues. At the current delivered cost of coal ($5.50 GJ) wood residues are cost competitive at sites that have an existing wood-fired heat plant, or where conversion to firing wood residues is not high.

3.1.7 Barriers and issues

A number of barriers and issues exist in New Zealand to limit the use of forest-derived biomass, including:

- Guaranteeing security of supply.
- Determining the actual volumes for a specific site available at a competitive cost.
- Mismatches in supply and demand at a local level.
- Variable quality of delivered fuels (moisture content and ash %).
- Environmental issues such as nutrient removal on forest sites.
- Forest harvest operational issues and integrating the residue operations with the conventional harvest system.
- Competition for the resource. If the collection and processing of forest harvesting residues improves (cost reductions and better feedstock quality) there may be demand for the output material from the reconstituted wood products industry.
- The potential for use of forest harvest and other wood residues as fuel is hampered by a lack of wood fuel standards meaning variable fuel quality is often produced.
- The need for guaranteed supply of the demanded volume, which is often difficult to obtain due to fluctuations in log harvest driven by overseas market conditions.

3.1.8 Key References

For more information on wood availability from New Zealand forests see the following reports:

- Wakelin, S.J. and B. Hock, 2007: Wood availability from New Zealand Forests. Report prepared for the Bioenergy Options programme, 2007. (Refer CD)
- Hall, P., 2007: Logging residues situation analysis – resource, supply costs, and barriers. Report prepared for the Bioenergy Options Programme, 2007. (Refer CD).

3.2 Wood processing residues

3.2.1 Background

The wood processing industry is one of the largest users and producers of bioenergy (45 PJ per annum) in New Zealand. The high use of bioenergy within the industry is driven by the fact that wood processors have a large demand for heat and electricity. In addition, residual material produced on site in the manufacturing process is suitable as a heat fuel. If not used, this material would have to be disposed of or utilised for other purposes, thereby incurring additional cost.

By far the biggest wood residue category is wood chips arising from sawmills where 26% of the log input volume ends up as chip. These wood chips are a high value raw material for the pulp and paper industry and reconstituted wood panel industries. These chip supplies are currently not available for energy production, although this would change if timber or panel or pulp production from these sectors were reduced for any reason.

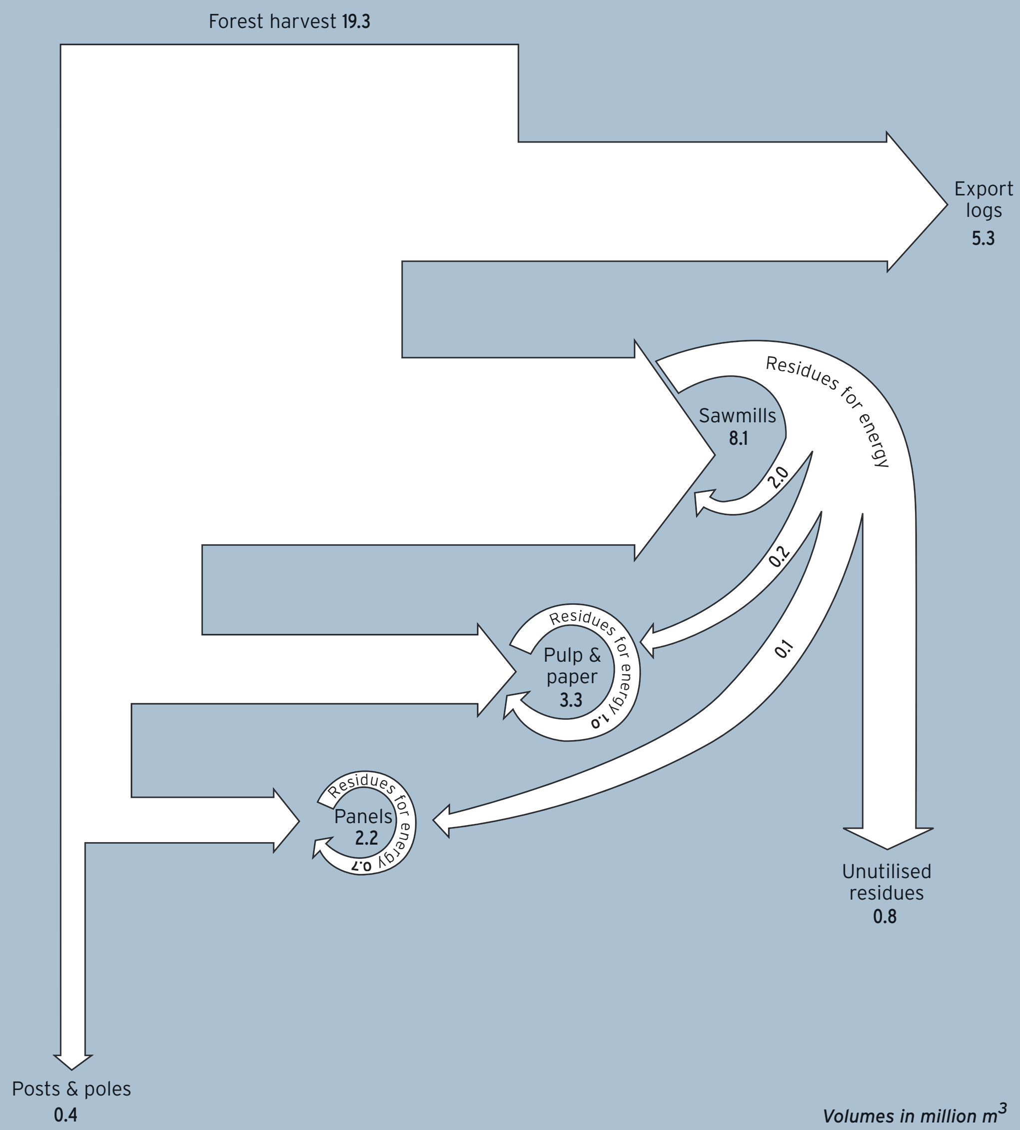
Sawdust is another residue which can be used as a raw material for medium density fibreboard (MDF), particle board, wood pellets or as a fuel. The value of sawdust is increasing as more uses for this material are identified.

Bark is used extensively for landscaping and as a solid fuel for boilers.

Shavings can be used as a raw material for wood pellets, animal bedding or as boiler fuel.

Off-cuts (sawn lumber trimmings) are often sold through firewood merchants as boxwood for domestic heating, or are hogged or chipped and used as boiler fuel or pulp mill feedstock.

Figure 5: Current national wood processing volumes and residue flows



3.2.2 Quantities

New Zealand sawmills produce 3.5 million tonnes of wood residue arising from debarking and primary breakdown operations, with an additional 0.6 million tonnes coming from other wood processing sectors. Over 3 million tonnes of this is used in other wood processing operations or for bioenergy, leaving approximately 1 million tonnes of residues available for expanding current uses or developing new opportunities.

Of this 1 million tonnes it is estimated that the wood pellet market uses 0.2 million tonnes and landscaping and other users use 0.1 million tonnes. Based on these assumptions it has been calculated that less than 0.8 million tonnes of mixed residues are available at a national level. This material is believed to be mostly from smaller sawmills, particularly in the Southern North Island (scattered and sometimes remote processing) and Central North Island (large volumes of processing, where supply of residues is exceeding demand).

It is often difficult to get exact measures of material flows within the industry, as much of this information is:

- Commercially sensitive.
- Changing with price and other industry circumstances.

- Inaccurately measured or estimated.
- Not centrally recorded or reported.

The residue flows for specific processing sites is dependant on local opportunities. There is often a mismatch between supply and demand at a local level. The lack of a trading platform is a barrier.

Until more accurate wood flow and residue flow statistics are derived from the wood processing sector, the amount of wood processing residues available for energy use by other industries will remain uncertain.

Future availability trends: There is on-going development of wood residue use in the wood processing industry, with recent conversions of lumber drying kilns from gas to wood processing residues. Lumber drying has been increasing in the last 10 years and demand for residues suitable for making wood fuel pellets is expected to increase. There is also predicted to be an expansion in wood supply, and if this leads to an associated increase in processing, then the supply of residues will also increase. However, as the processing volume increases so does the energy demand of the industry.

In the short term it is likely that the use of residues will continue at around the same proportion as it is currently. If fossil fuel (gas and coal) prices rise in the medium term, the proportion of residues that are used within the wood processing industry is likely to increase in response. The dynamics of the wood processing industry will have a pivotal role in influencing future availability of residues for bioenergy production, especially for sectors outside the wood processing sector.

3.2.3 Distribution of wood processing waste

Residues may be available in Auckland, Central North Island and Southern North Island regions (Table 4). Other regions such as East Coast/Hawke's Bay, Canterbury and Otago/Southland have residues available, but as these regions have a high percentage of smaller mills the residue produced is of smaller, dispersed quantities.

Northland and Nelson/Marlborough have negligible unutilised residues. The West Coast has low volumes of available residues. This is due to the large demand from panel mills operating in these regions. The deficit in Nelson/Marlborough for energy purposes is off-set by use of logging residues. Use of logging residues is also occurring in the Central North Island, Canterbury and Hawke's Bay and is developing in Northland.

Table 4: Regional production and use of wood processing residues. * Estimate of fuel used derived from capacity in the heat plant database (EECA, 2007). Thousands of green tonnes.

Based on processing 13.9 million m^3 roundwood			
Wood supply region	**Residue production**	**Estimated residue used as bioenergy**	**Residues available**
Northland	288	288	0
Auckland	256	91	164
CNI	2,139	1,508	631
East Coast/Hawke's Bay	373	299	74
SNI	267	130	137
Nelson/Marlborough	316	357	-41
West Coast	73	69	4
Canterbury	149	83	66
Otago/Southland	263	241	23
Total	**4,123**	**3,066**	**1,099**
Existing markets		**Estimated residue used**	
Wood pellets		200	
Landscaping and other uses		100	
Estimate of residue available			799

Estimates of wood processing residues available across New Zealand are shown in Figure 6.

Figure 6: Wood Process Residues, available for use 2005
Residues available (thousands of green tonnes)

3.2.4 Contribution to New Zealand's energy supply

While most wood processors produce residues, the bulk of these residues already have a use. Nationally around 3.3 million tonnes (27-30 PJ primary energy) of wood processing material regarded as residue is used annually as bioenergy fuel. The biggest users are pulp mills, panel plants and sawmills.

The use of sawdust and shavings to make wood fuel pellets is expanding. There is limited opportunity to use this material outside the wood processing sector without affecting the level of energy self sufficiency within the sector, or the sector's greenhouse gas emissions.

3.2.5 Costs of recovering wood processing residues

The viability of transporting residues is dependant on the volume and type of residues produced, distance from residue user, energy density of the residue, and truck configuration. A small sawmill in an isolated location far from a residue user will produce small amounts of residue which may not be viable to use on site or for transport to another user.

The costs to a large industrial site (pulp mills etc) which are using their own residues on site are minimal, with an on-site handling cost of $0.30 to $0.35 per GJ (primary energy).

Transport costs from site to site will vary with the type of product:

- Sawdust — $0.18 to $0.25 per tonne km
- Offcuts — $0.18 to $0.27 per tonne km
- Dry shavings — $0.54 to $0.81 per tonne km (shavings are very low density)

3.2.6 Barriers and issues

Issues exist in New Zealand to limit the understanding of how wood processing residues can be used, including:

- Quantifying the resource, as it is currently difficult to get accurate figures.
- Limited available excess.
- Nature and quality of the material, which can be highly variable.

Environmental issues are currently a driver of use as it avoids landfill disposal and associated costs. Drivers have outweighed barriers and a lack of national data has not stopped local, site-specific development.

Currently the wood processing sector uses 75% of its estimated residues. Around 6% is sold to other users, while the remaining 19% is likely to be used or considered for use in the future.

Key References

Hodgson, C.J. and P. Hall, 2007: Availability of Wood Processing Residues. Report prepared for the Bioenergy Options Programme, 2007. (Refer CD)

Nationally around 3.3 million tonnes (27-30 PJ primary energy) of wood processing material regarded as residue is used annually as bioenergy fuel.

3.3 Municipal Wood Waste

3.3.1 Background

Over 500,000 tonnes of woodwaste are landfilled each year in New Zealand. These woody residues are generally classified as green waste from gardens, and timber waste arising from construction and demolition activities. This municipal wood waste represents a potential resource for bioenergy options as incentives are put in place to reduce volumes being landfilled.

The New Zealand Waste Strategy (NZWS) outlines a policy to achieve a 50% reduction in the quantities of construction and demolition waste to landfill by December 2008. For green or garden waste, volumes to landfill are to be reduced by 95% by 2010. If the NZWS targets are met, the current volume of wood waste going to landfill could drop to around 270,000 tonnes per annum by 2030. However, it is likely that there will be some regions which do not manage to fully implement the strategy.

The Waste Minimisation Bill currently before Parliament will assist in making it more attractive for waste processors to redirect wood waste for other uses. Alternative uses for green waste include commercial compost, mulch or various bioenergy options. Alternative uses for timber waste include recycling and reusing, particleboard manufacturing, fuel for combustion, or production of other bioenergy-related fuels.

3.3.2 Quantities

Both green and timber waste is greatest around large population centres, particularly the Auckland Region. Actual volumes are difficult to measure due to a general lack of information about the size and nature of woody waste streams in New Zealand.

Most green wastes arise from domestic properties while the timber fraction of construction and demolition waste comes from commercial activities. In both cases the material could be delivered to a bioenergy facility as easily as to a landfill, with minor differences in transport.

Table 5: All wood waste to landfill, based on the effects of the NZ waste strategy (2002) (tonnes/year)

	2005	2010	2015	2020	2025	2030
Northland	16700	7000	4600	8100	8700	9300
Auckland	165400	74500	84300	95500	108100	122500
Waikato	40600	17400	18800	20200	21900	23600
Bay of Plenty	23900	11100	12000	12900	14000	15100
Gisborne	5600	2500	2800	3000	3400	3700
Hawke's Bay	17800	7400	7600	7900	8300	8600
Taranaki	9800	3900	4000	4100	4200	4300
Manawatu	26500	10700	10900	11000	11200	11400
Wellington	85100	36200	38700	41400	44300	47400
Tasman	6200	7000	2800	3100	3300	3600
Nelson	5800	2400	2500	2600	2700	2900
Marlborough	5900	2500	2800	3000	3300	3600
West Coast	4100	1700	1700	1800	1900	2000
Canterbury	58900	25700	28200	31000	34000	37300
Otago	27700	11900	12900	13900	15100	16300
Southland	17600	7000	7100	7200	7200	7300
New Zealand	**520000**	**229000**	**245000**	**267000**	**292000**	**319000**

3.3.3 Distribution of the municipal woodwaste

Municipal-derived wood biomass is concentrated near major population centres, however the cost of land for waste processing sites is also high in these areas. Also, the main current users of biomass fuel (in the forest industries) are located some distance from these centres. Costs can be balanced by the price to be paid for the fuel by the end user, and by transfer station or landfill operators through landfill levies. Such costs may be differential or fixed payments, but their scale will affect the viability of enterprises set up to process the wastes and provide biomass for fuel.

Figure 7: 2005 Estimated green waste potentially available for bioenergy (tonnes/year)

The main mechanism available for redirecting wood waste is to increase landfill levies.

Figure 8: Estimated timber waste to landfill 2005

3.3.4 Contribution to New Zealand's energy supply

The main mechanism available for redirecting wood waste is to increase landfill levies. For suitable bioenergy options to emerge, end-users will also require encouragement to invest in biomass-to-energy plants closer to the sources of waste produced. The timing as well as the scale of incentives will influence the degree of investment in waste processing for fuel. Currently this waste source is not getting widely used for fuel, although some companies are either considering, or trialling this option.

3.3.5 Cost of recovering municipal waste

Green waste has high moisture content and often contains contaminants such as soil. Alternative use of green wastes would need to overcome challenges associated with transport costs and environmental (clean air) regulations.

Wastes arising from construction and demolition activities contain a mixture of treated and untreated wood. There may also be contamination with glues and resins (from MDF or particle board) as well as nails, melamine, plastic and paint. Some of the contaminants can produce toxic emissions and ash residues when combusted.

Fuel quality may be improved by segregation prior to processing and screening and blending afterwards. For example, screening of fines <20mm (estimated cost $5-$7/tonne) and blending of higher moisture content green waste with drier woodwaste perhaps on a 1:2 basis will improve fuel quality (though reduce the weight/m^3 of fuel produced). For the end user a decision must be made balancing higher cost, high quality fuel with that of lower cost and of lower quality fuel. With blending, fuel can be produced to a user's specification and meet air emission specifications.

An estimate of the total cost to the end-user is of the order of $50/green tonne delivered of screened and blended fuel (approx. 50% moisture content), transported a distance of 80km.

The gross energy value of the fuel fraction has 40 times the energy of the fuel used to produce it (assuming the material is already delivered to the landfill and does not include transport to another site).

3.3.6 Barriers and Issues

The main issue that limits the use of municipal woody biomass in New Zealand is resource quality (moisture content and contaminants). Overall it is likely that the municipal wood waste (MWW) resource will have a lower energy content than wood from forests or wood processing sources due to higher levels of moisture and contamination.

Research is required to produce detailed analyses of costs and impacts on fuel properties of segregation and screening. Solid waste assessment programme (SWAP) analyses and studies of material going to landfills can address the information gaps.

A significant barrier is the perception that combustion of waste will create emissions that are unacceptable. This need not be the case if the bioenergy facility has been designed properly and a feedstock management regime can be instituted and maintained.

Key References

Evanson, T. and P. Hall, 2007: "Resource Assessment of Municipal Woodwaste - green waste and untreated wood waste". Report prepared for the Bioenergy Options Programme, 2007. (Refer CD)

3.4 Horticultural Wood Residues

3.4.1 Background

The horticultural sector produces woody residues through the removal of over-mature trees and orchard prunings. These residues could represent a potential source of woody biomass for energy production.

Wood is removed at pruning time, either in winter or summer, and is increasingly viewed as a component to be retained within the orchard system, by mulching into the soil.

Current energy potential from orchard prunings is largely from summer fruit orchards in Hawke's Bay and Central Otago and from older pipfruit orchards in the Tasman region and Hawke's Bay. Tree types that turn over more often due to short lifespan or changing markets for varieties will yield more wood availability.

An intention within the pipfruit sector to double the orchard turnover rate could see an increase in woody residues, but this is offset by the move to dwarfing rootstocks (reducing the standing biomass in trees). This trend is likely to develop for other orchard crops as well, lowering the physical potential for wood availability.

3.4.2 Quantities*

The horticultural biomass resource is approximately 46,000 od tonnes/year, nearly half of which is concentrated in Hawke's Bay.

Table 6: Energy resource from orchard wood. Estimated dried tonnes/year of wood when over-mature orchards are removed

	Apple/Pear	Peach / Nectarine	Cherry	Avocado	Citrus	Shelterbelt	Regional Total
Biomass DW (t/ha)	40	40	60	30	40	20	
Turnover (%/yr)	0.06	0.12	0.05	0.04	0.04	0.03	
Area by region (ha):							
Northland				1000	361	1361	
Bay of Plenty				1900		1900	
Gisborne	256				760	1016	
Hawke's Bay	6067	798			50	6915	
Tasman	2,902					2902	
Otago	622	580	450			1652	
DW prod. (t/yr)							
Northland				200	578	817	2594
Bay of Plenty				2280		1140	3420
Gisborne	614				1,216	610	2440
Hawke's Bay	14 561	3,830			80	4149	22 620
Tasman	6965					1741	8706
Otago	1493	2,784	1,350			991	6618
NZ total: tonnes DW/year							**46 398**

*Oven-dried tonnes

3.4.3 Distribution of horticultural residues

The woody resource from orchards is concentrated in Hawke's Bay (48%), Tasman (18%) and Otago (14%). The remaining 20% is shared between Northland Bay of Plenty and Gisborne.

3.4.5 Contribution to New Zealand's energy supply

This resource is of limited scale in its own right, but could be used to add volume where demand exceeds other supplies (e.g., wood processing residues in Nelson). Supply is likely to be seasonal and the prunings are likely to be used as mulch, hence the focus on the resource derived from orchard turnover.

The future aim for apple orchards is to double the turnover percent to take advantage of new cultivars and cultural systems. In terms of wood produced, there is a counteracting trend to grow new orchards on more dwarfing rootstocks, reducing wood yield at the time of removal. It is likely that trees will be chipped and composted, with the carbon resource remaining in the orchard soil.

3.4.6 Cost of recovering horticultural residues

The cost of recovering woody material from orchards is likely to be similar to that of forest landing residues ($3.40 to $4.00/ GJ primary energy) since similar equipment would be used. Transport distances are likely to be lower than for forest residues as orchard areas tend to be located closer to potential urban and industrial users.

3.4.7 Barriers and issues

The main barrier to using horticultural residues is that the resource is small in scale, scattered, and seasonal. However they may find a niche as a supplement to a larger fuel supply.

Key References

Saggar, S., D. Giltrap, V. Forgie, and R. Renquist, 2007: Bioenergy Options Report: Review of Agricultural Resources. Report prepared for the Bioenergy Options Programme, 2007. Refer CD)

3.5 Short-rotation forestry

3.5.1 Background

Fast-growing tree species such as eucalypts, acacia and willow have potential as purpose-grown bioenergy crops for New Zealand. These short-rotation forestry (SRF) crops can offer more favourable energy balance than agricultural crops, and offer a greater range of high value product streams in addition to ethanol where the biomass is converted into transport fuels. Short-rotation forestry crops could also provide a means of supplementing the wood residue resource available from forests or wood processing residues.

Eucalytus nitens is considered the main species suitable for short-fibre pulp production and bioenergy in New Zealand. Growth rates compare favourably with radiata pine on a normal (25 to 28 year) rotation.

Acceptable biomass values have been generated with Acacia species by using very high initial stockings. The Acacia resource in New Zealand was established to provide logs for chip exports. These resources are grown on medium-length rotations of 12 to 15 years.

The use of willows and the concept of harvesting with agricultural equipment, as is often carried out in Europe, suggests research in this area may be warranted for New Zealand conditions. A New Zealand willow project is currently under way to assess the bioenergy potential of this crop.

Woody material arising from SRF crops can be converted to energy either through combustion or biological processes. The use of enzymes in converting SRF crops into sugars is gaining international momentum for the purpose of producing ethanol.

3.5.2 Co-products and other benefits of short-rotation forestry

The use of co-products is required to make SRF competitive as a land use.

Co-products identified as having direct financial benefit include: charcoal; pharmaceutical products; electricity production; salinity mitigation; sawn timber; waste application; carbon credits; animal fodder; wood byproducts such as lignin and xylose; and the application of crop residues as fertiliser.

Co-products identified as currently having no direct recognised financial benefit, but which are important nonetheless, include: increased biodiversity; nutrient and sediment capture from agricultural crops; creation of landscape diversity; waste-water refining; phytoremediation, riparian strips; snow fences; erosion control; and social/community benefits.

3.5.3 Quantities

Currently there is no SRF resource in New Zealand being commercially used for bioenergy production, with a small area (<20 ha) established as trials. Some expansion of the willow SRF resource is planned for the Lake Taupo area, with the development of a 20 ha nursery to provide planting stock for a planned 1200-1500 ha planting programme in 2009.

It is unlikely that there will be any commercial SRF harvesting operations in New Zealand in the next 3-5 years as there is currently no resource to harvest.

In New Zealand, there are potentially 5.72 million hectares that could be used for SRF. However, at this level competition with food crops would be significant. It is estimated that 2.6 million hectares of SRF would be needed to meet New Zealand's current demand for liquid fuels (petrol and diesel). This estimate excludes the use of other feedstocks.

Estimates of lignocellulosic productivity per hectare and potential for conversion to ethanol (assuming 300 litres per dry tonne) suggest that around 70,000 ha of plantation land would be required to provide biomass and generate sufficient ethanol for the proposed biofuels obligation target of 3.4% via a petrol-ethanol blend.

One million ha would be needed to totally replace petrol with ethanol at current levels of consumption. Willow is the only species currently being considered for larger scale application of SRF.

The infrastructure required to achieve a significant expansion would include:

- Plant material of the correct type.
- Nurseries to produce this material in bulk.
- Planting equipment to mechanise the planting process.
- Specialised harvesting equipment.

3.5.4 Distribution of the SRF resource

No SRF resource currently exists in New Zealand. However, the most suitable land for this type of crop is neither excessively warm (land use competition, crop health issues) nor excessively cold (poor growth). In a New Zealand context this means that woody crops could potentially be grown on land with between 100 and 250 frost free days per annum, an area of approximately 4,926,150 hectares. However, this land is already being used, typically for cropping and grazing. Only a relatively small amount could be used before there are impacts on food production.

Table 7: Potential land area suitable for short rotation forestry

Classes	Area
Median no. consecutive frost-free days, slopes < 15 degrees	**Hectares**
0 - 100	4,493,814
100 - 175	1,535,903
175 - 200	1,922,321
200 - 250	2,262,312
250 - 275	2,134,852
275 - 350	1,702,662
Unavailable, unmanageable, > 15 degrees	12,518,289
Total	**26,570,153**

Blue highlighted rows indicate land with suitable climate

3.5.5 Contribution to New Zealand's energy sector

In many cases SRF is likely to be only part of the biomass supply to an energy plant, and will be used to make up a supply shortfall or act as a buffer in case of interrupted supply from other sources. The first material to be used will be residues, not SRF, due to the growing costs.

3.5.6 Cost of recovering SRF

Given the costs for land, planting stock, planting, weed control, cultivation, harvesting and transport, it is likely that the cost of the harvested (and chipped) material will be in the order of $70 to $90/green tonne. This is considerably higher than the cost of residual woody material sourced from traditional pine plantation forest harvesting, wood processing and municipal waste sources.

Current projections suggest that the delivered cost of SRF will only be competitive if grown near to the processing plant to reduce transport costs. Co-products such as effluent application, erosion control, nutrient management or carbon are needed to make the fuel price competitive.

3.5.7 Barriers and issues

The major constraints to SRF are land use competition and the costs of growing and harvesting. The issue of tree health must also be carefully managed to avoid resource collapse if the genetic base is not kept robust. Plantings of mixed clones are required to avoid total crop failure from a new insect or disease outbreak.

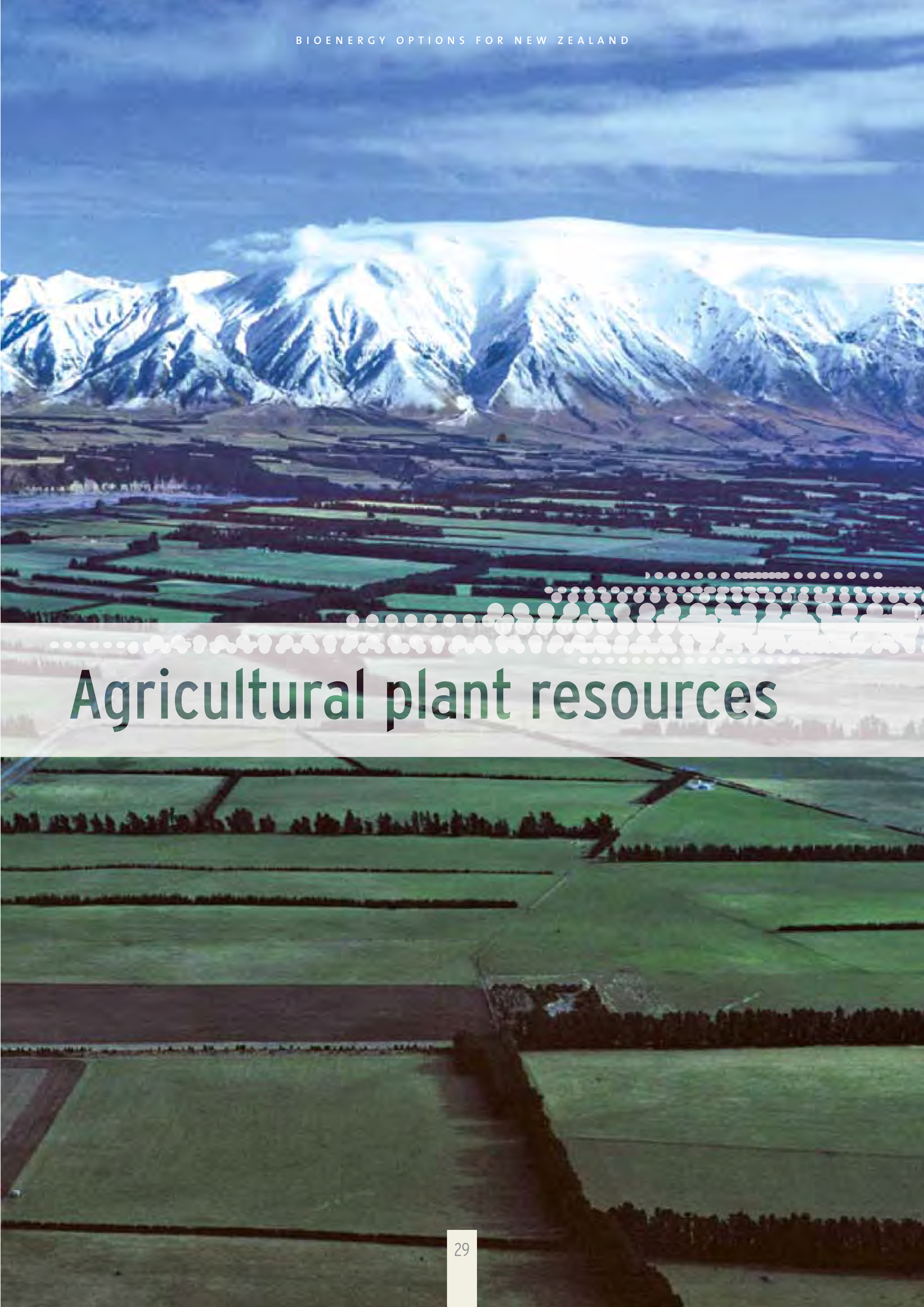
Water demand from SRF is only akin to plantation water use, there would be no irrigation systems used unless waste water schemes are included. Wastewater systems could be used for SRF crops.

Uncertainty around the future of planned development due to:

- The productivity of the crop being unproven in New Zealand.
- The conversion technology not being proven at a commercial scale.

Key References

Nicholas, I.D. 2007: "Resource assessment – short rotation forestry crops". Report prepared for the Bioenergy Options Programme, 2007 (Refer CD)



Agricultural plant resources

4.0 AGRICULTURAL PLANT RESOURCES

The agricultural sector contains potential bioenergy feedstocks from crops, agricultural residues and horticultural residues. Except for the use of agricultural and horticultural product processing residues, the potential contribution of this biomass to New Zealand's energy needs will depend on competing land-use options, demand for food crops, crop yields, biodiversity concerns, and needs for conserving soil and water.

This section includes assessments for the following types of plant-based agricultural feedstocks:

- Agricultural energy crops (e.g., grains, beets, grasses and oil seeds).
- Agricultural crop residues (e.g., straw, stover).
- Horticultural wastes (e.g., pips and skins, processing pulp and cake).

4.1 Agricultural energy crops

4.1.1 Background

Potential agricultural energy crops include grains, starch crops, oil seed crops, beets and perennial grasses. These crops can be converted into heat, electricity or liquid fuels using a number of different technologies, but the most common economic conversion is to liquid biofuels.

Grain crops and sugar beets can be used to produce ethanol using well-established "first generation" technologies. The United States is the second largest producer of ethanol in the world, using maize as the major feedstock. However, as both maize and ethanol production in the US is subsidised, the economic viability of maize ethanol production will be different in New Zealand, where there are no subsidies.

Other grains that have been used for ethanol production include: wheat in Australia, Canada, France and Sweden; and barley in Spain (IEA 2004).

In a 2003 survey, around 61% of world ethanol production was produced from sugar crops, be it sugar beet, sugar cane or molasses. While these crops are not currently grown in New Zealand, sugar beet crops can be produced in Tasmania, where similar growing conditions exist. Successful sugar beet trials were undertaken in Souhtland, but the economics did not support development.

Although oil crops can be used to produce biodiesel, in New Zealand oil seed crops will face competition from tallow as the price of tallow per tonne is consistently less. AgriEnergy (based in the South Island) are proposing to contract growers to produce oilseed rape with the crop price linked to wheat.

Perennial grasses, such as miscanthus or switchgrass, require less cultivation and fewer chemicals than grain crops, making them less harmful to the environment and cheaper to produce. They can also be grown on less valuable (poor quality) land. These grasses can be combusted directly for energy, but this requires mixing with coal and is unlikely to be economical in New Zealand. However, perennial grasses could become an important feedstock for cellulosic ethanol production.

4.1.2 Quantities

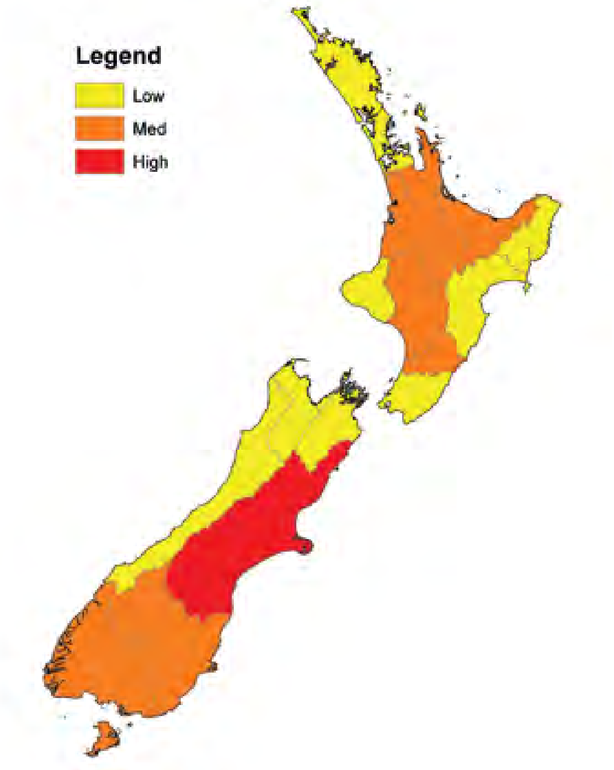
New Zealand has about 109,900 ha of grain crops planted, which are used for human and animal food. Around 915,950 ha of land (currently in sheep and beef production) could physically and economically (based on current gross marginal returns $/ha) be switched to grain production for ethanol production if demand for the resource increases sufficiently. This area of land could potentially produce enough maize grain to make 4.1 billion litres of ethanol (40% of current total liquid fuels demand). Canterbury, Southland and the Manawatu-Wanganui regions have the largest amounts of suitable cropland currently in sheep and beef farms, and make up the areas that could potentially be converted to grain crops.

4.1.3 Distribution of potential energy crop resources

Approximately 20,600 ha of maize grain (predominantly in the Waikato/Central North Island) and 39,400 ha of wheat and 49,900 ha of barley (predominantly in Canterbury) are currently grown in New Zealand. The use of agricultural grains for energy production is likely to lead to competition with food uses.

Grain crops and sugar beets can be used to produce ethanol using well-established "first generation" technologies.

Figure 9: Regional production of maize, wheat and barley crops. "Low" regions produce less than 30 000 tonnes of crops/year while "high" regions produce over 500 000 tonnes of crops/year.



4.1.4 Contribution to New Zealand energy sector

The two regions that currently grow sufficient volumes to support large scale production of biofuels are Canterbury and the Waikato. Locations within an economic cartage distance for suppliers is required as the amount of energy consumed in producing the grain (fertiliser and fuel for agricultural equipment), and transporting and processing the grain into ethanol, has to be balanced with conventional fossil fuel use. AgriEnergy (based in Temuka) advocate small scale plants located close to crop growers. Distribution costs can result after production if the market for the end-product is not in close proximity, as delivery to end users also requires energy. Distribution (transport) costs are in the order of $0.01/litre for every 50 km of transport of the liquid fuel. Liquid biofuels can ultimately substitute for fossil fuels in the production supply chain.

Land is only likely to switch to growing bioenergy crops if the gross margin from bioenergy farming is greater than the gross margin of any other suitable land use and the labour and management inputs are not vastly different. Some dairy farmers might choose to convert to maize growing for an easier lifestyle. Table 8 shows typical gross margins for potential land uses that might switch to bioenergy farming.

Table 8: Gross marginal returns from different farm types

	Gross marginal return ($/ha)	References
Sheep and beef farming	508	MAF Policy (2006b)
Maize grain 2003/04	1029	Lincoln University (2006)
Maize silage and winter feed	701	Lincoln University (2006)
Wheat	966	Lincoln University (2006)
Wheat silage	538	Lincoln University (2006)
Barley	709	Lincoln University (2006)
Sugar beet*	777	Thomson and Campbell (2005)
Rape seed (canola)**	456	Nix (2004)
Miscanthus**	118	Nix (2004)

* Based on Tasmania data for high risk commercial "worst case" scenario

** Based on UK values

4.1.5 Cost of recovering agricultural energy crops

Estimated costs of recovering agricultural energy crops are summarised below.

Table 9: Yields and farm working expenses for potential bioenergy crops, Fresh Weight (FW)

Production system	Typical yields (FW t/ha)	Farm working expenses ($/ha)
Maize grain with winter fallow	12.5	2400
Maize silage sold to stack with winter grazing	18.0	3500
Wheat	8.5	1500
Wheat silage	15.0	2300
Barley	7.5	1100
Sugar beet*	60.0	4400
Rape seed (canola), winter**	3.2	820
Miscanthus**	12.5 (oven dry)	680

* Based on data from Tasmania

** Based on UK data

4.1.6 Barriers and issues

There will be competition for land use for all potential energy crops. In general land will not switch to bioenergy production if there are more profitable alternatives. First-generation biofuels derived from conventional agricultural crops, such as rapeseed, corn and cereals generally require high-quality farm land, and substantial amounts of fertiliser and chemical pesticides are required to achieve high yields.

Many bioenergy crops have alternative uses as human or animal food.

Other goals, such as protecting New Zealand's biodiversity, may impede the introduction of potential bioenergy feedstock crops, for example, concern regarding the invasive nature of grasses such as miscanthus.

An important aspect of growing crops generally and bioenergy crops in particular, is whether or not this can be achieved continuously over many years with minimal soil deterioration. One New Zealand study (Ross et al. 1989) over six years indicated that harvesting crops for biogas production could be practised without detectable damage to the soil provided the digestor effluent was applied as a substitute fertiliser.

Water availability could limit the ability to grow bioenergy crops in some areas. Nationally water allocation increased by approximately 50% between 1999 and 2006. Irrigation accounts for 77% of water allocations by volume. In the future, climate change could lead to increased irrigation demand in some regions.

Key references

Saggar, S., D. Giltrap, V. Forgie and R. Renquist, 2007: Bioenergy Options Report: Review of Agricultural Resources. Report prepared for the Bioenergy Options programme, 2007. (Refer CD)

4.2 Agricultural crop residues

4.2.1 Background

Many agricultural crops produce stalks (straws) that are currently cultivated into the ground at the end of cropping. Some of this straw material could safely be removed without negative impact on soil quality. Should cellulose ethanol technology become commercially viable then there would be a potential market for these agricultural residues.

Cellulose ethanol technology would also enable the growing of perennial grasses such as miscanthus.

Straw and stover may be directly combusted, although this is unlikely to be economic, and has significant technology-related issues due to the chemical composition of this material. High chloride and sodium and other inorganics can contaminate boiler surfaces.

4.2.2 Quantities

There are approximately 500,000 tonnes (dry weight) of straws produced by agricultural crops that could potentially be collected for bioenergy applications.

Not all crop residue is available for use as feedstock. The available fraction should be decided on the basis of what is surplus to the needs of sustainable soil management. Typically it can be assumed that 50% of the crop residues can be removed on average.

Table 10: Available residue production (tonnes dry weight/year)

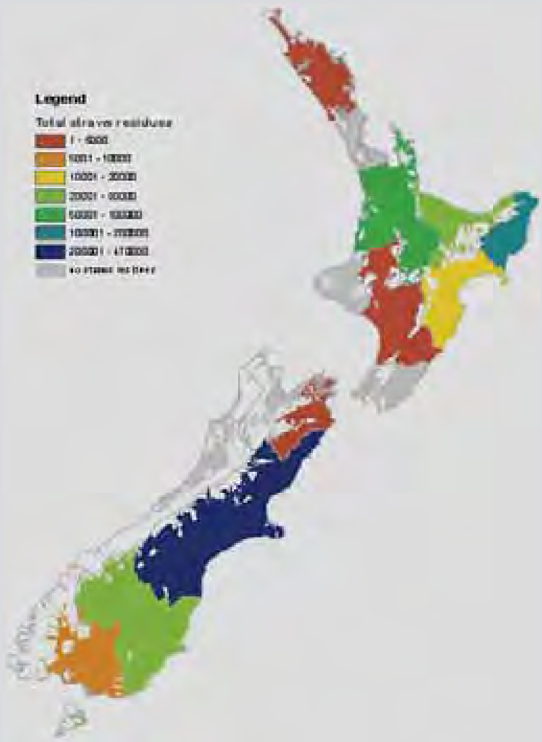
	Wheat	Barley	Maize	Field/ seed peas	Herbage seeds
Crop DW production	277,483	263,071	221,085	23,254	
Harvest index	0.5	0.5	0.5	0.3	
Residue DW production	277,483	263,071	221,085	54,260	200,000
Surplus residue DW	138,742	131,536	110,542	27,130	100,000
Energy content (PJ) of surplus residues*	2.2	2.1	1.8	0.4	1.6

* assumes 16.5 GJ/tonne dry weight

4.2.3 Distribution of agricultural crop residues

The distribution of agricultural crop residues is shown below.

Figure 10: Available straw residues (air dried weight/year)



4.2.4 Contribution to New Zealand's energy sector

The two regions that currently grow sufficient volumes to support large-scale production of biofuels are Canterbury and the Waikato. Location within an economic cartage distance for suppliers is required as the amount of energy consumed in producing the grain (fertiliser and fuel for agricultural equipment) and transporting and processing it into ethanol, has to be balanced with conventional fossil fuel use. However, once a certain scale of operation is achieved, the production processes can use biofuels.

The bioethanol market is likely to continue expanding as the processing of ligno-cellulose (woody plant materials) to sugars and glycerides matures. These compounds can be converted to ethanol, diesel, hydrogen and chemical intermediates to displace petro-chemicals. Such second-generation technologies are still in the demonstration phase so the extent of commercial viability remains uncertain.

Biomass tends to have low-energy density compared with equivalent fossil fuels, which makes transportation, storage and handling more costly per unit of energy. Costs are minimised if biomass can be sourced from a location where it is already concentrated, and then converted nearby. This means only two, or at most five bioethanol plant sites may be feasible in New Zealand. This is based on the assumption that to be economic these plants need to be large, with a feedstock intake in the order of 0.5-1.0 million green tonnes/year.

4.2.5 Cost of recovering agricultural residues

Residues are produced as a by-product of other farming activity, therefore only the additional handling costs are assigned to the residues as the growing costs have already been paid. This handling is well mechanised. The straw costs are estimates based on past production of baling and handling straw.

Table 11: Average residue production rate/hectare and handling costs from arable crops (Field peas have also been included as they produce a large amount of residues, based on dry weight.)

	Wheat	Barley	Maize	Field peas
Grain yield (tyear)	8.5	7.5	12.5	3.0
Grain (t/year)*	7.4	6.5	10.8	2.4
Harvest index	0.5	0.5	0.5	0.3
Straw/stover yield (t/year)	7.4	6.5	10.8	5.6
Surplus straw/ stover** (t/year)	3.7	3.3	5.4	2.8
Straw handling costs $/tonne	22.0	22.0	20.0	25.0

* Based on moisture content in wheat and barley = 13%; maize = 14%; field peas = 20%

** 50% of straw for typical scenario, but varies with soil and crop regime.

The two regions that currently grow sufficient volumes to support large-scale production of biofuels are Canterbury and the Waikato.

4.2.6 Barriers and issues:

There are two key issues to address in order to utilise this material:

- The distributed nature of the resource both in terms of location and ownership.
- The perception that removing the material will have a negative impact on site productivity.

Not only are the straw residues located over a wide area, they are owned by many individuals. Getting a sufficient number of these owners to agree to the removal of the material to make an energy project viable could be a challenge.

Whilst these figures allow for some retention of straw (50%) for soil nutrition there are issues to be addressed namely: how to collect half the residues (all every two years or half each year), and; convincing individual land owners that the removal will not be detrimental to site productivity.

Key references

Saggar, S., D. Giltrap, V. Forgie and R. Renquist, 2007: Bioenergy Options Report: Review of Agricultural Resources. Report prepared for the Bioenergy Options programme, 2007. (Refer CD)

4.3 Horticultural residues

4.3.1 Background

Significant volumes of fruit and vegetable residues arise from food harvesting, packaging and processing operations. Although these horticultural residues are frequently used as stock food or composted, they can also be used for energy production.

Horticulture residues could be used to produce biogas through anaerobic digestion, or converted to ethanol once enzymatic technologies are sufficiently developed.

4.3.2 Quantities

Approximately 126,000 tonnes (dry weight) of fruit and vegetable residues could be used for energy.

Table 12: Physical and economic potential of bioenergy feedstock supply from arable, vegetable and fruit crops (tonnes dry weight/year)

	Current production	Secondary processing	Economic potential	Future physical potential
Vegetable residues				
sweetcorn	39,530		35,000	44,000
green peas	14,190		9,000	18,000
potato	10,000		6,000	14,000
onions	2,640		2,600	2,500
squash	9,486	1,035	3,000	6,000
carrot	3,200		1,000	4,000
tomato	1,060		500	700
Fruit residues				
pipfruit	7,213	7,000	3,000	6,000
kiwifruit	5,251	900	2,000	7,000
citrus	620		300	800
grape	19,870		12,000	23,000
Total	**113,060**	**8,935**	**74,400**	**126,000**

4.3.3 Distribution of vegetable and fruit residues

The regional distribution of vegetable and fruit residues is shown below.

Table 13: Distribution of vegetable and fruit residues (dry weight tonnes/year)

	Fruit and vegetable residues
	2005
Northland	300
Auckland	2,650
CNI	10,400
Gisborne	12,000
Hawke's Bay	26,800
SNI	4,500
Total North Island	**56,650**
Nelson/Marlborough	15,500
West Coast	-
Canterbury	17,900
Otago/Southland	7,000
Total South Island	**40,400**
Total New Zealand	**97,050**

The resource is widely distributed throughout New Zealand, with a significant concentration in Hawke's Bay, Gisbourne, Nelson/Marlborough and Canterbury.

4.3.4 Contribution to New Zealand's energy sector

Co-location of the energy processing plant with the fruit/vegetable processing plant is likely to reduce transport requirements and lower the cost of biofuel production. The potential energy contribution is in the order of 1.5 PJ/year.

However, there are few growers or processors who have an adequate economy of scale to sustain energy conversion plant without linking with other growers and processors.

Anaerobic digestor technologies require a continuous and uniform feedstock, which is often difficult to achieve with agricultural growing and processing residues, due to the seasonal nature of the production cycle. Continuity of feedstock supply can be achieved through silaging of the feedstock to cover periods when it would be otherwise not be available.

4.3.5 Cost of recovering vegetable and fruit residues

Horticultural residues tend to have high moisture content. However, the residues are centralised at the packhouse/factory so it is feasible to minimise additional transport costs by locating the energy production plant close to (or within) the packhouse. An estimate of the cost for transporting kiwifruit from the Bay of Plenty to the Waikato is $20/tonne and the cost of transporting cull potatoes 100 km is $30/tonne.

Areas for each crop fluctuate with market expectations and, to some extent, compete for the same cropping land. The trend is for each crop type to be produced by fewer, larger growers. This concentration may increase the efficiency of handling field residues, but centralises the opportunities for energy production.

4.3.6 Barriers and issues

The most significant barriers to using this material are the two key existing demands:

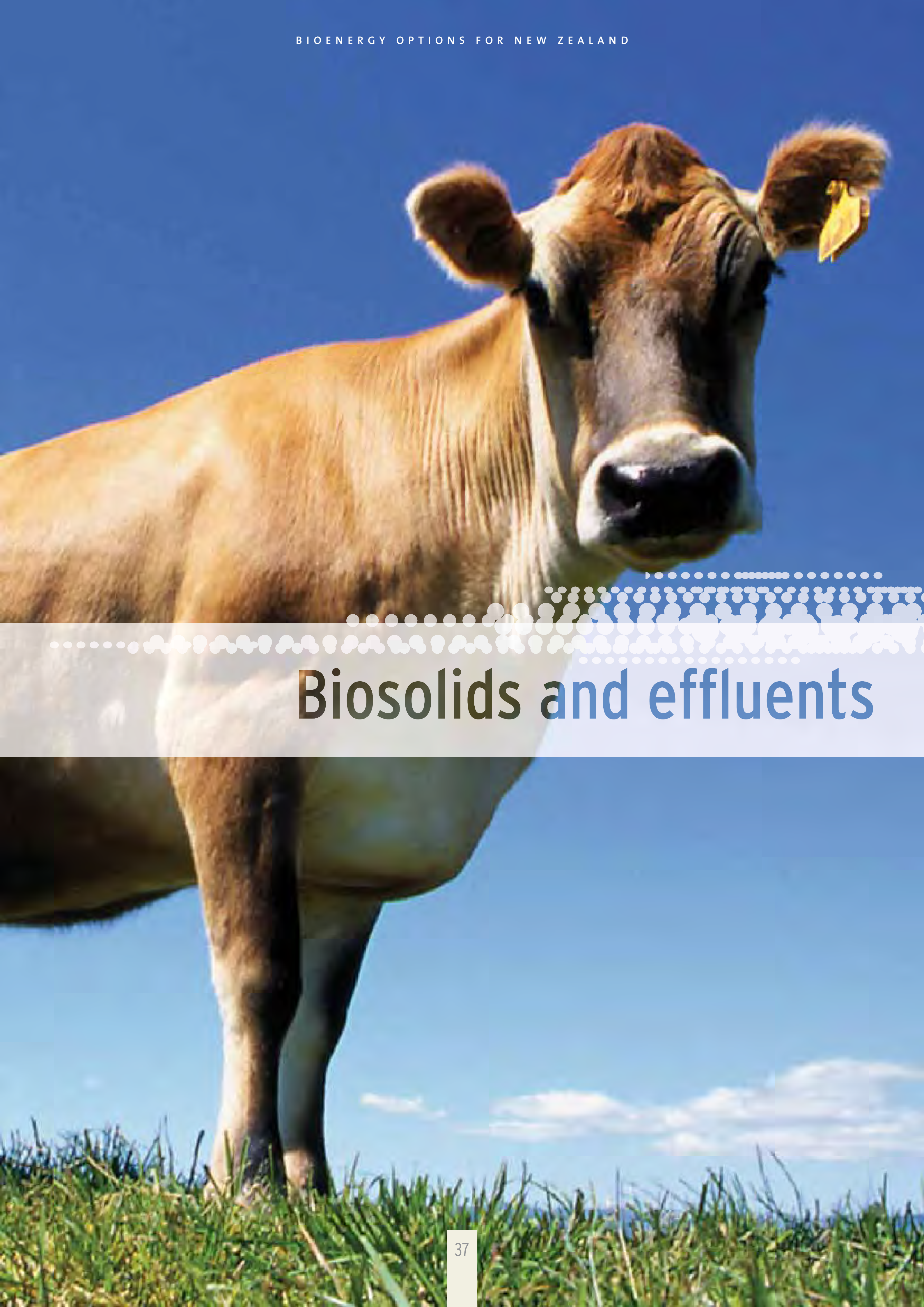
- Stock food.
- Mulch on site for soil nutrition.

A further barrier is the widely distributed nature of the resource, with all regions except the West Coast and Northland having several thousand tonnes of material. This, added to the high moisture content, make this resource a difficult one to utilise.

Key references

Saggar, S., D. Giltrap, V. Forgie and R. Renquist, 2007: Bioenergy Options Report: Review of Agricultural Resources. Report prepared for the Bioenergy Options programme, 2007. (Refer CD)

Areas for each crop fluctuate with market expectations and, to some extent, compete for the same cropping land.



Biosolids and effluents

5.0 BIOSOLIDS AND EFFLUENTS

Potential bioenergy feedstocks in the form of manure are produced by farm animals throughout New Zealand. Urban centres generate similar waste (municipal biosolids) that is processed at sewage treatment plants. Significant volumes of processing residues also arise from dairy factories and meat works. Collectively, these urban and municipal waste streams represent a large, under-utilised bioenergy resource.

Dairy farms, dairy factories, meat factories, sewage treatment plants and household rubbish could make a measurable contribution to national and regional energy security while safely disposing of nutrient-rich wastes. Achievement of environmental goals, including the reduction of greenhouse gas emissions (i.e., methane) will help to motivate a nationwide adoption of the technologies required to utilise these effluents and biosolids.

Excellent examples of using municipal wastes as a bioenergy resource are available in North America, throughout Europe (particularly Sweden) and in parts of Asia. The city of Christchurch uses municipal effluent to produce biogas for electricity production, as do other urban centres. Equally, anaerobic technologies for converting animal-based waste products into biogas are commonly used in other parts of the world, including developing countries.

The high-nutrient waste streams arising from farming, processing and municipal biosolids can provide a resource for growing algae, which can then be converted into biodiesel or liquid fuels.

This section covers:

- Municipal bio-solids (sewage).
- Farm manures (i.e., dairy, piggery, poultry).
- Industrial effluents (e.g. meat, dairy and wool factories).
- Solid waste (rubbish).
- Wool processing.

Dairy farms, dairy factories, meat factories, sewage treatment plants and household rubbish could make a measurable contribution to national and regional energy security

5.1 Municipal bio-solids

5.1.1 Background

Many reticulated sewage treatment plants in New Zealand produce sewage biosolids (60 % primary sludge, 40 % secondary sludge) that can be used to generate biogas at various scales of operation.

Sewage biosolids digestion is an industry standard in Europe and many other parts of the world but has not yet been widely deployed in New Zealand. However, some cities like Manukau, Christchurch, Hamilton and others have sewage biosolids digesters with biogas conversion to electricity.

The main purpose of anaerobic digestion of sewage sludge is to save on sludge disposal costs and improve sludge dewatering. The biogas energy can be used for electricity generation and contributes significantly to cost savings for treatment plant operation.

5.1.2 Quantities

Estimates of the quantities of material available and indicative energy is summarised below.

Table 14: Quantities of municipal biosolids available for energy production.

	Municipal biosolids			
	t/pa DM	t/pa DM	PJ gas pa	PJ gas pa
	2005	2020	2005	2020
Northland	1,095	1,204	0.014	0.02
Auckland	29,565	40,150	0.364	0.51
CNI	9,125	5,402	0.11	0.07
Gisborne	730	730	0.009	0.01
Hawke's Bay	2,920	2,774	0.034	0.04
SNI	14,235	15,074	0.176	0.19
Total North Island	**57,670**	**65,334**	**0.707**	**0.86**
Nelson/ Marlborough	2,190	2,445	0.025	0.03
West Coast	365	182	0.002	0.00
Canterbury	9,490	10,730	0.118	0.14
Otago/ Southland	3,650	3,758	0.046	0.05
Total South Island	**15,695**	**17,115**	**0.191**	**0.219**
Total New Zealand	**73,000**	**82,000**	**0.90**	**1.08**

5.1.3 Distribution of municipal bio-solids

The volume of available municipal bio-solids is directly proportional to the size of urban population centres, with the largest concentrations therefore being available from the Auckland, Wellington and Christchurch metropolitan areas.

5.1.4 Contribution to New Zealand's energy supply

The appropriate technology for cost effective sludge digestion on small scale (50-500 m^3 digester tank) is comparable to the sludge digestion technology recently demonstrated by Waste Solutions Ltd on a large Canterbury dairy farm. On larger scale sewage treatment plants, conventional sewage sludge digestion technology is suitable.

The total potential energy contribution is in the order of 1.5 PJ/year of gas. Although some expansion of this resource is expected out to 2020, the overall increase in potential energy is small.

5.1.5 Cost of recovering municipal bio-solids

The cost of gas from anaerobic digestion is likely to be around $16 to $22 GJ, and will be dependant on the scale of the operation.

5.1.6 Barriers and Issues

The most significant barriers to the use of anaerobic digestion to create biogas from municipal solid waste for local use are:

- The cost of the gas in comparison to other gas supply.
- Potential mismatch between gas supply and demand, and the need to flare excess biogas.
- Odours from digestors, although this should be no more and often less than the existing system.

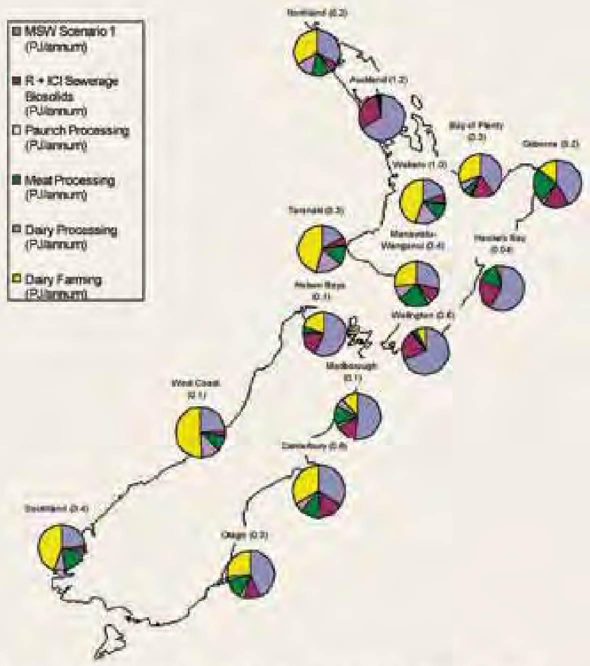
Key references

Thiele, J.H., "Bioenergy resource assessment: Municipal biosolid and effluent and dairy factory, meat processing and wool processing waste." Report prepared for the Bioenergy Options project, 2007 (Refer CD).

5.2 Farm manures

5.2.1 Background

New Zealand agriculture produces a large amount of manure. Most of this is produced by grazing animals and is not collected. However, most pig and poultry production



Regional breakdown of current Nett methane biofuel production potential from major wastes in regional areas. The process energy required for methane production (power, heat) is already subtracted.
The estimated total recoverable methane energy value for each region is given in PJ methane/yr in parenthesis
Values were calculated using MSW Scenario 1 and biosolids processing from domestic sewage + ICI sewage.

uses housed animals so the manure is collected. In addition, dairy cattle spend a significant amount of time in milking sheds and the effluent collected from milking sheds is a potentially useable resource.

Wet wastes of this kind could be suitable for anaerobic digestion or algae production. Utilising these agricultural manures for energy avoids any disposal costs and negative environmental effects, as long as the process is designed and operated appropriately.

5.2.2 Quantities

New Zealand livestock produce over 15 million tonnes of faecal dry matter/year, which is mostly deposited onto grazed pastures and raceways and cannot be easily collected. Most poultry and pig manure is collected in manure management systems. This represents a total resource of about 100 000 tonnes of dry matter/year.

In addition, a small fraction of dairy effluent (44 million m^3) is collected in effluent ponds on farms. While some of this is used for irrigation, there are limits on the amount that may be applied to a given land area. These animal wastes have an annual nutrient value as fertiliser of about $21 million.

Nationally there is around 4.077 million tonnes dry weight of animal manures produced annually with 97% of this material being sourced from dairy farming.

5.2.3 Distribution of farm manures

The distribution of farm manure that is potentially available for energy is summarised below.

Table 15: Distribution of farm manures by region

	Farm Feacal Material					
	Dairy	Piggery	Poultry	Dairy	Piggery	Poultry
	1,000s t/pa DM	1,000s t/pa DM	1,000s t/pa DM	PJ gas pa	PJ gas pa	PJ gas pa
	2005	2005	2005	2005	2005	2005
Northland	270	1	1.0	0.08	-	0.006
Auckland	96	-	18.8	0.02	0.01	0.112
CNI	1,608	5	15.0	0.54	0.03	0.090
Gisborne	-	-	0.2	0	-	0.001
Hawke's Bay	65	1	0.7	0.03	-	0.004
SNI	885	4	16.5	0.27	0.03	0.099
Total North Island	**2,924**	**10**	**52.2**	**0.94**	**0.07**	**0.313**
Nelson/Marlborough	78	-	0.0	0.03	-	0
West Coast	112	-	0.0	0.04	-	0
Canterbury	477	19	1.4	0.27	0.05	0.008
Otago/Southland	400	2	2.0	0.24	0.00	0.012
Total South Island	**1,067**	**21**	**3.4**	**0.58**	**0.05**	**0.020**
Total New Zealand	**3,990**	**30**	**55**	**1.52**	**0.1**	**0.040**

The manure resource is distributed according to farming types. Dairy is concentrated in the Central North Island, Taranaki, Canterbury and Otago/Southland. Piggeries are concentrated in Canterbury (60%) with the only other significant amount in the Central North Island. Poultry farms are concentrated in Auckland, central North Island and the Southern North Island, with 90% of the resource in these regions.

5.2.4 Contribution to New Zealand's energy sector

Methods exist for converting manures to energy that can be operated at the farm scale (or small co-operatives) to avoid the need to transport high moisture content feedstocks.

Currently the dairy industry is strong and Fonterra has a target of increasing sustainable milk supply by 3%. Increasing dairy farming will lead to an increase in the farm dairy effluent produced.

Some New Zealand dairy farmers are moving cows into stand-off pads or herd homes during the winter months for soil management reasons. Cows could spend up to 20 hours a day over three months in these systems, resulting in a greater amount of manure being collected.

The total energy contribution from digestion of farm manures is estimated to be 1.5 to 1.7 PJ.

5.2.5 Cost of recovering animal manures

Manure is a by-product of animal farming and costs nothing extra to produce. However, collection and storage costs will be significant, particularly for wastes that have high water content.

The cost of gas production from animal manures will be in the order of NZ$16-$22/GJ, but these costs will depend on the scale of the operation.

Currently the dairy industry is strong and Fonterra has a target of increasing sustainable milk supply by 3%.

5.2.6 Barriers and issues

The most significant barriers to using anaerobic digestion to create biogas from farm manure for local use are:

- The cost of the gas in comparison to other gas supply.
- Potential mismatch between gas supply and demand and the need to flare excess biogas.
- Odours from digestor, although this should be no more and many cases less than the existing system.
- Seasonality of the manure production on dairy farms, where for some months there is usually no cowshed effluent produced. This does not apply to pig and poultry operations.
- Scale is possibly the most important issue, with many dairy farms being at the bottom end of the size of plant that would currently be economically viable.
- Research on improved on-farm dairy shed effluent digestion economics (innovative gensets and high performance digester systems, improved synergy, improved carbon capture).
- Biogas motor performance improvements and cost reduction at very small scale.

Key references

Thiele, J.H., "Bioenergy resource assessment: Municipal biosolid and effluent and dairy factory, meat processing and wool processing waste." Report prepared for the Bioenergy Options Project, 2007 (Refer CD).

Saggar, S. D. Giltrap, V. Forgie and R. Renquist, 2007: Bioenergy Options Report: Review of Agricultural Resources. Report prepared for the Bioenergy Options Project, 2007. (Refer CD)

5.3 Industrial Effluents

5.3.1 Background

The potential for producing biogas from industrial effluent in New Zealand is significant. Such industrial waste streams include dairy factory, meat processing and wool processing waste.

5.3.2 Quantities

The quantities of industrial effluents available for energy production are summarised below.

Table 16: Quantities of wastes and estimates of energy from industrial effluents.

	Industry waste			
	Dairy processing	Meat processing	Dairy processing	Meat processing
	Methane tonnes/year	Methane tonnes/year	PJ gas/year	PJ gas/year
	2005	2005	2005	2005
Northland	818	896	0.04	0.04
Auckland	-	503	0.00	0.02
CNI	4,939	3980	0.25	0.20
Gisborne	11	165	0.00	0.01
Hawke's Bay	-	1339	0.00	0.06
SNI	2,334	4330	0.12	0.02
Total North Island	**8,100**	**11,210**	**0.41**	**0.36**
Nelson/Marlborough	185	387	0.01	0.02
West Coast	322	248	0.02	0.01
Canterbury	1,363	2585	0.07	0.12
Otago/Southland	1,184	2890	0.06	0.14
Total South Island	**3,054**	**6110**	**0.16**	**0.30**
Total New Zealand	**11,154**	**17,320**	**0.57**	**0.66**

The regional concentrations of dairy processing waste follow those of dairy farming, with significant potential in the Central North Island, Taranaki, and the south of the South Island. Meat processing potential follows the same pattern.

Wool processing wastes are not included in this table because effluent data from New Zealand wool scouring operations are not available due to commercial sensitivities. A confidential estimate from a New Zealand industry expert suggested that the total wool scouring effluent bioenergy resource would be insignificant in comparison to the other processing industries (less than 0.5% of total industrial processing waste resource). Any solid waste from tanneries and wool scouring operations is currently deposited to landfill.

5.3.3 Contribution to New Zealand's energy supply

The seasonality of the biogas from primary production processing waste fits well into the summer peak for the rural national power demand curve (dairy farm irrigation) and into the summer trough for hydroelectric power generation and also is most economically utilised in rural distributed systems.

Around 1.2 PJ of energy is feasible from conversion of wastes to methane.

5.3.4 Barriers and issues

Research gaps and priority energy research areas that need attention are:

- Regional case study on use of biomethane as commercial transport fuel.
- Regional case study on production of biomethanol.

Key references

Thiele, J.H., "Bioenergy resource assessment: Municipal biosolid and effluent and dairy factory, meat processing and wool processing waste." Report prepared for the Bioenergy Options project, 2007 (Refer CD).

5.4 Municipal Solid Waste

5.4.1 Background

A large quantity of putresible or digestable material is contained in domestic household refuse that goes to landfill. This material could be segregated and used to create biogas, sometimes called "landfill gas". Because this gas is principally methane, an important greenhouse gas, its capture and utilisation is of benefit to the environment.

5.4.2 Quantities

The quantities of this material that are potentially available for biogas production are presented in the table below.

Table 17: Quantities of municipal solid waste (putresibles) and indicative energy content

	Digestable MSW	Residual landfill	Digestable MSW	Residual landfill
	Tonnes/year dumped	Tonnes/year dumped	PJ gas/year potential	PJ gas/year potential
	2005	2005	2005	2005
Northland	13,000	91,000	0.09	0.08
Auckland	132,000	914,000	0.92	0.79
CNI	52,000	364,000	0.36	0.31
Gisborne	4,100	29,000	0.03	0.02
Hawke's Bay	14,000	97,000	0.10	0.08
SNI	95,000	661,000	0.66	0.58
Total North Island	**310,100**	**2,156,000**	**2.16**	**1.86**
Nelson/Marlborough	14,000	99,000	0.10	0.09
West Coast	3,000	23,000	0.02	0.02
Canterbury	46,000	322,000	0.32	0.28
Otago/Southland	35,000	246,000	0.25	0.21
Total South Island	**98,000**	**690,000**	**0.69**	**0.60**
Total New Zealand	**408,000**	**2,846,000**	**2.85**	**2.46**

5.4.3 Contribution to New Zealand's energy supply

The national distribution of municipal solid wastes is dictated by major population centres. Collectively the landfill gas resource is approximately 3 PJ and is therefore of some significance.

5.4.4 Cost of recovering municipal solid waste

Currently the cost of recovering gas from digesting putrescible waste is higher than that of conventional gas supply. These costs are typically within the range of NZ$9-18 /GJ and is highly site specific. However if the methane captured is able to attract carbon credits the economics of conversion may change. Legislation will force land fill gas capture at large landfills from 2008.

5.4.5 Barriers and issues

The most significant barriers to wide-scale use of municipal solid wastes are:

- The cost of the gas in comparison to other gas supply.
- Potential mismatch between gas supply and demand and the need to flare excess biogas
- Odours from digestor, although this will be no more, and often less, than the existing system

5.5 Anaerobic digestion

Anaerobic digestion is the most logical energy recovery route for some biologically derived resources. These materials are typically fluids (industrial effluents) or very high moisture content solids (municipal biosolids), and are unsuitable for other conversion pathways without a lot of drying.

The cost of the biogas produced from anaerobic digestion is marginally competitive with natural gas in some cases.

There is a need for some further development of digestion technology and adaptation of low cost digestion systems to New Zealand conditions in order to increase the use of anaerobic digestion for bioenergy purposes.

Proven technologies exist to convert those materials to biogas and then to biomethanol. Biomethanol is useful in the manufacture of biodiesel transport fuel from waste fat and tallow. Methanol costs in New Zealand have recently increased due to the gradual depletion of low cost natural gas resources.

Significant additional opportunities exist to produce bioalcohol from all those putrescible waste resources that appear unsuitable for ethanol fermentation with current technology (low carbohydrate, high protein, high lipid, high water content; effluent treatment flotation foams, paunch and feedlot manure).

A potentially significant issue is that anaerobic digestion systems require continuous supply of material whereas some of the feedstocks are produced seasonally.

Key references

Thiele, J.H., "Bioenergy resource assessment: Municipal biosolid and effluent and dairy factory, meat processing and wool processing waste." Report prepared for the Bioenergy Options Project, 2007 (Refer CD).

Algal biomass

6.0 ALGAL BIOMASS

6.0.1 Background

Micro-algae are widely believed to be the precursor of much of the world's fossil oil and gas reserves. Today, algal biomass is seen as a resource for bio-energy production. Algae are potentially far more productive (t/ha) than conventional agricultural crops and can be grown cost-effectively in open pond systems as a by-product of wastewater treatment.

Oxidation ponds, which are the most common form of waste stabilisation pond (WSP) in New Zealand, are ideal for algal biomass production. Conventional WSP, are, however, not optimised for the production of algal biomass, and algae production can be significantly increased by upgrading to High Rate Algal Ponds (HRAP). This process will also enhance the wastewater treatment performance both in terms of absolute pollutant removal and treatment consistency.

Conversion products for realising the bioenergy potential of algae biomass include biodiesel, biogas, bioethanol, and bio-oil. Of these conversion options, bio-oil production using super critical water reactors shows considerable promise but requires further research. Super-critical water technology is a possible approach for cost-effective conversion of algae to energy products.

Biogas production from anaerobic digestion of algal biomass is a mature and effective technology that is readily available for commercial application. This is a common method of providing fuel on a village-scale for heating and cooking in India. In Germany there are over 4,000 farm-scale biogas plants, many of which digest cultivated crops for electricity generation.

Biogas can be purified to natural (methane) gas quality and exported into the national natural gas network, thereby displacing the use of a fossil fuel if economics became favourable.

6.0.2 Quantities

At present there is no commercial production of algal biomass in New Zealand. However, existing waste streams offer the following potential:

Municipal wastewater:	The potential daily algal biomass yield from each existing WSP in New Zealand was calculated from wastewater flow data to give a total of 41 tonnes per day (dry weight). By converting all existing WSP in New Zealand to HRAP the potential daily algal biomass yield could increase to 164 tonnes dry weight/day. If all municipal wastewater was treated in HRAP with addition, the potential daily algal biomass yield could be further increased to 475 tonnes dry weight/day.
Dairy farm wastewater:	The daily algae production potential from dairy farm wastewater in NZ using HRAP with CO_2 addition would be 1093 tonnes dry weight/day. This is more than double that which could be produced from all municipal wastewater, however, with the production spread over many farms, cost-effective small-scale harvesting and processing technology will be required to realise this potential.
Pig farm wastewater:	There are approximately 250 commercial pig farms in New Zealand, each with an average of 1000 pigs. As all of the daily manure production is treated, the daily algae production potential from piggery wastewater in NZ using HRAP with CO_2 addition would be 83 tonnes dry weight/day. The high and concentrated wastewater flows of commercial piggeries compared to those of the largest dairy farms makes piggeries attractive potential sites for algae biomass production.
Poultry waste:	Poultry farming is gaining popularity in New Zealand with approximately 350 laying hen and broiler chicken farms with a total of 24 million chickens. The daily algae production potential from chicken farm manure in NZ using HRAP with CO_2 addition would be 136 tonnes dry weight/day. However, as most poultry farms have solid manure collection systems, often with 100% export of the manure, the potential for algae production may be harder to realise that for other agricultural manures.

6.0.3 Distribution of pond systems for algal production

The geographic distribution of algal biomass production from municipal wastewater would mirror New Zealand's population distribution, with more than half of the potential being associated with the three main population centres (Auckland, Wellington and Christchurch).

Agricultural effluents are distributed widely throughout New Zealand.

6.0.4 Contribution to New Zealand's energy supply

Algal biomass is an unfavourable feedstock for conventional biomass conversion technologies (e.g. combustion), because drying is an unavoidable and expensive step. Converting microalgae biomass (5-30% solids) to crude oil, using super critical water conversion may be a more achievable goal.

Recently a New Zealand company, Aquaflow Bionomic Corporation, announced that they were the first in the world to extract microalgae-derived crude oil. This enterprise is however still very much in the preliminary stages of design and commercialisation.

Algae production solely for energy production is currently unviable, but the value of co-benefits such as wastewater treatment or co-products like bioplastics and fertiliser (wastewater nutrient recovery or cyanobacteria nitrogen-fixation) could greatly improve economics.

6.0.5 Barriers and Issues

There are several constraints to algae biomass resource production from wastewater ponds that will limit realisation of the resource's potential. These include: suitability and availability of low-cost land; suitable climate for algae growth, and; harvest cost and efficiency.

Harvesting of microalgal biomass is regarded as the single most limiting factor in expanding application of microalgae for production of feedstocks. Options for harvesting algae from pond effluent include filtration and microstraining, centrifugation, settling, (augmented by bioflocculation or chemical flocculation) and flotation.

Microalgal biomass must be dried before conversion into liquid products such as biodiesel or bio-oil, but this is energy intensive. The total energy requirement may be several times that of the biofuel produced from the algae, unless waste heat or energy efficient drying methods (e.g. solar drying) are used.

Key References

Heubeck, S. and R. Craggs, 2007: "Resource Assessment of Algae Biomass for Potential Bioenergy Production in New Zealand". Report prepared for Bioenergy Options Programme, 2007. (Refer CD)

Conversion technologies

7.0 CONVERSION TECHNOLOGIES

7.1 Combustion

7.1.1 Overview

Combustion of biomass is the conversion of the carbon in plant materials to heat, carbon dioxide (CO_2) and water by burning. This is currently the most common way that energy is derived from fresh biomass in New Zealand. The most efficient combustion processes optimise the heat produced and minimise secondary emission products like tars, smoke and ash.

Combustion is ideally the complete oxidation of fuel, and the hot gases from the combustion process are typically used for direct heating in small combustion units, or for water heating in small central heating boilers. In larger scale applications, water is heated for electricity production (steam turbines), as a source of process heat or for water for larger scale central heating applications.

The wood processing industry (pulp and paper, panel products and sawn timber production) is the largest user of combustion technology in New Zealand as they burn their own wood residues to generate process heat, steam, hot water and, in some cases, electricity. The other major user of combustion systems are homeowners who burn pellets or solid wood for space heating and hot water.

Where biomass is sourced from materials that are either wastes or from sustainable crops (e.g., plantation forests which are replanted) then the energy is considered renewable and or sustainable. The CO_2 emissions are neutral as any carbon released during combustion is reabsorbed during the subsequent growth cycle of the biomass.

7.1.2 Technology Options

There are many types of combustion appliances which can be used for domestic or industrial applications such as:

Domestic combustion appliances	• Wood stoves • Wood pellet burners • Wood log burners • Wood chip appliances
Industrial combustion appliances	• Grate furnaces • Under feed stokers • Fluidised bed combustors

The types of industrial boilers used for biomass combustion in New Zealand are summarised below.

Table 18: Summary of combustion technologies available for biomass

	Pile burner	Underfed stoker	Vibrating grate	Inclined reciprocating (Kablitz)	Fluid bed
Fuel feed system	Dropped from above	Screwed from below	Mechanical feeders or air swept spouts	Air swept spouts	Air swept spouts into or onto bed
Grate	Solid floor i.e. none	Optional solid floor or fixed grate	Water cooled with air inlets and periodic vibration	Inclined and reciprocating	Air blown bubbling bed
Fuel	Sawdust and shavings with low ash	Sawdust and shavings with low ash	Sawdust, shavings, bark and greenwood	Sawdust, shavings, bark and greenwood	Sawdust, shavings, bark and greenwood
Max fuel moisture (% fresh basis)(1)	60	60	62 - 65	62 - 65	68+
Max fuel moisture to combustor (% fresh basis)(1)	55	55	62 - 65	62 - 65	68+
Wood pre-drying	Yes	Yes	No	No	No
FD air pre-heating	No	For wet fuels	For wet fuels	For wet fuels	For wet fuels
Max. ash content (% weighs/weight)	1	1	10	10	20+
Max. fuel size (mm)	150	150	150	150	150
Max. boiler size (MW)	8	8	30	50+	50+
Deashing	Manual	Manual	Automated	Automated	Automated, with bed regrading
Controls	Relatively simple	Relatively simple	Automated with tuning functions	Automated with tuning functions	Automated with tuning functions
Staffing	Unattended	Unattended	Typically limited attendance	Typically limited attendance	Typically limited attendance

Existing combustion systems designed to use coal or gas can be converted to biomass firing with the installation of fuel handling and storage facilities; reconfiguration of the combustor, and; installation of flue gas cleaning.

Combustion processes have the advantage that different fuel materials (coal, gas, biomass and wastes) are amenable to being burned together (co-fired). Co-firing coal boilers with a small amount (10 to 15 % of the fuel) of biomass is possible. In several parts of the world, many pulverised coal combustors are co-firing biomass, with the quantity of biomass determined by the design of the boiler and the condition of the fuel being added. It is also common for larger wood fired boilers to co-fire with gas or coal. For example, the biomass boiler at the Kawerau industrial site can add coal if the biomass is coming in with high moisture content and/or the steam demand rises.

7.1.3 Feedstocks

Many different sources of biomass are suitable for combustion (forest residues, wood processing residues, short rotation crops, municipal green waste, dried sludges and industrial wastes, crop residues and grasses).

Critical feedstock properties for effective biomass combustion are moisture content, fuel consistency, and ash content.

The moisture content of biomass must be managed as part of the combustion process. Conventional boilers cannot operate on woodwastes with moisture contents exceeding around 67% w/w. When moisture content is above this threshold the cooling effect of water evaporating from the woodwaste is so great that it will not ignite properly, and there is an increase in carbon monoxide (CO) emissions. Below this level, the efficiency of the boiler improves with lowering moisture content. To burn effectively, biomass needs to be either dried prior to combustion or as part of the combustion process itself.

Ash Content is inherent in all fuels and varies considerably: clean wood is 0.3-0.5 % (ww) depending on the species; bark is typically around 3% (ww), and; other organic matter (for example chicken litter) can be 15-25% (ww) ash. For wood residues, the ash content of the fuel is related to soil mixed in with the material. This soil material can lead to problems in combustion and handling. Scrubbers can be used to reduce ash particle emissions. The ash produced from biomass naturally contains phosphorus, potassium and trace elements required for plant growth, making it a useful fertiliser with minimal (wetting and granulation to avoid dust) further treatment.

Biomass has virtually no sulphur content so, in contrast to coal, sulphur dioxide emissions are negligible.

7.1.4 Current and Future Deployment

The use of woody biomass as a source of energy based on combustion technology in New Zealand is principally driven by the wood processing industry. In addition, there will be increased use of woody biomass in the residential commercial and industrial sectors in the form of high-quality biomass fuels, such as wood pellets and high-quality chip, as a replacement for coal and gas.

The wood processing industry is, and will continue to be, the major user of woody biomass for heat in New Zealand. It is estimated that presently, 94% of South Island sawmills and 74% of North Island sawmills use some biomass as fuel (evaluated by installed heat production capacity), resulting in 9.5 PJ/year of primary energy use. In addition, biomass makes up 82% of the fuel mix in the wood panel manufacturing industry resulting in another 9.5 PJ/year of primary energy and the pulp and paper industry 25.6 PJ/year, mainly in the form of black liquor. The total use in 2005 was 44.6 PJ/year. One of the main drivers for this uptake in bioenergy is the cost of otherwise disposing of processing residue.

7.1.5 Costs and Lifecycle

Using a 40 MW woodwaste fired boiler as an example, capital cost and operating data for the three energy centre configuration options are as follows:

Table 19: Indicative costs of large-scale combustion processes

	Process steam	Cogeneration*	Electricity generation
Boiler capacity	40 MW	40 MW	40 MW
Steam turbine Generator	-	7.5 MW	12 MW
Capital costs			
Boiler	$20,000,000	$20,000,000	$20,000,000
Steam turbine generator	-	$14,000,000	$16,000,000
Total	$20,000,000	$34,000,000	$36,000,000
Operating data			
Steam to turbine	-	40 MW	40 MW
Process steam	40 MW	20 MW	-
Boiler efficiency	60%	60%	60%
Energy in/out	1:0.6	1:0.4	1:0.2

* Electricity is generally regarded as a higher value form of energy than heat or steam. In this example, of the 0.4 energy, out, 27% is electricity and 73% is heat.

7.1.6 Barriers and Issues

A number of barriers and issues exist in New Zealand to limit the implementation of biomass combustion these are:

- Both new, or conversion to biomass for existing facilities, are capital intensive due to added cost of fuel feed systems, fuel storage areas, emission controls and boiler design and operation, compared to gas or coal fired plants.
- Although combustion processes can accept a wide range of fuel quality, there is a critical link between fuel quality and engineering and operating costs. Fuel supplies need to be well defined and secured prior to committing to this conversion technology.
- Air emission issues arising from biomass combustion add cost for consent compliance and mitigation.
- Integrating biomass systems into existing plants is complex and costly as it depends on current technology, energy demand, and requirements for feedstock storage, plant operator skills, and on-site logistics.

Key References

(Connell Wagner Ltd, 2007, Combustion of Biomass, Report prepared as part of the Bioenergy Options Programme (refer CD).

EECA and CAE, 1996, New and Emerging Renewable Energy Opportunities in New Zealand. Published by EECA and CAE ISBN 0-908993-11-0 265pp.

Van Loo, S. and J. Koppejan (eds), 2002, Handbook of Biomass Combustion and Co-Firing. Published by Twente University Press, 348pp.

East Harbour Management Services and Scion, 2007: Assessment of possible renewable energy targets: Direct use of biomass. Report prepared for the Energy Efficiency and Conservation Authority, 2007.

7.2 Gasification

7.2.1 Overview

Biomass gasification provides a means of deriving more diverse forms of energy from the thermochemical conversion of biomass than conventional combustion. Gasification involves the incomplete combustion of a carbon-based fuel when burned with a restricted supply of air, oxygen, or other oxidising source. The basic gasification process involves devolatisation, combustion and reduction.

During devolatisation, methane and other hydrocarbons are evolved from the biomass by the action of heat which leaves a reactive char. During combustion the volatiles and char are partially burned in air or oxygen to generate heat and carbon dioxide. In the reduction phase carbon dioxide absorbs heat and reacts with the remaining char to produce carbon monoxide (producer gas). The presence of water vapour in a gasifier results in the production of hydrogen as a secondary fuel component.

The products of gasification are a mixture of carbon monoxide, carbon dioxide, methane, hydrogen and various hydrocarbons, which can then be used directly in gas turbines, and boilers, or used as precursors for synthesising a wide range of other chemicals. In addition there are a number of methods that can be used to produce higher quality product gases, including indirect heating, oxygen blowing, and pressurisation. Gasification is an effective way to convert biomass into a gas stream which can subsequently be used for a wide range of other applications.

7.2.2 Technology Options

Several different types of gasifiers have been developed, including:

- Updraft.
- Downdraft.
- Bubbling Fluid Bed.
- Circulating Fluid Bed.
- Entrained Flow.

Each has different performance characteristics, product gas qualities, feedstock requirements, and differing levels of sophistication. The application and feedstock play a significant role in determining which gasifier is suitable.

Due to their greater complexity, gasifiers will require a higher level of operator skill than is required for a combustor.

There are a number of large biomass gasifiers around the world being operated as pilot projects, or semi-commercial. The majority are integrated into combined cycle power generation systems while others are used to provide product gas for direct use in boilers.

Interest in biomass gasification followed by processing the gas to liquid fuels is increasing world wide, with demonstration plants being built in Germany (Choren - Biodiesel) and USA (Range Fuels - Bioethanol).

7.2.3 Feedstocks

A diverse range of biomass feedstocks are suitable for gasification processes however, some of the more critical characteristics are moisture content, ash content, particle size, and reactivity of char.

The chemical composition of the feedstock influences the constituents in the product gas, and the gasification design and product gas cleanup method must be matched with the intended use. Some feedstocks may prove more costly or challenging to gasify and clean if the product gas has a high level of contaminants. For example, a forest waste feedstock with high alkali content (sodium, potassium) must have the alkali cleaned from the product gas prior to use in a gas turbine. In general, feedstocks should have a high carbon-to-nitrogen ratio, relatively little sulphur, and moisture content of less than 20-30 percent fresh weight basis.

In contrast to coal, which is currently used in several commercial gasification processes, biomass is more reactive and can be effectively gasified at lower temperatures than coal. However, unlike mined coal and petroleum drawn from wells, biomass resources are dispersed and heterogeneous in nature. Consequently, special handling and feeding systems have to be designed, taking into consideration the heterogeneous nature and the low bulk density of biomass. The fibrous nature of herbaceous feedstocks means they are more difficult to handle than woody biomass. Another frequently encountered problem is the low-ash fusion temperatures of certain biomass, particularly under reducing conditions, which require special care in the design and operation of biomass gasifiers.

7.2.4 Current and Future Deployment

Currently, there are no gasification systems in New Zealand producing energy for industrial or domestic applications, although Page Macrae has a pilot experimental facility. The main work currently being undertaken on gasification is the development of experimental facilities at the University of Canterbury which are focused on integrated syn-gas/producer gas systems for electricity generation derived from forest residues. Alternative Energy Systems has recently established a small-scale gasification demonstration system for running gas or motors for power and heat production.

Biomass gasification has significant potential for New Zealand situations to produce heat, electricity and synthetic gas for chemical and liquid biofuel production. Technology development and research have been extensive internationally with gasification programmes being supported by the European Commission, Austria, Denmark, Finland, the Netherlands, Sweden and the USA.

Biomass gasification can be deployed from very small scale (30 kWth) to up to over 100 MWth, depending on application and requirements.

A summary of key plant operating in the countries that are member of IEA Bioenergy is summarised below.

Table 20: Summary of major gasification technologies

Country	Technologies and systems
Austria	• 8 MWth TUV FICFB BMG CHP demonstration at Güssing • 2 MWth down-draft BMG CHP at demonstration at Wr. Neustadt
Denmark	• 5 MWth VØlund up-draft CHP demonstration at HarbØre • 70 KWth, Viking 2-stage gasification and power generation at Lyngby • 3+MWth, TKEnergi 3-stage, gasification process demonstration at Gjøl (an 833 KWth plant is demonstrated in Japan) • 30 MWth Carbona Renugas fluidized bed CHP demonstration at Skive
Finland	• 4 to 5 MWth Bioneer up-draft gasifiers (8 in Finland and one in Sweden) • 60 MWth, Foster Wheeler Energy CFB co-firing plant at Lahti (50 to 86 MWth co-firing plant in Ruien, Belgium) • 40 MWth Foster Wheeler Energy fluidized bed metal recovery gasifier in Varkaus • 7 MWth NOVEL Updraft demonstration at Kokemäki
Germany*	• 130 MWth commercial waste to methanol plant at Schwarze Pumpe • 100 MWth Lurgi CFB gasifier firing cement kiln at Rüdersdorf • 0.5 MWth Fraunhofer Umsicht CFB pilot plant at Oberhausen • 45 MWth CHOREN Carbo-V 2-stage entrained pilot plant in Freiberg • 3-5 MWth Future Energy pyrolysis/entrained flow GSP gasifier in Freiberg
Italy	• 15 MWth TPS CFB RDF plant at Greve in Chianti • 500 KWth ENEA CFBG pilot plant at Trisaia (similar plant in operation in China)
Netherlands	• 85 MWth AMER/Essent/Lurgi CFB gasification co-firing plant at Geertruidenberg • Biomass co-gasification at the 250 MWe (35 MWe from biomass) Shell entrained coal gasification plant at Willem-Alexander Centrale • 3MWth CFBG Plant in Tzum NL • Several pilot plants at ECN, Petten
New Zealand	• Fluidyne commercial down-draft gasification plants (2 MWe plant in Canada) • AB Powerhearth Ltd down-draft BMG (3MWe plant in Maine, USA) • 2 MWth Page Macrae updraft BMG plant at Tauranga

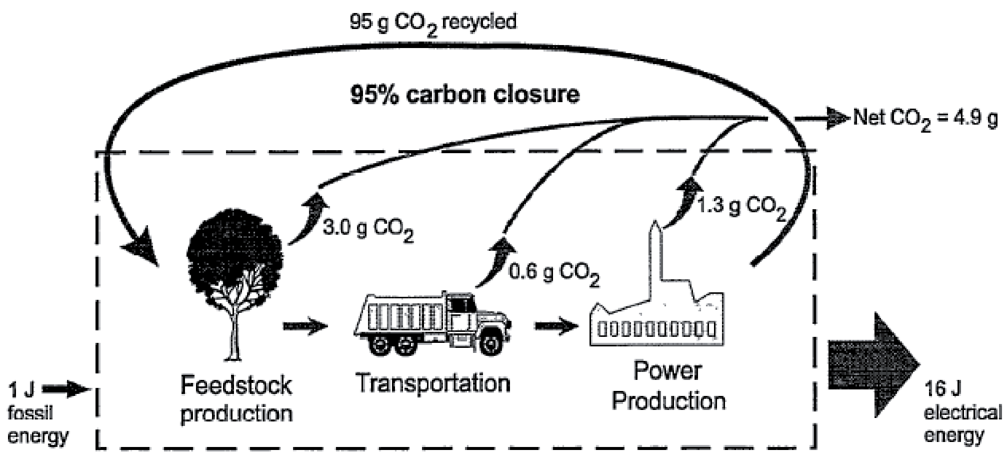
Sweden	• Bioneer up-draft BMG plant • 30 MWth Foster Wheeler Energy CFBG at Karlsborg paper mill • 20 MWth Foster Wheeler Energy CFBG at Norrsundet paper mill • 30 MWth Gotaverken CFBG at Södracell paper mill • 18 MWth Bioflow/Sydkraft/ Foster Wheeler Energy CHP demonstration at Värnamo
Switzerland	• 200 KWe Pyroforce down draft BMG system at Spiez (scale-up to 1 MWe plant in Austria)
UK	• 100 KWe Rural Generation downdraft BMG system in Northern Ireland • Up to 250 KWe Biomass Engineering Ltd., down draft BMG CHP systems in Northern Ireland • Up to 300 KWe Exus Energy down draft BMG CHP systems in Northern Ireland • Charlton Energy rotary kiln waste gasification in Gloucestershire • Compact Power two-stage waste gasification plant in Bristol
USA	• Up to 120 MWth Primenergy gasification/combustion systems (6 in USA and 1 in Italy) • Up to 22 KWe Community Power Corporation small modular down-draft gasification systems • FERCo SilvaGas dual CFBG Process • RENUGAS fluidized bed BMG Process

7.2.5 Costs and Lifecycle

The different types of gasifier technology and gasifier operating conditions have quite different capital costs. However, since the output gas quality and downstream processing needs depend on the technologies, the capital and operating costs on a product gas energy output basis are relatively independent of the technology used. The typical range of capital costs for gasifiers is around $1000 - $1600/kW gas output with operating costs of approximately 4.5-6.6c/kWh gas output. These figures were derived from reported project costs, using the assumption that the electricity generation block is 40-45% of the total plant costs, and the air separation unit (where present) was 10-13% of the cost.

Based on a life cycle assessment undertaken on a Battelle Ferco gasifier, which was a two-stage system (gasification reactor and combustion reactor) used to produce electricity, the energy balance and CO_2 emissions are shown below (Mann and Spath 1997).

Figure 11: Life cycle balance for CO_2 for a Battelle Ferco gasifier



From the Battelle Ferco gasifier the net energy production was highly positive and there was effectively 95% carbon closure (i.e., a loss of 5% of carbon dioxide from the system). This indicates that the production of electricity based on this approach is greenhouse-gas-favourable compared to coal- and gas-based electricity production.

7.2.6 Barriers and Issues

Despite the widely acknowledged benefits, commercialisation of biomass gasification has fallen short of expectations. The reasons include:

- Absence of consumer demand due to competition from conventional fuels.
- Inadequate government policies globally and few incentives for biomass gasification projects.
- Lack of infrastructure for the quality control of feedstock supply at a guaranteed price.
- Inability to obtain performance guarantees by many technology developers.
- Competition from proven (combustion) tecnology.

These issues apply internationally and to the New Zealand situation as well.

Gas clean-up, in particular the removal of tars, alkalis, ammonia, chlorides, sulphides and particulates has been a significant technical hurdle and a wide range of technologies have been trialled. Nickel catalysts have been deployed to aid the removal of tars, and a range of ceramic and sintered filter systems have been developed to successfully remove particulate matter. Gas clean-up is critical for upgrading gas quality prior to use in turbines or other downstream chemical processing.

Biomass gasification is now being trialled as a means of gas supply for high temperature fuel cells.

Biomass gasification and combustion compares environmentally favourably with coal combustion as it has lower SOx and NOx emissions, lower fine particulate emissions, lower heavy metal content in the fuels, and hence a cleaner ash.

Key Additional References

EECA and CAE, 1996, New and Emerging Renewable Energy Opportunities in New Zealand. Published by EECA and CAE ISBN 0-908993-11-0 265pp.

Mann, M and Spath, P, 1997: Life Cycle Assessment of a Biomass Gasification Combined-Cycle Power Plant.

Babu, S, 2006: Perspectives on Biomass Gasification. Paper presented to IEA Bioenergy, Task 33, Thermal Gasification of Biomass May 2006.

Trolove, H. and M. Garrood, 2007: Bioenergy feedstock combustion and handling properties: Biomass gasification. Report prepared for the Bioenergy Options Programme, 2007. (Refer CD)

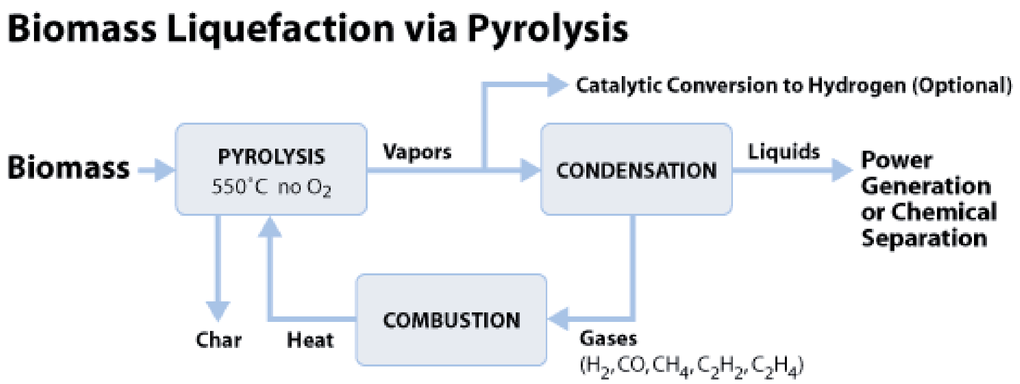
7.3 Pyrolysis

7.3.1 Overview

The pyrolysis of biomass, in contrast to combustion and gasification, typically produces a bio-oil derived from condensed wood vapour. It also produces a char or gases, with the mix being dependent on the temperature and process reaction times. Lower process temperatures and longer vapour residence times favour the production of charcoal, while high temperature and long residence times favour gas production. Moderate temperatures and short vapour residence times are optimum for producing bio-oils.

Pyrolysis is the thermal decomposition of biomass occurring in the absence of oxygen. It is also always the first step in combustion and gasification. Pyrolysis occurs naturally in the first two seconds in a combustion or gasification process. In the combustion process, it is pyrolysis that generates the visible cloud of persistent smoke-aerosol. These volatiles, or pyrolysis gases, can be condensed into a liquid (bio-oil). Any form of biomass or other organic matter can be pyrolysised.

Figure 12: Process conditions for the pyrolysis of biomass



7.3.2 Technology Options

The reactor design and configuration are the critical part of the pyrolysis process and this has been the focus of much research and development to date. A range of different reactor designs exist for fast pyrolysis.

Bubbling fluid beds

Bubbling fluid beds are a well-understood technology that is simple to construct and operate. It typically has good temperature control and efficient heat transfer to biomass particles. Fluid beds have consistent performance with high liquid yields of typically 70-75% weight from wood on a dry weight basis.

Particular features that require consideration in the design and operation of fluid beds include:

- The effective heating of the reactor.
- Effective control of the residence times of solids and vapours by the fluidising gas.
- The rapid and effective separation of char to avoid the char from acting as a vapour-cracking catalyst at fast pyrolysis reaction temperatures.
- Preparation of the biomass feedstock to less than 2 mm to achieve high yields.
- Effective char separation, which is often achieved by having one or more cyclones in the process chain.

Circulating fluid beds and transported bed

Circulating fluid bed (CFB) systems have many similarities to bubbling beds described above. The exceptions are that the residence time of the char is almost the same as for vapours and gas, and the char is more worn into fine particles due to the higher gas velocities, which can lead to higher char contents in the collected bio-oil. CFBs are potentially suitable for larger reactors even though the hydrodynamics are more complex.

Particular features that require consideration for the design and operation of these systems include:

- Good temperature control in the reactor.
- Residence time for the char is almost the same as for vapours and gas.
- CFB's are suitable for very large throughputs.
- CFB is a well understood technology.
- Hydrodynamics are more complex than bubbling fluid-bed reactors.

Ablative pyrolysis

Ablative pyrolysis is substantially different to the previous processes where the rate of reaction is limited by the rate of heat transfer through the biomass particles, which explains the general need for small particles (< 0.2 mm). The ablative process is like melting butter in a frying pan, where melting can be significantly enhanced by pressing the butter down and moving it over the heated pan surface. In ablative pyrolysis, heat is transferred from the hot reactor wall to melt biomass that is in contact with it under pressure.

The key features of ablative pyrolysis are:

- High pressure of particles on hot reactor wall, achieved by mechanical and centrifugal force.
- High relative velocity between particle and reactor wall.
- Reactor wall temperature less than 600 °C.

As reaction rates are not limited by heat transfer through the biomass particle, large particles can be used in this process. In principle, there is no upper limit to the size that can be processed, with the rate being limited by the heat supply to the reactor rather than the rate of heat absorption by the pyrolysing biomass, as occurs for the other reactor systems.

Entrained flow

Entrained flow fast pyrolysis is a relatively simple technology, but most developments have not been successful, because of the poor heat transfer between a hot gas and a solid particle. High relative gas velocities and high turbulence are required to enable sufficient heat transfer. This requires large plant size and high gas flow rates, which results in more difficult liquid collection from the low vapour partial pressure. Liquid yields have usually been lower than for fluid bed and CFB systems.

7.3.3 Feedstocks

A wide range of biomass feedstocks can be used in pyrolysis processes.

The pyrolysis process is very dependent on the moisture content of the feedstock, which should be around 10%. At higher moisture contents, high levels of water are produced and at lower levels there is a risk that the process only produces dust instead of oil. It is desirable to have as low water content as possible in the feedstock, as this ultimately affects the calorific value of the bio-oil. Where waste streams such as sludges and meat processing wastes are to be pyrolysed the waste needs be dried. The cost of drying feedstocks adds to the total cost of turning a biomass material into bio-oil.

The efficiency and nature of the pyrolysis process is dependent on the particle size of feedstocks. Most of the pyrolysis technologies can only process small particles to a maximum of 2mm. This is due to the need for rapid heat transfer through the particle. One technology, the ablative pyrolysis technology, can take much larger particles. The demand for small particle size means that the feedstock has to be size-reduced before being used for pyrolysis.

The ash content of feedstocks is also important as this can be higher in fuels used for fluid bed technologies where sand is the fluidising medium.

7.3.4 Current and Future Deployment

Currently, there are no commercial operating pyrolysis systems in New Zealand producing energy for industrial or domestic applications.

Limited research and technical development on pyrolysis process has been undertaken in New Zealand. There is a lab-scale pyrolysis plant in New Zealand, at AgResearch in Christchurch. It is an auger-type unit designed for the pyrolysis of waste. At the commercial scale, Alternative Energy Solutions (AES) has proposed to import a pyrolysis plant from Advanced BioRefinery in Canada. This technology is small scale and is suitable to process forest residues into bio-oil product.

Bio-oil is a dark brown liquid and has a similar composition to biomass (see Table 21). It is composed of a complex mixture of oxygenated hydrocarbons with an appreciable proportion of water. Furthermore the bio-oil may contain solid char particles.

Table 21: Properties of bio-oil

Physical Property	Typical value
Moisture content	25.0%
pH	2.5
Elemental analysis:	
• Carbon	56.0%
• Hydrogen	6.5%
• Oxygen	37.5%
• Nitrogen	0.1%
• Ash	0.0
Higher heating value	17MJ/kg at 25% wt water
• Liquid fuel	
• Ready substitution for conventional fuels in many stationary applications such as boilers, furnaces, engines, and turbines.	
• Does not mix with hydrocarbon fuels	

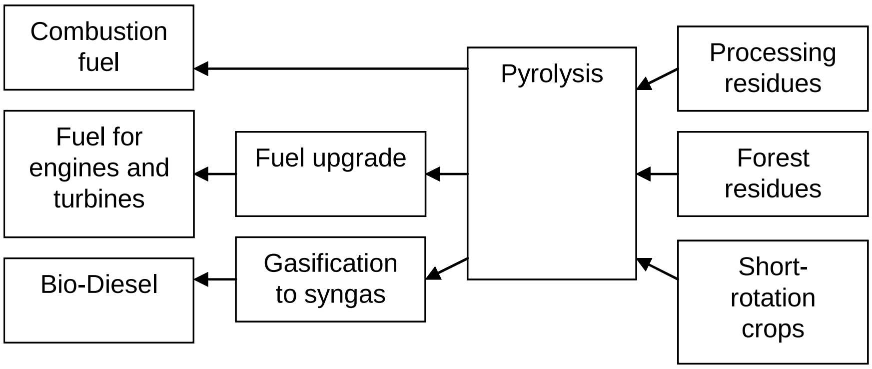
Bio-oil has a much higher density than woody materials (three to six times, depending on form), which reduces storage and transport costs.

Bio-oil is not suitable for direct use in standard internal combustion engines, however, PyTec in Germany is working on modifying a Mercedes engine to make it suitable for the use of bio-oil. Alternatively, the oil can be upgraded to either a special engine fuel or through gasification processes to a syngas and then bio-diesel. However, each additional processing step adds cost to the final products. An overview of the end-use options and their related technologies and resources is shown on the following page.

Bio-oil is particularly attractive for co-firing because it can be more readily handled and burned than solid fuel and is cheaper to transport and store. Bio-oil has been trial co-fired in gas and coal-fired power stations.

A potential advantage that pyrolysis has is that can be done at relatively small scale, at remote locations. The mobile plant increases the energy density of the resource, reducing transport and handling costs. The bio-oil produced can then be further refined at a central plant. Research on the upgrading of bio-oil to liquid fuel products is on-going.

Figure 13: Feedstocks and products that can be used and produced using pyrolysis technology



In addition to pyrolysis being used to produce energy and bio-oil, there is rapidly emerging interest in the use of the char as a soil fertiliser. Use of this process would reduce nitrogous oxide and methane emissions for agricultural soils, which in turn impacts on greenhouse gas emissions. The use of char in soils potentially provides a means to achieve carbon negative biofuels – as the soils become a carbon reservoir.

A forest estate of 30,000 ha on sustainable harvest of 500,000 tonne per annum could support one of these plants, and it would expected to produce approximately 30 tonnes, or 25,000 litres of bio-oil per day.

7.3.5 Costs and Lifecycle

A recently completed study in New Zealand (AES, 2007) has assessed the potential of using pyrolysis technology to convert forest residues to bio-oil based on technology from Advanced Biorefinery in Canada. The 100 tonne (fresh weight)/day plant operating in New Zealand forests over a 10-year period appeared to be economically viable. Further investigations are planned to trial this specific technology.

Key economic challenges with pyrolysis are reducing the capital cost, partly from scaling up and partly by developing and improving technology. A key factor for pyrolysis plants is that they will typically be smaller than fossil fuel options and therefore must be technically and economically competitive at much smaller scales of operation. It is the ability to improve economies of scale in applications for bio-oil that provides one of the best justifications for fast pyrolysis. This system allows bio-oil to be produced at decentralised plants and transported to central processing facilities for either direct use or further conversion to other value-added products.

7.3.6 Barriers and Issues

The high water content and the low pH of bio-oil make the oil corrosive and difficult to use, in particular, for standard engines. One way of overcoming this problem is to reduce the water content of the oil. Current research is focussing on technologies to take the oil through a refinery process or upgrade the oil to syngas. However this latter conversion adds another costly component to energy recovery processes.

Pyrolysis processes have the distinct advantage of being able to produce a complex range of chemical precursors which can be used for food flavourings, speciality chemicals, agri-chemicals, fertilisers and emission control agents. Increasingly, pyrolysis is being seen as a critical part of future biorefinery systems where biomass is converted in to several marketable products in particular fuels and chemicals. As biorefineries are highly integrated processes, complete resource use, efficiency, effectiveness, economics and environmental outcomes across all products (not just energy) are important and will need to be considered.

Key Additional References

Nielsen, P., 2007: Conversion Technology Assessment Pyrolysis. Report prepared for the Bioenergy Options Programme. (Refer CD)

EECA and CAE, 1996: New and Emerging Renewable Energy Opportunities in New Zealand. Published by EECA and CAE ISBN 0-908993-11-0 265pp.

IEA Bioenergy Annual Report, 2006: Biomass Pyrolysis – an overview prepared by Task 34.

AES, 2007: FIDA Engineering Solutions Remote Bio Energy. Report submitted to EECA, September 2007.

7.4 Biochemical/Enzyme Conversion Technologies

7.4.1 Overview

Biochemical conversion technology relates to the use of biological agents, in particular enzymes and micro-organisms, to bring about the degradation of biomass into more useful components. Typical processes involve: the extraction of plant sugars which can be directly converted into ethanol through fermentation processes; the extraction of starch or carbohydrates which can be converted to sugars and then fermented; or the breakdown of cellulosic components into sugars that can be fermented to ethanol. Two dominant bioconversion processes currently being deployed for the production of biofuels are: the extraction of sugars from sugarcane, with the fermentation and distillation of liquor to produce ethanol, and; the fermentation of glucose from maize starch. These biochemical processes are referred to as first generation biofuel technologies.

Second-generation technologies seek ways to use plant biomass which is less 'energy rich', such as sugars and starch, for the production of simple sugars that can subsequently be fermented to ethanol. The plant biomass consists of cellulose (carbohydrate) and lignin matrices and is usually referred to 'cellulosics' or 'lignocellulosics'.

The conversion of cellulosics combines process elements of pretreatment with enzymatic hydrolysis to release carbohydrates and lignin from the wood, followed by the fermentation step to create end products.

A biochemical process for obtaining lignocellulosic bioethanol would typically have four stages:

1. Pre-treatment of substrate to expose carbohydrates, particularly cellulose.
2. Enzymatic hydrolysis of the carbohydrates.
3. Fermentation of the simple sugars to ethanol.
4. Distillation to purify the bioethanol product.

This is a highly simplified process scheme as biochemical processing will often include options to integrate with other industrial processes, combine stages, recover reactants and water, generate co-products, or handle wastes. Furthermore, they may include fractionation of the substrate into separate streams to produce different products, maximise value and optimise individual processes.

Each of these four main phases are summarised below to indicate key processing stages and their benefits and attributes from the point of view of process improvement.

7.4.2 Technology Options

Pretreatment

Biomass often requires some form of pre-processing which makes the biomass more accessible to chemical and enzymatic catalysis. Such processing includes size reduction of the biomass, increase in the surface area, changes in porosity, decreases in cellulose crystallinity and separation of cellulose from lignin and hemicellulose.

The main forms of pretreatment include steam, the use of dilute acid, exposure to hot water, a process called ammonia fibre explosion (AFEX), treatment with lime, wet oxidation and organosolv. Dilute acid and wet oxidation have been successfully tested on softwood substrates, and several pilot facilities have been constructed. Although lignin degradation occurs in both acidic and alkaline pre-treatments, a major difference between them is that hemicelluloses tend to be preserved as polymers in the latter. Certain processes, such as AFEX, seem to be only suitable for nonwoods as they appear to be only marginally effective on woody substrates with relatively high lignin concentrations. With the possible exception of organosolv, there appears to be little cost difference in using the different technologies for the pre-treatment of non-wood lignocellulosics. It is likely that organosolv pre-treatment will be limited by cost considerations, which have restricted similar processes from being widely adopted for pulping wood into papermaking fibres.

Increasing the harshness of the pretreatment stage using heat, duration and acid is required as substrate recalcitrance increases from nonwoods to hardwoods to softwoods. However, increasing severity reduces yields and generates more inhibitors to enzymatic hydrolysis and fermentation.

The current relatively low value of ethanol does not favour elaborate pre-treatment options that have multiple stages, use multiple chemical reactants, or require high energy intensity.

Hydrolysis

Hydrolysis refers to the breakdown of plant material through a process of water molecules being used to split other macromolecules into subunits (i.e. cellulose into sugars). The advantages of enzymatic hydrolysis compared to acid hydrolysis include it being a milder process that requires less energy and equipment demands, and reduces the formation of undesirable by-products (such as inhibitors, residual acids) that need to be either removed or tolerated downstream. Its disadvantages include lower hydrolysis yields.

Three major groups of enzymes are recognised as necessary components of cellulolytic systems that degrade insoluble, particularly crystalline, cellulose into glucose:

1. Cellobiohydrolases that release cellobiose (glucosyl dimers) from the ends of the cellulose polymer.
2. Endoglucanases that "randomly" hydrolyse -1,4 glucosyl bonds within the cellulose polymer.
3. Glucosidases that release glucose from cellobiose and cello-oligosaccharides.

The high cost of commercial cellulases has long been recognised as a limiting factor to the commercial success of bioprocessing routes to bioethanol. Major projects funded by the US Department of Energy over the past decade have aimed to reduce enzyme cost. Successful reduction of cost by 30-fold was claimed by the large enzyme producers, such as Novozymes and Genencor (now part of Danisco). Alternative strategies to reduce the cost of using enzymes in the hydrolysis of lignocellulosics include the recycling of enzymes and the use of polymers and surfactants to reduce non-productive binding of enzymes to substrates.

Fermentation and downstream processing

Several innovations could be developed to tune fermentation to produce lignocellulosic ethanol. These could include: engineering micro-organisms to be more tolerant of inhibitors generated from substrate pre-treatment; engineering micro-organisms to ferment a wider range of monosaccharides, and; combining hydrolysis and fermentation into a single stage.

Simultaneous Saccharification and Fermentation (SSF) increases the final ethanol yield from pre-treated substrates. Its advantages include reducing the number of stages, the alleviation of end-product inhibition of cellulase, and the metabolic reduction of inhibitors of carbohydrate-degrading enzymes that are generated during substrate pre-treatment. The desire to avoid separate stages for the fermentation of hexoses (glucose) and pentoses (xylose) led to the engineering of yeasts to ferment both types of sugars, which could be used in simultaneous saccharification and co-fermentation processes. A more recent approach is the development of "consolidated bioprocesses" in which micro-organisms are engineered to perform both hydrolysis and fermentation.

Metabolic engineering is a highly sophisticated technique for designing micro-organisms for the production of lignocellulosic ethanol. It often involves a very large investment of effort committed to a specific end-product, which is one of its disadvantages.

Separating hydrolysis from fermentation allows more process flexibility because fermentation could be more readily switched toward different products.

Other technology options may include:

- The use of xylose isomerase added to yeast to promote the fermentation of xylose into ethanol.
- The use of carbohydrate-degrading enzymes for the extraction of oil from plants for the production of biodiesel.
- The use of enzymes for the catalytic conversion of gasification products. For example, large scale biological conversion of gasification products from wood is being developed by Alico and the catalytic conversion of syngas by Range Fuels.

7.4.3 Feedstocks

A wide range of feedstocks are suitable for biochemical conversion. These can include: dairy waste products; crops and forestry residues purpose grown crops plant and animal oil derivatives, and; a range of waste and residues sourced from food processing, effluents and solid wastes.

Table 22: Feedstocks and products for biochemical conversion processes

Bioethanol	Biodiesel
Residues	Residues
Whey (current feedstock)	Tallow
Crop residues	Recycled cooking oil
Forestry residues	
Gorse (?)	
Purpose grown	Purpose grown
Crops (e.g. maize, sugar beet, fodder beet)	Oilseeds (e.g. rapeseed, soya, sunflower)
Short rotation forestry (e.g. salix, eucalyptus)	Algae (still experimental)
Switchgrass, Miscanthus	Jatropha, Chinese Tallow Tree

The above list does not include sugarcane as this crop is not suitable in New Zealand. Sugarcane would otherwise be an attractive feedstock because the process generates little waste when cogeneration is included and ash is used as fertiliser.

Although Anchor Ethanol of New Zealand produces 16 ML/y of ethanol from lactose generated as a by-product in the dairy industry, the economic viability of using lactose is highly dependent on other uses of lactose that could obtain higher prices.

Lignocelluosic feedstocks are sought for second-generation bioethanol because they could involve use of wastes and residues, use of marginal land, higher productivity per unit land area, availability year round, and/or less competition with food crops. Agricultural residues are favoured for biochemical processing because they are more accessible to enzymatic hydrolysis than hardwoods, and even more so than softwoods. However, wood feedstocks are more available throughout the year and have higher productivity per unit land area. The recalcitrance of wood substrates is predominantly due to lignin content and composition, which can be modified using genetic engineering.

Past work on genetic engineering of tree species has focused on increasing productivity in different environments or modifying lignin content and reactivity to facilitate pulping. Many of these factors remain relevant for designing wood for the production of biofuels. Genetic engineering could also be used to modify algae to increase yields of oils for biodiesel production or carbohydrates for bioethanol production.

7.4.4 Current and Future Deployment

New Zealand has no commercial deployment of biochemical-based conversion systems for energy production. A range of different technologies are currently being considered with the main emphasis being on wood-to-ethanol via pretreatment, hydrolysis, fermentation and distillation. Preliminary feasibility assessments of this approach have indicated that wood-to-ethanol conversion is not economic leveraging off pulp and paper technology, with production costs being well over $NZ1/litre and 38% to 50% greater than imported Brazilian ethanol. However, through current technology reviews and New Zealand-international partnerships there is a real chance that biochemical conversion costs can be reduced to bring it closer to competitive pricing with alternative biofuel sources.

There are a range of other processes under investigation that integrate both biochemical and thermochemical systems that could potentially further reduce the delivered cost of liquid fuels from biomass.

7.4.5 Costs and Lifecycle

The cost of biochemical conversion of biomass to biofuels was extensively reviewed by the International Energy Agency. This review concluded that the costs of biofuels are highly dependent on feedstock, process, land and labour costs, credits for byproducts, agricultural subsidies, food (sugar) and oil market.

Ethanol energy content by volume is two-thirds that of gasoline, so it is useful to compare costs on the basis of litre of gasoline equivalent (lge). Sugar cane ethanol in Brazil costs $0.30/lge free-on-board (FOB). This cost is competitive with that of gasoline at oil prices of $40-$50/bbl ($0.3-$0.4/lge). In other regions, costs can be more than $0.40-$0.50/lge, although potential exists for cost reduction. Ethanol from maize, sugar-beet and wheat cost around $0.6-$0.8/lge (excl. subsidies), potentially reducible to $0.4-$0.6/lge.

Lignocellulosic ethanol currently costs around $1.0/lge at the pilot scale, assuming a basic feedstock price of $3.6/GJ for delivered straw (whereas cereals for ethanol production may cost $10-$20/GJ). The cost is projected to halve in the next decade with process improvement, scaling up of plants, low-cost waste feedstock and co-production of other by-products (bio-refineries).

The cost of biomass-to-biodiesel from lignocellulose is more than $0.9/lde (feedstock $3.6/GJ), with a potential reduction to $0.7- $0.8/litres of diesel equivalent (lde).

Fossil energy inputs and emissions levels from biofuel production are sensitive to process and feedstock, to energy embedded in fertilizers, and to local conditions. Production of ethanol from sugar cane (Brazil) is energy-efficient since the crop produces high yields per hectare and the sugar is relatively easy to extract.

If sugar cane residues are used to provide the heat and electricity for the process, and ethanol and biodiesel are used for crop production and transport, the fossil energy input needed for each ethanol energy unit can be very low compared with 60%-80% for ethanol from grains. As a consequence, ethanol well-to-wheels CO_2 emissions can be as low as 0.2-0.3 CO_2/litre ethanol compared with 2.8 kg CO_2/litre for conventional gasoline (90% reduction).

Ethanol from sugar beet requires more energy input and provides 50%-60% emission reduction compared with gasoline. Ethanol production from cereals and corn (maize) can be even more energy intensive and debate exists on the net energy gain. Estimates, which are very sensitive to the process used, suggest that ethanol from maize may displace petroleum use by up to 95%, but total fossil energy input currently amounts to some 60%-80% of the energy contained in the final fuel (20% diesel fuel, the rest being coal and natural gas). Hence the CO_2 emissions reduction may be as low as 15%-25% vs. gasoline.

Ethanol from lignocellulosic feedstock – at present, the total energy input needed for the production process may be even higher as compared to bioethanol from corn, but in some cases most of such energy can be provided by the biomass feedstock itself.

Net CO_2 emissions reduction from lignocellulosic ethanol can be close to 70% vs. gasoline, and could approach 100% if electricity co-generation displaced gas or coal-fired electricity. Current R&D aims to exploit the large potential from improving efficiency in enzymatic hydrolysis.

Energy input and overall emissions for biodiesel production also depend on feedstock and process. Typical values are fossil fuel inputs of 30% and CO_2 emission reductions of 40%-60% vs. diesel. Using recycled oils and animal fats reduces the CO_2 emissions.

7.4.6 Barriers and Issues

The most fundamental issues for bioconversion processes include improving the effectiveness of the pre-treatment stage, decreasing the cost of the enzymatic hydrolysis stage, and improving overall process efficiencies by capitalising on synergies between various process stages. There is also a need to improve process economics by creating co-products that can add revenue to the process.

Fundamental research into the dynamics of bioconversion has also focused on the cost of enzymatic hydrolysis, which must be tailored to the complexity of the lignocellulosic matrix. Over four years, coordinated projects between Novozymes, Genencor, and the National Renewable Energy Laboratory in the United States succeeded in reducing the cost of enzymatic hydrolysis on ideal substrates by about 30-fold. Finally, the fermentation of pentose sugars must be achieved in order to reach maximum biofuel production. While 5-carbon fermentation has been achieved on ideal substrates, significant work remains to apply this to realistic lignocellulosic feedstocks.

Increasing overall process efficiency is being improved by integrated research programmes, which combine process development units with pilot or demonstration-scale facilities being developed by a wide range of agencies. It is reasonable to assume that the time horizon for commercial installations will be relatively short, possibly less than five years.

Key Additional References

Wong, K., 2007: Enzyme technology for processing biomass to liquid fuels. Report prepared for the Bioenergy Options Programme, 200.7 (Refer CD)

EECA and CAE, 1996, New and Emerging Renewable Energy Opportunities in New Zealand. Published by EECA and CAE ISBN 0-908993-11-0 265pp.

IEA 2007: IEA Energy Technology Essential IETE.02 Biofuel Production.

7.5 Chemical and Mechanical Processing

7.5.1 Overview

The New Zealand Government has announced a sales obligation that requires 3.4% of liquid transport fuels to be bio-based (biofuels) by 2012. New Zealand will begin to meet this obligation by using existing resources and proven, viable technologies which can create biofuel at reasonable cost. The creation of biodiesel from oily plant material (seeds and nuts) is an obvious starting point, because the process of transesterification of animal fats with alcohol and a catalyst is common technology.

Biodiesel can be manufactured to a high fuel quality, suitable for use in compression ignition engines. Well-tuned modern diesel engines can run on biodiesel at high blend levels. Typically biodiesel has 94% of the energy per unit of petro-chemical diesel. The fuel is widely accepted in Europe and North America.

7.5.2 Technology Options

Biodiesel consists of the methyl esters of the fatty acid component of the trigylcerides that make up most vegetable oils and animal fats. Transesterification (reacting the fats or oils with methanol) produces biodiesel and a glycerol by-product. Glycerol comprises 9% of the material produced during the process.

Both oils and fats can be processed using the same plant, although a different pre-treatment process is required for each feedstock.

The transesterification process contains four principle steps:

1. Pre-treatment of the tallow or oil feedstock to remove components that will be detrimental to subsequent processing. (i.e. free fatty acids and gummy materials respectively).
2. Transestrification (reacting methanol with triglycerides to form methyl esters and glycerol) and the subsequent separation of the methyl ester and glycerol streams.
3. Purification of the methyl esters, removing the excess methanol, catalyst and glycerol.
4. Glycerol purification, where methanol is removed (in both of the last 2 stages the recovered methanol is recycled into the transesterification).

Use of waste cooking oil can produce a fuel that is cost competitive with current diesel pump prices.

It can be described in simple terms as;

Triglyceride + alcohol → fatty acid esters + glycerol

Transesterification can be done using simple equipment and can be manufactured on a small scale, typically using waste cooking oil as a feedstock. Large scale production is also common, with plants of up to 100,000 tonnes per annum having been built. It is a well understood technology, with yields close to theoretical limits.

7.5.3 Feedstocks

Oilseed rape (canola) and sunflower are the most common sources of biodiesel globally. In New Zealand, biodiesel is already being made from waste cooking oil and is available for public purchase at small scale. There are plans to establish a canola resource sufficient to provide up to 70 million litres of biodiesel per annum based in South Canterbury. Feasibility studies are also being done on using tallow (animal fats) from the New Zealand meat industry to produce 50+ million litres of biodiesel per annum.

Waste cooking oil

In New Zealand biodiesel is produced from used cooking oil collected throughout the country. For example oil is processed at an Addington (Christchurch) plant, with production currently around 1 million litres per year. In the North Island there are a number of producers, one being Bay Biodiesel who process 2 to 3000 litres per week. The total New Zealand resource of waste cooking oil is estimated to be 5-6 million litres per annum, largely sourced from major population centres.

Tallow

Beef tallow has a low degree of unsaturation, relative to vegetable fats, so it produces biodiesel that is more stable in storage. On the other hand, tallow begins to solidify at relatively low temperatures, which limits its use in cold climates. New Zealand produces sufficient tallow as a by-product of the meat industry to produce enough biodiesel to satisfy around 5% of total diesel fuel needs (2.3% of all road transport fuels). This equates to 145 million litres of biodiesel per annum, assuming that all tallow is used for fuel. There is competition for some grades of tallow as an ingredient in processed food products and soap. Much of the tallow produced is exported and can attract a price of up to $850 per tonne.

Oilseed Rape (Canola)

Rapeseed has been targeted as a major source of biodiesel in New Zealand. Biodiesel New Zealand is encouraging farmers to grow oilseed rape in order to supply a biodiesel production plant with a target capacity of 70 million litres of biodiesel per year by 2011 (www.Canterburybiodiesel.com). This level of production would meet about one third of the Government's 2012 target for biofuels. The land area required to meet this level of production would be around 50-55,000 ha, in a region that already has over 100,000 ha of arable cropping land. Some competition with land for growing food crops and animal grazing is inevitable if the stated levels of production are to be achieved. Oil is extracted from the oil seed by pressing and heating.

7.5.4 Current and Future Deployment

The biodiesel currently produced in New Zealand comes from waste cooking oil. The supply of this material is small in relation to the scale of the demand (less than one tenth of a percent of liquid fuel demand) and unlikely to expand greatly.

The use of some biodiesel is inevitable if fuel suppliers are to avoid the penalty costs implied in the Governments biofuels sales obligations targets. In order to meet this need, the establishment of a canola resource seems likely. The use of tallow-based biofuels will depend on the export price of tallow.

7.5.5 Costs

Use of waste cooking oil can produce a fuel that is cost competitive with current diesel pump prices. Biodiesel can be purchased in the Bay of Plenty for $0.90 per litre.

Tallow comprises about 80% of the cost of a fat-based biodiesel product, so the cost (export price) of tallow will drive the cost of the biodiesel product. It is likely to be at least $1.10 litre at the plant, prior to distribution and tax. There is interest in developing tallow-based plant in New Zealand driven by the demand created by the Government's biofuels target.

The cost of growing vegetable oils (e.g., canola) make this the most expensive option for producing biodiesel. The cost of the oil is likely to be tied to the cost of alternative arable crops such as wheat, in order to make

the returns to the grower sufficiently attractive to make them convert to canola. For this reason it is difficult to estimate the costs as it will vary with wheat price and crop yield.

The ability to find a market for the glycerol will also be a significant factor in the price of the fuel product. Glycerol has traded at high prices and is around US $780 per tonne (2007). However, as world production of biodiesel increases the supply of glycerol will also increase, and prices are likely to trend down.

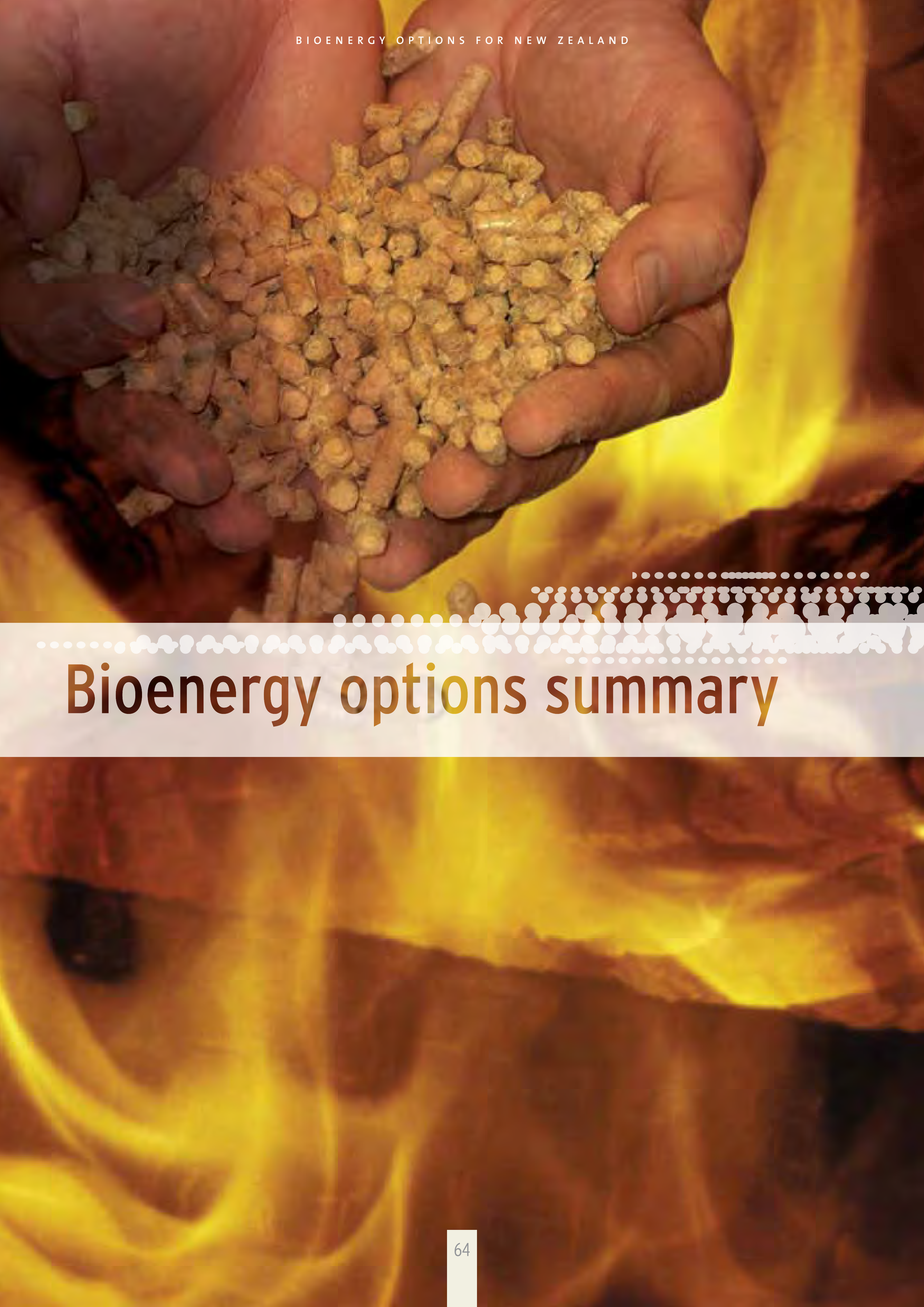
The capital costs of a large biodiesel plant (70,000 tonnes per annum) are likely to be NZ$25 to 30 million.

7.5.6 Barriers and Issues

- Blending rates and fitting the product into infrastructure.
- Fuel quality and standards.
- Land use competition for canola crop.
- Export competition for tallow.

Key Reference

Newman, R. (2007) Chemical and Mechanical Processing of oils and fats – potential for biodiesel in New Zealand. In Scion report "Bioenergy Options for New Zealand". (Refer to CD)



Bioenergy options summary

8.0 BIOENERGY OPTIONS SUMMARY

8.1 Resources

New Zealand has a variety of biomass resources suitable for energy production which arise from forestry, agriculture, processing and municipal sources. The contribution that these resources could make to New Zealand's energy demand is outlined below.

Table 23: Total possible residual biomass resource for energy production (PJ/year)

Type/source	2005	2030	2050
Forest residues	18.3	43.0	36.9
Wood process residues	8.8	11.4	23.0
Municipal wood waste	4.4	2.7	3.6
Horticultural wood residues	0.4	0.4	0.4
Straw	9.1	9.1	9.1
Stover	3.8	3.8	3.9
Fruit and vegetable culls	1.5	1.5	1.6
Municipal biosolids	0.9	1.1	1.2
Municipal solid waste, putrescible	2.8	2.9	2.9
Farm dairy effluent	1.5	1.5	1.6
Farm piggery effluent	0.1	0.1	0.1
Farm poultry litter	0.04	0.0	0.1
Dairy industry effluent	0.5	0.5	0.6
Meat industry effluent	0.6	0.6	0.7
Waste oil	0.2	0.2	0.2
Tallow	4.5	4.5	4.5
Total	**57.3**	**83.1**	**90**
NZ primary energy	690.0	890.0	1090.0
NZ consumer energy	540.0	720.0	880.0
All biomass, as % of consumer energy	10.6	11.5	10.2
All biomass, as % of primary energy	8.3	9.3	8.2

Today forest residue is the single largest resource, with agricultural straws and stovers second. Over time the wood processing residues sector (3rd currently) is expected to exceed agricultural residues, on the assumption that increased processing will follow the increased availability of harvested wood. Agricultural residues are assumed to stay relatively static, with little room for major expansion of arable land, although there may be some change in the type of crop being grown.

Tallow could potentially make a significant contribution to the production of liquid biofuel, but there is competition for the resource, with the bulk of it already being sold, much of it for export.

Gas from municipal waste could also make a contribution of several PJs. Effluents and biosolids come from a variety of sources and are widely dispersed around New Zealand. Collectively they are estimated to be capable of producing 4.5 PJ of energy.

Woody residues from all sources are currently over half of the total biomass resource in terms of energy content. By 2050 this could be as high as 65%.

A significant driver of the use of biomass resources for the production of energy will be the relative cost of coal, gas and petroleum. Rising costs will increase demand for bio-energy.

8.2 Potential vs Economic Resources

There may be a difference between the total amount of a resource which is potentially available, and the proportion that is technically and economically available.

Useable quantities may vary from resource to resource, based on scale, location and accessibility. For logging residues, some allowance has been made in the initial estimates for the fact that not all material will be collected. This is also the case for agricultural straw residues. If the table below had a uniform reduction of 80% to allow for the fact that some of the resource is small, scattered and difficult to access, the figures for biomass energy would be as follows:

Table 24: Assessment of resources available, assuming 80% is available to use (PJ/year)

Type/source	2005	2030	2050
Forest residues	14.6	34.4	29.5
Wood process residues	7.0	9.1	18.4
Municipal wood waste	3.5	2.2	2.9
Horticultural wood residues	0.3	0.3	0.3
Straw	7.3	7.3	7.3
Stover	3.0	3.0	3.1
Fruit and vegetable culls	1.2	1.2	1.2
Municipal biosolids	0.6	0.7	0.7
Municipal solid waste, putrescible	2.2	2.3	2.3
Farm dairy	1.2	1.2	1.3
Farm piggery	0.1	0.1	0.1
Farm poultry	0.0	0.0	0.0
Dairy industry	0.4	0.4	0.5
Meat industry (effluent only)	0.5	0.5	0.6
Waste oil	0.2	0.2	0.2
Tallow	3.6	3.6	3.6
Total	**45.9**	**66.5**	**72.0**
Available biomass as % of consumer energy	8.5	9.2	8.2
Available biomass as % of primary energy	6.6	7.3	6.6

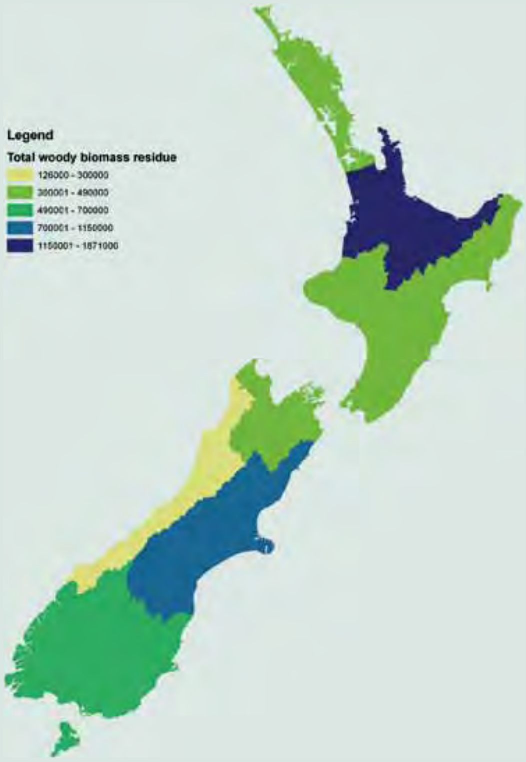
Moving to an estimate of available energy reduces the total amount of energy from biomass by 20%, but does not change the relativities between resources. Woody residues are still dominant. The focus of future research and development in use of biomass must be on utilising this woody material if New Zealand to take advantage of existing residual resources.

At a local or site specific level biomass resources are often very small, and getting economic scale can be difficult. This means that aggregation of similar resources and or co-location of energy plant will need to occur in order to utilise the smaller scale resources.

8.3 Regional Distribution of Woody Biomass

If woody biomass resources are to be utilised, they have to match demand. Biomass resources are typically widely distributed. Apart from knowing the energy potential of these resources, it is also essential to know where the resources are. The map below outlines the location of woody biomass resources.

Figure 13: Distribution of all woody biomass resources for New Zealand (2007) (tonnes/year)



The Central North Island has the largest concentration of woody biomass (Forest residues and wood processing residues). The potential contribution of straws in Canterbury should not be overlooked, straws were counted as lignocellulosic in the context of this map.

8.4 Land Use Potential

New Zealand has a significant area of land that is medium to low productivity grazing, or in unproductive use. This land is often steep, erodable and in remote locations. However it represents an opportunity to store carbon and provide biomass which can substitute for fossil fuels.

A conservative estimate of this area is 831,000 ha. However, depending on the criteria used, this area might be as high as 5.1 million ha. The 830,000 ha is the area identified as low quality pasture in land uses classes (LUC) 5, 6 and 7 in the New Zealand land cover database (LCDB2), using an altitude limit of 800 m in the North Island, 700m in the South Island and a slope limit of 45 degrees.

If 20% the land area that is identified in the database as Unknown Use is included then this figure rises to 1,043,000 ha.

If medium quality pasture/grazing in these land uses classes is included (sheep, beef, deer but not dairy), and using the same altitude and slope criteria, then the potential area becomes 4.462 million ha. However it would be unrealistic to assume that all of this land would be available, accepting that only 20% of the high quality grazing land in land use classes 5 , 6 and 7 can be changed to forestry the total available becomes 1,726,000 ha.

If the altitude limits are lifted to 1000m for both the North and South Islands and LUC 4 is added, then the area potentially available becomes 5.169 million ha.

Realistically the land area that could be swapped from low productivity grazing to forestry (for carbon, erosion and energy as well as timber production) will be somewhere between the low of 830,000 ha and the high of 5.169 million ha. A realistic figure may be 2.5 to 2.7 million ha.

Further analysis of the LUC database will give greater accuracy on land availability, possible use versus current use and the location of the land. Distribution of the land potentially available varies with the criteria used. In the first case (830,000 ha) 89% is in the South Island, in the highest area case (5.1269 million ha) 54% is in the North Island.

The implications of this area of land being in plantation pine forest (or similar) for energy production are significant.

There are a number of options which could be considered; 100% of the wood to energy (purpose grown energy forest), 50% of the wood to energy and the other half to timber products, 25% of the wood and all residuals to energy and 75% to timber products. The energy contribution of this land area under these scenarios is outlined in the table on the following page.

Table 25: Potential Forest Area, Harvest Volume and energy scenarios

Area (ha)	Harvest volume, m^3 per annum	100% to energy		50% to energy		25% to energy	
		PJ	l/biodiesel (billions)	PJ	l/biodiesel (billions)	PJ	l/biodiesel (billions)
830,000	18,260,000	164	1.9	82	0.94	41	0.47
2,500,000	55,000,000	495	5.7	248	2.83	124	1.42
4,400,000	96,800,000	871	10.0	436	4.99	218	2.49
5,100,000	112,200,000	1,010	11.6	505	5.78	252	2.89

If the low productivity grazing land was converted to forestry, and only 50% of the biomass was used for energy (the rest being used for traditional log products) the potential contribution to either heat or liquid fuels is substantial (shaded figures) and contributes a significant component of New Zealand's energy demand. (Table 25)

There is also potential to use significant areas of land for short rotation forestry, although this land is generally of easy contour, and would be more likely to compete with dairy and cropping land. There is around 5 million ha that could be used for SRF in New Zealand, and to meet our liquid fuels requirement (based on conversion to ethanol) it is estimated that we would require around 2.55 million ha. A similar area would be required to grow fuel using conventional forestry 100% for energy. However, SRF requires land that is traversable by ground based harvesting machinery. Conventional forestry is not limited in this way as the use of hauler systems on steep land is potentially possible provided the stem piece size is large enough to make recovery economic.

There is potential to grow crops for energy on arable land using annual species, the two that have been investigated in detail in New Zealand, are sugar beets and canola. There are plans to establish a large enough canola crop to supply a commercial biodiesel operation in South Canterbury (70 million litres from 45,000 ha or 1.2% of the national fuel demand from 1.8% of New Zealand's arable land). This crop will be competing for arable land, and the price paid for the canola crop is likely to be linked to the price of wheat. The driver for this development is the Government's biofuel target (3.4% by 2012). To meet New Zealand's total liquid fuels demand in this manner would require around 4,000,000 ha of arable land. New Zealand currently has 2,375,000 of land use classes I and II (suitable for cropping). This means of generating liquid fuels will impact on food production if the volumes grown exceed a few percent. It has the advantage that land can be converted back to food crops very rapidly at minimal cost.

It is interesting to compare fuel from canola and fuel from wood in terms of land use and supply. A broad estimate is that to create 100% of current liquid fuels demand from canola would take 150% of New Zealand's arable land. This is not achievable, so the country would need to import staple foods (grains etc) for food supply displaced by energy crops. On the other hand to make 100% of the liquid fuel demand from wood, would require about 30% of available lower quality grazing land, and none of the high quality grazing land.

This is a reflection of the area in each land use class in New Zealand, with only around 2.3 million ha of arable land, and 7.6 million ha medium to low quality pasture (+3.3 million ha in high-quality pasture).

8.5 Conversion Options

Combustion

Combustion of biomass is a mature technology widely used both in New Zealand and overseas. In New Zealand the largest user of biomass combustion is the wood processing industry. Wood residues contribute 19 PJ of energy to sawmilling and panel manufacture and a further 25 PJ (including black liquor) to the pulp and paper industry.

Combustion can be used in a variety of ways to create heat, or to make steam for a combined heat and electricity, or electricity-only system. The efficiency of combustion systems is influenced by the size of the installation, with larger systems being more efficient. Combustion for heat is the most efficient of these systems, and can be over 90% in large scale applications. Combined heat and power systems are 60 to 70% efficient and power generation only around 30%.

Combustion systems can cope with green biomass fuels, with moisture contents of up to 60% acceptable in some systems. However, system efficiency improves with lowering moisture content. Industrial combustion systems can cope with particle sizes of up to 150mm, or can be designed to run on fine material such as sawdust.

In many biomass systems co-firing with coal is possible and is used to meet rapid changes in heat or steam demand. In some case coal fired systems can have 10 to 15% of the input fuel substituted with biomass.

Almost any biomass can be combusted, including de-watered biosolids and meat works effluents, although ash contents in these fuels is very high (25 to 30%), where clean wood has an ash content of less than 1%.

Combustion of biomass is considered to be carbon neutral as the carbon was absorbed from the atmosphere during the production of the biomass. The sulphur emissions from woody biomass are very low compared to coal. Biomass ash, particularly that from plant material has lower heavy metal levels than coal ash and can be applied to soils.

Pelletising wood residues is a recent development and the pellets are being used to replace coal in small boiler systems (schools) and in domestic fireplaces and boilers. Due to their flowable nature the materials infeed can be automated.

Due to its technological maturity, existing widespread use and flexibility of scale and fuel type, combustion will typically be the primary means of converting biomass to energy in the short term. It is also a very efficient means of converting biomass to user energy, particularly heat. The current scale of the heat demand exceeds the energy available from residual biomass resources, so all of this material could theoretically be used in this manner. However, it is unlikely that this will occur due to mismatches in heat demand and biomass resource locations and the much higher values per unit placed on other energy forms, particularly transport fuels and electricity.

Barriers

- Biomass combustion systems are more capital intensive than coal and gas systems and take up more land than gas plant.
- Fuel supply is critical to efficiency and getting a guaranteed supply at a guaranteed quality is often difficult for those outside the forest and wood processing industry.

Gasification

Biomass gasification is incomplete combustion in a restricted air supply. This produces a gas containing, CO, CO_2, hydrogen and methane. This gas can be used in internal combustion engines, gas turbines or converted into other products, including liquid fuels such as ethanol and biodiesel, or a wide range of chemicals. Gasification is an effective way to convert biomass into a gas stream that can be used for a wide range of applications.

There are five principle configurations of gasifier and they range in size from 20KW to 100MW.

Gasifiers are complex and have higher demands in terms of feedstock specifications than combustion systems. The feedstocks typically need to be dry (< 50% mc w/w) and have small particles size (<10mm). The feedstock influences the gas produced and the design of the system must be matched to the intended use.

There is significant development underway worldwide looking at gasification at both small and large scale. The large scale gasifiers are aimed at combined cycle heat and power systems and production of liquid biofuels. Gasification offers significant potential to utilise biomass to produce heat, power and gas for chemical and biofuel production.

There are no commercial gasifying systems operating in New Zealand. Experimental facilities operate at Page Macrae and University of Canterbury, and Alternative Energy Solutions have imported a 30kW gasifier coupled to an internal combustion engine/electric generator for demonstration (2007) and sale.

Installation and operating costs (derived from overseas data) are $1000 to $1600 per KW of gas output and 4.5 to 6.6 cents per kWh of gas.

Life cycle analysis of a Battelle Ferco gasifier-to-electricity system found that net energy was highly positive and carbon closure was 95%. Biomass gasification compares favourably with coal combustion as it has lower SOx, NOx and fine particulate matter emissions and cleaner ash.

Gasification of biomass has been researched extensively for the past 15 years, and there are indications that some of the technologies are approaching commercialisation, albeit in countries where biofuel production is subsidised. If oil prices remain high, gasification of biomass and then conversion to liquid fuels will become more prominent and closer to economic viability. Gasification coupled with heat plant or combined cycle heat and power generation may be viable in some New Zealand industries depending on the cost of carbon emissions.

Possible barriers to gasification technology include:

- Competition from conventional fuels.
- Lack of controlled quality feedstock at guaranteed price and supply volume.
- Lack of performance guarantees from developers.
- Gas cleanup has been a significant technical hurdle.

Pyrolysis

The pyrolysis process produces a mixture of materials, bio-oil, char and gases, the mix and proportions being dependant on the temperature and vapour residence times. To produce bio-oil requires moderate temperatures and short residence times, biochar production requires lower temperatures and longer residence times.

Any organic matter can be pyrolysed, but it needs to dried and size reduced prior to processing.

There are four principle designs of pyrolysis reactor, which system is best depends on the feedstock available, the desired products, scale and available infrastructure, including skilled staff.

Feedstocks should be less than 10% moisture content w/w and particle size is generally very small (< 2mm) although ablative systems can use larger piece size (10 mm). The moisture content of the feedstock has a direct impact on the energy content of the fuel (bio-oil) produced, as the water ends up in the bio-oil. Low ash content fuels are better, but fluidised bed reactors can cope with higher ash levels than other systems.

Currently there are no commercial pyrolysis systems in New Zealand and few worldwide. There is a lab scale system at AgResearch in Christchurch and Alternative Energy Solutions is investigating the importation of a small scale system from Advanced BioRefinery (Canada).

The oil produced typically has a fuel energy content of 17 MJ/kg, which is denser than raw biomass, this reduces storage and transport costs.

Bio-oil is not suitable for use in internal combustion engines but is being trialled for use in gas and coal fired power stations.

Biochar from pyrolysis is being investigated for use as a carbon capture and storage method, with the char being incorporated into soils.

Further refining or gasification of bio-oil can produce fuel for turbines or biodiesel, but these options are still under development.

Pyrolysis is seen as part of the bio-refinery concept

Pyrolysis is currently receiving greater research investment than in the past. Much of this is in the area of creating chemical product from the biomass as much as the energy or bio-oil. The creation of biochar as a carbon storage mechanism is a relatively recent development and is also receiving greater research investment. Many of the possible technology options are still developmental, and there is little solid information on production and cost.

Key barriers affecting deployment of this technology are:

- Bio-oil has high water content, low pH and is corrosive.
- Capital cost of plant is high.
- Some of the processing is still developmental.

Anaerobic Digestion

Anaerobic digestion is an established technology that is used widely around the world and is well established in New Zealand, with a variety of waste streams being treated. It can take a wide range of biomass resources and effluents and produce biogas that has an energy content of around 23-24 per m3. This gas can be upgraded and then fed directly into natural gas pipelines.

The potential energy from anaerobic digestion suitable resources (biosolids, effluents and putrescible wastes) is in the order of 4 to 5 PJ/year, with a slight rise probable over time following population trends and any dairy farm expansion.

The cost of gas from anaerobic digestion is likely to be higher than the current cost of commercial gas. However, it has the benefit that the materials used are wastes and residues, which usually have a disposal cost (both monetary and environmental) attached to them. The anaerobic digestion of these waste streams removes the organic matter and leaves a nutrient rich water, this can be reused several times and then used as a fertiliser. Recent developments in algal research also suggest that this nutrient rich water could be used for growing algae, which can in turn be used for anaerobic digestion or possibly production of biodiesel.

The anaerobic digestion of these waste streams may have considerable environmental value (GHG abatement, nutrient runoff reduction).

Drivers for increased use may come from improved economics around increased gas production and reduced capital costs as well as environmental marketing and differentiation for export products.

Enzymes

The use of enzymes in a New Zealand context is likely to be (and currently is) focussed on using second-generation technologies for the conversion of biomass to liquid biofuels. The reasons for this are that we have a large and uncommitted woody biomass resource available to utilise and are unlikely to be able to create first generation fuels cost competitively with imports or the demand for food crops. The potential to expand the supply of woody biomass is also likely to be larger than the alternatives due to the ability to grow forests on marginal lands at reasonable levels of productivity and produce a stem piece size that is economic to recover.

Feasibility studies of utilising enzymes on woody biomass to make 2nd generation biofuels are under way in New Zealand. Indications are that achieving the feedstock supply needed by the larger scale plant required to achieve optimum economic size will be a challenge if only residues are being considered.

Costs are estimated to be in the order of $1.00 per litre of gasoline equivalent at the plant (before distribution, tax and margin are added).

Challenges to be addressed are reducing the delivered cost of woody biomass feedstock, the cost of enzymes and creating co-products to add value.

Overseas research and development in this area is expected to see commercial scale plant in operating within five to 10 years.

Barriers

- Integration of ethanol in the existing liquid fuel infastructure
- Blending rates (ethanol to petrol).

Chemical and Mechanical

The creation of liquid fuels from oils, fats and oil crops is a well understood technology (transesterification) and processing yields are near to theoretical limits. The three main sources of raw material in New Zealand are, or are likely to be; waste cooking oil, tallow from meat processing and oil crops (canola).

The use of waste cooking oils is well established with a number of operations selling biodiesel made from waste cooking oil. These operations range from 250,000 to 1,000,000 litres per annum. This source of fuel is limited as the resource of oil is estimated at 5 to 6 million litres per annum. However, it can be produced at a cost competitive with diesel pump prices and is already making a contribution to New Zealand's liquid fuel supply. It is likely that the supply of biodiesel made from waste oil will have a maximum of around 5 million litres per annum, currently it can be bought for $0.90 per litre (Bay Biodiesel, November, 2007).

Tallow from meat processing is a larger resource, with a maximum (depending on stock slaughter numbers) of around 170,000 tonnes per annum. Much of this material is exported and has a value (approximately $850 per tonne, 2007). There is the potential for a large tallow-to-biodiesel processing plant to be built in New Zealand (Argent Energy), in the range of 50,000 to 70,000 tonnes of feedstock capacity (50 million litres of biodiesel). The cost of the biodiesel would be competitive with current pump price of diesel, but the decision to invest is likely to be driven by the government's biofuels target.

The crop most likely to be used for producing oil for biodiesel is canola (oil seed rape). Biodiesel New Zealand has announced plans to establish a crop resource sufficient to provide 70 million litres of biodiesel. This project will be centred in South Canterbury, and will take in the order of 45,000 ha of arable land.

There is room to expand the production of biodiesel from tallow up to a maximum of around 140 million litres, and the amount of biodiesel from canola crops will be limited by the demand for land to grow food. It is likely that there will be a move to growing some oils crop in the short term to meet the Government's biofuel target, but the land can move quickly back to food production as both canola and food crops such as wheat are annuals. Growing biofuels on arable land in this way is not a large scale solution to New Zealand's liquid fuels demand as it would take more arable land than we have to grow all the liquids fuels we use.

Other

International trends for biomass processing are towards multiple products from the biomass resource, not just energy, with the term bio-refinery being used. This is not that different from the concept of an oil refinery that also typically produce many different products, not all of them energy. Conversion technologies are merging into integrated systems (gasification and pyrolysis giving energy + other products). Even combustion technology is being viewed as having other products (ash for fertiliser) and high CO gas streams having the potential to be processed to create liquid fuels (LanzaTech).

There is significant research and development investment being made in Europe and North America, this has currently developed a focus on biomass to liquid fuels technologies, especially biomass gasification to liquids.

New Zealand situation

There are significant issues still to be solved:

- Continuity and guarantee of feedstock supply.
- Cost per unit of fuel.
- Capital cost of plant.
- Cost of feedstock.
- Feedstock specification and handling characteristics.
- Effect of scale on cost, large plants have an advantage in some areas around infrastructure and permitting, but it can create issues around getting sufficient biomass to make a viable supply. For example biomass to ethanol plants using enzymes target a plant size of 100 to 150 million litres of product, requiring up to 1,000,000 tonnes of biomass per annum.

There are still technical issues to solve around chemical extraction from biomass, especially around multiple chemicals within a process.

Energy Product Costs

For many of the resources it is possible to put a value on the cost of delivering the raw material to some point of use. However, due to the dispersed nature of the resources, transport of the resources is often involved and is difficult to be precise, so a range of likely costs is given (Table 26).

Table 26: Delivered cost of raw material (in a fuel form)

Resource type	Cost range $/GJ
Forest trees	$8.70 to $15.50/GJ
Forest residues landing	$3.20 to $3.70/GJ
Forest cutover easy	$4.10 to $4.70/GJ
Forest cutover steep	$6.00 to $7.00/GJ
Municipal wood waste	$2.00 to $2.60/GJ
Wood process waste	$0.25 to $2.30/GJ
Horticultural wood residues	$3.70 to $4.70/GJ
Straw	$2.6 to $5.20/GJ
Stover	$2.6 to $5.21/GJ
Fruit and vegetable culls	$1.45 to $4.10/GJ
*Biosolids	$9.00 to $18.00/GJ
*MSW	$9.00 to $18.00/GJ
* Landfill gas	$9.00 to $18.00/GJ
*Dairy	$9.00 to $18.00/GJ
*Piggery	$9.00 to $18.00/GJ
*Poultry	$9.00 to $18.00/GJ
*Dairy	$9.00 to $18.00/GJ
*Meat	$9.00 to $18.00/GJ
Waste oil	$29.50 to $32.00/GJ
Tallow biodiesel	$21.50 to $25.00/GJ

* The fuel form for these resources is biogas from a digester. No transport cost is applied, as it is assumed it will be utilised close to the digester.

Once the material goes to a site for conversion from a fuel to an energy product (for example hogged forest residues to industrial heat) more cost is added. Costs for many of the more advanced conversion technologies are not well defined as they are still at demonstration level. In Table 27 the high and low delivered costs have had two different assumptions applied to them to get from a raw fuel to an energy product; these are that the fuel is either 40% of the cost of the final product or 60% of the final product.

Tabel 27: Cost of delivered energy from biomass.

	Low $/GJ	High $/GJ	Low 40%	High 40%	Low 60%	High 60%	Low 80%	High 80%
Forest, purpose grown	$8.70	$15.50	$21.75	$38.75	$14.50	$25.83		
Forest residues, landing	$3.20	$3.70	$8.00	$9.25	$ 5.33	$6.17		
Forest residues, easy	$4.10	$4.70	$10.25	$11.75	$ 6.83	$7.83		
Forest residues, steep	$6.00	$7.00	$15.00	$17.50	$10.00	$11.67		
Municipal wood waste	$2.00	$2.60	$5.00	$6.50	$3.33	$4.33		
Wood process waste	$0.25	$2.30	$0.63	$5.75	$0.42	$3.83		
Horticultural wood residues	$3.70	$4.70	$9.25	$11.75	$6.17	$7.83		
Straw	$2.60	$5.20	$6.50	$13.00	$4.33	$8.67		
Stover	$2.60	$5.20	$6.50	$13.00	$4.33	$8.67		
Fruit and vegetable culls	$1.45	$1.75	$3.63	$4.38	$2.42	$2.92		
Biosolids	$17.00	$19.00					$21.00	$23.00
MSW	$17.00	$19.00					$21.00	$23.00
Landfill gas	$18.00	$22.00					$21.00	$23.00
Dairy	$17.00	$19.00					$21.00	$23.00
Piggery	$17.00	$19.00					$21.00	$23.00
Poultry	$17.00	$19.00					$21.00	$23.00
Dairy	$17.00	$19.00					$21.00	$23.00
Meat	$17.00	$19.00					$21.00	$23.00
Waste cooking oil biodiesel	$27.00	$29.00	Finished Product					
*Tallow biodiesel	$21.00	$22.00	$35.00	$36.67	$26.25	$27.50		

* Uses the assumption that 60% and 80% of the final cost is in the raw material

The costs presented here are based on calculations of real cost, which may be different from the market price being charged, due to different perceptions of the return that investors look for, to cover risk.

The costs presented cover large ranges, and are very general, which is all that is possible given the impact of the many variable on these costs, including the impact of scale. In the later phases of the bioenergy options project it is intended to cover the issue of cost in more detail, but on fewer options, once some of the realistic pathways have been determined.

In order to assess the cost of biomass fuels with fossil fuels some comparative prices for coal, gas and electricity are provided in Table 28.

Table 28: Comparative prices for major fuels

	Cost	(less tax)	$/GJ	(less tax)	
Petrol, l	$1.76	($1.06)	$54.65	($32.92)	Pump, November 2007
Diesel, l	$1.18	($0.86)	$32.96	($24.02)	Pump, November 2008
Coal, t	$125.00		$5.50		Industrial
Natural Gas, GJ	$12.00		$12.00		Commercial
Biodiesel, l	$0.90		$26.78		Local Supply, Rotorua, November 2007
Electricity, c /kwh	$0.04		$16.67		Commercial
	$0.16		$44.44		Domestic (includes line charge)

From these two tables it can be seen that making liquid biofuels from waste cooking oil and tallow are either currently cost competitive, or close to it.

It is also apparent that several of the woody biomass resources are cost competitive with coal (wood processing residues, municipal wood waste, landing residues, horticultural wood residues, and forest residues off easy slopes). Recovering material from steep slopes in forests is not cost competitive. However, the use of some residues will rely on finding or developing a demand of a scale to match the resource, which is widely distributed, often far from urban and industrial centres and costly to accumulate at a central point.

The use of straw residues would appear to be cost competitive, assuming that a user for this resource can be developed (the majority of the resource is in Canterbury).

There are a variety of resources for which the current obvious conversion pathway is anaerobic digestion. It would appear that most of these resources are marginally cost competitive with gas on a straight cost of production basis. However, if the cost of the avoided alternative treatment and disposal of the effluent is included in the calculations the outcome may well be different for some resources. The environmental benefits of using these waste materials for energy and treating it along the way are hard to define in dollar terms.

Where to now?

Global Energy Influence

The World Energy Outlook (WEO) 2007 (IEA) projects the world's energy demand to increase to 2030, driven largely by economic development in China and India. It is expected that much of this demand will be fuelled by coal, but there will also be an increasing demand for transport fuels (oil) and natural gas (especially India). Whilst some OECD countries are expected to reduce energy demand and GHG emissions from efficiency gains and use of renewable energy (including biomass) these reductions will require that many countries meet their stated energy and GHG targets. The USA is expected to continue relying heavily on coal and oil. New Zealand can expect increased demand for coal exports and focus to remain on getting GHG emissions down, from a combination of efficiency improvements and increasing use of renewables across electricity, heat and transport demands. The WEO expects that there will be sufficient oil to meet demand until 2030, albeit from increasingly difficult to recover sources. It also states that there may be a supply crunch and subsequent price spike in the years up to 2015.

For New Zealand this would appear to mean that there will international pressure on the cost of coal, oil and gas for the next 25 years. If prices for oil stay at the current levels (US $90+ per barrel) then the current focus on development of liquid biofuels is likely to continue. If the price of coal rises due to international demand then the use of biomass as a substitute for coal may be more viable than at present.

NZ Energy Strategy

The recently released New Zealand Energy Strategy to 2050 has set some ambitious goals, some of these are: 90% renewable electricity by 2050; 60% electric cars by 2050; 10.5 PJ of additional energy from woody biomass with 7 PJ from forest residues, and; 3.5PJ from other wood residues by 2025. Linked to these targets are some forest policies and the emissions trading scheme. These aim to reduce the amount of deforestation and encourage increased afforestation with a target of 250,000 ha of new forest by 2025.

There is a significant focus on increasing renewable electricity from geothermal, hydro wind and marine sources. At a smaller scale there is interest in expanding use of solar hot water at a domestic and commercial level.

Biomass use is going to have to increase markedly to meet government targets with forest residues use becoming wide spread (an 8 fold increase over current levels) and use of wood processing and municipal wood waste expanding by 45%. The biomass targets are potentially achievable with our existing resources and established use in the wood processing industry. However, in order to make forest residues derived fuels competitive with coal, significant gains in the efficiency of the delivery system will be required, with the potential to make improvements in all parts of the supply chain. Research in this area will have to be a priority if the targets are to be met.

There is also room to make much greater use of municipal and farm effluents through anaerobic digestion. Use of these resources has a two-fold benefit, it treats the effluent (removing organic matter) and generates biogas that can be used for distributed heat and power or urban transport. Further, there is substantial optimism amongst researchers that the nutrient rich water, which is left after anaerobic digestion of the effluent, can be used to grow algae. The algae produced can be used either in an anaerobic digester to produce more biogas, or if developments meet their claimed potential, liquid biofuels (biodiesel).

NZ Scenarios

A scenario is a high level view of what the future will be like, for example: an electricity-centric energy supply; high renewable content, and; urban densification with less use of personal transport. There are many alternatives that could be realistic, including one that sees major oil discoveries (NZ and world wide) along with significant gains in the efficiency of cars, continued reliance on fossil fuels, with reduced GHG emissions from the transport sector due to efficiency improvements.

One of the problems with trying to predict what the future will look like is that there are many uncertain factors, that can have a major influence on how things develop in the short or long term. In short, no one knows. However, in order to have a plan we have to make a best guess as to where things will probably head. The general consensus (with a few notable exceptions) is that we face a future that will be driven by: high oil prices; constricted oil supply; climate change and pressure to reduce our GHG emissions; increasing use of renewable energy, and; a move to distributed generation and distributed biofuel refining.

Pathways for Bioenergy in New Zealand

A pathway is defined in this context as the route from raw resource through some conversion process to a consumer energy product (heat, power or transport fuel). For example; farm dairy effluent through anaerobic digestion to an ICE and producing on farm (distributed) heat and power.

Given that we need to have at least the option of alternative energy supply to the BAU case, it is worthwhile to consider which pathways are going to work for bioenergy in New Zealand. Having defined what resources are significant in volume (forest and other wood residues) or environmental impact (effluents) we then decide what possible options (conversion) there are for their use, and how they compare to each other.

Pathways that are likely to work in New Zealand, that will meet a demand, cost effectively and energy efficiently (NB – not necessarily now but in 2020/2030) are presented in Table 29. (Derived from; Bioenergy Options reports and Bioenergy Workshop, November 1 2007, Wellington.)

Table 29: Potential Bioenergy Pathways

Raw material	Conversion	Energy product
Wood residues	Combustion	Heat Combined heat and power
	Enzymes	Ethanol Biobutanol
	Gasification	Combined heat and power
	Gasification + Fischer Tropsch	Biodiesel
	Pyrolysis/oil	Combined heat and power
Effluents, industrial, farm waste effluent, municipal biosolids	Anaerobic digestion/gas	Combined heat and power Gas for transport Liquid fuels
	+ Algae anaerobic digestion/gas	Combined heat and power
	+ Algae chemical mechanical	Biodiesel
	+ Algae/supercritical water	Liquid fuels
Agricultural residues (straws)	Combustion	Heat
	Enzymes	Combined heat and power Ethanol and biobutanol
	Gasification + Fischer Tropsch	Biodiesel
Horticulture residues (fruit wastes)	Anaerobic digestion/gas	Combined heat and power
	Enzymes	Ethanol
Agricultural crops (canola)	Chemical mechanical	Biodiesel
Waste oil	Chemical mechanical	Biodiesel
Landfill gas	Capture	Heat and power
Tallow	Chemical mechanical	Biodiesel

Issues constraining bioenergy

Barriers to the uptake of bioenergy can be summarised as:

- Supply - Guaranteeing the quality and quantity of biomass feed-stocks so that demand can be met every day.
- Cost - Availability and efficiency of feedstock delivery systems and conversion technologies.
- Land - Availability and cost of suitable land, and productivity of purpose grown energy crops.

Regardless of biomass resource, conversion technology or energy product, some of the most significant barriers relate to: feedstock quality; volume and continuity of supply; resource access guarantees; cost of feedstock, and measurement of feedstock materials.

There is also significant uncertainty about the productivity and energy balance of some developing conversion technologies. Until these can be verified or guaranteed there will be resistance to investment.

For energy derived from purpose grown crops, the productivity of the crop will be critical to its success.

Research and development identified as being required

(i) **Focus on woody biomass –** including harvesting (integration with logs), steep slope extraction of residues, materials handling including freight specifications, logistics, processing feedstock (reducing costs), feedstock characterisation, alternative comminution (size reduction) equipment to create flowable fuel, screening, segregation, upgrading. Total aim; reduce the cost of the feedstock.

(ii) **LCA –** NZ LCA databases required, LCA of combustion versus other means of disposing of industrial wastes, eco-verification (LCA/LCC). LCA/LCC of biofuels pathways, Industry and society awareness), exergy analysis of bio-energy systems.

(iii) **Resource information –** how much of what resource we have and where it is, municipal wood waste and wood processing waste an area for attention to improve poor quality data.

(iv) **Anaerobic digestion –** catalysts to improve gas production, feed stock characterisation and pre-treatment, competition for resource (bio-materials), environmental benefits of use, cost of alternatives (disposal versus use for energy).

(v) **Enzymes –** for wood to biobutanol and ethanol.

(vi) **Gasification –** including scalability, gas clean up technology, syn gas processing, Hydrogen injection for gas upgrading, gas to liquids.

(vii) **Pyrolysis –** biochar, biomass to synthetic natural gas, Fischer Tropsch, Haber Bosch Process , Bio-oil, densification.

(viii) **Algae –** systems, species, material handling including collection, algae on nutrient rich waters from anaerobic digestion of effluent.

(ix) **Carbon Capture and Storage (CCS) –** including using biochar and algal sequestration.

(x) **Social, economic and environmental impacts of bioenergy –** land use change (rural communities), land use impacts, economic impacts of biofuels (feedback loops), integrated systems for NZ, distributed vs centralised plant, nutrient management, soil conservation and biodiversity benefits, non-dollar benefits (GHG, Energy Security, Waste disposal, Sustain Overseas markets for NZ food by use of renewable energy).

(xi) **Policy –** effects of policy, monitoring, goals and targets - how to get there?, role and effect of local government, how to focus industry on research and technology development via tax relief and incentives, develop a framework to enable the fast follower approach - adaptive of overseas systems.

(xii) **Pursue Incremental improvements in existing technology –** wood fuels, drying, efficiency gains.

(xiii) **Low PM wood burners (all scales) –** air quality impacts, health benefits.

Research and Development Strategy Focus

(i) Woody biomass supply and conversion (heat, power and liquid fuels).

(ii) Anaerobic digestion production and use (heat power and transport fuel).

(iii) Comparison of options (Exergy, energy, LCA, LCC).

(iv) Fast adaption of new technology from overseas developments.

(v) Social, economic and environmental impacts.

(vi) Support innovative research underway in NZ; Supercritical water, algae.

CONCLUSION: WILL A BIOENERGY STRATEGY WORK FOR NEW ZEALAND?

The New Zealand Government seeks carbon neutrality in the electricity sector by 2025, in the industrial energy sector by 2030, and in the transport sector by 2040. Bioenergy provides a route to achieving these goals, with forestry crops playing a major role.

Central to New Zealand's goal for being sustainable, carbon neutral and internationally competitive is the need to support economic growth in a resource-constrained world. Viable solutions must:

- Meet our demand for energy using renewable resources, preferably those that New Zealanders have direct influence on and which are closely linked to economic growth sectors.
- Manage our land resources in a sustainable manner which balances productive and urban requirements.
- Maintain robust domestic and export sectors that undertake their activities in a sustainable manner that can be verified and is defensible.

A bio-based economy focused on expanding forest-based or other plant-based materials provides a way of meeting these needs and transforming New Zealand into an internationally-competitive, sustainable economy.

Biomass as sustainable energy

Biomass can be used to produce a diverse range of energy products (heat, power, and liquid biofuels) and energy carriers (gas, chars, chemicals). Biomass-based energy has advantages over other fuels or energy forms because it is:

- Renewable.
- Currently used for energy production and fits with existing infrastructure.
- A widely distributed resource.
- Available in a range of forms (purpose grown crops, residues from existing crops, residues and wastes from agricultural and industrial processes, municipal wastes.)
- Carbon-neutral when based on sustainable crops, forests or residue streams.

Biomass is the only energy resource arising solely from human activity, so the expansion, maintenance and use of biomass resources are fundamental to sustainable development. Coal, oil and mineral resources exist independent of human activity, as do solar, wind and water energy. Bio-based industries are the only sectors that can become increasingly self sufficient in terms of material inputs and energy, therefore sustainable development is dependent on fostering such sectors.

The logical role for biomass in realising Government targets is in heat production (including some combined heat and electricity) or transport biofuels. The role of biomass in generating electricity is limited since New Zealand is presently 75% carbon neutral in electricity and has a wide range of unexploited resources for producing more.

Transport biofuels and biomass for heat have an important role in meeting Government climate change aspirations. New Zealand's energy strategy aims for a light transport sector driven by electricity. This will require increased generating capacity and significant infrastructure development. The need for liquid transportation fuels is likely to remain, particularly in freight and air transport, with demand still in the order of 2–3 billion litres in the long term.

If the climate change scenarios presented by the UN IPCC are correct, we need to act quickly and on a large scale to reduce GHG emissions and store carbon. The use of residual biomass material is a great place to start, but the scale of the residual resource is small in comparison to demand. Nevertheless, these materials should and will be used first in any push to sustainability, partly because they are available and relatively cheap, and partly because using them can solve environmental issues (e.g., dumping of waste, disposal of municipal effluents). Future needs can be met through developing new forestry-based energy crops.

A Bioenergy Solution is Achievable

Situation:

New Zealand has 8.7 million hectares of medium to low quality grazing land. Assuming New Zealand's gross energy demand grows at only low to moderate rates, then its total heat and transport fuels demand could be met by sourcing biomass from around 3.2 million hectares of energy production forests – this is 37% of the available medium and low quality grazing land. In contrast, to produce biofuels from agricultural crops, around 150% of the total arable land available would be required.

Competition with high quality pasture land is not viable for energy production due to high returns from dairying and the need for locally produced food. If biomass is to make a significant contribution to New Zealand's future energy supply it must not be grown on the arable or high quality pastoral land.

Typically, land of low grazing quality is elevated and on steeper country. Forest crops which produce large stem sizes and wood volumes are the only crops that will be economic to harvest from this land. Forest crops provide the only viable biomass crop for energy at large scales, but they also have the advantage of being able to be used for wood or chemicals as well.

Solution:

A forest resource capable of supplying New Zealand's energy demands will take around 25 years to establish. This can be achieved by planting forests of various species at a planting rate of around 100,000+ ha/year.

A possible initial regime would be 30,000 hectares of short rotation coppice on the 'low-slope' land, 20,000 hectares of medium rotation crop on steeper land and 70,000 hectares of radiata on steep hill country land. Phase planting to give a balance of short term crops for energy production, but with a longer term transition to longer rotation forests on the steep marginal land.

The establishment of these forests would cost around $2 to $3 billion a year. A large part of the costs could be offset by carbon credits and substitution of fossils fuels with renewable energy. Furthermore, New Zealand's liability for carbon may be in the vicinity of $1 billion if carbon emissions continue at existing rates. Planting forests would protect against this potential liability.

Other forms of bioenergy (utilisation of residues) would be maximised over the initial 10 years. The use of the biomass would be directed to heat applications short term and more material would be diverted to biofuels as second generation biofuels technologies mature. The biomass resource would predominantly be used for heat and liquid fuels – although increasingly material would be used for combined heat and power.

The planting of marginal land in forest future-proofs New Zealand's options – as the resource offers a range of energy and non-energy uses.

The benefits

Economic Growth

An expanded forest, wood processing and biomaterial sector can provide significant economic growth opportunities in lucrative international markets.

Innovative design processes will enable New Zealand suppliers to compete more effectively than by selling undifferentiated products, such as logs and lumber.

Land use

Land is a valuable resource which must be protected and effectively managed to provide future economic wealth, a healthy environment and quality of life. Land and land use is also a critical element of Maoritanga. In terms of growing bioenergy crops, land is the limiting resource.

The best use of land for energy crop production is to grow forests on steep terrain and marginal grazing lands. Whilst this land presents some cost issues around harvesting, it is the only class of land that is of sufficient scale to make a real contribution, without adversely affecting local food supply and export production.

Strategic drivers include:

- The relatively high proportion of medium and low productivity land which can be used for energy production, and at the same time reduce land degradation.
- Mature, technically-advanced forest sector and developing biomaterial sector based on industrial biotechnology.
- Carbon neutral economy which is sustainable with a high degree of self-sufficiency.
- Minimal competition for high quality arable and pastoral land for energy production.
- No competition for water resources.

New Zealand's pathway to sustainable energy

The national goal is to be sustainable and to have carbon neutral energy. The logical route is to use the resources already in abundance, namely, rolling to steep lands, on often erodable hill country best suited to growing trees. Energy supply in New Zealand could be forestry based.

Forests provide significant environmental values such as enhanced biodiversity, flood management and control and soil protection, recreational and scenic enhancement, carbon sequestration – all contributing to long term sustainable development.

The concept strategy diagram on the following page shows how New Zealand can achieve energy self sufficiency based on biomass resources, and at the same time future-proof both economic growth and environmental management.

The research strategy should be focussed on enabling this to happen, covering resource development, conversion technologies and land use change.

NEW ZEALAND CONCEPT STRATEGY TO SUSTAINABLE ENERGY

CURRENT SITUATION

Fossil Dependant

- 12th highest per capita CO_2 emissions in the world
- Expecting 40% increase in transport energy use by 2030

Developments

- Conversion technologies mature
- Gasification to biofuels
- Enzymes to biofuels
- Combined heat and power – small-scale
- Bio refineries

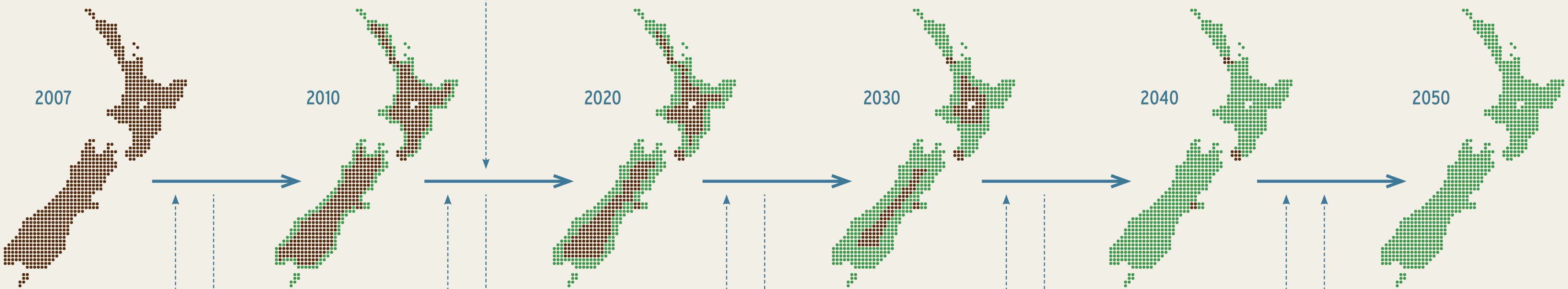
Focus

- Biofuel (liquids from biomass)
- Heat (with some electricity from CHP – combined heat and power)

Note: Electricity provided by renewables from hydro, geothermal, wind, marine and solar.

GOALS

- NZ sustainable in heat and transport fuels derived from biomass (carbon neutral energy)
- Optimised land use
- Improved water quality



2007

Actions

- Plant 70,000 ha short rotation forests
- Plant 20,000 ha/year medium rotation forests
- Plant 80,000 ha/year pine forest (or equivalent)

Outcomes

- Future resource under development
- Mixed land use, nutrient and erosion control

2010

Actions

- Begin to harvest short rotation forests
- Plant 30,000 ha/year in medium rotation forest
- Plant 100,000 ha/year pine forest (or equivalent)
- Convert all effluents using anaerobic digestion

Outcomes

- Biofuels from short rotation forests
- Biomass heat
- Biogas (combined heat and power)

2020

Actions

- Plant 130,000 ha of forest
- Reduce fuel use via efficiency (freight and urban)

Outcomes

- Wood to gas for industrial heat and power
- Biofuels from short and medium rotation forests
- Erosion and flooding control
- Greenhouse gas reduction

2030

Actions

- Plant 100,000ha/year
- Develop distributed biofuel refineries based on forest resource

Outcomes

- Biofuels for transport meeting a significant % of demand
- Biomass for combined heat and power to meet a large % of heat demand

2040

Actions

- Manage sustainable harvest 130,000 ha/year from 3.2 million ha energy forest estate

Outcomes

- 100% of liquid fuels and heat from wood and effluents

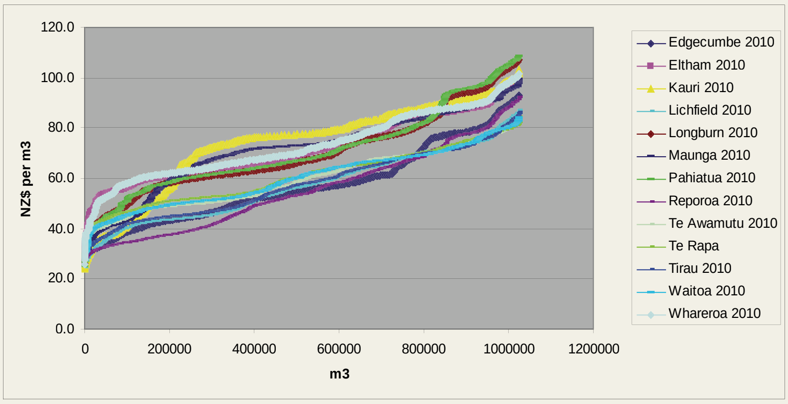
APPENDIX A

Dairy Case study

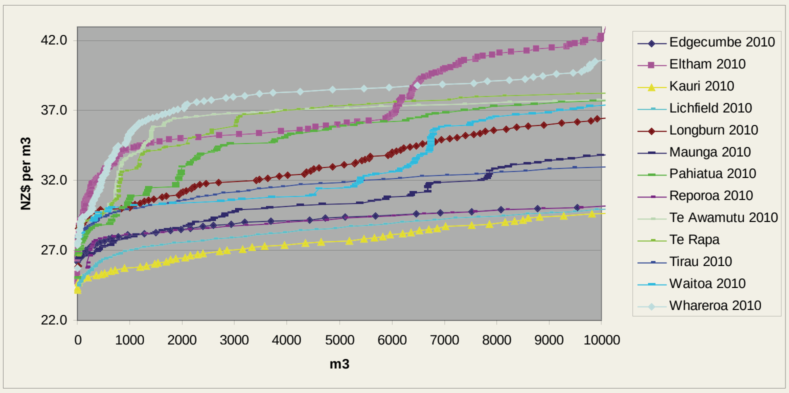
As demonstration of how an industry with an energy demand could approach a change in its energy supply (from fossils fuels [gas and coal] to biomass) the dairy industry in New Zealand was examined. It was found that there were several dairy processing plants operating that were in reasonable proximity to significant forest areas.

Analysis by GIS model showed the volume of forest derived resides that could be delivered to the chosen sites. In several cases it was found that there was sufficient residue to meet the energy demand of the processing plant. At other sites the residues could meet a significant part of the energy demand, and in three there was the possibility of co-firing biomass with the current coal or lignite fuel.

Graph 1 - Cost of forest residue by volume, delivered to specific sites (2010 resource base)



Graph 2 - Cost of supply at small scale



Graphs 1 and 2 show cost supply graphs for each location in the North Island, year 2010. The biofuel available at each location always adds up to 1,025,248 m^3 as that is what is available in the whole of North Island, and no limitation was used in this case.

According to graph 2 Kauri, Lichfield, Edgecumbe and Reporoa seem to be the best locations, in the North Island, to start using biofuel as they all end up below 30 NZ$ per m^3 for 10 000 m^3. However, the amount of biofuel required decides which location should be considered the best.

Biofuel demand and cost of supply

Site	Biofuel demand, 000s tonnes	Cost of fuel to meet demand, $/t & $/GJ
Kauri	102	$36.5 & $4.29 *
Maungatoroto	80	$38.5 & $4.52 *
Edgecombe	133	$39.2 & $4.61 *
Reporoa	53	$31.3 & $3.68 *
Longburn	31	$39.5 & $4.67 *
Brightwater	18	$29.6 & $3.48 *
Waitoa	85	$40.6 & $4.77 a
Lichfield	111	$34.7 & $4.08 b
Pahiatua	75	$42.2 & $4.96 c
Stirling	76	$37.6 & $4.42 d
Edendale	244	$40.2 & $4.73 e

* = supply meets 100% of demand, a = supply meets 47% of demand

b = supply meets 60% of demand, c = supply meets 60% of demand

d = supply meets 60% of demand, e = supply meets 10% of demand

In the North Island; Lichfield, Edgecumbe and Reporoa are the best locations to start using biofuel as they all end up below about $30 per m3 for 10 000 m3 in both 2010 and 2030. In the South Island Brightwater and Stirling are the destinations best suited for biofuel utilisation.

When there is more biofuel available at shorter distances, the price will be lower. So at many locations the biofuel may be cheaper in 2030 than in 2010, because of a predicted rise in forest harvest levels and subsequent increase in potential biofuel harvest. Because of the variations between years it is important to look at multiple years to decide which locations are best suited for biofuel utilization. However, even though the lines change with the years, the locations usually keep their positions compared to the others.

For some of the locations the lines change a lot when restricted with a mask (constraining the fuel supply area). This could imply that the location is quite sensitive to competition. When the lines stay quite stable, even though a mask was used, it implies that these locations would be less affected by competition (as long as the competing buyer is not situated close by).

This study is an example of an energy pathway or pathways, from forest residues, via combustion to industrial heat. The possibility of biomass gasification to fit the fuel to plant with existing gas fuelled heat plant or gas turbines is a possibility worthy of further investigation.

APPENDIX B

There is significant development being undertaken in Europe and America, on creating biofuels from various forms of biomass. Some of these are listed here, but the list is not comprehensive, and it will be important for New Zealand researchers and energy companies and energy users to watch overseas developments closely, with the aim of identifying significant breakthrough technologies and adapting them to a New Zealand context.

Biomass to liquid fuel (Biofuels)

CHOREN INDUSTRIES GMBH, GERMANY

The BTL demonstration activities of Choren GmbH began in 1998 with the construction of a 1 MW pilot plant (alpha-plant) in Freiberg, Germany. A high-temperature oxygen-blown slagging entrained flow gasifier, developed by Choren in 1994 and patented in 1995 as the Carbo-V Process is used. The claimed thermal efficiency of the Carbo-V process is 95-98%, while the gasification efficiency is stated as 82% for capacities larger than 10 MW. In October 2003 Choren began the construction of its first industrial plant for manufacturing 15,000 tonnes of BTL fuels per year (the beta-plant), which is due for completion in 2005. The project preparation for a third, much larger plant with annual capacity of 200,000 tonnes of BTL fuels has been outlined. From website information it is estimated that the Beta plant will produce in the order of 106 litres of biodiesel for each green tonne of woody biomass.

CHEMREC A.B., SWEDEN

The gasification technology, being developed by Chemrec is designed to run on a specific feedstock – black liquor which is a residual product from the production of chemical pulp and paper. The system was originally conceived for electricity generation, employing air-blown entrained flow gasification. Recently the option of producing BTL transport fuels (methanol, DME and hydrogen) has been also investigated. The comparison between the black liquor gasification approach of Chemrec and the biomass gasification approach of Choren indicates many similarities. The black liquor gasification combined cycle system, aims at replacing the black liquor recovery boilers, and is in a development phase, as well as the system for black liquor gasification for producing alternative motor fuels and hydrogen. The efficiency of biomass to methanol conversion of the plant is predicted to be 65-75% that is slightly higher than that of Fischer-Tropsch synthesis.

ECN & SHELL, THE NETHERLANDS

Since 2000 the Energy Research Centre of the Netherlands (ECN), in co-operation with Shell Global Solutions Int., has performed thorough research work on different biomass pathways to syngas for further processing into BTL fuels. Various gasification concepts and system configurations have been examined and evaluated. With respect to the production of biosyngas, the pressurised oxygen-blown entrained-flow gasifier of slagging type has been found to be the optimum system configuration. Although the experimental work has been performed at a lab-scale and for the moment there are no indications for development into a larger scale pilot plant, it deserves particular attention, since a detailed technoeconomic analysis, including simulations of large-scale industrial applications, has been performed and has been made publicly available. The involvement of a major industrial stakeholder with experience in the development of GTL technologies as a partner in the project puts additional value onto the research results.

VÄRNAMO IGCC PLANT, SWEDEN

The Värnamo demonstration Integrated Gasification Combined Cycle (IGCC) plant was built by Sydkaft A.B. in 1991-1993 and was fully commissioned in 1995. The demonstration programme began in 1996 with electricity and heat generation, and was concluded in 2000. The next steps in the demonstration activities foresee conversion to oxygen-blown gasification (with tar cracker) for producing syngas and automotive fuels – initially DME and methanol, later hydrogen and F-T synthesis. Scaling-up the plant is also proposed. The start of the syngas production is envisaged for 2005, while the synthesis of F-T fuels is expected for 2007-2008.

GÜSSING CHP PLANT, AUSTRIA

The CHP demonstration plant in Güssing/Austria, employing a steam-blown circulating fluidised bed gasifier and gas engine with 8 MW fuel input (mainly wood chips), was built in 2000-2001. The initial CHP programme was intended for evolution towards production of syngas from herbaceous-derived pyrolysis slurry for further processing into substitute natural gas, methanol and F-T liquids. The plant's design is relatively suitable for such a development, since steam gasification results in low contamination of tars and nitrogen in the product gas. However, some retrofitting is needed – additional gas cleaning facilities, tar cracker, F-T reactor. At present the production of BTL fuels is at an experimental stage. Despite that BTL fuels are gaining an increasing interest, it would be extremely challenging to expect significant quantities of such fuels to reach the automotive market before 2010.

Range Fuels

Range Fuels has one of the six technologies being funded by the US government to build demonstration plants for biomass to liquid fuels. The Range Fuels technology can take lignocellulosic biomass and convert it to liquid fuel via gasification and catalytic conversion to ethanol. The demonstration plant in Georgia is planned to open in 2008 and produce 75–80 million litres per annum from a variety of resources including wood chips.

Biobutanol

It is possible to produce biobutanol from biomass using enzymes, in a way similar to that used to produce ethanol. The perceived advantages of biobutanol are that it is more similar to petrol than ethanol. Butanol is more tolerant of water contamination than ethanol, and is less corrosive. It is more suitable for distribution through pipelines than ethanol. Using the ABE (Acetone Butanol Ethanol) process other products are also produced, including acetone, hydrogen, acetic, lactic and propionic acids and ethanol. Dupont and BP are investigating the production of biobutanol.

Supercritical Water Oxidation

Super critical water oxidation (SCWO) is a process that occurs in water at temperatures and pressures above a mixtures thermodynamic critical point. Under these conditions the fluid has a density between that of water vapour and liquid and exhibits high gas like diffusion rates along with high liquid like collision rates. Solubility behaviour is reversed so that chlorinated hydrocarbons become soluble in water. These characteristics have been used in the toxic waste treatment industry. Solvent Rescue, a Christchurch company is experimenting with using SCWO to treat algal slurry with the aim of producing crude oil and a nutrient rich water that can be used as fertiliser or be fed back into algae growing ponds.

Other LanzaTech

This New Zealand company recently received venture capital to further develop its lab scale work on using microbial bacteria to convert carbon monoxide (CO) to ethanol, and ultimately to other fossil oil derived products. The initial work is focussed on industrial gas streams (steel making) that have high concentrations of CO. The technology may not be limited to steel plants, and may be fitted to other high CO gas stream sites, and in the future it has been suggested that high temperature combustion of woody biomass may provide a gas stream that is suitable. (Source Radio New Zealand - National Radio)

Biomass to Furfurans (furfurals)

Furfural is the industrial source of furfuryl alcohol, which is a high quality resin component. It is currently commonly extracted from agricultural wastes by acid hydrolysis. Research and development is underway to use pyrolysis (2 stage) to create furfural from hemicellulose and phenols from lignin. Furfuryl alcohol and phenols have very high market values (> $1000 per tonne) which is driving the research on producing them from woody biomass.

General References

Hale and Twomey, 2006. Enabling biofuels – biofuel supply options. Report prepared for NZ Ministry of Transport. March 2006

Taylor M., 2007. Alternative liquid fuels: Global availability, Economics and Environmental Impacts. Report for Ministry of Economic Development. March 2007.

MoRST 2006: Energy Research – Roadmaps for Science. December 2006

Glossary of abbreviations

BAU – Business as usual

BTL – Biomass to liquid

C – Carbon

CO – Carbon monoxide

CO_2 – Carbon dioxide

DM – Dry matter

DME – Dimethyl ether

DW – Dry weight

EJ – exa joule (1×10^{18})

F-T – Fischer Tropsch

FRST – Foundation for Research, Science and Technology

GJ – giga joule (1×10^{9})

GTL – Gas to liquid

ha – hectares

ICE – Internal Combustion Engine

kW – Kilowatt

kWh – Kilowatt hour

MRF – Medium rotation forest

MW – mega watt

NOx – Nitrous oxide

ODT – Oven dry tonnes

pa – per annum

PJ – peta joule (1×10^{15})

SCWO – Super critical water oxidation

SOx – Sulphur oxide gases

SRC – Short rotation coppice

SRF – Short rotation forest

t – tonne

Taken from New Zealand Energy Research and Development Committee report No. 46 (August 1979) "The Potential of Energy Farming for Transport Fuels in New Zealand

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More information

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