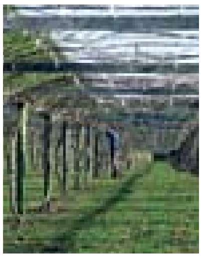
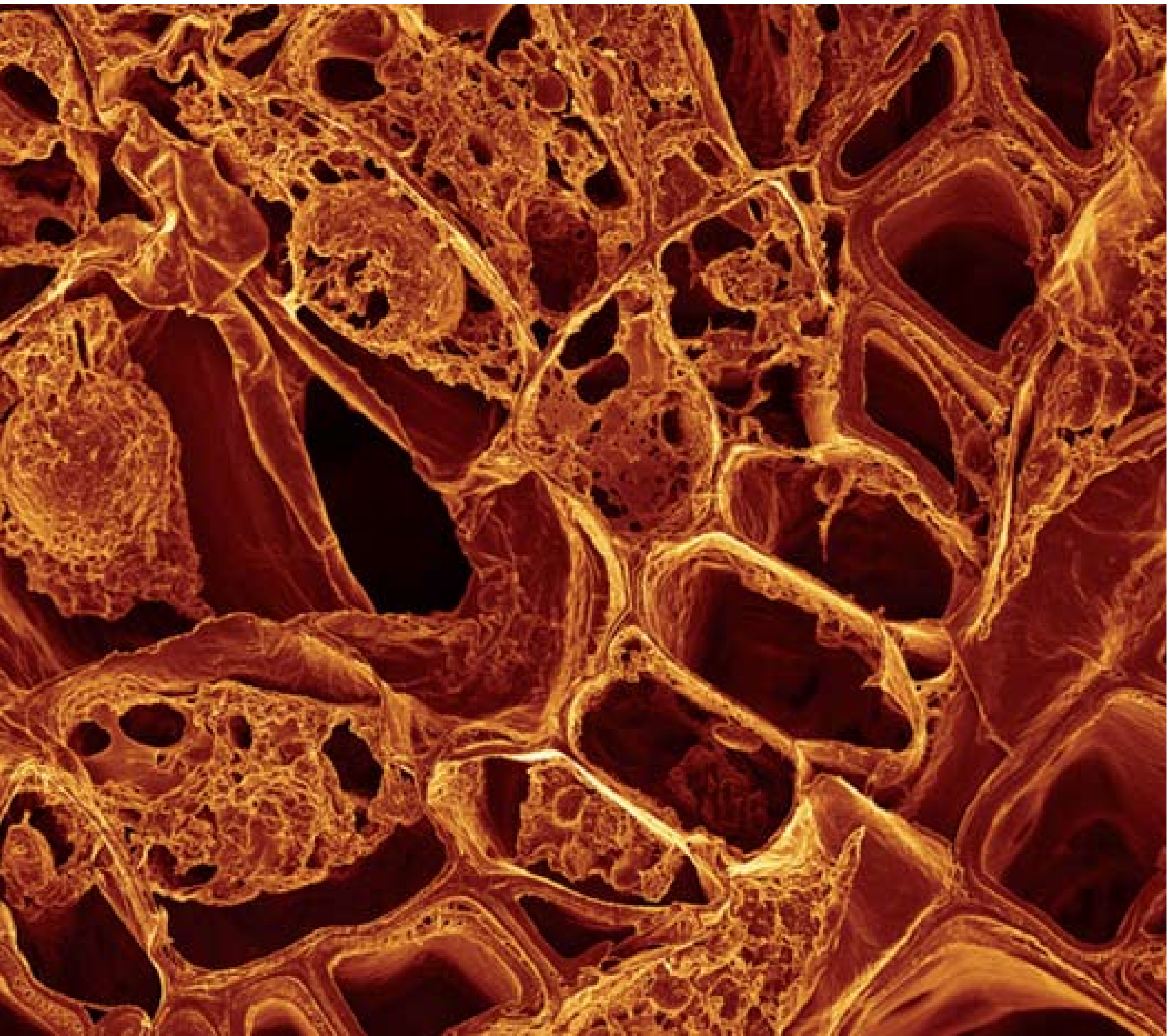
Next generation biomaterials

Bioenergy Options for New Zealand

RESEARCH AND DEVELOPMENT STRATEGY





This report (Bioenergy Options for New Zealand – Research and Development Strategy) covers phase 3 of the Bioenergy Options study. This phase is:

- Propose a Research and Development strategy for Bioenergy in New Zealand.

The previous two phases of the project were reported in the Bioenergy Options-Situation Analysis and Bioenergy Options-Pathway Analysis.

The Bioenergy Options-Situation Analysis report covered:

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

The Bioenergy Options-Pathway Analysis report covered;

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

An extension of the original Bioenergy Options project has also been carried out that covers:

- Land-use scenarios for a future national-scale forest resource producing transport fuels as one of the products;
- An analysis of the environmental and macro-economic implications of these scenarios for New Zealand.

The findings from this study have also been incorporated into this research strategy.

The following organisations have contributed to the Bioenergy Options study:

• Landcare Research
• CRL Energy Ltd
• Waste Solutions
• NIWA
• NZCEE
• Process Developments (now Connell Wagner)
• Infometrics
• Motu

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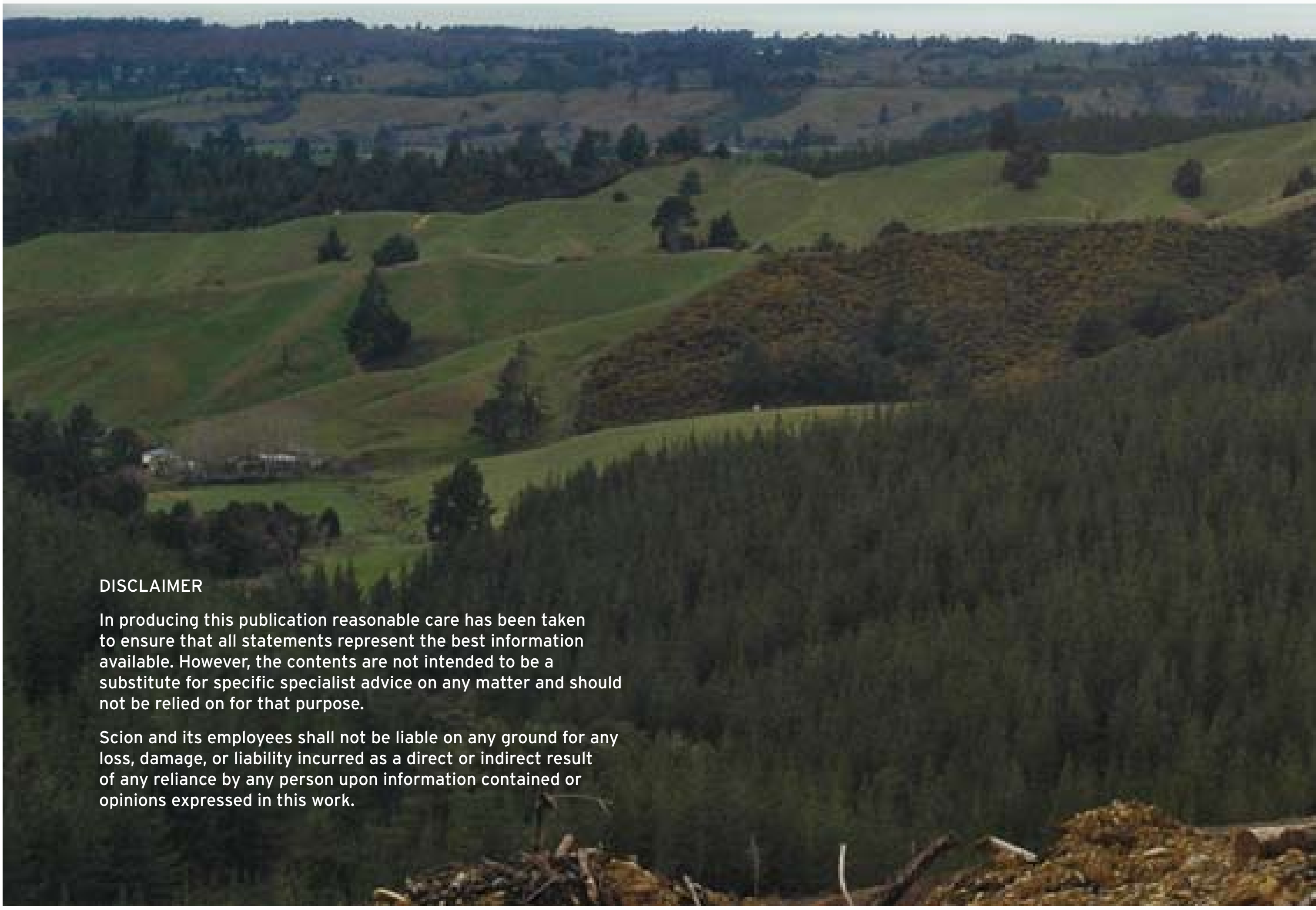

Bioenergy Options for New Zealand

Research and Development Strategy

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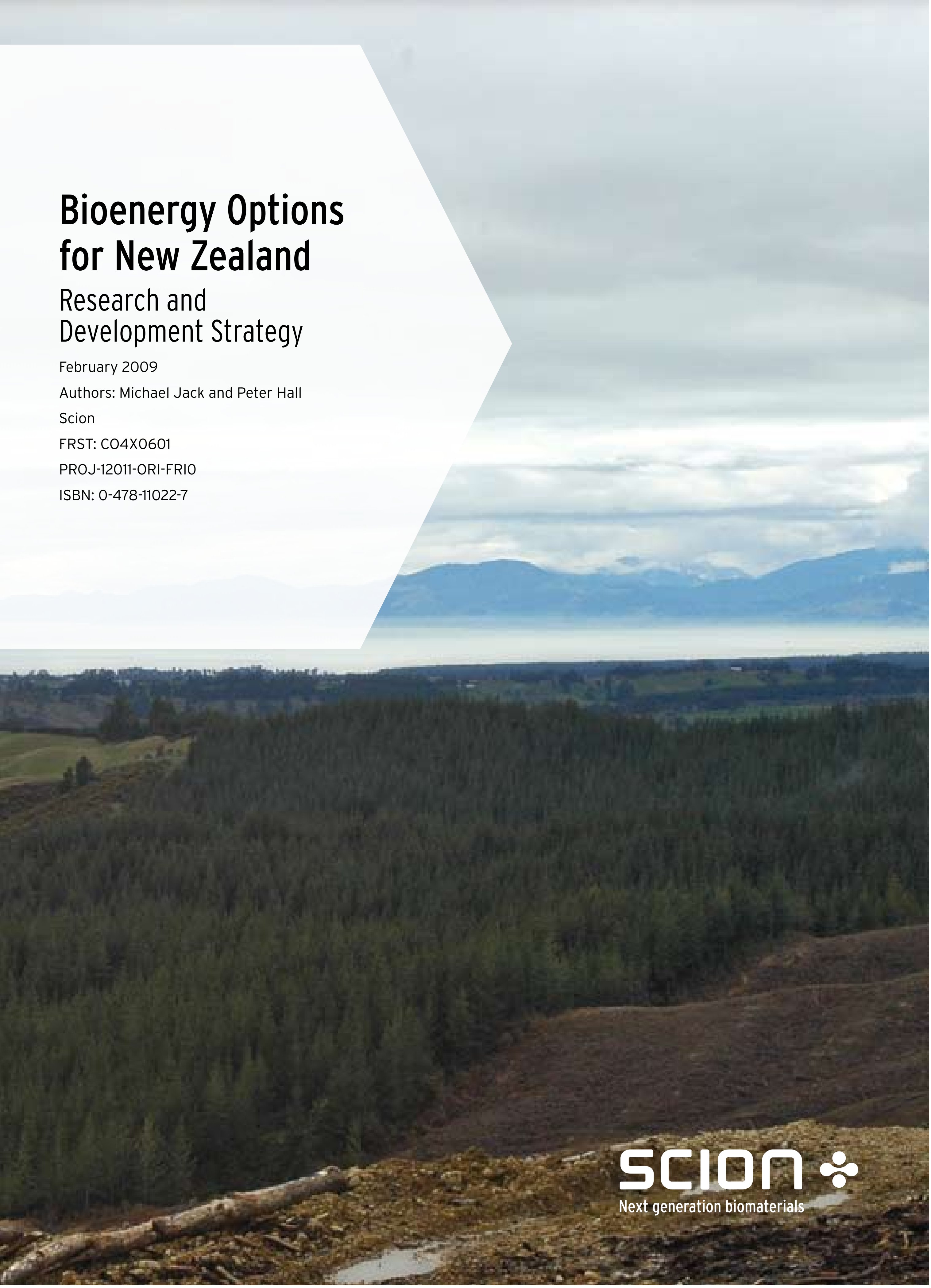


EXECUTIVE SUMMARY

This document proposes a strategic direction for bioenergy research in New Zealand. This strategy has been guided by the conclusions of the FRST funded Bioenergy Options study, the EnergyScape programme, of which it is a part, and the broader international research context.

Global Climate, Change Resource Depletion, Economic Development and Energy

Energy is vital to New Zealand's economy. A large percentage of our energy supply, particularly for transport fuels, is imported, volatile in price and comes from non-renewable fossil fuels that are a major cause of global climate change. Because of these problems, and the world's dwindling supply of oil and gas over the next 25 to 50 years, finding sustainable alternatives is becoming increasingly urgent. Due to these challenges, New Zealands energy future is defined by the three themes of (i) increasing energy security; (ii) affordability and; (iii) reducing greenhouse gas emissions. The core strategy for achieving these aims is to move away from fossil fuels through increased energy efficiency and increased domestic supply of renewable energy, while enhancing our standard of living.

Due to the magnitude of the energy problem it is likely that a diverse and distributed range of renewable energy options will be required. Renewable energy from biomass has a number of unique attributes that give it the potential to play an important role. In particular, a number of countries have identified bioenergy as a source of renewable transport fuels in the medium term. Due to concerns about the sustainability of some first-generation fuels based on agricultural crops, attention has shifted to second generation, lignocellulosic feedstocks, such as wood and grasses. A significant amount of R&D investment in bioenergy and lignocellulosic biofuels is occurring world-wide as a result of this shift.

The Bioenergy Opportunity

Bioenergy represents a significant opportunity to address New Zealand's challenges through the production of energy from underutilised land and waste resources. It also enables the decoupling of economic well-being from increasing international oil prices, dwindling gas supplies and the production of greenhouse gases. Three areas where bioenergy could play an important role in low-carbon energy generation as part of New Zealand's energy mix have been identified as:

- Transport fuels;
- Industrial and residential heat (and also possibly some electricity through combined heat and power (CHP) plants);
- Distributed and demand-driven electricity generation.

A comprehensive assessment of New Zealand's residual and potential biomass resources and conversion technologies has found that residual, or unutilised biomass resources, were limited in their ability to meet national-scale demands. To meet more than a few percent of national energy demands requires purpose-grown biomass. The purpose-grown biomass with the most promise in the medium term was determined to be woody-biomass grown on marginal lands.

Strategic Approach to Research in New Zealand

The strategic direction developed in this report is designed to focus New Zealand- funded bioenergy research and development on realising the potential of bioenergy in New Zealand. The development of this direction was guided by the following two principles:

1. New Zealand-funded research should pursue the greatest opportunity to provide overall benefits for New Zealand
2. New Zealand-funded research should link to overseas research that could be adapted to New Zealand, rather than duplicate this work.

Research Themes

Five strategic themes have been identified for bioenergy research in New Zealand.

Following is a summary of the themes and their associated research and development priorities. The relationship between national drivers, the role assigned to bioenergy, the strategic themes, and research and development requirements are shown in the diagram on page 7.

Bioenergy from plantation forestry
The potential benefits of this theme are:

- Potential for significant contribution to low-carbon energy demand of gas, liquid and solid fuel;
- Of sufficient scale to reduce New Zealands exposure to international energy prices;
- Does not compete for arable and high-value pastoral land;
- Provides environmental services, such as, stabilising erosion prone land and improving water quality;
- Significant business opportunity for forest industries, landowners and new energy industries;
- Regional development.

Time frame: Medium-to-long

Research and development priorities:

- Develop new high-yield, low-input forest systems (for both existing and new species) for multiple products including energy;
- Develop efficient harvesting and logistics systems;
- Adapt transport fuel conversion processes for New Zealand feedstocks;
- Develop an implementation plan for New Zealand.

From scale, green-house gas mitigation, energy balance and technological maturity perspectives, this theme was identified as the most promising approach for bioenergy to make a significant contribution to New Zealand.

Realising this strategy for New Zealand will require multi-disciplinary research, strong industry and pan-government involvement. It will also require close collaboration with international researchers and industries.

Biomass waste utilisation
Utilisation of municipal waste, industrial effluent and agricultural waste for energy has the potential benefits of:

- Reducing greenhouse gases by displacing fossil fuels;
- Reducing greenhouse gases released during decomposition;
- Reducing effluent and landfill waste disposal volumes and toxicity;
- Reducing nutrient loading of waterways;
- Off-setting waste management costs;
- Regional business opportunities.

Time frame: Short-to-medium term

Research and development priorities:

- Demonstrate existing technologies on site

Biomass residuals for distributed generation
Utilisation of residual biomass for energy at a regional, rural or remote community level has the potential benefits of:

- Reduced greenhouse gases by displacing fossil fuels;
- Increasing local energy security;
- Reduced need for energy distribution infrastructure;
- Regional development.

Time frame: Short-to-medium term

Research and development priorities:

- Develop integrated industrial solutions;
- Demonstrate technologies at different scales.

Next-generation feedstocks and conversion technologies
Next generation feedstocks such as algae, perennial grasses and designer trees, together with new conversion technologies for these feedstocks, could have an important future role. These resources could have benefits of:

- Reduced land use requirements;
- Improved cost effectiveness.

Time frame: Long term

Research and development priorities:

- Review and assess technologies and feedstocks;
- Develop new feedstocks and conversion technologies.

First-generation biofuels
Some first-generation biofuels options are near economic viability and are likely to be commercially deployed in the shorter term. Research should focus on assessing sustainability and progressing towards more sustainable systems.

Time frame: Short term

Research and development priorities:

- Science-based assessment of environmental impacts.

Development of a Bioenergy Industry in New Zealand: A partnership approach

Bioenergy crosses a number of traditional boundaries between existing industries, energy security, climate change, sustainable land-use, waste mitigation and regional and national economic development. For this reason, cross-government collaboration and cooperation between industry, government and research is critical to the development of a bioenergy industry in New Zealand.

The development of the Brazilian sugarcane-based biofuel industry could serve as a model for New Zealand. Between 1975 and today Brazil transformed a portion of its traditional sugar industry into a biofuels industry that produces half of its light-vehicle fuel and is currently competitive with imported oil. This transition was associated with substantial technological innovation right along the biofuel production chain. These advances occurred through the combination of long-term strategic approach to energy by government, and strong partnerships between the private, public and research sectors.

A future forest bioenergy scenario

We have developed a "prefered" scenario for 2030 and 2050, assuming long-term increases in oil prices, and that the production costs of transport biofuels from sustainably managed plantation forests will be reduced through a concerted research and development effort. This scenario takes into account the environmental and economic limitations on land use. It also considers the fact that economic drivers are likely to divert some of the existing forest harvest to biofuels, resulting in the production of multiple products from commercial forests. This scenario includes:

- Utilisation of 30% of the existing wood harvest to biofuels in 2030/2050;
- 1.1-1.2 million ha of new forest by 2050, 44% of which is utilised for energy production.

This scenario is able to meet 10% of current petrol and diesel demand by 2030 and 51% by 2050. The forest bioenergy scenario, in combination with reduced consumption, energy efficiency gains and the deployment of electric vehicles in urban settings could enable the achievement of a 50% reduction in greenhouse gas emmission from transport per capita by 2050.

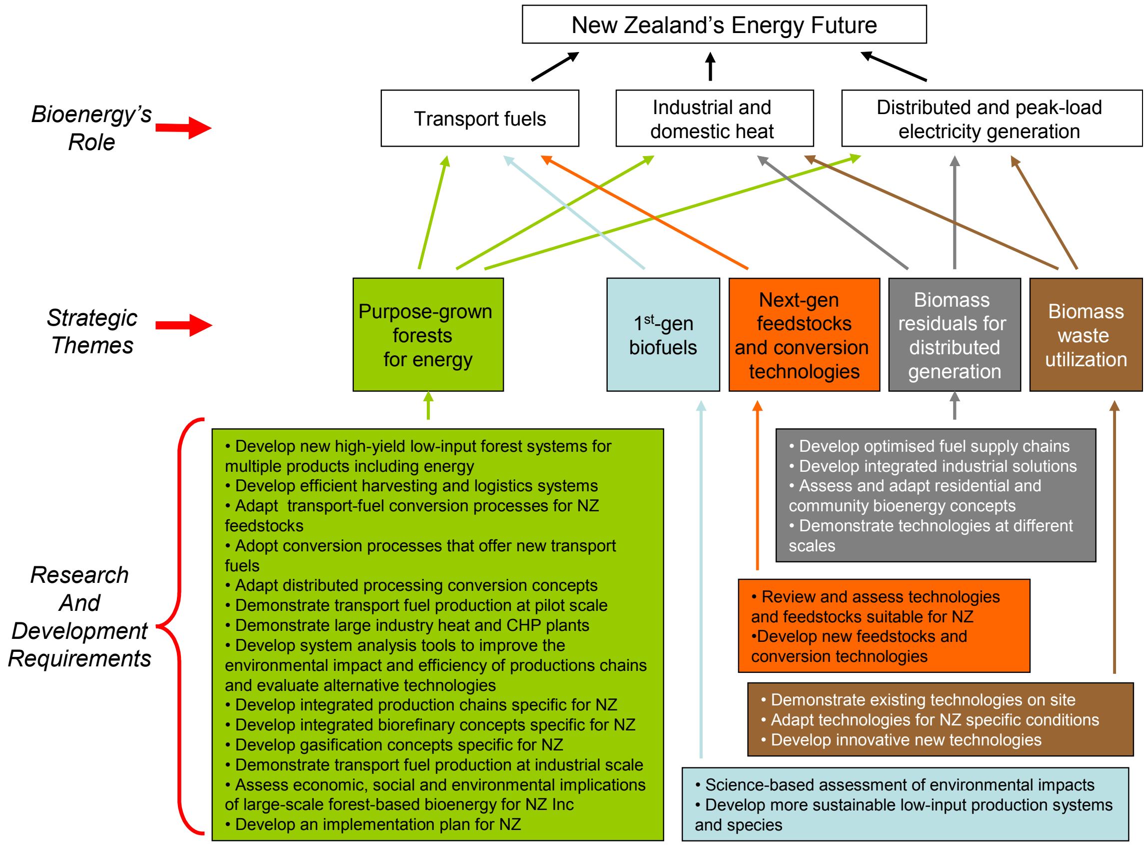


Figure 1 – Schematic of strategic themes and research priorities and their relationship to bioenergy's role in realising a sustainable energy future for New Zealand

Contents

1.0 INTRODUCTION

1.1 International Context

"Currently, biomass is the only clean, renewable energy source that can help to significantly diversify transportation fuels …", US Department of Energy, 2008

"The debate around climate change is shifting from cost and risk towards the question of how to capitalise on exciting opportunities", Mark Fulton, Global Head of Climate Change Investment Research, Deutsche Bank Group, October 2008

One of the greatest challenges in realising a sustainable future is energy consumption. Energy is ultimately the basis for a large part of the global economy and more of it will be required to raise living standards in the developing world (Amigun et. al. 2006). The world is mostly dependent on non-renewable fossil fuels that have been, and will continue to be, a major cause of pollution and climate change (Lee et al., 2008). Because of these problems and the world's dwindling supply of oil over the next 25 to 50 years, the need to find sustainable alternatives is becoming increasingly urgent.

Internationally, biomass is expected to play an important role as a renewable energy source, especially for the production of transport fuel (IEA Bioenergy, 2008). For example, since 2000 global demand for liquid biofuels has more than tripled (IEA, 2008). In addition, the European Union plans to produce a quarter of its transportation fuels by 2030 (Biofuels Research Advisory Council, 2006) and the U.S. Department of Energy has developed a scenario for supplying 30% of the 2004 motor gasoline demand with biofuels by the year 2030. These ambitious aims are designed to engender a self-sustaining biofuels industry which achieves the environmental, economic and social goals of each particular country.

Due to concerns about the sustainability of first-generation biomass feedstocks for transport fuel production (Farrell, 2008; Righelato, 2007; Fargione, 2008; Serchinger, 2008), attention has shifted to second generation, lignocellulosic feedstocks. Such feedstocks include woody-biomass and perennial grasses, which can grow with few inputs and are less likely to compete with land for food crops (Hall & Jack, 2008). To realise the promise of these second generation biofuels, significant R&D investment in bioenergy and lignocellulosic biofuels has occurred worldwide. For example: the U.S. Department of Energy selected six lignocellulosic ethanol plants for up to US$385 million in federal funding (US DoE press release – 28 February 2007; BANZ Bioenergy News – April 2007). The US DoE also invested US$125 million over five years, to build two new bioenergy research centres for lignocellulosic ethanol (Clery, 2007). In Europe, research investment in FP7 includes $1.5 billion on renewable energy and energy efficiency. These examples are among numerous others announced over the past few years by different governmental agencies around the world. Another indication of investment is the proliferation of partnerships formed between companies, involving many of the petrochemical companies. In total there are about 40 pilot or demonstration projects currently in commercial development worldwide.

1.2 New Zealand's Energy System

Due to global resource depletion, increasing energy demand from developing nations and growing international momentum to put a price on carbon, the long term international price of fossil fuel, particularly oil, is likely to rise. As half of New Zealand's consumer energy comes from imported oil[1] our economy is particularly exposed to these price increases. New Zealand's oil use relative to GDP is the 3rd highest in the world after Canada and the US (Delbruck 2005). We use relatively more oil for transport than other OECD countries and a relatively large portion of this is used by businesses rather than private households (Delbruck, 2005). Increases in oil prices therefore have the potential to reduce the competitiveness of New Zealand businesses and exporters.

What effect could this exposure have on the New Zealand economy in the long term? At present, in very simplistic terms, New Zealand exports agricultural products in order to purchase oil from overseas. Since oil prices are expected to increase faster than those for agricultural products, this means a decrease in New Zealand's terms of trade. Therefore more product will have to be exported in order to import a barrel of oil. This decrease in the terms of trade will impact negatively on economic welfare (Infometrics, 2009). The impact of price volatility, which is expected to increase (IEA 2008), is also detrimental to the economy.

New Zealand indigenous natural gas resources are in decline due to the depletion of the Maui gas field. Natural gas also plays an important role in supplying process heat for New Zealand industries and electricity

[1] *Oil and petroleum products accounted for 50.6 per cent of total consumer energy demand in 2005, of which 93 percent is imported on a net basis. (MED, 2006)*

to supplement other sources and rising gas prices will also negatively impact the economy. Importing gas is an expensive option that requires major new infrastructure and will expose the New Zealand economy even more to international prices.

On top of this, use of fossil fuels is a significant contributor to global climate change. Forty-three percent of New Zealand's greenhouse gas emissions come from the energy sector (MED, 2006) and New Zealand is ranked 4th in GHG emissions per capita from transport. In addition to negatively impacting the environment, as international carbon prices rise this could have a significant cost to the New Zealand economy. This also implies that using New Zealand's coal resources to meet future energy demands is presently not a favoured option.

To overcome these challenges New Zealand needs to take a long term strategic approach to energy, increasing energy efficiency, using our remaining fossil fuel resources wisely and developing large-scale renewable energy alternatives. Fortunately, New Zealand is particularly rich in unexploited renewable energy resources, such as, hydro, marine, wind, geothermal and land for growing biomass.

These considerations define the context for a bioenergy research and development strategy for New Zealand.

1.3 Bioenergy Options for New Zealand

1.3.1 Bioenergy's Role

Bioenergy has the potential to play an important role in meeting New Zealand's energy challenges. Biomass resources are much more under human control than most other renewables, such as wind, solar, hydro and marine, which are cyclical or weather dependent (de Vos et al, in prep.). Biomass resources can also be increased with planned intervention, limited only by land availability and the growth rate of the plants used. Due to this flexibility, bioenergy can be used to fill areas of demand not met by other renewable sources. Thus bioenergy complements many other alternative renewable solutions.

The aim of the Bioenergy Options study was to determine the options for bioenergy in New Zealand. The broader EnergyScape programme (de Vos et al, in prep.), to which the Bioenergy Options study contributed, has helped inform the role that bioenergy could play in New Zealand's energy mix. The EnergyScape programme has assessed all of New Zealand's renewable energy resources. Based on the results of this study and the work carried out in the Bioenergy Options study (Hall & Gifford, 2007; Hall & Jack 2008), three areas have been identified where bioenergy could play an important role in New Zealand's energy mix. These are supply of:

- Transport fuels;
- Industrial and residential heat (and also possibly some electricity through combined heat and power (CHP) plants);
- Distributed and demand-driven electricity generation.

New Zealand has a number of unexploited renewable resources for producing base-load electricity generation, such as geothermal and hydro. Further potential exists for electricity generation from wind and marine resources, which are considered to be better sources of electricity than biomass. Biomass has a role in distributed generation of electricity and, due to its flexibility, may also have a role in renewable demand-driven electricity generation or electricity generation that cannot be met by more weather dependent renewables, perhaps through gasification technologies and gas turbines or co-firing with coal.

Bioenergy can also potentially play an important role in environmentally-sustainable economic development. In particular, the production and use of bioenergy has the potential to:

- Generate income from wastes and underutilised land;
- Be a more environmentally sustainable use of certain land;
- Lead to regional development and job creation;
- Reduce the environmental footprint of exports by displacing fossil fuels in industrial production chains.

1.3.2 Strategic Themes

To determine the potential scale of bioenergy's role the *Bioenergy Options: Situation Analysis* report assessed New Zealand's residual and potential biomass resources.

The key finding of this study was that residual, or unutilised biomass resources, were limited in their ability to meet national-scale demands. Purpose-grown biomass is required to meet more than a few percent of national energy demands.

There are a number of possible pathways to produce consumer energy from biomass resources (such as transport fuels, heat and electricity) through a variety of conversion process. It is important to establish the environmental sustainability of a particular pathway if it is to contribute to the reduction of greenhouse gas emissions relative to fossil fuels. *The Pathways Analysis* part of the Bioenergy Options study (Hall & Jack 2008), evaluated a number of the most promising pathways. To determine the potential for a pathway to contribute to national aims we must consider a number of factors including:

1. the scale or potential scale of the biomass resource;
2. the environmental sustainability of the pathway, in particular the greenhouse gas emissions and the energy balance;
3. the economic viability of the pathway;
4. the maturity of the technology associated with the pathway.

Based on the results of the *Bioenergy Options: Pathways Analysis* report, a qualitative comparison of a number of example pathways against these 4 criteria are shown in Table 1.

Table 1: Qualitative comparison of energy pathway options over a number of criteria.

Energy Pathway	Potential Scale of Energy Supply	Environmental Sustainability	Economic Viability	Technological Maturity
Forest residues to heat	Regional	Good	Yes	Commercial
Forest residues to ethanol	Regional	Good	Marginal	Pilot/Demo
Purpose grown forest to ethanol	National	Good	-	Pilot/Demo
Industrial effluent to CHP via anaerobic digestion	Local	Excellent	Site specific	Commercial
Straw to combined heat and power (CHP)	Regional	Excellent	-	Commercial
Canola crops to Biodiesel	Regional	Ok	Yes	Commercial
Pond algae on effluent to biofuel	Local	Good	?	Lab/Pilot
Purpose grown algae to biofuel	National	?	?	Lab

It is possible to group the pathways that could contribute to New Zealand's energy system into 5 broad categories. These categories become the "Strategic Themes" of the present research strategy:

1. *Bioenergy from plantation forestry*
- National scale;
- Good green-house gas reductions and energy balance;
- Sustainable co-products, environmental services.

2. *1st generation biofuels*
- Close to commercially viable;
- Regional scale.

3. *Next-generation feedstocks and conversion technologies*
- Potential for future contribution at national scale.

4. *Biomass residuals for distributed generation*
- Currently commercially viable;
- Good greenhouse gas reductions;
- Regional scale;
- Distributed energy generation.

5. *Biomass waste utilisation*
- Excellent greenhouse gas emissions;
- Other environmental benefits such as, reduced waste to landfill.

Each of these categories is underpinned by different drivers and these will be associated with different weightings by different government policy directions.

It is important to note that the only theme of potentially national scale in the medium term is purpose-grown forests for energy. The rationale for selecting the sustainable plantation forestry option over other potential purpose-grown biomass resources is discussed further in the next section.

1.3.3 Bioenergy from plantation forestry

To tackle bioenergy supply at a national scale we need to go beyond wastes and residuals and consider purpose-grown biomass. The most likely purpose-grown biomass resources are:

- Woody biomass from dedicated energy forests or forests where wood energy is a significant part of the product mix;
- Oilseed (e.g. canola) and carbohydrate (e.g. corn, or sugar beet) crops;
- Algae;
- Other lignocellulosic crops (grasses).

Energy production from oilseed, carbohydrate and grass-like crops suffer from restricted land availability (Hall & Gifford, 2007), competition with food production, high value export products, and limited environmental benefits (Hall & Jack, 2008). Lignocellulosic crops like perennial grasses require fewer inputs than food crops, but they still require high-value arable land for cost-effective harvesting.

Energy production from algae suffers from risks due to technology immaturity and infrastructural requirements (Heubeck & Craggs, 2007). The cheapest proposed approach grows algae on open effluent ponds. To meet New Zealand's current transport fuel demand would require around 330,000 ha (5.5 times the area of Lake Taupo) of man made ponds[2], the vast majority of which would require fertilising. At the other end of the scale are photobioreactor systems, which can provide much higher yields per ha. However, current estimates are that costs of production would have to decline by a factor of 9 to be a feasible option (Chisti, 2007).

In contrast, energy production from sustainable plantation forestry does not have the same land availability restrictions. To emphasise this potential we have estimated that all of New Zealand's current liquid fuel demand (8.1 billion litres of petrol, diesel, fuel oil and jet fuel) could be produced from 42% of New Zealand's low-to-medium productivity land. Energy production from forestry also shows significant environmental benefits (Hall & Jack, 2008). The considerable drawback of this option is that it is not currently economically viable and would require production cost reductions by a factor of three (Hall & Jack, 2008). Conservative estimates (assuming current technology, feedstocks, and no return from co-products) show that the price of oil would have to reach a sustained US$180-210/bbl for purpose-grown forests-to-biofuels to be economically viable. However, assuming long-term oil price trends this could occur before 2020. In reality bioenergy is likely to be produced alongside other forestry products including traditional timber products, which reduces the cost significantly. In addition, there is potential for reducing costs through new high-value co-products, technology improvements, new feedstock development and production chain optimisation (US DoE, 2007). The economic potential of energy from forests and its impact on forestry's future is beginning to gain recognition both nationally (MAF 2008) and internationally (Hawkins Wright, 2008).

Establishment of a large-scale woody biomass resource made up of a variety of short-to-long (4-25 year) rotation tree species could mitigate a number of risks that are associated with other options, by:

- Being based on an existing industry with mature sustainability certification schemes;
- Stimulating regional development;

[2] *Assumes total fuel demand of 8.1 billion litres p.a. and algae production of 25,000 l/ha/year (Heubeck, S. et al. 2007).*

- Not competing with arable, high-value pastoral land or causing deforestation;
- Providing a significant long term energy store;
- Providing carbon sequestration during the establishment phase and additional carbon stocks from new forest area;
- Providing environmental services, such as, sustainable land management: stabilising erosion prone land, low input (e.g. fertiliser, pesticides) land use, improving water quality;
- Producing sustainable co-products such as traditional timber products and high-value biomaterials and chemicals, and providing the forest industry with a significant alternative market for low value products.

1.3.4 Developing National-scale Forests for Energy: A New Zealand Inc. Perspective

A forest resource producing energy sufficient to meet a large percentage of national energy demands would require a significant national development effort. To determine whether this is an appropriate direction, or how this development should occur, a New Zealand Inc. perspective that weighs up the consequences is necessary. The Bioenergy Options study was granted funding to carry out a preliminary study to develop answers to some of the questions about future large-scale energy forest scenarios (Hall & Jack, 2009). A brief summary of the key findings follows.

Land use impacts
Key results taken from report prepared by Scion (Hall et. al. 2009)

- The land identified in the scenario development combined with a biomass focussed regime gave biomass production rates of 640 to 900 m^3 per ha, which is higher than current forest log production rates.
- Molecular biology could further enhance the new forest growth rates, reduce management costs and would thus lead to less land area required for production of a given volume of wood.
- Costs of delivered biomass from the afforestation scenarios were estimated to be between $76 and $87 per m^3.
- Otago and South Canterbury had large areas of land identified for afforestation in all scenarios.
- In the larger area scenarios Manawatu/Wanganui and Gisborne and Southern Hawke's Bay also had large areas of land potentially suitable for afforestation.

Key results taken from a report prepared by Motu (Todd et al. 2009)

- At petrol prices of $2.75, estimates of land converted to biofuels ranges from 200,000ha to 4 million ha. The high estimate assumes that biofuels are not regarded as a high risk option and that the emissions trading scheme significantly affects the profitability of sheep/beef farming.
- Economics favours multi-purpose forests that yield carbon credits, saw logs and biofuels.
- Initial impacts on meat production of expanding biofuels onto sheep and beef land would be relatively low, as this is comparitively unproductive land.
- Drivers for land use change are likely to be much more complex than straight economics. For example, historically farmers have tended to stay with sheep and beef farming for long periods even when more profitable alternatives exist.

Environmental impacts
Key results taken from a study by Landcare and Scion (Giltrap et. al. 2009)

- Large-scale bioenergy can result in substantial reductions in greenhouse gases both by reducing fossil fuel use in transport and by removing land from agricultural production. In addition, once plantation forests are fully established they will store substantial amounts of carbon, as long as they remain sustainably harvested.
- Converting land from low-productivity pastoral grazing to forestry has a number of additional environmental benefits, including reduced erosion (particularly in the central and lower North Island regions) and reduced nutrient leaching into waterways.
- By removing land from pastoral grazing, the impacts of afforestation on biodiversity are largely positive, however afforestation of land that has historically never been forested (e.g. native grasslands) is not desirable from a biodiversity perspective.
- Afforestation is likely to have important impacts on water availability. This is particularly relevant in Canterbury and Otago which already have high levels of water allocation (mainly for irrigation). Impacts on water availability needs to be further assessed at a catchment level.

Economic impacts

Key results from a general equilibrium analysis of transport biofuel production from plantation forestry by Infometrics (Infometrics 2009)

- If (mandated) biofuels cost more to produce than fuel from imported oil, there is likely to be a loss in national productive efficiency, reflected in a lower Gross Domestic Product. However, under high-oil prices, (or highly volatile prices) the economy would benefit from an increase in the terms of trade from biofuels displacing imported oil. In addition, domestic production leads to increases in economic welfare (through private consumption) and the real wage rate (or increased employment, in a high unemployment scenario).
- The production of biofuels reduces CO_2 emissions, so if there is a price on carbon, New Zealand's liability to purchase offshore emission units is ameliorated. This generates a gain in real national disposable income.
- The results of the analysis are sensitive to the oil and carbon price, but are not sensitive to world agricultural food prices (which affect export revenue).
- The right combination of oil prices, carbon prices and efficiency in biofuels production can lead to biofuels being competitive with petrol and diesel at the pump, as well as enhancing consumer welfare (private consumption and real national disposable income). This avoids the need for regulatory intervention such as mandatory biofuel requirements which are less likely to enhance consumer welfare. In this situation biofuels can play a significant role in decreasing the New Zealand economy's exposure to increasing oil and carbon prices.

Assuming plantation forest derived biofuel production becomes competitive with oil, and taking into account the environmental and economic limitations on land use and the economic directions of the results we have developed a "prefered" scenario for 2030 and 2050 (Hall & Jack, 2009). This scenario includes:

- Utilisation of 30% of the existing wood harvest to biofuels in 2030/2050
- 1.1-1.2 million ha of new forest by 2050, 44% of which is utilised for to energy production.

This scenario amounts to meeting 10% of current petrol and diesel demand by 2030 and 51% by 2050. Combined with reduced consumption, energy efficiency gains and the deployment of electric vehicles in urban settings, this scenario suggests that achieving a 50% reduction in greenhouse gas emissions from transport per capita by 2050 is achievable.

1.4 Research and Bioenergy Industry Development: The Brazilian Story

To realise the potential of bioenergy in New Zealand requires the development of a new bioenergy industry. Research can play an important role in the development of this industry. The sugarcane-based ethanol industry in Brazil is an example of the achievements that can occur through a collaborative partnership between industry government and research in bioenergy.

Brazil has one of the most advanced international bioenergy programmes. For example, half of light-vehicle transport fuel is currently provided by sugarcane-based biofuels and bioenergy as a whole makes up 28% of the primary energy mix. The development of the sugarcane-based biofuels industry in Brazil is a research and development success story, with impressive gains and innovation throughout the biofuels production chain over the last 25 years (BNDES and CGEE, 2008). These gains and innovations include:

- doubling sugarcane productivity per hectare and the introduction of over 500 new sugarcane varieties;
- tripling ethanol yield per hectare through increased feedstock yields but also increases in production efficiency;
- reduction in production costs by more than 60% resulting in Brazilian ethanol being competitive with oil at US$50 a barrel;
- development of the flexi-fuel vehicle that can take blends of petrol with ethanol from 0 to 100%.

These advances occurred through the combination of long-term consistent government policies, and strong partnerships between the private, public and research sectors. To coordinate government activities in the bioenergy area the Brazilian government has formed an inter-ministerial working group on biofuels made up of high-level government officials from the major ministries, including the Chief of Staff, the Minister of Mines and Energy and the Minister of Agriculture.

There is an important similarity between the Brazilian example and a potential biofuels industry based on plantation forestry in New Zealand; both are based on an existing industry. There are significant learnings for New Zealand in studying the Brazilian example, especially in understanding mechanisms for technology uptake by industry.

A detailed review of international bioenergy policy can be found in IEA Bioenergy (2008).

2.0 STRUCTURE AND ROLE OF THIS RESEARCH STRATEGY

2.1 International Bioenergy Research and Development Strategies

A number of research and development strategies or roadmaps for bioenergy or biofuels have recently been released internationally, including:

- Bioenergy, Bioproducts and Energy: A framework for research and development (O'Connell et al., 2007); Rural Industries Research and Development Corporation, Australian Government;
- Future Biofuels for Australia: Issues and opportunities for conversion of second generation lignocellulosics (Warden, & Haritos, 2008) - Rural Industries Research and Development Corporation, Australian Government;
- Strategic Research Agenda & Strategy Deployment Document, (European Biofuels Technology Platform, 2008);
- Developing a bioenergy roadmap for the UK (UK Energy Research Centre, 2008);
- Biomass: Multi-year Programme Plan (US Department Of Energy, 2008);
- From 1st-to-2nd-Generation Biofuel Technologies: An overview of current industry and RD&D activities (IEA 2008).

These documents provide very different levels of strategic direction, based on the information available on biomass resources in each country and the clarity of government policy directions. In New Zealand's case, the Bioenergy Options study has completed a comprehensive review of New Zealand's current and potential biomass resources based on our land resources (Hall & Gifford, 2007). This has been backed up by a more detailed study confirming the environmental benefits of a number of chosen pathways (Hall & Jack, 2008). Combining this information with an understanding of the potential of other indigenous renewable energy sources (de Vos. et. al., in prep.) has put New Zealand in a strong position. A relatively focused strategic direction for bioenergy and bioenergy research is now achievable.

Further work on land-use, environmental and macro-economic impacts of national-scale forestry for energy has also informed the R & D Strategy (Hall & Jack, 2009).

2.2 A Strategic Approach to Bioenergy Research in New Zealand

There are a number of options for bioenergy research in New Zealand and, at the same time, a large amount of well-funded research is being carried out internationally. Due to this existing research effort, New Zealand needs to be strategic in its funding of research and development in the Bioenergy area. Two requirements inform this strategy:

- New Zealand-funded research must pursue the greatest opportunity to provide benefits for New Zealand.
- New Zealand-funded research should not needlessly duplicate research and development of technologies being pursued overseas that could be adapted to New Zealand conditions.

Based on these considerations, this report has developed focused research directions captured by the strategic themes presented in Section 3. The research and development requirements of each strategic theme have been identified based on the Bioenergy Options study and international literature. For completeness, Appendix I contains a compilation of the key knowledge gaps and research recommendations from the contributing reports.

For each of the research and development requirements we have used the MoRST defined research roles: 'New Zealand led'; Fast adapter'; 'Emerging opportunities', to indicate the role that New Zealand should play in each of the proposed research and development requirements. This work has tended to focus on research critical to New Zealand so the majority of the identified requirements are 'New Zealand led'.

For some research areas we have suggested that New Zealand play a fast adaptor role. This should not be taken as implying that these areas do not require research investment. Effective fast adaptation requires a strong base capability and a very active international research engagement process.

An attempt has been made to keep the research requirement of each theme at a general level and not narrow the discussion to specific technologies. The conclusions, however, were often made based on studies of specific cases. Therefore, along side the general comments we have placed specific example boxes which illustrate the points.

2.2.1 Niche/commercial opportunities

Bioenergy research and development can be divided into two distinctly different categories:

- Research that will contribute directly to New Zealand's renewable energy supply (e.g. R&D that enables the development or conversion of a national scale bioenergy resource);
- Research that has little potential to contribute to New Zealand's energy supply but could have a significant market off-shore, thereby generating overseas earnings (e.g. a niche bioenergy conversion technology).

The present research strategy is focused on the first bullet point, based on the findings of the Bioenergy Options study, and does not attempt to provide research directions for the area referred to in the second bullet point. This latter area is assigned the research role of: 'niche/commercial opportunity' in the MoRST Energy Research Roadmap (MoRST, 2006).

2.2.2 The innovation process

The innovation process for energy systems typically starts with basic lab or computer simulation-based research; moves through scale-up to pilot-scale trials; then through a demonstration phase; until it reaches widespread application in business and the consumer. For the purposes of this strategy, the innovation processes is divided into a series of stages:

Underpinning: Basic or underpinning energy research – research that underpins the more applied research.

Applied: Applied energy research.

Demonstration: Piloting, demonstrating and proving – including scale-up.

Implementation: Commercial deployment or implementation.

The research requirements of each strategic theme presented in this document are matched to specific stages of this innovation pathway. Figure 2 shows an approximation of how each of these stages are currently addressed by different government funding initiatives.

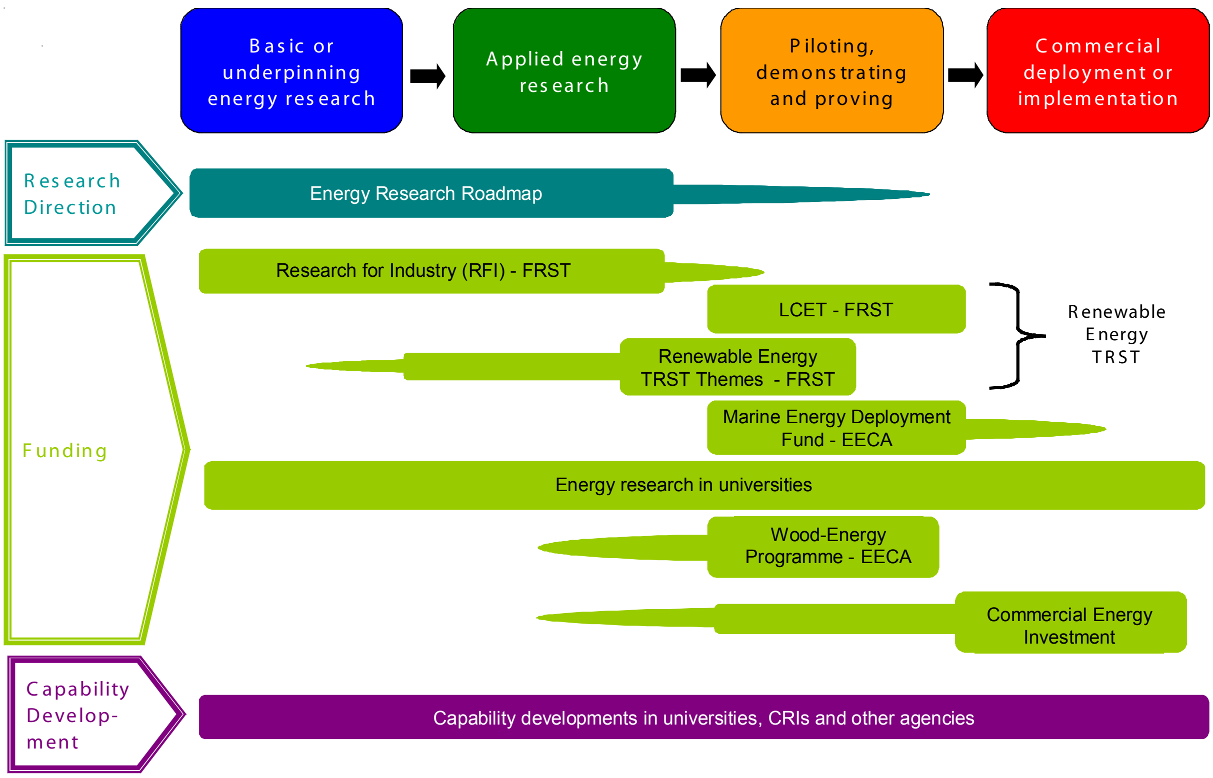


Figure 2 – Diagram illustrating stages of the innovation chain and approximate allocation of a number of current research funds in the energy area. Based on a Ministry of Research Science and Technology (MoRST) presentation. See MoRST website (www.morst.govt.nz) for an explanation of terms.

2.2.3 Structure of this Research Strategy: Strategic Themes and Research and Development Requirements

This section summarises the structure of this research strategy, which is broken up into "Strategic Themes" and "Research and Development Requirements" as illustrated in Figure 1. Broad strategic research directions that have been identified as having significant potential for contributing to New Zealand are referred to as "Strategic Themes". These themes have different drivers due to, for example, different scale of contribution (i.e. national/regional/local), level of technological maturity, likely timescale of contribution and different environmental benefits.

Under each of these strategic themes we have identified specific "Research and Development Requirements". These research and development requirements have been characterised as "Underpinning", "Applied", "Demonstration" or "Implementation", depending on estimates of how far they are along the innovation chain. In the case of Underpinning or Applied research priorities, the role of New Zealand-based research has been specified as one of either: 'New Zealand led'; Fast adapter'; 'Emerging opportunities', based on the current international context.

2.3 Strategic Investment in Research and Development

Investment in Research and Development is often seen as risky because results are uncertain and time horizons are long. However, some of these risks can be mitigated by active management of the technology development process as uncertainty is partially resolved. For example, investing in basic research that underpins a new product may seem daunting considering all the additional investment that will be required for commercialisation, such as scale-up and demonstration, without any guarantee of return (especially important for new energy technologies that are often large scale). There is always the option to not invest in the commercialisation phase if the technology no longer looks promising, due to increased technical understanding or changing markets. This active management of the technology development process can markedly reduce risks and increase the value of investing in research and development.

Understanding the value of actively managing the technology innovation process is the basis of the Real Options approach to research and development valuation (Faulkner 1996, Lackner 1999). The Real Options approach applies methods developed for pricing stock options to research and development valuation. See Appendix II for a simple worked example of this valuation approach. The Real Options approach represents a shift in thinking about risk and risk management in research

and development investment. In this document, rather than attempt a complex quantitative valuation of the present research strategy based on Real Options, we instead consider the general implications of "options thinking" for the present strategy. An "options thinking" mindset emphasises the uncertainty of the future and encourages an adaptive approach that monitors the resolution of future uncertainties and anticipates that course adjustments will be required.

The implications of Real Options thinking for strategic R&D investment include (Faulkner 1996):

1. Recognition of uncertainty by considering "optimistic" and pessimistic" scenarios, and identifying critical future uncertainties;
2. Identification of decisions that can be made after uncertainties are resolved, recognising these as opportunities to adjust;
3. Use of 'flexibility' as criteria for evaluating projects, recognising that flexible projects can allow decisions to move one way or another as uncertainty is resolved;
4. Building a 'phased approach' into project investment decisions, so that future decisions are conditional on downstream information;
5. Maintaining a long-term focus;
6. A tool for valuing intangibles such as flexibility and learning.

Applying this thinking to the current research strategy we can conclude that:

- The Bioenergy Options study, and the broader EnergyScape project, has had the effect of resolving some of the uncertainties around the role and potential of bioenergy in New Zealand, and the opportunities identified should be acted on.
- The present R&D strategy is the result of information available at this point in time and there remain many uncertainties. Due to the fast-moving nature of this area, we therefore recommend that this present strategy be reassessed on a 3-5 year timescale.
- Any R&D strategy should be accompanied by an active management process that continually reassesses the position in light of new developments and acts decisively. One option is to walk away from an R&D investment and decide not to exercise the commercialisation option.
- Investment in R&D should be correctly valued taking into account the value of risk mitigation from active management of options.
- Investment in research should proceed as a staged process with critical re-evaluation points at each stage before further investment is made.
- A bioenergy strategy should not be developed in isolation and should be part of an overall renewable energy strategy, where the end goal is renewable energy supply for New Zealand.

These considerations should be balanced by the urgency of issues that New Zealand is facing and the benefits of being first to market.

3.0 STRATEGIC THEMES

This section describes the strategic themes in more detail and gives details of the research and development requirements for each of these themes.

A comprehensive assessment of New Zealand's residual and potential biomass resources has found that residual, or unutilised biomass resources, were limited in their ability to meet national-scale demands (Hall & Gifford,2008). To meet more than a few percent of national energy demands requires purpose-grown biomass. The purpose-grown biomass with the most promise in the medium term was determined to be woody-biomass grown on marginal lands. This is discussed in more detail in Sec 1.3. These considerations have resulted in the relative emphasis placed on the "Bioenergy from plantation forests" theme in this strategy.

3.1 Bioenergy from plantation forests

Summary

The potential benefits of this theme are:

- Significant potential for meeting a large percentage of New Zealand's renewable energy demands without utilising arable or high-value pastoral land;
- Reducing New Zealand's exposure to increasing oil and carbon prices;
- Carbon sequestration during establishment phase and additional carbon stocks from new forest area;
- Providing environmental services, such as, stabilising erosion prone land and water quality improvement.

Time frame: Medium to long term

The research and development requirements of this theme are:

Feedstocks
- Develop new high-yield, low-input forest systems for multiple products including energy; New Zealand led (Underpinning/Applied).
- Develop efficient harvesting and logistics systems; New Zealand led (Underpinning/Applied).

Conversion technologies
- Adapt transport fuel conversion processes for New Zealand feedstocks; Fast Adapter (Underpinning/ Applied).
- Adopt conversion processes that offer new transport fuels; Emerging opportunities (Underpinning).
- Adapt conversion concepts that allow more distributed processing; Fast adapter (Underpinning/ Applied).
- Demonstrate transport fuel production at pilot scale (Demonstration)
- Demonstrate large industry heat and combined heat and power plants (Implementation).

Integrated systems
- Develop system analysis tools to improve the environmental impact and efficiency of production chains and evaluate alterative technologies; New Zealand led (Underpinning/Applied).
- Develop integrated production chains specific for New Zealand; New Zealand led (Underpinning/Applied).
- Develop integrated biorefinery concepts specific for New Zealand; New Zealand led (Underpinning/Applied).
- Adapt gasification concepts specific for New Zealand; Fast Adapter (Applied).
- Demonstrate transport fuel production at commercial scale (Implementation).

Energy policy
- Assess the economic, social, and environmental implications of large-scale forestry-based bioenergy for New Zealand Inc; New Zealand led (Underpinning/ Applied).
- Develop an implementation plan for New Zealand (Implementation).

Figure 4 shows these research requirements in relation to the whole production chain.

Realising this strategy for New Zealand will require multi-disciplinary research, strong industry and pan-government involvement. It will also require close collaboration with international researchers and industries.

The first implementation step of this theme must be the establishment of a biomass resource. Regardless of the conversion technology utilised, it is the existence of a large scale biomass resource that is key to realising the potential of this theme.

Background

New Zealand is in a unique position of having enough land available to grow biomass to supply up to 100% of our heat and land transport fuel demands without utilising arable or high-value pastoral land (Hall & Gifford, 2007). Most of this land is steep hill country and the most viable biomass crop is plantation forestry. In addition, forestry does not suffer from the environmental concerns that are associated with intensive cropping of arable land (Hall & Jack, 2008). Unlike arable crops, forests can store solar energy for a number of years (decades). Technologies presently exist for turning this woody biomass into heat, electricity and transport fuels. This can significantly reduce greenhouse gas emissions when fossil fuels are displaced (Hall & Jack, 2008).

Pursuing this strategic direction is one of the most promising options for New Zealand. Figure 3 shows a bioenergy vision for New Zealand in 2040 based on this strategy.

A more likely scenario would see some of the current forest harvest being diverted to energy and only a portion of new forest being utilised for energy (see Sec 1.3.4 for more details of this "prefered" scenario).

The large-scale forestry land-use option proposed here has significant potential for multiple sustainable co-products and also has a number of other potential benefits that impact on several policy areas outside the core energy area.

This solution also has economic benefits in:

- Not impacting key exports from arable and high-value pastoral land;
- Benefiting the NZ clean green image for exports and tourism;
- Developing a sustainable resource base for multiple products for both export and domestic use;
- Developing a new large-scale biofuels industry for New Zealand;
- Mitigating concerns over long term supply and price of oil and gas.

This theme therefore impacts on and aligns with a number of the government's climate change and sustainable development directions in addition to those in the energy area.

Much of the technology associated with this theme is not yet commercially available, particularly for conversion to transport fuels, and a forestry-based biomass resource will take a significant time to be established so this theme is relevant in the medium to long term.

The key barriers to this theme are:

- Transport biofuel production from woody-biomass requires significant cost reductions to be competitive with fossil fuels at current prices;
- Industrial heat production from biomass has traditionally been uncommon outside the wood processing sector, but is developing (e.g. Finegand Meatworks, Balclutha and NZ Foam Latex);
- Lack of a coherent implementation plan that includes government and industry.

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

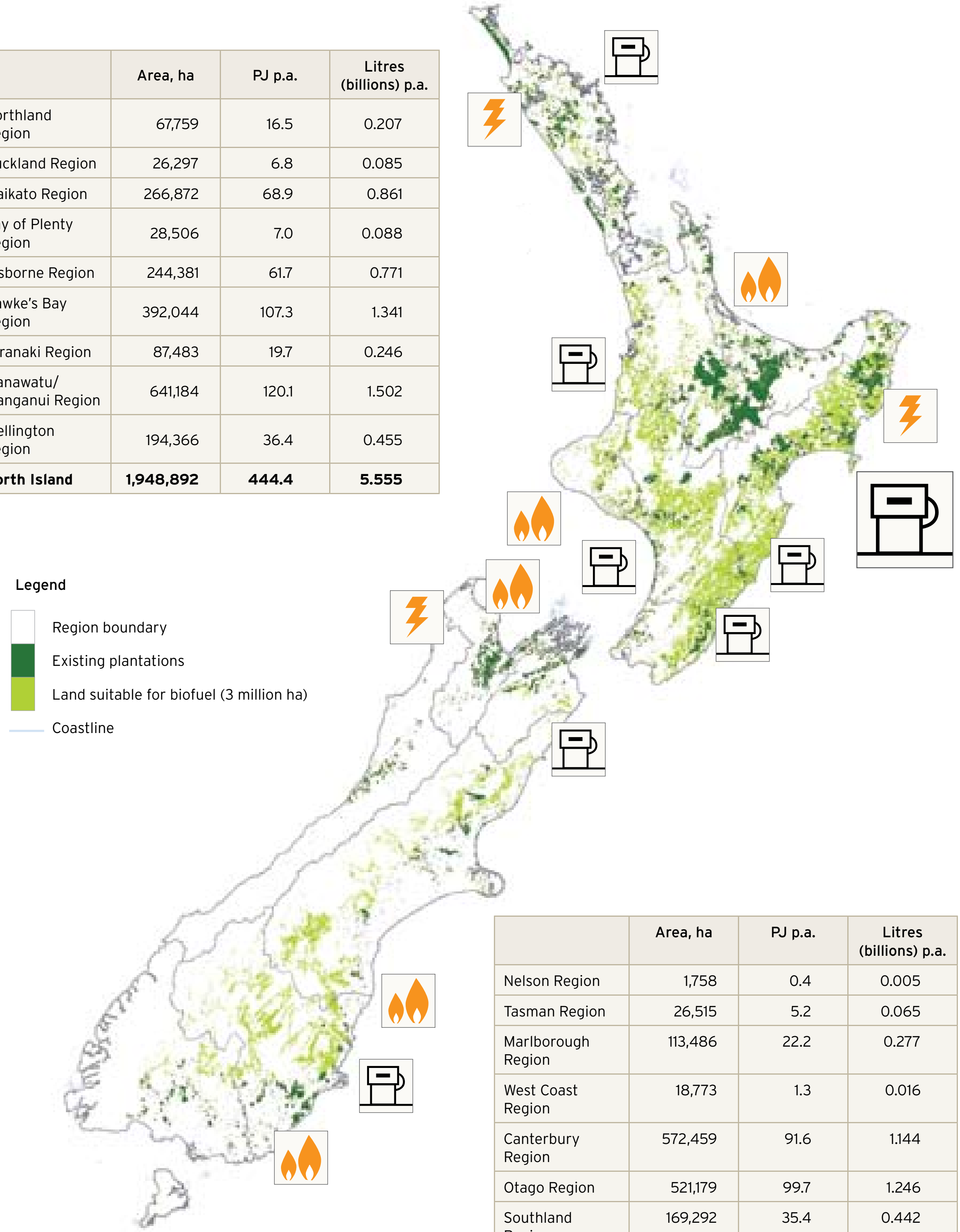


Figure 3 – Map representing a large-scale forestry for bioenergy scenario

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

Realising this strategy for New Zealand will require multi-disciplinary research, and strong industry and pan-government involvement. It will also require close collaboration with international researchers and industries.

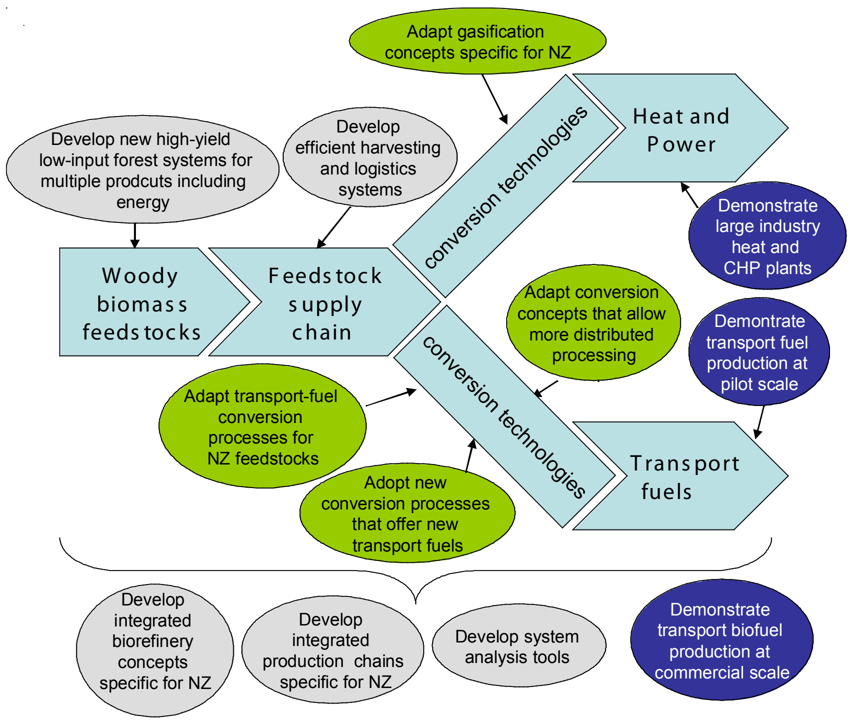


Figure 4: Research requirements for the theme: bioenergy from plantation forests. The grey ovals are the NZ led research requirements the green the fast adaptor and dark blue demonstration and implementation requirements

Feedstocks

The research and development of feedstocks specific to New Zealand's conditions needs to be New Zealand-led. This research covers all aspects of species selection and breeding, crop management and biomass harvesting, recovery and supply chain logistics.

For any bioenergy pathway, regardless of the particular bioenergy conversion technology, a low-cost, high-volume, environmentally-acceptable biomass feedstock, must be established for the pathway to make a significant contribution to New Zealand's energy supply.

3.1.1 Develop new high-yield low-input forest systems for multiple products including energy

To reduce feedstock costs there is a need for high-yield, low-input forest systems (Hall & Jack, 2008). These forests systems are likely to be very different from current plantation forestry and will require:

- Development of optimised stocking and management regimes for existing species;
- Species selection and breeding (both hardwoods and softwoods) for multiple products;
- Species-site matching;
- Understanding the sustainable land management, landscape, environmental, and biodiversity aspects of species and different land management regimes;
- Determining the bioenergy yield from different species undergoing different kinds of conversion process. This is particulary important for conversion processes that are sensitive to initial feedstocks.

Forests designed for a mixture of end products should be a focus for investigation, for example, a mixture of sawlogs, bioenergy feedstocks and high-value biomaterials and chemicals. Much of the significant body of knowledge on plantation forests in New Zealand is directly relevant to this area. However this knowledge has previously been focused on the production of high quality timber products and not biomass for energy or other products. The existing New Zealand plantation forest estate is 90% radiata pine (MAF, 2007), suggesting that it has proven to be a productive, robust, managable and adaptable option across a range of soils and climates. In any establishment of forest for energy radiata pine will inevitably be part of the species mix, but by no means the sole species. Much development needs to occur to determine potential new species and management systems that are optimised for the production of energy and multiple other products. Knowledge gaps such as investigating high yield species which are not yet common in New Zealand, could be filled by carrying out regionalised species trials under different management regimes. The focus should be on species suitable for marginal lands that do not compete with food crops or high value pasture.

An additional consideration for these new forest systems is the impact of future pests and the potential impacts of climate change, requiring robust species selection and management.

There is a variety of potential land uses involving forests including carbon forestry and other environmental services, and forests producing multiple products including energy. Given this variety, there is a need from both the government and landowners for tools to help them decide between the options. These decision making tools (probably Geographic Information Systems based) must be able to accept data about a particular site, such as climate, soil and distance from potential energy plants, and determine economic and environmental indicators for different types of land use and species.

This research will need to be New Zealand-led and can leverage New Zealand's world-class research standing in tree breeding, sustainable plantation forestry management and biotechnology capabilities. This research falls into the categories of underpinning and applied.

3.1.2 Develop efficient harvesting and logistics systems

In current log production systems the extraction and delivery of the logs contributes a significant proportion (~40%) of the delivered cost of transport biofuel production (Sandilands et al. 2008). If road construction is included this can rise to 50% of the delivered cost. In order to maximise the efficiency of the delivery system all steps in the supply chain must receive attention, especially:

- Harvesting (steep terrain);
- fuel upgrading (see Section 3.3.1);
- logistics.

This analysis must take into account different conversion concepts at different scales as harvesting and logistics requirements will be different.

The research effort should include attempts to increase the efficiency of the current system, as well as fundamental research that considers paradigm shifts offering substantially different approaches to existing systems. Note that aspects of this research are not specific to bioenergy and should be linked to broader forestry research. Energy harvesting must be integrated with the entire forest management system to maximise its potential (Anderson et al. 2002; Bjorheden 2000). The aim must be to have a low cost, low impact harvesting and transportation system.

Due to the uniquely New Zealand aspects of this theme, this research must be New Zealand-led and falls into the category of underpinning and applied research.

Conversion

Mature technologies exist for converting lignocellulosic feedstocks (like wood) to heat and electricity, and are ready for implementation. However, at present there is no successful operation for the full scale, commercial conversion of lignocellulosics to liquid biofuels (Farrell & Morris, 2008 p. 18). Significant developments are occurring in lignocellulosic biofuel conversion technologies in Europe and the US due to large investments in research and development. The prime focus is reducing the cost of production so that liquid biofuels are competitive with fossil fuels (US DoE, 2008).

There exists a huge range of potential conversion pathways and possible fuels from lignocelluose and a number of different avenues are being pursued in different countries (Warden & Haritos, 2008). The main conversion pathways at present are:

- Enzymatic conversion to ethanol;
- Gasification followed by Fischer-Tropsch process to a Fischer-Tropsch diesel;
- Pyrolysis to a bio-oil followed by further upgrading to a biofuel.

Enzymatic conversion to ethanol
A simplified biochemical process for obtaining lignocellulosic bioethanol has 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. Purify the bioethanol product.

A more realistic scheme would also include options to integrate with other industrial processes, combine stages, recover reactants and water, generate co-products and handle wastes. It would also include fractionation of the substrate into separate streams to produce different products, maximise value and optimise individual processes. Substrate fractionation remains an active field of research (e.g., Zhang et al. 2007) that could lead to numerous variants of the basic process scheme.

From the assessment carried out in Wong (2007), the biochemical platform involving the use of enzymes still appears to be a viable option, but its success will depend on future advances in the adaptation of enzymatic and associated technologies to suit the available feedstocks.

The US Department of Energy programme believes enzymatic conversion will be the first to commercialisation for non-wood lignocellulosic feedstocks and aims to make cellulosic ethanol via enzymatic conversion cost-competitive with corn-based ethanol by 2012 (US DoE, 2008). This estimate is supported by the company DONG Energy in Denmark (Larsen, et al. 2008). Estimates of the cost of production of lignocellulosic ethanol in short, medium and long time frames have been made by Hamelinck et. al. (2005) under various assumptions.

Although there are distribution and infrastructure issues with ethanol as a fuel, flexi-fuel vehicles are now available which can take anything from a 0% to 100% ethanol/petrol mix. The marginal cost of manufacturing these flexi-fuel vehicles is expected to be in the order of $100.

Gasification followed by Fischer-Tropsch process to a biodiesel

Gasification decomposes biomass by heating to very high temperatures under little or no oxygen to produce a synthesis gas (syngas). Syngas is composed primarily of hydrogen and carbon monoxide. Fischer-Tropsch synthesis is the most well-established method of building up hydrocarbon fuels from syngas. This technology is mature and has been used in conventional coal-to-liquids and gas-to-liquids fossil fuel conversions and attention is now being turned to its application to biomass-to-liquids technology. In general Fischer-Tropsch is a very efficient process but it currently has to be performed at large scale to be economically viable (IEA Bioenergy 2007). A German company, Choren Industries is building the world's first commercial scale biomass-to-liquid plant. They are developing a semi-distributed biofuel/biodiesel production system where they will have a series of standard size plants (200,000 t/pa biofuel from 1,000,000 t/pa dry biomass per plant) placed at strategic locations according to biomass availability (spatial density).

One of the advantages of a gasification platform is its flexibility. There are a variety of biomass resources that can be gasified to produce syngas and there are a variety of products that can be produced from syngas (ethanol, FT diesel, gas fuels, hydrogen). This flexibility lessens the risk of biomass availability and unknown markets for products.

The pulp and paper industry tends to favour this route because gasification is seen as a viable alternative for the recovery process in Kraft mills – i.e. converting lignin to process energy and recovering process chemicals (Agenda 2020 CTO Committee working group, 2008).

Estimates of the cost of production of Fisher-Tropsch diesel from lignocellulosic biomass in short, medium and long time frames have been made by Hamelinck et. al. (2004).

Pyrolysis to a bio-oil followed by further upgrading to a biofuel

Fast pyrolysis, where finely ground biomass is heated rapidly (in about 1 second) to 500 deg C in the absence of oxygen, can produce a dark, viscous liquid know as bio-oil. This low quality fuel can be used directly for heat or power or upgraded to a transport fuel. This technology is being commercialised by a number of companies including Dynamotive in Canada. Bio-oil is not suitable for direct use in standard internal combustion engines, although, PyTec in Germany is working on modifying a Mercedies engine to work on bio-oil. Alternatively, the oil can be upgraded to a transportation fuel, e.g. by means of hydro- or catalytic cracking (Dale & Kim, 2006). In spite of a considerable amount of research on bio-oil upgrading, no efficient route to a motor fuel has been established (Bridgewater, 2003; Czernik & Bridgewater, 2004; Elliott, 2007). 'BioCoup' a European consortium of 17 research laboratories including Shell's, has been put in place to develop technologies for co-processing biobased liquids, such as pyrolysis oil, in standard refinery units.

A potential advantage with pyrolysis, that is particularly relevant to the New Zealand situation, is that it can be carried out by small-scale semi-mobile plants close to where the woody biomass resources are harvested. The mobile plant can produce a bio-oil that has a much higher energy density than woody materials (three to four times), which reduces handling, storage and transport costs (Badger & Fransham, 2006). The bio-oil can then be transported to a centralised plant for upgrading.

Pyrolysis is also a central technique in many biorefinery concepts where cellulose and hemicellulose are converted to ethanol via enzymatic processes and the "left-over" lignin and extractives are pyrolysed to a liquid fuel, increasing the overall biomass to liquid conversion efficiency (Kleinert & Barth, 2008; Bain 2006).

Conversion options

Of these options, no single conversion technology has clearly emerged as the most promising option (Wright and Brown, 2007, IEA 2008). Moreover when the US government awarded $385 million in grants aimed at the development of commercial lignocellulosic bioethanol production in March 2007, half the chosen projects were based on thermo-chemical and half on biochemical processes, further illustrating the current lack of dominance of one conversion method. In fact, these technologies may be utilised together as part of an integrated energy plant (Bain, 2006).

More than one conversion technology may be required in order to meet different fuel demands, for example ethanol for light vehicles and biodiesel for heavy vehicles. In addition, given the range of biomass feedstocks, diversity in conversion technologies could be an advantage.

Due to the long history of research and the amount of research currently occurring overseas, New Zealand should not attempt to duplicate these efforts and instead should play a fast adaptation role in this area. Fast adaptation will be facilitated by strong links with international research programmes, a base capability and support for flexible models for international partnerships.

3.1.3 Adapt transport fuel conversion processes for New Zealand feedstocks

A focus of conversion research in New Zealand should be placed on fast adaptation of international developments in conversion technologies to New Zealand feedstocks. For example, much international research on enzymatic conversion of wood to ethanol has focused on hardwoods, while the vast majority (97%) of New Zealand's current plantation forestry are softwoods (MAF, 2007). The most important stage of the conversion for different feedstocks is pre-treatment. The main forms of pre-treatment include steam, the use of dilute acid, exposure to hot water, a process called ammonia fibre explosion, treatment with lime, wet oxidation and Organasolv. Dilute acid and wet oxidation have been successfully tested on softwood substrates, and several pilot facilities have been constructed. Mechanical pre-treatment is also considered a promising area.

The composition of bio-oil is also affected by different feedstocks, and trials should be carried out with New Zealand feedstocks, beginning with major potential resources such as softwoods.

New Zealand research should be focused on adaptation of existing or rapidly developing technologies to local feedstocks with emphasis on the pre-treatment phase or development of softwood specific processes. International partnerships are an important part of research in this area. This research can be regarded as underpinning/applied. This research should consider a range of the most promising conversion options at present but reassess the conversion options before going to the demonstration phase.

3.1.4 Adopt conversion processes that offer new transport fuels

Due to infrastructure changes associated with ethanol and its comparitive incompatibility with hydrocarbons, there is much interest in biofuels that are more compatible with the hydrocarbon fuels infrastructure, such as biobutanol, biomethanol and biodimethylether (US DoE, 2008). Fuels that can be used in fuel cell vehicles also provide an interesting option which bridges the gap between biofuels for internal combustion engines and electric cars (Clemens et. al., In Prep.). The attraction of fuel cells is their more efficient conversion of fuel into motive force (Bossel, 2003).

International partnerships are a key part of research in this area and oil companies have a particularly strong interest. This is an emerging opportunity for New Zealand which is still at the underpinning research stage.

3.1.5 Adapt conversion concepts that allow more distributed processing

Fundamental aspects of biomass are its low energy density and wide distribution. This has an impact on the costs and energy use required for transportation and on the location and scale of processing plant (Moeller and Nielsen, 2008). For this reason, more distributed processing is an attractive option. In a distributed processing scenario, biomass is partially processed into a higher-density fuel in small distributed (possibly mobile) plants before being transported to a central plant for processing. Examples of this type of technology are mobile pyrolysis units (Badger & Fransham, 2006).

Significant research is being carried out on distributed processing options overseas (US DoE, 2008), and New Zealand's low population density conditions and the nature of the forest industry may favour this particular technology. However, New Zealand's feedstocks and operating conditions are likely to be different to those found overseas. New Zealand should look at playing a fast adaptor in this area. This is underpinning/applied research.

Example: Pyrolysis to biodiesel or other liquid fuel

Small scale pyrolysis plants that convert woody-biomass into a more energy-dense bio-oil have potential for distributed production of biofuels (Badger & Fransham, 2006). The bio-oil produced can then be transported to a central refinery for conversion to biodiesel or used directly as a boiler fuel. This area warrants detailed investigation, including testing of bio-oil derived from New Zealand specific feedstocks (straw, radiata pine, Douglas Fir, other softwoods, bark, eucalyptus species, food/feed processing wastes and grasses), as well as investigating the potential of these bio-oils to be further refined into transport fuels. A small-scale pyrolysis plant is currently under construction in New Zealand (AES, 2009), and potentially available for feedstock testing and bio-oil chemical analysis.

The following research priorities have been identified for a project based on trialling this technology (Nielsen, 2007):

- Feedstock influence on the pyrolysis process and end products.
- Understanding pre-treatment processes' impact on final product.
- Investigate upgrading or refining opportunities for the end product (bio-oil).
- In field demonstration.
- Potential co-products such as biochar.

3.1.6 Demonstrate transport fuel production at pilot scale

To promote industry investment confidence in new technology, pilot and demonstration plants will be required. Public private partnerships are required to reduce investment risk. A staged investment plan and active management of research directions and options can help to mitigate some of the risks involved investing in demonstration plants (see Section 2.3). This is a medium-term requirement.

3.1.7 Demonstrate large industry heat and combined heat and power plants

There are several examples of large (>20 MW) biomass-fuelled heat plant and a few large biomass-fired combined heat and power (CHP) plant in New Zealand. These are almost exclusively centred on the wood processing industry. There are recent developments, where wood fuel is being used at a meat processing plant (Finegand) and plans for use of woody biomass in conjunction with municipal biosolids to solve the issue of landfilling municipal wastes. However, a key issue holding back further developments is the supply of fuel at known quality, quantity and price.

Demonstrations or case studies of a non-wood processing industry based biomass heat or CHP plant would be valuable in determining issues and demonstrating the viability of this option. Public/private partnerships are an option here.

Integrated Systems

An important area of research is the development of low-cost, environmentally sustainable and energy-efficient integrated production chains for multiple products. These integrated chains include all aspects of production from feedstock supply chains to conversion technologies. The importance of considering the whole integrated production chain has also been highlighted internationally (European Biofuels Technology Platform, 2008; US DoE, 2008). Due to New Zealand specific feedstocks, conditions and complementary resources (such as geothermal heat) this research will need to be New Zealand-led.

3.1.8 Develop system analysis tools to improve the environmental impact and efficiency of production chains and evaluate alternative technologies

System analysis of complex integrated biofuel production chains both prior to construction and alongside ongoing development is a high-priority research area for New Zealand. Full system analysis enables:

- Assessment of economics, sustainability and energy efficiency of entire production chain taking into account all energy inputs and outputs and using these as part of a system design process. Life cycle assessment (LCA) is an important established methodology that could be used as part of this[4];
- Pinpointing the significant thermodynamic losses along the chain through thermodynamic analysis (e.g. exergy analysis (Bejan,1997));
- Technology evaluation and selection as part of a complete production chain, which will assist fast adaptation decision making (Wooley et al. 1999);
- The ability to take into account the transport of distributed biomass resources to a centralised plant as part of determining the optimum plant size and site;
- Evaluation of the technical feasibility and economic implications of the production of multiple products.

Accurate data from throughout the production chain is required for accurate system analysis. There is also a

[4] However, using net energy as an indicator has been questioned (Dale, 2008) due to the non-equivalence of energy forms. Exergy (Bejan, 1997) may be a better indicator from this perspective.

need for continued development of New Zealand specific environmental (such as Life Cycle Assessment) and Geographic Information System databases for evaluating sustainability of these systems (Hall & Jack, 2008). This database can build on existing New Zealand capability in the GIS modelling of biomass extraction (Moeller and Nielsen, 2008).

System analysis addresses the need for strategic decisions related to research and policy issues based on scientifically sound analysis (IEA Bioenergy Task 41; Wooley et al. 1999). This can feed into the development of decision support tool for evaluating biofuel alternatives and environmental certification standards and quality assurance schemes for biofuels. System analysis research will need to be New Zealand-led and underpins a number of other research priorities. This is applied research.

3.1.9 Develop integrated production chains specific for New Zealand

Co-development of feedstock, logistics, and conversion technology and product range is the key to more energy-efficient, cost effective and sustainable systems (Sassner & Zacchi 2008). Research in this area is highly interdisciplinary. It requires knowledge of feedstock breeding, silviculture, harvesting and transporting biomass, and an understanding of mechanical, thermochemical and biochemical conversion processes to energy products and potential co-products. It also requires understanding the integrated waste, energy and water management and recovery systems within the conversion processes and how complementary energy sources (such as geothermal) can be integrated into the production systems. New Zealand is well positioned to exploit its research base in biotechnology and across the wood processing/pulp and paper sector to develop internationally competitive teams in this area.

Development of integrated production chains specific for New Zealand also provides the ability to take advantage of unique New Zealand resources, for example, utilising geothermal heat for process heat requirements in biofuel plant or biorefinery. In addition, there are opportunities to convert existing industrial infrastructure to the production of biofuels. For example, pulp and paper mills have feedstock supply and biomass processing and waste management infrastructure that could be used as part of a biofuel production chain. Scale that is suitable for New Zealand

This research will need to be New Zealand-led and falls into the category of underpinning and applied research.

3.1.10 Develop integrated biorefinery concepts specific for New Zealand

The biorefinery concept (Kamm & Kamm, 2004) is based on the oil refinery model where, in addition to production of commodity fuel products, a biorefinery also produces a range of higher-value chemicals (Dodds, 2007; Ragaukas et. al., 2006; Zhang, 2008). Biorefineries make full use of biomass feedstocks to obtain diverse high-value co-products. Due to the potential cost reductions, biorefineries are seen as a key step towards the commercial implementation of biofuels (European Biofuels Technology Platform, 2008; US. Department of Energy, 2008). This will depend on the creation of markets for the co-products.

The wide diversity of biomass feedstocks, conversion technologies, integration options, and potential products together create a multitude of scenarios possible for biorefinery options. Unique feedstocks and different markets for products may result in biorefineries being very specific to their environments. Moreover, biorefineries may possibly evolve out of existing industry infrastructure (Agenda 2020 CTO Committee working group, 2008).

Areas of research to progress the biorefinery concept are (European Biofuels Technology Platform, 2008; O'Connell et al., 2007):

- Market analysis on current and future types, volumes and prices of value added materials and/or chemicals to be co-produced with biofuels to increase their market competitiveness;
- Identification and lab-scale production of most promising platforms and functionalised bio-based chemicals that can be applied in existing petrochemical infrastructure.

Biorefineries represent an emerging opportunity and research in this area will need to be New Zealand-led due to unique feedstocks and matching the size of the local resource with markets where New Zealand could be competitive. For example, focus might have to be high value co-products, or agrochemicals that suit Australasian primary production. New Zealand's existing biotechnology industry and wood-processing expertise could be leveraged to develop leading international research in this area. A strong and active connection to international research is crucial to stay abreast of overseas developments, as are international partnerships. Much of the research in this area falls into the category of underpinning and applied research.

3.1.11 Adapt gasification concepts specific for New Zealand

Gasification of biomass produces a gas of medium-to-low calorific value consisting of mainly carbon monoxide and hydrogen. This gas, or syngas, has a variety of uses including direct combustion for heat, combustion in a turbine for electricity production and conversion to liquid fuels. A potentially important application in New Zealand is as a renewable substitute for natural gas. This would have applications at a number of industrial sites but could also be used in gas infrastructure, such as reticulated gas pipelines.

A research priority is to adapt gasification technology that can be integrated with existing natural gas infrastructure. This is applied research.

3.1.12 Demonstrate transport biofuel production at commercial scale

The final stage of the innovation process for biofuels is the demonstration of commercial scale biofuel production. This will require a fully integrated production chain. This is likely to be carried out largely by industry and will need to be de-risked before investment via public private partnerships.

Energy policy

3.1.13 Assess the economic, social and environmental implications of large-scale forestry-based bioenergy for New Zealand Inc.

Implementation of large-scale forestry-based bioenergy in New Zealand will require significant land use change, have infrastructure demands, and will also have large environmental, economic and social impacts. Some of these are shown in Figure 5. The extent of these impacts needs to be understood more fully, under a variety of future scenarios (oil/food price, climate change, etc). A preliminary analysis of the land use change, environmental and economic impacts has been carried out in an extension of the Bioenergy Options study: Analysis of the Large-scale impacts of energy from forestry (Hall et. al. 2009). A number of areas that have been identified as requiring further investigation are:

Existing forest estate and resource
- Potential volumes of pulp and export grade logs that could be diverted to energy production by region, assessing resource competition and prices.

Environmental
- Impacts on soil carbon, biodiversity and water yield.

Economic
- Transition issues.
- Role of existing forest estate.
- Risk mitigation role of carbon and wood product options.
- Insulating effects (if any) of domestic energy production on fluctuating international energy prices.
- Mixed end use of new afforestation harvest volumes.

Social
- Drivers and barriers to land-use change and land substitutability.
- Impacts on regional development.

This research underpins a successful bioenergy from plantation forest resource and will need to be taken into account in any implementation plan. This research will need to be New Zealand-led.

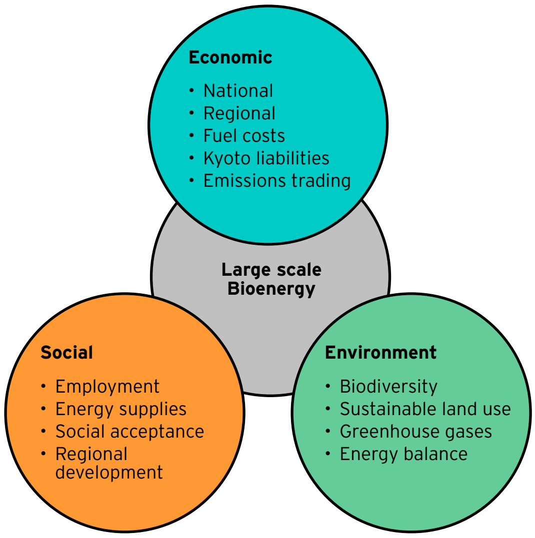


Figure 5: Multi-dimensional impacts of large scale bioenergy.

3.1.14 Develop an implementation plan for New Zealand

To realise the bioenergy from plantation forest strategy proposed in this theme, a detailed implementation plan showing a pathway from research through to industry development is required. This plan must contain elements of:

- resource establishment;
- multiple log product options analysis;
- infrastructure development;
- demonstration plants;
- first commercial plant;
- access to markets;
- role of current forestry estate.

Research is required to determine the most promising approach to implementation and must be developed with wide ranging consultation with industry and government.

A critical part of the plan is the early initiation of establishing a biomass resource. Having a resource of sufficient scale available by the time conversion technologies reach commercial implementation stage is critical for the speed at which biofuel production can begin. Initially, feedstocks could come from residues or pulp and other low value logs from existing forests with the key requirement being supply security. Also important is access to markets so policies need to pay attention to standardisation of feedstocks and biofuels and grid access for distributed electricity generation (IEA Bioenergy, 2008).

Large-scale bioenergy can contribute to: reducing greenhouse gases; energy security; national and regional economic development; and, if based on forestry, improve sustainable land management (erosion control, improved water quality) and other environmental goals (carbon sequestration during growth phase). These aspects of bioenergy are not confined to the energy and transport area, they span a number of government ministries. In addition, because of the distributed nature of biomass resources, economic and environmental benefits will occur at the regional level. To realise the potential benefits from this opportunity it is critical that there is coordination between all the regional councils and across the national government ministries. It is suggested that a cross-government working group is formed to coordinate efforts and funding across the ministries.

The implementation of a national-scale bioenergy initiative requires a collaborative partnership between industry, government and research. Public/private partnerships in demonstration plants and infrastructure are an important part of this collaboration.

The Brazilian sugarcane ethanol example demonstrates how industry and research can respond to a combination of research funding and mandates put in place by the government (BNDES and CGEE, 2008).

In its Strategic Research Agenda & Strategy Deployment Document, the European Biofuels Technology Platform (2008) has laid out a number of non-technical deployment measures that have to be addressed in order to develop a large scale transport biofuels industry in the European Union. These are also relevant to New Zealand and should be considered in the development of an implementation roadmap. The measures are:

- *A coherent, long term political and open market framework to secure confidence of investors in capital-intensive innovative technologies.*
- *Joint public/private financing of R&D and Demonstration of new biofuel production routes and end-use applications. Additional public funding for higher risk large-scale demonstration facilities.*

An implementation plan must also consider the risks involved in large-scale bioenergy from forests and put in place risk management strategies to deal with these. The International risk governance council (2008) have published guidelines on risk management for biofuels, which include:

- *Establishing proper land-use policies.*
- *Agreeing upon and implementing sustainability criteria and certification schemes.*
- *Setting up performance standards and mandates.*
- *Choosing appropriate economic instruments.*
- *Negotiating trade agreements.*

An advantage with the forestry-based biofuel industry proposed here is that mature sustainability certification schemes already exist for forestry and can be adapted and extended to cover the whole biofuel production chain.

This research is part of the implementation part of the innovation pathway. An implementation plan must be fully integrated with planned research outcomes, other renewable energy implementation plans and must be flexible and actively managed to take advantage of new information.

3.2 Biomass waste utilisation

Summary

Utilisation of municipal waste, industrial effluent and agricultural waste for energy has the potential benefits of reducing:

- greenhouse gases by displacing fossil fuels;
- greenhouse gases released during decomposition;
- effluent and landfill waste disposal volumes and toxicity;
- nutrient loading of waterways;
- waste management costs.

Time frame: Short-to-medium term

The research and development requirements of this theme are:

- Demonstrate technologies on site (Implementation);
- Adapt technologies for New Zealand specific conditions; Fast Adapter (Applied);
- Develop innovative new technologies; New Zealand lead/Fast Adapter (Underpinning/Applied).

Background

The focus of this theme is the use of technologies to utilise biomass waste streams for energy production. The major focus is on waste remediation where, for example, energy is generated as a by-product to improve cost viability.

Some major pathways associated with this theme at present are:

- Industrial, municipal and farm effluent to heat or CHP via anaerobic digestion (Thiele, 2007) and effluent to gaseous transport fuels (Fletcher, 2008);
- Municipal green waste, wood processing waste and demolition wood waste to CHP via combustion, gasification or pyrolysis (Evanson & Hall, 2007);
- Algal energy systems coupled to anaerobic digestion of effluents (Heubeck & Craggs, 2007);
- Short rotation energy crops for nutrient stripping of land applications of industrial, municipal and farm effluent (Nicholas, 2007).
- Displacement of reticulated natural gas with gas from anaerobic digestion and other biomass sources.

In addition to these established technologies, the concept of deriving value from waste streams is presently undergoing a lot of development and there is significant potential for new innovation and the development of new technologies for reducing costs and for utilising a wider range of waste streams for energy (Thiele, 2007, Thiele and Mayes 2008, Schulz et. Al. 2005, Boisen 2007).

This is an opportunity that is available now and the drivers for this theme will remain in the medium term so research in this area should be focused on the short-to-medium term.

3.2.1 Demonstrate existing technologies on site

A number of mature technologies for deriving energy from waste already exist. To develop industry confidence in these technologies and to determine costs at full-scale, demonstration projects in realistic situations are required (see anaerobic digestion case study). One of the significant barriers to widespread uptake of these systems is that economic viability is often highly site specific (Thiele, 2008). There are also issues with security of feedstock supply in some waste systems, particularly in the case of seasonal production (Saggar et. al., 2007). These demonstration projects will ideally occur as government/industry partnerships.

Example: Nutrient stripping via short-rotation forests

Waste water, often with high nutrient loadings, can be applied as a fertility enhancer to short rotation forests being grown as an energy feedstock. The application can promote fast growth, with the crop removed at a young age to maximise nutrient removal via stem and crown material. Several small townships/communities have initiated such schemes, but are stalled by the lack of markets for young forest material, which is also suitable for bioenergy purposes. The development of wood fuel markets could springboard this concept for many rural/coastal communities which have a waste water issue and a potential bioenergy application.

Example: Anaerobic digestion of wastes to electricity

Anaerobic digestion is a mature technology that can yield energy from a wide range of organic waste streams. The biogas produced by anaerobic digestion can be used to generate a combination of heat and power (CHP) through a gas motor and a genset. Using current technology, New Zealand has the potential to produce 5-6PJ/annum of consumer energy from industrial waste and municipal solids/animal manure.

Anaerobic digestion of wastes and effluents has significant environmental benefits, mainly from avoided greenhouse gas emissions from decomposing organic matter and reduced waste volumes going to landfill, but also from avoided electricity generation from fossil fuels.

The technology is sufficiently mature to proceed to implementation. Barriers to implementation are:

- lack of site specific and technology specific LCA reports and business case proposals.
- cheap fossil fuel alternatives (coal and gas).

Uptake could be accelerated by identification of early implementation sites nationwide and by the creation of demonstration facilities (Thiele, 2008). Note that New Zealand already has a number of biogas-to-electricity systems based on landfill gas.

3.2.2 Adapt technologies for New Zealand-specific conditions

There is a need for further New Zealand-focused technology adaptation or development in waste utilisation due to differences in the scale of New Zealand industries and New Zealand-specific conditions (e.g. waste streams, climatic conditions etc). For example, for anaerobic digestion technology, scale is possibly the most important issue, with many dairy farms being at the bottom end of the size of the plant that would be economically viable (Saggar et al., 2007). There is therefore a need to develop technologies that improve energy yield and cost effectiveness for a broader range of waste streams and also technologies that are low cost at small scales. Technology development could be either via New Zealand-led development or adaptation of overseas technology. This is underpinning or applied research.

For many of the waste streams, there are issues around seasonal supply, where the effluent or residue is only produced for part of the year (e.g. meat works) or is available in large batches for short periods (e.g. grape skins). The potential of matching and amalgamating different waste streams and storage of feedstock or product should be investigated to improve the economics of plants due to this intermittent supply. This is an additional area for New Zealand-focused technology adaptation. In addition, New Zealand has a history of using gaseous transport fuels and may be in a position able to rapidly pick up vehicle and distribution infrastructure technologies based on utilising biogas as a vehicle fuel (Fletcher, 2008).

3.2.3 Develop innovative new technologies

Converting municipal and industrial organic waste to heat and electricity or to gaseous and liquid fuel is an area undergoing significant international development. A number of new technologies are presently at lab scale and demonstration stages of development. These technologies cover a broad spectrum of thermochemical and biochemical conversion process (Thiele and Mayes 2008, Schulz et. al. 2005). New Zealand's significant biotechnology and waste treatment expertise can be leveraged to develop new innovations in this area. This research should be focused on reducing costs and/or utilising a wider range of waste streams.

This research should be a combination of New Zealand-led and Fast adaptation due to New Zealand-specific waste streams. This is an area of underpinning and applied research.

3.3 Biomass residuals for distributed generation

Summary

Utilisation of residual biomass for energy at a regional, rural or remote community level has the potential benefits of:

- Reduced greenhouse gases by displacing fossil fuels;
- Increasing energy security;
- Reducing need for energy distribution infrastructure.

Time frame: Short-to-medium term

The research and development requirements of this theme are:

- Develop optimised fuel supply chains; New Zealand-led (Applied);
- Develop integrated industrial solutions; New Zealand led/Fast adapter (Applied);
- Assess and adapt residential and community bioenergy concepts; Fast adapter (applied);
- Demonstrate technologies at different scales (Implementation).

This theme is focused on the use of mature technologies for generation of energy to meet a regional, rural or industrial site demand.

Biomass is a low energy density, distributed resource and utilisation for local heat or combined heat and power (CHP) generation is logical. Heat must be generated locally as it cannot be transported long distances efficiently. One of the advantages of biomass as a renewable energy source is its storeability. This is in contrast to solar and wind which are cyclical or weather dependent. In a grid-connected scenario, biomass could be used to assist in matching peak electricity load and in smoothing out the intermittent generation from other renewable sources such as wind power (Trolove & Garrood, 2007)

Some of the major pathways likely to contribute to this theme are:

- Forest residues to CHP or heat via combustion, gasification or pyrolysis;
- Industrial and municipal effluents to heat or CHP via anaerobic digestion;
- Agricultural residues (such as straw) to heat or CHP via combustion.

Mature technologies exist for taking advantage of this opportunity now and residual biomass will continue to be produced so this is an opportunity for the short-to-medium term and research should be focused on this time frame.

The issues with utilising residues for distributed generation are:

- Security of supply/resource competition;
- Difficulties estimating resource volumes and costs of extraction;
- Variable quality of feedstocks and lack of fuel and feedstock standards;
- Economic viability;
- Lack of working examples in New Zealand;
- Lack of grid access for electrical generation.

A number of these issues will need to be addressed by policy. This requires coordination among government and working with industry to build robust frameworks (IEA Bioenergy, 2008).

3.3.1 Develop optimised fuel supply chains

Biomass is fundamentally geographically distributed and often of low energy density and variable quality (Hall & Gifford, 2007). This means that collection and transportation are significant contributors to the economic and energy cost of utilising biomass. A critical research requirement is the development of optimised fuel supply chains. This includes analysis of the following for different resources and site types:

- Recovery;
- Handling;
- Transportation systems;
- Integration of residue recovery with primary production
- Fuel upgrading technologies.

Fuel upgrading can reduce costs and energy inputs in the feedstock supply chain, due to reduced transportation per unit of energy. Upgrading can be achieved by densification (e.g. pelletisation of sawdust), by torrefaction (a roasting process at 200-250°C) to dry the biomass and increase its grindability, and by hydrothermal upgrading or pyrolysis to produce bio-oil (Trolove & Garrood, 2007). Different biomass resources will require different systems. This research should build on the current New Zealand capability in Geographic Information Systems modelling of biomass extraction, which has been able to provide good cost estimates for forest residue extraction (Moeller & Nielsen, 2008).

Some research is already underway in this area through the Wood-Energy programme being run by the Energy Efficiency and Conservation Authority.

This research is specific to New Zealand scales of operation and biomass resources and should be New Zealand-led. This priority is categorised as applied research. Similar research is required in 3.1.2.

Example: Forest residues to CHP

Forest residues are a highly variable resource in terms of its composition, piece size and location. Transport alone can contribute as much as 33% of the delivered cost. The supply chain to recover this material needs to be flexible as well as efficient. Residues are created at roadside (logging landings, including super-skids and central processing yards) and at the stump. The material produced at the stump requires extra steps in the supply chain to recover the material. A supply chain for cutover residues would contain the following steps; 1. Produced at stump; 2. Collect/bale; 3. Transport to roadside; 4. Store; 5. Load; 6. Transport; 7. Size reduction (chip/hog); 8. Screen and dry (optional); 9. Utilisation infeed.

There are a range of options and variations on this supply chain, including where the chip/hog step occurs. The supply chain may be specific to the site and end user needs and vary depending on local conditions. Minimising costs by gaining efficiencies, including integrating residue harvesting with traditional log harvesting and minimising transport and handling costs and material losses are central to optimising delivered costs.

3.3.2 Develop integrated industrial solutions

One of the most promising options for distributed generation from biomass is at industrial and commercial sites. Integrating biomass energy generation at industrial sites has two aspects:

1. Handling and storage of biomass fuels on site;
2. Energy generation technologies that meet on-site energy demands.

Due to the low bulk density of the fuel, the main impact of the use of biomass fuels on industrial sites will be the expense of storing and handling biomass on-site (Trolove & Garrood, 2007). Securing low-cost biomass feedstocks is a critical part of this option.

For greatest efficiency at industrial sites energy production should be highly integrated with industrial processes. Energy generation should be carefully matched with demand. This applies to the type of energy produced, i.e. heat or electricity and the temporal match between supply and demand. For example, in the case of woody biomass, technologies like gasification plus a generator set may offer advantages over combustion plus a steam turbine in being able to produce a higher electricity to heat ratio (Hall & Gifford, 2007). In addition, energy storage devices may be able to address temporal mismatches in supply and demand.

This includes investigation of the potential for industrial clusters using centralised heating scheme and 'industrial ecology' approaches where one industry utilises waste from another industry as a feedstock or energy source.

In addition to new systems, there is also scope to convert existing energy plants to biomass. This is particularly true in the case of conversions from coal to woody biomass (Trolove & Garrood, 2007). Over the last two years more than thirty schools have converted coal boilers to wood pellet systems. There is also potential for benefit from co-firing biomass in coal fired heat, cogen and electricity plants. Some of this activity requires operational testing and some requires research.

The nature of biomass means there are also opportunities for bioenergy to be used as a backup fuel or to meet peak demand in conjunction with other renewable resources such as, wind, solar and geothermal.

There is a need for New Zealand-led research and fast adaptation of international technologies in these areas to arrive at practical solutions for New Zealand industries. This priority is categorised as applied research.

3.3.3 Assess and adapt residential and community bioenergy concepts

Bioenergy can play a beneficial role in distributed generation of electricity, heat and solid and gaseous fuels in rural and urban communities. Firewood is already widely used for domestic heating (Isaacs et.al.2006). Biomass could also provide the fuel for a community CHP plant for example, or the fuel for a gasification plant feeding syngas into a reticulated gas pipeline. These systems could be integrated with other renewable resources in the vicinity.

The viability of various options at different scales needs to be assessed based on site specific biomass resources and costs. The environmental aspects such as particulate emissions of such systems also require assessment. Social research into the acceptability and impact of such schemes on communities would also be required.

There are a number of established technologies for community bioenergy schemes in both developed and developing countries. New Zealand can play a fast adapter role in this area. This is applied research.

3.3.4 Demonstrate technologies at different scales

A number of mature technologies for distributed generation of energy from biomass already exist (Hall & Gifford, 2007). To develop industry confidence in these technologies and to determine costs at different scales, demonstration projects in realistic situations are required.

These demonstration projects will ideally occur as government/industry partnerships.

Example: Straw to CHP

Canterbury is the principle region where arable crop residues are available in sufficient quantities to consider combined heat and power (CHP) generation from straw. The total resource of surplus straw in Canterbury is 210,000 tonnes per annum. In one CHP scenario this resource is equivalent to 0.6 PJ electricity and 1.8 PJ heat.

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

CHP technology for straws is mature and is widely used in Europe. The main barrier at present is economic. Implementation could be accelerated by:

- review of the use of straws for heat and CHP (UK and Denmark) to determine status and issues and opportunities for New Zealand
- creation of demonstration facilities

3.4 Next-generation feedstocks and conversion technologies

Summary

Next generation feedstocks such as algae, perennial grasses and designer trees together with new conversion technologies for these feedstocks could potentially have an important future role. These resources could have benefits of:

- Reduced land use requirements;
- Improved cost effectiveness.
- Increased range of biofuel product options.

Time frame: Long term

The research and development requirements of this theme are:

- Review and assess technologies and feedstocks; suitable for New Zealand Emerging opportunity (Underpinning);
- Develop new feedstocks and conversion technologies; Emerging opportunity (Underpinning).

Background

The focus of this theme is next-generation feedstocks such as: algae (Heubeck and Craggs 2007, Chisti, 2007); perennial grasses (Saggar et. al. 2007); and designer feedstocks (Ragauskas et. al., 2006, Han et al., 2007) together with new conversion technologies such as hydro-thermal upgrading for these and other feedstocks (Kruse, 2008; Trolove and Garrood, 2007).

Blue sky (Lal, 2007) and curiosity research (Somerville, 2006) are important for future development of the biofuels industry.

International research on biofuels is progressing at a rapid rate and New Zealand should position itself to be able to pick up quickly on promising developments. International connectivity will play a key role in this. This is an area of long term research.

3.4.1 Review and assess technologies and feedstocks suitable for New Zealand

International research is progressing rapidly and New Zealand needs to keep an active eye on results. A process of continual review and independent assessment is necessary. This assessment should include:

- Assess ecological risks of energy crops before expansion of existing species or introducing new species into New Zealand (Raghu et. al 2006);
- New Zealand specific trials to determine production rates, including regional and climate variability;
- Identification of any niche areas where New Zealand has a particular advantages in terms of environmental conditions and existing expertise base;
- Energy system analysis and life-cycle assessment of full energy pathways including harvesting and transportation.

This is an area of emerging opportunity and its role in assisting the realisation of more renewable energy for New Zealand is unknown. This research can be considered as underpinning a robust bioenergy strategy for New Zealand by enabling the incorporation of improved systems at future dates.

3.4.2 Develop new feedstocks and conversion technologies

There is significant potential for the development of designer feedstocks and conversion technologies that offer lower costs and higher yields per hectare, especially for the production of transport biofuels (Ragauskas et. al., 2006, Han et al., 2007). New Zealand's world class research in forest biotechnology could be utilized in this area (Flenning et. al. 2008). Genetic modification and molecular biology has potential to lead to increased growth rates, density, and resistance to diseases. It can also be used to improve tolerance of site-limiting factors (e.g. temperature and frost) and altering the properties of wood for use as an energy feedstock. A significant amount of this research may be focused on overcoming biomass recalcitrance or the natural resistance of plant cell walls to microbial and enzymatic deconstruction via synthetic biology (Himmel et. al., 2007).

There is also the opportunity for New Zealand-based bioprospecting to discover new microorganisims that could be used to develop new conversion technologies.

Research in this area will often involve international partnerships this will require flexible partnering mechanisms.

This is an emerging area and this research can be considered as underpinning a robust bioenergy strategy for New Zealand by enabling the development of improved systems in the future.

Example: Algae to biodiesel

During the 1980s and 1990s, the US Aquatic Species Program (ASP) researched the production of biodiesel from algae biomass (Sheehan et al., 1998). The main findings of this US$50 million programme were:

- Algae are far more productive than conventional agricultural crops;
- Purpose built photo-bioreactors are too expensive to grow algae for energy production. Open pond systems, particularly, high-rate algae ponds (HRAP) may offer an economical option;
- Algae production solely for energy production is unlikely to be viable. 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;
- The high costs of fertilisers suggest that wastewater is the most appropriate nutrient source for algae production.

The findings of the ASP have yet to be credibly challenged by recent research on algae production systems (Heubeck & Craggs, 2007).

An assessment by Heubeck and Craggs (2007) as part of the Bioenergy Options study arrived at the following conclusions regarding algae research for New Zealand:

To fully realise the potential of bio-energy production from wastewater grown algae biomass further research is required in several areas including:

- More accurate population / stock number and waste production data.
- Enhancement of algae production in HRAP (400 g/m^3 = 20 g/m2/d is achievable in New Zealand, although further research is required to realise and exceed this potential).
- Efficient cost-effective harvest has still not been demonstrated at large scale and requires further research. In particular, the mechanisms for passive algae harvest through autoflocculation and bioflocculation need to be identified.
- Efficient cost-effective algae dewatering technologies must also be developed to concentrate algae biomass to 10% - 30% solids.
- While all of the algae to bio-energy conversion pathways are possible more research is required to improve the conversion efficiencies and economics of these processes.

Example: Supercritical water gasification/oxidation

Supercritical water gasification and oxidation are experimental processes that make use of the unique solvating and transport properties of supercritical fluids when compared to the same fluid as a gas or a liquid. Above the critical point of water (374°C, 22.1 MPa) the water is able to readily dissolve lignocellulosic material. Once dissolved, the supercritical water will efficiently breakdown the molecules of lignocellulosic materials into gaseous or liquid products. As the process is based on water, it is ideally suited to wet feedstocks.

A number of research organisations and companies are working on supercritical water gasification and hydrothermal upgrading of biomass. The supercritical water gasification technology is still in the early stages of development with only a small number of laboratory scale units, and pilot scale plants operating (Kruse, A., 2008). Due to its ability to accept wet biomass, and produce high quality gas streams, it has the potential to become a significant technology in the future (Trolove and Garrood, 2007).

A New Zealand company, Solvent Rescue, is developing a super-critical water plant for processing biomass (algae, wood, etc) into a liquid similar to crude oil.

Due to the temperature requirement of the processing system, integrating a supercritical water operation with a site that has a demand for low-grade heat could have significant benefits.

Example: Miscanthus

Miscanthus has been identified as a potential second generation biofuel crop due to its rapid growth rate (Saggar et al., 2007). Some of these grasses are already in New Zealand. For example, Miscanthus sinensis and Miscanthus nepalensis are naturalised, especially in the northern half of the North Island.

Miscanthus giganteus, a sterile hybrid of miscanthus has been approved by ERMA and is being propagated for experimental plantings in New Zealand by a private company. Miscanthus giganteus is regarded as the best miscanthus species for producing bioenergy because of its ability to achieve high efficiencies of energy conversion and accumulate large amounts of biomass at low temperatures. Commercial yields tend to be below what is theoretically possible, given variations in rainfall, soil types, radiation interception, and conversion efficiencies (Saggar et al., 2007).

3.5 First-generation biofuels

Summary

Some first generation biofuels are near economic viability and are likely to enter commercial production. Research should focus on assessing and improving the environmental sustainability of these systems.

Time frame: Short term

Research and development requirements of this theme are:

- Science-based assessment of environmental impacts; New Zealand led (Underpinning/Applied);
- Develop more sustainable low-input production systems and species; New Zealand-led/Fast adapter (Underpinning/Applied).

Background

The focus of this theme is first generation biofuels from crops grown on arable land (Saggar et. al., 2007). First generation energy crops such as canola, maize and sugar beet can be converted into transport biofuels via a number of standard processes (Newman, 2007; Wong, 2007). At present, of all the options for producing transport biofuels, production from first generation energy crops is the closest to economic viability (Hall & Jack, 2008). This option is limited to supplying only a small percentage of New Zealand transport fuel demand due to the amount of arable land that New Zealand has available and the competing demand for this land for staple food production (Hall & Gifford, 2007).

Production of first-generation biofuels looks close to being economically viable so this is an opportunity that can occur now and research priorities are mainly focused on the short term. These biofuels are predicted to give way to more sustainable second generation biofuels (IEA Bioenergy, 2008). However, it has been argued that there is an ongoing need for a broad portfolio of feedstocks that will lead to geographic diversity and greater resistance to pests and climate and other production shocks and first generation feedstocks have a role to play in this (BR&Di, 2008).

The issues with first generation biofuels are:

- Their environmental sustainability has been questioned (Farrell, 2008; Righelato, 2007;Fargione, 2008; Serchinger, 2008)[5];
- They require high-quality farmland and, to achieve high yields, substantial amounts of fertiliser and chemical pesticides (Taylor, 2007) negating some of the environmental benefits (Andrew & Forgie, 2008).

[5] "UN expert calls turning food crops into fuel: a crime against humanity", Article in the International Herald Tribune (October 26 2007).

3.5.1 Science-based assessment of environmental impacts

The environmental sustainability of these systems is a concern (Andrew & Forgie, 2008; Saggar et. al., 2007). Therefore emphasis should be placed on the detailed energy balance, and life-cycle assessment of these systems. There is a need for improved data and methodology and site-specific studies. This information will help industry and government weigh up the pros and cons of the various existing first generation biofuels and feed into environmental certification standards and quality assurance schemes for biofuels.

Detailed energy-system analysis and life cycle assessment will also enable the pinpointing of areas where improvements of the sustainability of the production chains can be made.

This research should be New Zealand-led and utilise New Zealand-specific data (Hall & Jack, 2008). This research can be considered to be applied.

The development of LCA tools which are New Zealand specific and use a standardised scientific approach will also have value in other research themes.

3.5.2 Develop more sustainable low-input production systems and species

Some of the most significant costs and contributions to greenhouse gases in these systems come from growing the crops (Andrew & Forgie, 2008). Of these costs, farm inputs such as nitrogen fertiliser, weed and pest control and electricity for irrigation, are the most significant (Andrew & Forgie, 2008). This suggests that focus should be on the development of low-input production systems and species, which would both decrease costs and increase the overall environmental benefits.

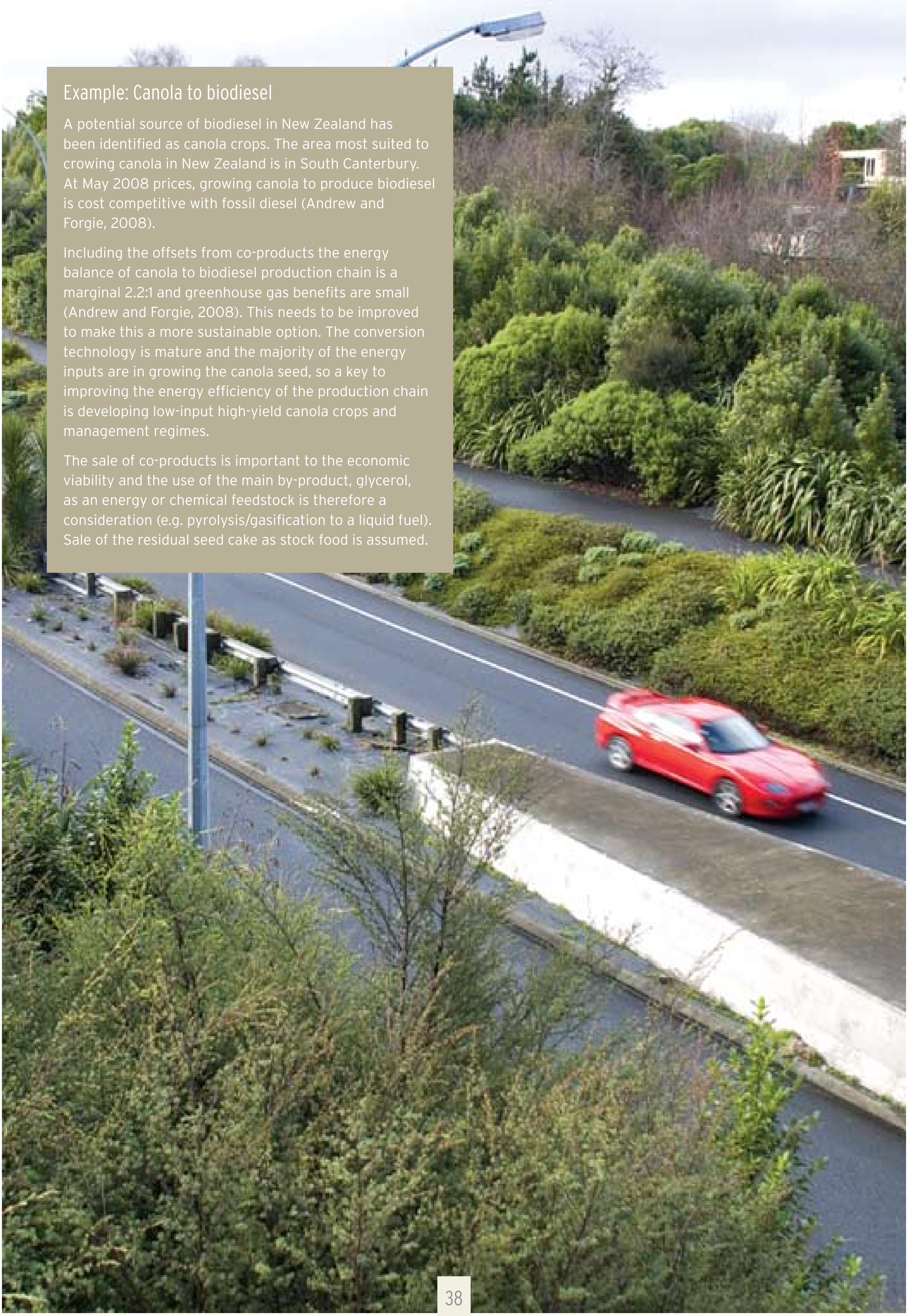
This research requires components of New Zealand-led and fast adaptor approaches. Promising new species and production system developed internationally should be adapted to New Zealand conditions. In addition, there is potential for New Zealand agricultural expertise to make us leaders in this area (Saggar et. al., 2007). This research priority can be regarded as underpinning/applied research.

Example: Canola to biodiesel

A potential source of biodiesel in New Zealand has been identified as canola crops. The area most suited to crowing canola in New Zealand is in South Canterbury. At May 2008 prices, growing canola to produce biodiesel is cost competitive with fossil diesel (Andrew and Forgie, 2008).

Including the offsets from co-products the energy balance of canola to biodiesel production chain is a marginal 2.2:1 and greenhouse gas benefits are small (Andrew and Forgie, 2008). This needs to be improved to make this a more sustainable option. The conversion technology is mature and the majority of the energy inputs are in growing the canola seed, so a key to improving the energy efficiency of the production chain is developing low-input high-yield canola crops and management regimes.

The sale of co-products is important to the economic viability and the use of the main by-product, glycerol, as an energy or chemical feedstock is therefore a consideration (e.g. pyrolysis/gasification to a liquid fuel). Sale of the residual seed cake as stock food is assumed.



4.0 CONCLUSION: BEYOND BUSINESS AS USUAL

The scale of global resource depletion and the ecological crisis, coupled with the current financial crisis, challenge us to reinvent ourselves. We need to take a fresh look at the metrics we use for measuring our success and to think of radical solutions that cut across traditional boundaries. The plantation-forestry based bioenergy concept described here is an example of this. This concept takes an existing industry and redirects it at energy security and current climate change problems by sequestering carbon and producing renewable energy so that we are less reliant on imported fossil fuels. The multiple benefits from this concept cross a number of traditional boundaries between energy security, climate change, sustainable land-use and regional and national economic development. It also renders many of the issues with biofuels from agricultural crops redundant, such as impacts on food security and deforestation.

Bioenergy Uptake and Business as Usual

This document proposes a research and development strategy for bioenergy in New Zealand. As part of this strategy, five strategic themes have been presented that can develop bioenergy's role in New Zealand. Some of the roles of bioenergy are summarised here:

- There is room to significantly improve our environmental performance by increasing the use of biomass wastes (municipal and industrial) for energy.
- The distributed nature of biomass residuals mean that they are suited to distributed generation of industrial heat and electricity. Forest residues, other woody biomass and some agricultural residues, are a particularly significant resource for this.
- Next generation feedstocks (algae and designer plants and trees) combined with innovative conversion technologies could also play a significant role in the longer term as these technologies are further developed.
- Bioenergy from plantation forests represents a significant national opportunity in terms of scale of renewable energy supply and spin-off environmental benefits. This includes the use of the existing estate and development of new forests

These roles have been associated with strategic themes in this research strategy. A number of these themes incorporate bioenergy pathways that are based on mature technologies and would not be much more expensive than the current fossil fuels alternatives. Under business-as-usual these options have not been taken up and this is unlikely to change, despite the fact that these pathways have obvious long-term benefits for New Zealand, including reducing greenhouse gases, long-term energy security and waste reduction. Under business-as-usual external costs and benefits are simply not reflected in energy prices. In addition, business as usual does not provide renewable alternatives with the room to improve through 'learning by doing' so they can compete with already well-established fossil fuels.

The most significant of the proposed strategic themes is Bioenergy from plantation forestry. This theme is important due to its potential contribution to New Zealand – in improving energy security and reducing greenhouse gas emissions. Pursuing this theme is a major departure from business-as-usual and would require a national development effort. It is a theme that also offers new economic opportunities, spin-off environmental benefits and a chance to reinvent ourselves.

Climate Change, Resource Depletion and Business as Usual

New Zealand's future energy system will be defined by responses to: energy affordability - due to the importance of energy to the economy; energy security - due to concerns about oil and gas depletion; and greenhouse gas reductions – due to global issues of climate change.

The International Energy Agency business-as-usual scenario, which embodies the effects of government policies adopted up to mid 2008, sees global demand for energy and energy from oil and coal, in particular, continue to grow to 2030 (IEA, 2008). Due to this increasing demand, both the average and the volatility of oil prices continue to increase. Continuing with business as usual exposes the New Zealand economy to these prices. This business-as-usual scenario also puts us on course for doubling the concentration of greenhouse gases (GHG) in the atmosphere by the end of the century leading to an eventual global average temperature rise of up to 6º C. Temperature rises of this magnitude have been predicted to result in irreversible changes in climate patterns throughout the world and disastrous consequences for the people and biodiversity of the globe (IPCC, 2007). With New Zealand ranked 4th in GHG emissions per capita from transport, 11th over all, and dependent on agricultural production, we are both a contributor to climate change and potentially a causality of its consequences.

In an alternative scenario, New Zealand is able to mobilise itself to utilize it's significant potential for renewable energy generation and reduce the economy's exposure to international energy prices. Similar world-wide initiatives result in greenhouse gas concentration being stabilised at 550 ppm CO2-equivalent which results in a temperature rise of 3º C. This stabilisation comes about by rapid and revolutionary changes to New Zealand's and the world's energy system. This includes a combination of energy-efficiency/demand-side management; renewable energy; carbon capture and storage; and nuclear power (IEA, 2008). More holistic approaches to reducing greenhouse gases also include: afforestation and reduced deforestation and improved agricultural, forest and waste management for GHG reductions (IPCC 2007).

Beyond Business as Usual...

The challenge is how to transition from our current economic environment to a new future. Research and development has an important role to play, but a transition of this type also requires collaborative partnership between research industry and government. Between 1975 and today Brazil transformed a portion of its traditional sugar industry into a biofuels industry that produces half of its light-vehicle fuel and is currently competitive with imported oil and resulting in an economy much less exposed to international oil prices. A key to this transformation was a long term or strategic approach to energy supply by government. This transition was also associated with substantial technological innovation right along the biofuel production chain. Some of the highlights of this 25 year transition are:

- doubling sugarcane productivity per hectare through improved sugarcane varieties (6 new varieties of sugarcane introduced per year resulting in 500 varieties currently cultivated);
- tripling ethanol yield per hectare through increased feedstock yields but also increases in production efficiency;
- reduction in production costs by more than 60% resulting in Brazilian ethanol being competitive with oil at US$50 a barrel;
- development of the flexi-fuel vehicle that can take blends of petrol with ethanol from 0 to 100%.

By any measure, these are impressive results. These gains are the result of an effective industry, research and government partnership that facilitates research and the uptake of this research by industry. The Brazilian story potentially points the way for New Zealand.

... To Leadership

In the future, transportation energy is likely to come from much more diverse, distributed and sustainable sources. There are a number of energy-efficiency and renewable transport options that New Zealand could pursue. However, the scale and nature of our present and likely future transport energy demand means the transport fuels from biomass are likely to be a significant part of the mix, at least in the medium term. This is particularly true for freight and air transport. This is a problem facing all developed and developing countries.

In New Zealand, the only resource that is potentially of sufficient scale to impact on energy security in the medium term, that also has clear environmental benefits, is transport fuels from plantation forestry. Plantation-forestry based biofuels grown on marginal land have a number of advantages over biofuels from many other sources:

- Are of sufficient scale to reduce New Zealand's exposure to international energy prices.
- Based on an existing industry with mature sustainability certification schemes;
- Do not compete with arable, high-value pastoral land or cause deforestation;
- Provide a significant long term energy store;
- Provide carbon sequestration during the establishment phase and additional carbon stocks from new forest area;

- Provide environmental services, such as, sustainable land management: stabilising erosion-prone land, low input (e.g. fertiliser, pesticides) land use, improving water quality;
- Produce sustainable co-products such as traditional timber products and high-value biomaterials and chemicals, and providing the forest industry with a significant alternative market for low value products;
- Provide large volumes of solid fuel for CHP.

New Zealand has the opportunity to adapt the lignocellulosic conversion technology developed overseas; build on our expertise in sustainable plantation forestry to match them with NZ-specific, low-input, high-yielding woody-biomass feedstocks; and develop integrated production chains for sustainable transport biofuels. By grasping this opportunity now, New Zealand has an opportunity to leverage our unique sustainable resources and play a leadership role in not only solving our own problems but in demonstrating a feasible approach to facing global energy challenges.

The first implementation step of this theme must be the establishment of a biomass resource. Regardless of the conversion technology that is eventually utilised, the existence of a large scale biomass resource is key to realising the potential of this theme. From a long-term strategic perspective, this is an opportunity to establish a sustainable renewable resource for the next generation. This forest resource reduces the risks associated with at business-as-usual future by sequestering carbon as it grows and offering a number of potential future uses, including vital energy.

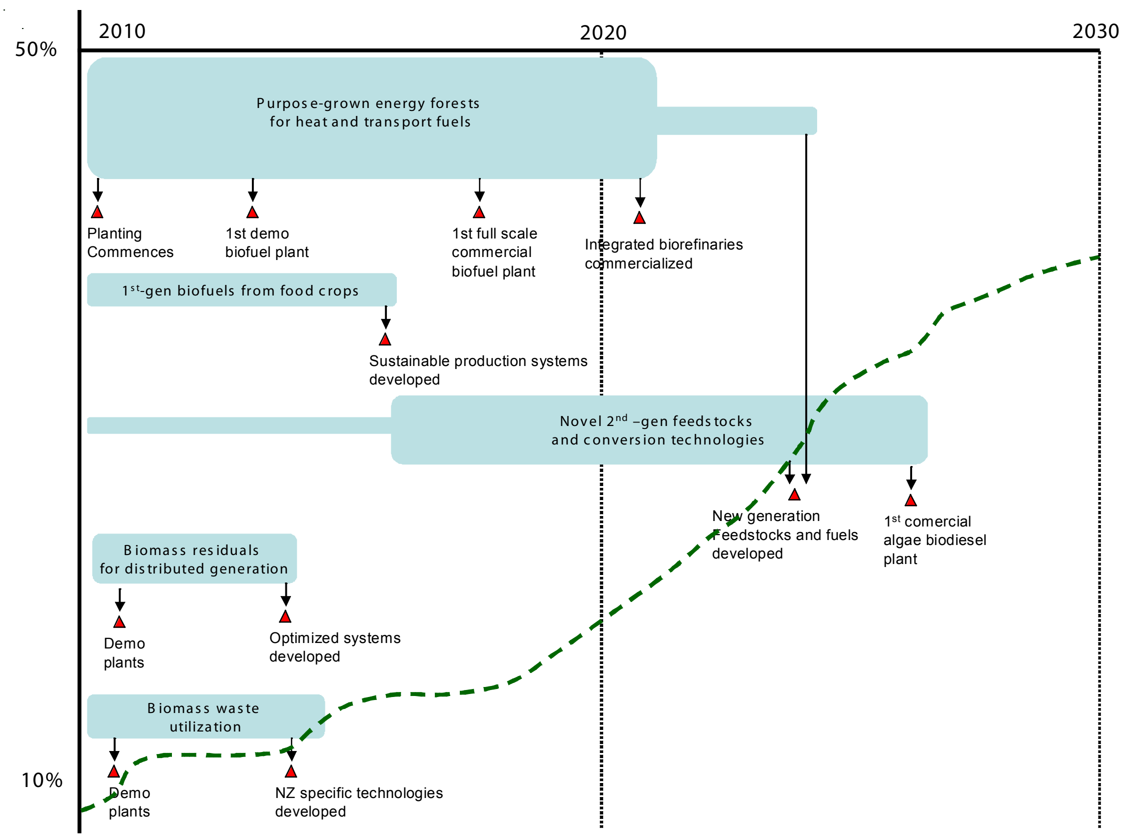


Figure 6: Future scenario showing the critical interaction between research and development and implementation milestones. Dotted line shows projected growth in energy from biomass as a percentage of heat and transport fuel demand.

APPENDIX I:

Information gaps and further research identified in contributing reports

In preparing reports on biomass resources and conversion technologies, contributing authors were asked to identify any knowledge gaps and future research directions. These identified areas have informed the development of the above strategy. The relevant sections of these reports have been compiled here for completeness.

"Resource Assessment of Algae Biomass for Potential Bioenergy Production in New Zealand" - S. Heubeck and R. Craggs (NIWA)

To fully realise the potential of bio-energy production from wastewater grown algae biomass further research is required in several areas including:

- *More accurate population / stock number and waste production data.*
- *Enhancement of algae production in HRAP (400 g/m³ = 20 g/m2/d is achievable in New Zealand, although further research is required to realise and exceed this potential).*
- *Efficient cost-effective harvest has still not been demonstrated at large scale and requires further research. In particular, the mechanisms for passive algae harvest through autoflocculation and bioflocculation need to be identified.*
- *Efficient cost-effective algae dewatering technologies must also be developed to concentrate algae biomass to 10% - 30% solids.*
- *While all of the algae to bio-energy conversion pathways are possible more research is required to improve the conversion efficiencies and economics of these processes.*

"Availability of Wood Processing Residues" C. J. Hodgson and P. Hall (Scion)

It has been found that the surveys are useful only as a guide and that specific knowledge of residue flows is lacking. It is possible to predict the amounts of residues produced, however, it is very difficult to know what this material is used for, by whom, where, and especially for what price.

More research on the wood processing industry is required in order to obtain an accurate regional assessment of the amount of unused residues and their location. Information should be gathered from industry associations, published literature, mail surveys, telephone surveys and site visits.

"Review of Agricultural Resources" S. Saggar, D. Giltrap, V. Forgie, R. Renquist (Landcare Research, New Zealand Centre for Ecological Economics, Crop and Food Research)

The following information gaps have been identified:

- *New Zealand specific data on production rates and costs for miscanthus, switchgrass, oilseed rape and sugar beets.*
- *Region specific values for production rates and costs.*
- *More accurate estimates of crop production rates including variability due to weather conditions.*
- *Potential changes in crop production rates due to climate change.*
- *Site selection for processing plant to minimise overall costs (particularly transport costs).*
- *Impact of international markets on the economic viability of energy crops in New Zealand.*
- *Quantification of the environmental impacts and benefits of using agricultural crops and/or residues for energy production.*

"Logging residues -situation analysis: Resource, supply costs and barriers", P. Hall (Scion)

Areas where information is lacking have been identified as:

1. *Comminution efficiency: What drives this, what machines are most fuel efficient; and which give the greatest volume of the best product for the energy consumed?*
2. *Transport efficiency + system design: There is room to improve both the design of the trucks being used and the logistics of the systems in which they are used. Lowering transport costs will lower delivered fuel cost and improve the energy balance.*
3. *Loading and handling + system design: Many current systems are inherently wasteful of the material they produce. They can leave anything from 5% to 10% of*

the comminuted residues on the ground. System and logistic design changes would substantially reduce these losses.

4. *GIS Modelling – sensitivities: It is possible to use a GIS system to model cost supply curves for forest residues to selected destinations. It would also be possible to use the model to determine what the cost supply curve is sensitive to. That is, what are the main drivers of cost? Transport distance, slope, yield, residue yield, material losses?*

5. *Effect of policy: The impact of changes to government policy on forestry and agriculture can be significant, especially rules around land use, carbon emissions and environmental performance. Modelling these changes and predicting their effect would be valuable in the areas of land use, primary industry outputs, emissions and energy planning.*

6. *Effect of economic changes: Long-range forecasts looking at likely scenarios would be helpful in the area of land use change and the impacts of such factors as a continuing high dollar on primary industry.*

7. *Annual update of National Exotic Forest Description (NEFD) to residue figures: The NEFD is updated on an annual basis, and associated yield tables are updated about once every 5 to 6 years. The impact of these updates on predicted harvest and subsequent residue volumes can be significant. As technology and the survey method change, so too does the accuracy of the information. As well as updating the wood supply forecasts, it would be useful to update the residue supply forecasts (which are derived from the wood supply, NEFD and yield tables). Tracking of residue use would also be useful. Currently it is estimated that 250,000 tonnes per annum of forest harvest residues is utilised (27 % of the landing residues).*

8. *Demand modelling: Knowledge of the effect of demand and supply is somewhat limited in the renewable energy area. What are the future demands for energy, and what are the limits of supply and predicted price of fossil fuels? What are the tipping points at which the demand for energy makes biomass alternatives viable, and what is the effect of legislation and macro economics? Where are the current users and potential future users of forest-derived bioenergy fuels, and where should future forests be planted in order to best accommodate these industries?*

9. *Energy balance of the fuel delivery system: A common question asked is: Is it worth spending all that fuel to collect the wood? The answer is yes, but it needs to be refined and modelled. This could be done at two levels; a very simple level to demonstrate the energy benefits, and a detailed level to identify where the most energy is being used in the biomass delivery system, loss points and areas for potential gain.*

10. *Wood process residues: The production of wood processing residues is closely allied with forest harvesting (regions with large historical levels of harvest have lots of processing – CNI). However, despite the obvious linkages and potential to combine the two resources to achieve scale, there is a limited amount of information available on the volume, type and destination of a significant proportion of the residues from the wood processing industry. In order to fully capture the potential benefits from this resource it needs to be more accurately described.*

11. *The impact of scale and dedicated plant: Currently many of the forestry residue fuel systems are of medium scale, with comminution plant capable of processing 50,000 to 90,000 tonnes per annum. These machines are not dedicated to a single site and have to be mobile, as they frequently work across several customers. If there was an increase in scale and it was at a single site there would be the opportunity to develop different systems with potentially greater efficiency and lower costs. Modelling to determine where these sites could be and their potential costs savings is possible. This would lead to identification of prime sites and their possible energy contribution.*

12. *Impacts and costs of dispersing ash from wood fired boilers onto forests, as a nutrient source and as alternative to land filling: Ash disposal in forests is common in Scandinavia and there is some New Zealand literature. Further review of overseas work is warranted as a precursor to developing a research programme on this topic in New Zealand.*

"Resource Assessment – Short-rotation Forestry crops", Ian Nicholas (Scion)

Information Gaps:

- *There is limited growth data available for SRF crops in New Zealand, where the crop has been specifically grown as an energy crop on any scale. The bulk of the data is from forest stands, and is indicative only. Because of the lack of growth data from large scale bioenergy crops of a range of species it is difficult to derive growing costs.*
- *There are some current trials on energy crops, but these are only part way through their growth cycle and so the data is incomplete, and the trials will not reach maturity for another 12 to 18 months (as of October 2007).*

- *As there are only a few trials areas established, there is no data on harvesting system costs specifically for New Zealand. However, there is some overseas data that is broadly applicable and this has been used in the above cost estimate. The limitation is that the harvesting cost is related to the volume per ha to some extent, and without robust data from bioenergy plantations the costs estimates are indicative only.*

Research Needs:

- *Based on the above information gaps it would be appropriate to establish trials that are designed to give growth data from woody crops grown specifically to produce maximum biomass rather than merchantable sawlogs. The tree species that show promise are Eucalyptus nitens, regnans, maidenii and ovata, with only the latter recognised as an excellent coppicing species. There are also a number of shrub willow and poplar varieties as well as some acacia species that are worthy of further study, beyond the current set of trials.*
- *More detailed information on the productivity of the crop would allow better economic assessment.*
- *There is some overseas experience with coppice harvesters, and this information should be summarised and applied to the New Zealand situation as best it can.*
- *The wood properties of the selected species should be assessed against a number of potential end uses, combustion trials have been done, but there is scope for work on gasification, pyrolysis and enzyme digestion for a range of SRF fuels and the performance of various short rotation tree crops when subject to these processes.*

"Conversion Technology Assessment: Pyrolysis", Per Nielsen (Scion)

Recommendations:

- *Fundamental research into understanding the process kinetics is still important.*
- *It would make sense to develop a research project with a lab scale plant similar to the demonstration plant proposed to be imported by AES, as the technology has been identified to be suitable for New Zealand biomass resources (forest residues).*
- *Research around understanding the feedstock's impact on the pyrolysis process would improve the quality of the end-product.*
- *The research could cover understanding various pre-treatment processes' impact on final product. The research should also cover upgrading or refining opportunities for the end product (bio-oil)*
- *Bio-oil is not the only product out of the pyrolysis process therefore research focussing on producing other products is important.*

"Life cycle analysis of energy production from forest residues and purpose grown forests", J. Sandilands, S. Love, and P. Hall (Scion).

The bioenergy research needs that have been highlighted from this analysis are;

A. New Zealand Specific Research;

1. *Purpose grown forests; productivity, species, yields, management*
2. *Delivery systems and logistics (harvest, transport and comminution)*

These are high priority as they are applicable to all conversion pathways, and the delivery systems apply to residues or purpose grown material

B. Knowledge gaps that need to be filled from overseas data and experience or from New Zealand research;

1. *Ethanol – process efficiency and raw material costs*
2. *Gasification and Fischer-Tropsch - process and productivity*
3. *Pyrolysis and refining of bio-oil into liquid transport fuels*
4. *Biobutanol – process and process efficiency.*
5. *Application opportunities for mature technologies such as combustion to heat and combustion to co-generation where technology development will yield only small gains, but where there is little national level information on what the site specific opportunities are for medium to large scale bio-heat and bio-cogeneration*

"Anaerobic Digestion of DAF Sludge from a Meat Processing Plant", Jürgen H Thiele (Waste Solutions Ltd)

Recommended pathway to implementation:

We recommend [therefore] to commission a nationwide anaerobic digestion research & demonstration program with the purpose to identify these early implementation sites by conducting side-by-side ASD(Anaerobic Sludge Digestion) LCA studies for a simple and a more advanced effluent treatment scenario.

Knowledge gaps preventing implementation:

This report has demonstrated that significant knowledge and information gaps for LCA analysis and business case development of ASD facilities do not exist and that the ASD technology is sufficiently mature to proceed to private sector implementation in the NZ primary processing industries.

"Comparison of Cost, Energy Balance and GHG Emissions of Selected Biomass to Energy Production chains", A. Campbell[1], M. McCurdy[2] and G. Williamson[2] ([1]Fuel Technology Limited, [2]CRL Energy Limited)

(refer to table)

Description	Research requirements
Wood to Heat	• Improve harvesting options. • Improve transport logistics.
Wood to CHP	• Improve harvesting options. • Improve transport logistics.
Wood to EtOH	• Develop enzymatic method. • Consider co-firing with purpose grown forest (PGF). • Reduce the size of commercial plant.
Wood-Gas-Heat	None recommended
Wood-Gas-CHP	None recommended
Wood to FT	• Make FT plant smaller. • Improve transport logistics. • Improve gasification cleanup. • Investigate co-firing with coal or PGF
Wood to Pyrolysis	• Improve understanding of bio-oil stabilization. • Develop pilot scale facilities for complete chain.
PGF to Heat	• Establish PGF resource • Reduce cost of PGF
PGF to CHP	• Establish PGF resource • Reduce cost of PGF
PGF to EtOH	• Establish PGF resource • Reduce cost of PGF • Develop enzymatic method. Improve efficiency. • Reduce the size of commercial plant. • Improve transport logistics

Description	Research requirements
PGF to Biodiesel	• Establish PGF resource • Reduce cost of PGF • Develop enzymatic method. Improve efficiency. • Reduce the size of commercial plant. • Improve transport logistics
PGF-gas-heat	None recommended
PGF-gas-CHP	None recommended
PGF to FT	• Establish PGF resource • Reduce cost of PGF • Make FT plant smaller. • Improve transport logistics. • Improve gasification cleanup.
PGF to Pyrolysis	• Establish PGF resource • Improve understanding of bio-oil stabilization. • Develop pilot scale facilities for complete chain.
Straw to Heat	• Improve harvesting technology. • Improve feedstock density
Straw to CHP	• Improve harvesting technology. • Improve feedstock density
WVO to Biodiesel	• Develop low-cost quality testing kits.
Tallow to Biodiesel	• Develop low-cost quality testing kits.
Rapeseed to Biodiesel	• Improve crop yields. • Reduce farm fertilizer use • Reduce time displacing other crops
Coal to Heat	• Improve boiler efficiency
Coal to FT	• Investigate options for CCS

APPENDIX II:

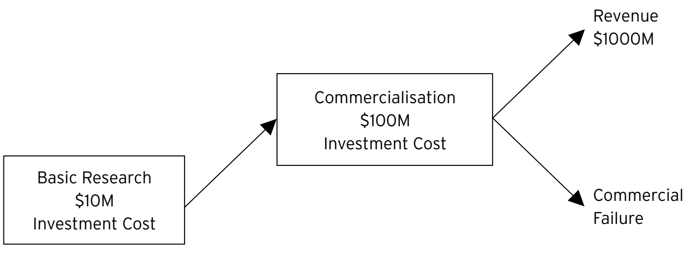
Applying 'Options Thinking' to R&D investment

To illustrate the application of options thinking to Research and Development investment decision making consider the following simplified example:

The development of a renewable energy technology to pilot scale requires a $10M investment. To commercialise the technology requires a further $100M to develop a demonstration plant etc. The potential return from this technology is $1000M. If the overall probability of reaching commercialisation is 10% then the expected return, or net present value, using traditional methods of valuation is -$10M (Figure 7).

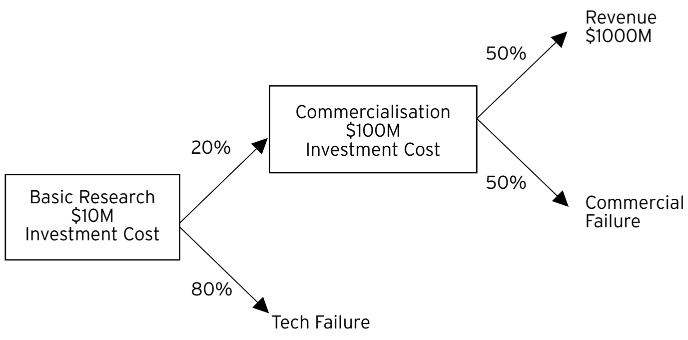
Taking into account the fact that the technology developer is able to actively manage the technology development pathway produces a different story. In this case there is a value associated with not perusing the commercialisation options. An alternative scenario is shown in Figure 8. In this case, there is the same 10% probability of reaching commercialisation; however there is an 80% probability that the product is simply dropped and never reaches the commercialisation phase. Evaluating the options value gives an expected return of $90M, in sharp contrast to the approach that did not take the value of the "walk-away" option into account.

In addition to general conclusions, there are a number of particular situations where this thinking has interesting implications for the current strategy. For example, the Bioenergy Options study did not have enough information to select a particular conversion technology for producing liquid biofuels from woody-biomass (see Section 3.1). Due to this, rather than pick a winner, a better strategy may be to investigate a number of the most promising conversion technologies, with the presumption that technological development and market changes will occur that result in a clearer picture of which technology should be taken through to commercialisation. Let us presume we choose 3 technologies instead of one and triple the initial investment in basic research. This results in doubling the chance of one of these technologies being taken through to commercialisation. This situation is shown in figure 9. The result of the valuation shows that this strategy is superior to that of just choosing a single technology even though the investment was tripled and the probability of getting to commercialisation only doubled.



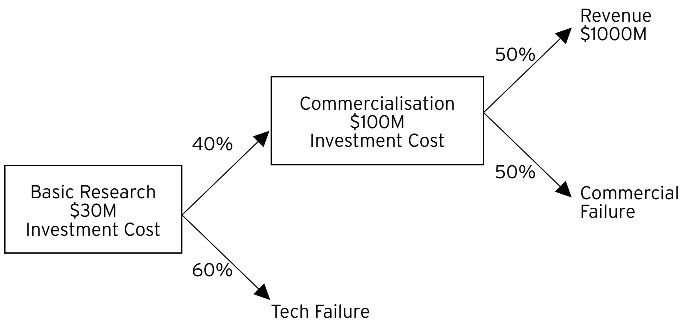
Expected Net Present Value= 0.1 x 1000 - 110= -$10 M

Figure 7: Valuation of research investment using traditional approaches.



Options Value= (1000 x 0.5 - 100)0.2 - 10 = $70 M

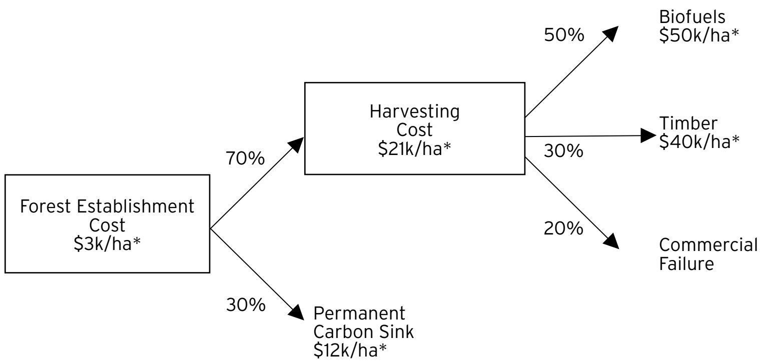
Figure 8: Valuation of a technology development project using the real options approach.



Options Value= (1000 x 0.5 – 100)0.4 – 30 = $130 M

Figure 9: Valuation of an alternative strategy for a technology development project using the real options approach.

Another situation where options thinking seems to provide insight relevant to this particular strategy document is to the proposal to immediately begin the establishment of a purpose grown biomass resource so that it is ready when needed. There is an element of risk involved in this as the commercial viability of biofuels depends on technology development and is uncertain at this stage. This situation is analogous to the R&D investment case, as investment in forest establishment (c.f. basic research) is a relatively low cost process compared to the cost of harvesting at maturity (c.f. commercialisation). This is shown in Figure 10. Suppose the probability of biofuels being commercially viable is 35%, then using a traditional valuation approach would determine that this is not a viable proposition. However, taking into account other options, such as producing timber products rather that biofuels, or not taking up the harvesting option and leaving the forest as a permanent carbon sink, the proposal becomes more viable.



Expected Return (without options)= 50 x 0.5 x 0.7-24 = -$6,500/ha
Options Value= (50 x 0.5 +40 x 0.3 – 21)0.7 +12 x 0.3– 3 = $12,000/ha
*Illustrative costs and returns only.

Figure 10: Valuing the establishment of purpose grown forest for biofuels given the multitude of other options.

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