Bioenergy Association of New Zealand

Occasional Paper 19

Bioenergy Utilisation Opportunities in Christchurch & Recommendations from European Experiences

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Table of Contents

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Approval for Publication

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List of Abbreviations

Abbreviation	Definition
BANZ	Bioenergy Association of New Zealand
CAfE	Christchurch Agency for Energy
CBD	Central Business District
CCA	Copper Chromium Arsenic
CCHL	Christchurch City Holdings Limited
CCC	Christchurch City Council
CDHB	Christchurch District Health Board
CERA	Christchurch Earthquake Recovery Authority
CHP	Combined Heat and Power
CoP	Coefficient of Performance
CRI	Crown Research Institute
DES	District Energy Scheme
ECan	Environment Canterbury
EECA	Energy Efficiency and Conservation Authority
EFI	Energy for Industry
EPA	Environmental Protection Authority (New Zealand) or Environmental Protection Agency (USA)
EPR	Energy Power Resources (Ltd.)
ETS	Emissions Trading Scheme
EU	European Union
FAR	Foundation for Arable Research
GHG	Greenhouse Gas
IRR	Internal Rate of Return
LFG	Landfill Gas
LPG	Liquefied Petroleum Gas
MAF	Ministry of Agriculture and Forestry
MDF	Medium Density Fibreboard
MED	Ministry of Economic Development
MfE	Ministry for the Environment
NIWA	National Institute of Water and Atmospheric Research
NZ	New Zealand
NZD	New Zealand Dollar (NZ$)
NZU	New Zealand Unit (= 1 tonne of CO_2 equivalents)
O&M	Operational and Maintenance
SDH	Solar District Heating
SNG	Synthetic Natural Gas
SRF	Short-Rotation Forestry
T	Temperature
USA	United States of America
WENZ	Wood Energy New Zealand
WWTP	Wastewater Treatment Plant

Abstract

Following the devastating earthquake in Christchurch, New Zealand, in February 2011, the city began a process of cleanup, repairing and rebuilding. A district energy scheme (DES) was proposed as part of the rebuild, and feasibility studies identified the need for further quantification and assessment of bioenergy resources. This thesis is written to fulfil that need, taking into account other renewable energy sources, and with the aim transferring European knowledge of renewable energy utilisation to New Zealand.

Background research was begun in January 2013, followed by face-to-face interviews with New Zealand energy professionals in February. In March and April, European experts were interviewed, followed by data collation and writing of the main report. Assessment of resource quantities was completed using primary data, information from previous studies, and other literature. Modern energy conversion technologies and their potential fuel feedstocks have been described and assessed, with international examples of each. The context for bioenergy in Christchurch is described, including the differences between New Zealand and Europe that affect renewable energy uptake. Costs for heat and electricity generation from the various energy sources have been estimated, to aid decision-marking. Finally, short-, medium- and long-term recommendations are made for improving bioenergy uptake in the Canterbury region.

The research found that Canterbury has a large straw research, yet the market is very much under-developed. Wood chips suffer from the same problem, alongside decreasing forest area due to conversion to dairying. Landfill gas, dried sewage biosolids and piggery waste all have the potential to contribute to a central city energy system, and non-bioenergy technologies also offer promising options for the city, namely solar thermal collectors and ground source heat pumps. Finally, sources of waste heat, as well as sites with spare boiler capacity were identified, to aid in further energy decision making.

Short-term recommendations from this research include improving communication of the current DES decision-making process, and encouraging Christchurch Hospital as the starting point for a DES. In addition, a comprehensive database of waste heat sources in the city should be compiled. For bioenergy, co-firing of straw in the Canterbury Fonterra and Synlait boilers should be investigated. In the medium term, wood fuel suppliers in the region should transition towards more advanced 'Biomass Logistic & Trade Centres', to improve the wood fuels market, and research into collection of forest residues could be funded by the upcoming forest products levy. Further research into energy systems which combine multiple technologies must be a focus, and the government should look at cost-effective methods to reduce risk for early adopters of new technologies. In the long term, it is recommended that Christchurch incorporate energy goals into its vision, something that is currently missing from strategy documents. Spatial and energy planning must be linked, and the city should seek to become an active member of international smart city networks. Strengthening of connections with overseas research institutions can help to accelerate bioenergy development, and involvement of the private sector through research and development clusters could turn Christchurch into a world-leading centre for bioenergy.

Introduction

This thesis investigates the area of potential renewable fuels (focusing on bioenergy) for medium- to large-scale use in Canterbury, New Zealand, and was started based on the need to further investigate different fuel options for a proposed district energy scheme (DES) for Christchurch City. The DES was first proposed as part of the rebuild process, after the city suffered a devastating earthquake in February 2011. Initial feasibility studies outlined the need for further research into renewable fuel quantities and prices, and this thesis was devised to assist with that research. While bioenergy sources are one of the greatest resources in the region, research must also take into account all possible types of energy. In addition, the conversion technologies for each fuel must be considered, alongside practical implementation issues, and social and political issues. District heating and bioenergy conversion to heat and power are mature technologies in Europe, and many European countries (including Austria) lead the world in terms of bioenergy utilisation. This thesis aims to capture and transfer some of that knowledge to the New Zealand context.

Therefore the research question of this thesis is:

> ***How could the available bioenergy and agricultural residue resources in the Christchurch area be brought together and utilized, in the context of other available renewable energy sources and the proposed district energy system, and how can examples from Europe aid in improving this utilization?***

This area is worthwhile studying for a few main reasons. Firstly, the opportunity to rebuild almost an entire city centre at once is a very rare occurrence, and interesting in itself. This unique situation could streamline some of the processes normally associated with district energy schemes, such as pipe-laying. Secondly, there are currently no district energy schemes in New Zealand. The technology is therefore new to the country, and the success or failure of this scheme could strongly influence the adoption of similar systems in other parts of the country. Thirdly, Christchurch city has access to many natural resources – it is surrounded by the Canterbury Plains, a large area containing arable cropland, grassland used for pasture, and some areas of forests. Successful utilisation of renewable resources from this area could provide sustainable energy to the city in future years. Finally, the chance to transfer knowledge from Europe, the leader in bioenergy and DES technology, to New Zealand, at a time where there is a real chance of a DES being constructed, allows this thesis to have the opportunity of providing useful and practical advice.

The objective of the thesis is therefore to provide useful qualitative and quantitative information on renewable fuels, to assist the city if Christchurch to make decisions on a DES, or on other medium or large-scale energy systems.

The outputs of this thesis are**:**

- A review of suitable bioenergy sources and conversion technologies for a DES or for other large energy requirements in Christchurch
- A review of other renewable energy sources suitable for a DES or large-scale uses
- Maps of Christchurch and surrounding areas showing available energy sources and spare boiler capacity
- Fuel cost estimates, along with capital and operational and maintenance costs for different bioenergy sources
- Practical recommendations for implementation of these renewable energy sources
- Long-term institutional recommendations based on information gathered during the project

Target Group

The target groups of this thesis are decision-makers in Christchurch such as the Christchurch City Council (CCC) and its infrastructure investment arm, Christchurch City Holdings Limited (CCHL), central government, consultants, investors, and researchers continuing in this area.

Personal Motivation

I am familiar with many people affected by the earthquake in Christchurch. Seeing an empty city centre two years later was both a reminder of the destruction that was caused by the earthquake, but also a 'clean slate'– a blank canvas on which a new, modern city centre could be built. The thought of the same buildings being reconstructed and the same infrastructure being used seemed to me to be a wasted opportunity. Therefore I wanted to contribute to the rebuilding of the city in a modern and sustainable way, and this thesis offered a chance to do just that. There is a movement in Europe towards 'smart cities' – those with integrated solutions for energy, transport and other important issues, and my hope is that this thesis inspires people in Christchurch and New Zealand to find new ways of making better, more liveable, environmentally responsible cities.

Research Method in Brief

The research method of this thesis consisted of five main phases:

1) Background literature research, and networking with parties involved in the Christchurch DES thus far
2) Interviews with New Zealand parties knowledgeable about the DES, potential fuels, potential technologies and related projects, as well as email contact with further experts
3) Interviews with Austrian and other European experts with knowledge about renewable fuel technologies, especially those related to DESs
4) Collation of data from literature and interviews, mapping of energy sources, and assessment of bioenergy and other renewable resources
5) Writing of the thesis, conclusions and recommendations for fuel and technology utilisation.

Structure of the Report

This thesis begins in chapter one with an introduction to the city of Christchurch, how the recent earthquakes that have drastically changed the city, and how these earthquakes spurred ideas of incorporating modern energy systems and a DES into the rebuild of the city centre. The chapter explains how this research project was chosen, and how it aims to help with the unanswered questions left after completion of the DES feasibility studies.

Chapter two provides the New Zealand theoretical basis for this research. It compiles results from the DES feasibility studies, as well as from previous research into bioenergy and other renewable energy systems, both at the local and national level. This theoretical basis also allows further justification of the topic, and a narrowing-down of focus areas.

Chapter three provides the international and technical theoretical basis in terms of how different energy sources are used internationally, and which conversion technologies exist to make use of these energy sources. The main conversion technologies for biomass investigated are combustion and gasification, along with anaerobic digestion, as these technologies are currently available and used. The chapter also includes a look at how district energy systems are currently designed and used.

Chapter four outlines the research method of this study. It firstly outlines the experts in New Zealand and Europe that were contacted, including the reasons for contact and the information they were able to provide. These experts are sorted by geographical location and divided into those that were able to be interviewed fully, and those that contributed smaller amounts of information.

In chapter five, Christchurch is characterised in terms of resources, physical characteristics, political context, the maturity of the bioenergy industry, and other aspects that are relevant to the implementation of bioenergy systems. This chapter also highlights some of the key differences between New Zealand and Europe, which has a much higher uptake of bioenergy. Literature and personal interviews were both used as sources for this chapter.

Chapter six provides the main results of the research, including quantification of different energy sources (both bioenergy and other renewable sources) in Christchurch. These resources are assessed in both a qualitative and quantitative way, and cost estimates based on previous studies, literature, anecdotal evidence and personally-gathered data are used. Comments are made on how the quantities and costs for these resources may change in the future.

Finally, in chapter seven, findings are discussed and conclusions are made. Recommendations are given based on time frame (short-, medium- and long-term) as well as suggestions for institutional changes that may be required for bioenergy to be used on a significant scale in Canterbury and New Zealand.

1. Christchurch, Bioenergy and the History of the District Energy Scheme

1.1 The Earthquakes and the Changes in the Central City

In the early hours of September 4, 2010, an earthquake of magnitude 7.1 hit the city of Christchurch and surrounding areas. This earthquake caused widespread damage, mainly in older buildings, however no lives were lost. Aftershocks continued in the following months, until on 22 February 2011 the city was hit by a magnitude 6.3 earthquake, which was much shallower and closer to the city centre. The earthquake occurred during office hours, and resulted in the deaths of 185 people, as well as destroying or seriously damaging many buildings. The central business district of Christchurch was cordoned off to the public, and a programme of repair, demolition and deconstruction was implemented.

To give an idea of the scale of the rebuild, the satellite images below show the extent of the damage. Figure 1 shows an aerial view of the central business district (CBD) on February 7, 2011 – before the most damaging earthquake.

Figure 1: Christchurch City on February 7, 2011 - 15 days before the most damaging earthquake (Source: Google Earth)

Figure 2 shows the same area of Christchurch in March 2013, two years after the most damaging earthquake. Much of the area in the centre of the picture is still in what is termed the 'red zone' (CERA, 2013). This is the zone which is still unsafe for the general public to enter, and where active demolition and rebuilding work is being completed. Many of the buildings have already been completely demolished.

Figure 2: Christchurch City in March 2013 (Source: Google Earth)

1.2 The Origins of the District Energy Scheme

Since the earthquakes, much effort has gone into planning the rebuild of the city. A separate governmental agency was set up, called the Christchurch Earthquake Recovery Authority (CERA), and out of CERA came the 'Recovery Strategy for Greater Christchurch' (CERA, 2012b). This strategy document estimates the recovery cost at approximately NZ$20 billion (approximately €13 billion), and included in this budget is $3 billion for infrastructure recovery. The strategy includes nine 'guiding principles'; the principle most relevant to this thesis is the third of these, which reads:

> ***Look to the future: Development and recovery initiatives will be undertaken in a sustainable manner. They will meet the needs of future generations, taking into account climate change and the need to reduce risk from natural hazards. They will also ensure community safety and wellbeing now and in the future. If the process of repair reveals a way of enriching people's quality of life, that opportunity will be taken.*** **(CERA, 2012b)**

The recovery strategy also outlines a timeline for the rebuild, in three phases. The first phase, which is already completed, is entitled "Repair, patch and plan". This phase involved restoration of crucial services such as water, sewage and electricity, repairing of roads, and the beginning of demolition processes. The second and current phase is entitled "Begin to rebuild, repair and reconstruct". This phase includes the milestone "Continue repair of infrastructure and make decisions about long-term repair and provision of infrastructure". This milestone directly relates to the provision of heat and electricity (potentially with a DES), and therefore is most relevant to this thesis.

The first party to suggest a DES was the Christchurch Agency for Energy (CAfE), a charitable trust whose goal is to raise awareness and promote renewable energy in Christchurch (CAfE, 2013). In 2011, CAfE contracted the consultancy Beca to write an information report looking at the basis for a DES in Christchurch. This report indicated the need for more detailed feasibility studies to be completed (Hill, 2011). In November 2011, CAfE and the Energy Efficiency and Conservation Authority (EECA) co-funded three feasibility reports on the DES, covering the technical feasibility, social economic and environmental feasibility, and the investment and ownership feasibility of the system (Bizcat Aurecon & FVB, 2012, Newton et al., 2011, Rudkin et al., 2011).

The conclusions from all three feasibility reports were brought together in May 2012 into a summary document (Newton and Llewelyn, 2012). This summary document made it clear that a DES in Christchurch is technically feasible, commercially viable, attractive to suppliers and customers, and could have wide-ranging economic, social and environmental benefits. The summary also notes the potential for a significant amount of the energy for a DES to come from agricultural residues, and that fuel flexibility would be one way to avoid risks associated with future fuel price fluctuations.

The technical feasibility study contained detail of potential fuels, and included an analysis of fuel costs and supply availability. It however noted that due to the time constraints, much of the data was based on assumptions, and was unable to be cross-checked (Bizcat Aurecon & FVB, 2012). Crucially, the technical feasibility study stated that:

> ***"We are confident in the basic system solutions but recommend some further studies particularly into biomass fuel supplies and prices. This is one area of considerable uncertainty and little detailed information."*** **(Bizcat Aurecon & FVB, 2012)**

It also noted that:

> ***"There are several options for the supply of renewable and local/regional fuels, but there are still some doubts about the amount available, the price and possible competition for the resources. However, the DES is not to be dependent on one source only, but will be built up according to available sources, without losing the benefits of sustainability. Fuel supply to a DES is an important factor to investigate further." (Bizcat Aurecon & FVB, 2012)***

1.3 A Focus on Biomass

Based on these conclusions, this thesis project was designed to further quantify renewable energy sources available in the area surrounding Christchurch, with a focus on wood and agricultural residues (and taking into account wind, solar and others). Even if these resources are not used in a district energy scheme, this quantification should aid decision-making for future energy projects in Christchurch and the surrounding areas.

In other words, the object was not purely to find a way to use biomass in a DES, but rather to assess how the various available biomass resources could be brought together and utilised in the best way possible, in the context of the DES and other energy sources in the region.

2. Theoretical Basis – Christchurch-Specific Literature Review

2.1 Summary of District Energy Scheme Feasibility Study Results

This section summarises the results of the three feasibility studies that were commissioned by CAfE in 2011. This information is relevant for how the renewable resources in the area around Christchurch could be used effectively in a DES context.

Technical Feasibility Study

The technical feasibility study for the DES is perhaps the most important, because if the system were not technically possible, then it would not be worth investigating further. The scope of the study includes the heating system (capacity and geographical area), fuel supply (fossil and renewable), demand analysis, and planning considerations. New Zealand and Swedish experts contributed to the study (Bizcat Aurecon & FVB, 2012).

Key areas for the DES have been identified. These include the central city, which will have an appropriate heating demand, as well as educational, civic and health facilities in the city. These include the University of Canterbury, which already has a large (18 MW) boiler system and distribution network, and the Christchurch Hospital, which has a 16 MW boiler capacity with approximately 8 MW of excess capacity, decreasing as the hospital grows. Figure 3 shows these areas – the large yellow area west of the city centre is the University of Canterbury. The pink area within Hagley Park (the large park in the centre of the image) is Christchurch hospital, and the civic buildings in blue can be seen in the central city area.

Figure 3: Educational (yellow), Health (pink) and civic (blue) buildings suitable for DES connection in Christchurch. Adapted from Bizcat Aurecon & FVB (2012)

The recommendation from the study for a heating temperature is to not exceed 100 °C in winter, and to possibly have a lower temperature such as 70° C in summer. The proposed DES in the technical feasibility study involves a 50 MW main boiler (cogeneration or heat-only) running on wood chips, and a 30 MW secondary boiler running on wood waste or straw, plus peak load taken up by boilers running on renewable oils or gas. Temporary boiler sites would likely be needed to provide heat to new customers as they appear. The authors assume that if cogeneration were possible, it would be recommended that it is only utilised in the 6 coldest months of the year. Because cogeneration requires the largest possible temperature difference (ΔT) between the send and return pipes, excess waste heat could not be fed into the system in these months. In the other months, without cogeneration, the DES could accept waste heat (such as from supermarket chillers). It was noted that no significant sources of industrial waste heat were found to exist in Christchurch.

The heating duration curve for Christchurch is shown in Figure 4. This curve shows that a boiler capacity covering 40% of peak load (line A) would be able to provide approximately 80% of the heat requirements for Christchurch. The remaining 60% would be taken up as needed by peak load boilers. The potential heating demand, including the central city and the university area, was estimated at 128 MW peak load.

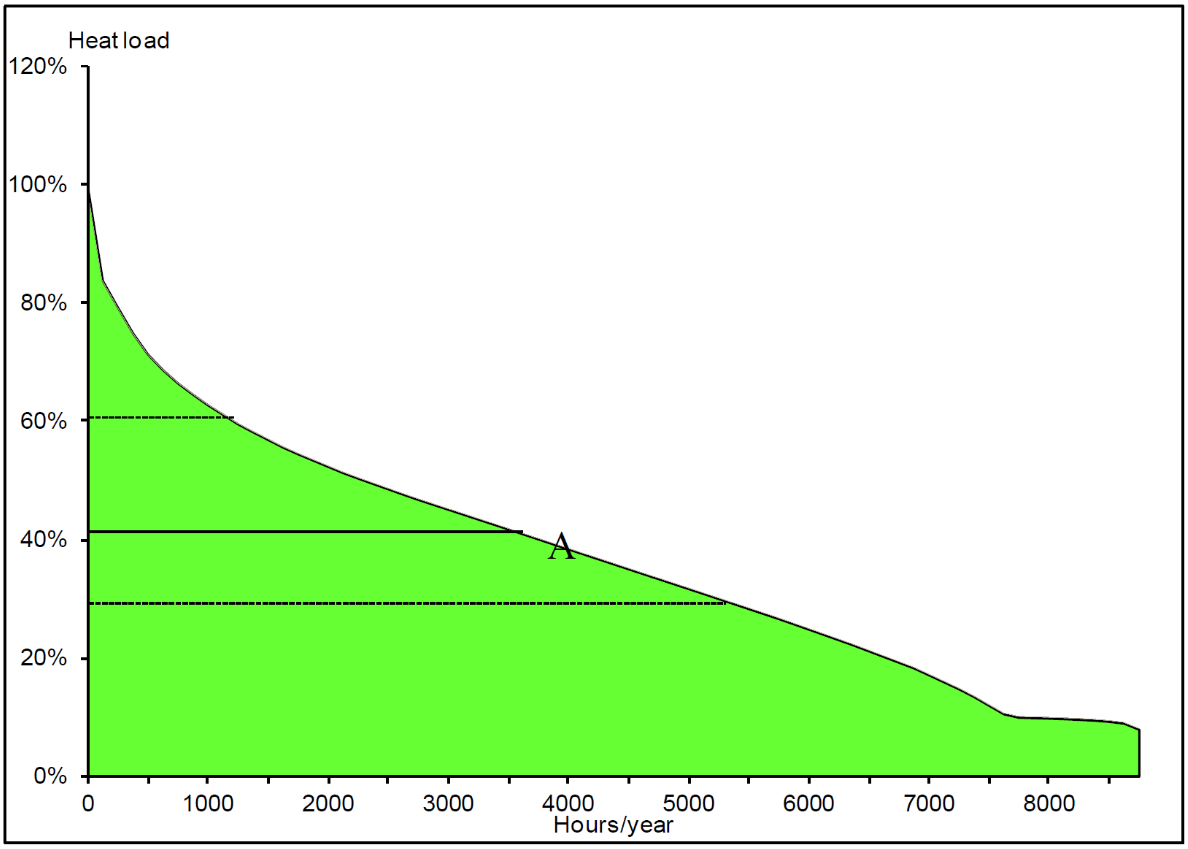

Figure 4: The Christchurch heat duration curve. Line A shows that a unit providing base load heat at a capacity 40% of peak could provide approximately 80% of the yearly heat requirements (Bizcat Aurecon & FVB, 2012)

If the scenario described above (one 50 MW boiler, one 30 MW boiler and multiple peak boilers) were to be employed, then the main (50 MW) boiler could cover approximately 80% of the heating needs, and the secondary (30 MW) boiler the next 15%. This would account for 95% of heat demand, and the peak boilers could take up the final 5%. The report notes that main boilers typically are designed to have low fuel costs, while peak boilers have low capital costs yet may run on more expensive fuels, as their hours of operation are much lower.

The authors estimate that biomass fuel demand will start out below 500 TJ for the first two years, and then steadily grow to over 2000 TJ by year 9. Fuel sources are estimated, but the authors note that further research is required for fuel costs and resources. For capital costs, the all-inclusive boiler costs were estimated for a range of boiler types, and these are shown in Table 1. It is clear that biomass boilers are much more expensive than the equivalent oil boilers, and so capital costs will be a significant obstacle for a DES using bioenergy sources as fuels.

Table 1: Boiler costs for potential boilers of different sizes in Christchurch. Adapted from Bizcat Aurecon & FVB (2012)

Boiler Type	Capacity (MW)	Cost (million NZ$)
Oil	5	1.4
	10	1.9
	20	2.9
	30	3.8
Straw	10	12.5
Wood Chip	30	31.7
Wood Pellet	5	2.2
	10	5.4
Wood Chip CHP	23/50 MW	122

Estimates of fuel costs are also given in the technical feasibility study. These have been given for both fossil fuels and renewable fuels, and are shown below in Table 2. Straw is given as the lowest-cost fuel per energy unit, followed by coal and wood chips. Wood pellets and landfill gas are again higher. The highest fuel costs are for liquefied petroleum gas (LPG), diesel, and biodiesel. The authors stress that these fuel costs are estimates and more work into availability and prices is required.

Table 2: Fuel cost estimates for Christchurch. Adapted from Bizcat Aurecon & FVB (2012)

Fuel	NZ$/MWh	NZ$/GJ
Coal	27.5	7.6
Diesel	130	36.1
LPG	144	40.0
Recycled Refined Oil	100	27.8
Recycled Lube Oil	64	17.8
Bio-oil (crude)	115	31.9
Biodiesel	130	36.1
Wood Chips	27.5	7.6
Wood Pellets	57	15.8
Straw	22	6.1
Biogas (Kate Valley Landfill)	54	15.0

A final section in the technical feasibility study outlines the potential for district cooling using conventional chillers and/or groundwater from bore holes in the central city. This appears to be feasible, however, district cooling is not a main focus of this thesis and is therefore only discussed briefly in this study to provide context.

Social, Economic and Environmental Feasibility Study

The social, economic and environmental feasibility study was completed by experts from MWH, PriceWaterhouseCoopers and Taylor Baynes & Associates, for CAfE (Rudkin et al., 2011).One assumption of the study is that the DES provides lower end-user prices for heat. Due to the difficult economic situation post-earthquake, many customers (including the government) have limited budgets, and would be unwilling to pay for heat that is more expensive than the 'business as usual' scenario. Another assumed benefit of the DES is that fuel prices will be more stable than any individual fuel, because the DES will use multiple fuels in multiple boilers, and therefore be shielded from sudden price changes in one fuel.

The study indicated that the CCC wants to increase the amount of people living in the central city, and estimates range from 9,000 to 45,000 residents within the coming years. This trend is positive for a DES as the heat density in the central city will increase, due to higher-density housing being necessary for these numbers. The study also noted that the primary planning hurdle for the DES is obtaining consents, and this would need to be for air and water discharges, water abstraction, and land use consent. Other issues could include dust and transport noise when considering wood and straw as fuels.

Benefits and drawbacks of the scheme were described, and summarised in tables, which are given below in Table 3 and Table 4.

Table 3: Economic, Social and Environmental benefits of the proposed Christchurch DES (Rudkin et al., 2011)

Economic Benefits	Social Benefits	Environmental Benefits
More stable energy prices	Enhance the commercial business case for apartment and mixed-use developments in the central city, and increase the inner-city population	Potentially will decrease air emissions (depending on technology)
Flexibility of fuel sources	Security of supply for winter heating for residents	Climate change improvements from using renewable fuels
Resilience (including to natural disasters)	Fewer central-city boiler units, reducing noise, air emissions etc	
	Employment gains from construction, operation and maintenance	

Table 4: Economic, Social and Environmental drawbacks of the proposed Christchurch DES (Rudkin et al., 2011)

Economic Drawbacks	Social Drawbacks	Environmental Drawbacks
Infrastructure spending could increase	No improvement to indoor amenity values (neutral)	Any non-compliance with emissions regulations would have negative health effects
	No improvement to social equity (neutral)	Gravel resource use for construction
		Potential noise and dust from biomass fuel handling
		Potential soil quality effects from removal of straw

Many stakeholder interviews were held as part of the feasibility study. Three key points from these interviews were that the DES must:

- Be technologically modern but not experimental
- Be environmentally clean, especially with respect to air emissions

- Use predominantly sustainable energy sources

Vital to the success of the DES is the timing. A quick decision on whether or not to proceed with the DES is required so that building owners can plan for connection at an early stage. The report, which was published in December 2011, stated that “the next 3 months is the critical period for getting property owners and investors interested, involved and committed to DES readiness”. This period has already passed, and so it may already be too late for some buildings. Another crucial observation in the study is that around 60% of the underground infrastructure in the CBD is damaged, meaning that total replacement may be an option. This significantly improves the opportunity for laying DES pipes.

Out of a second round of stakeholder consultation came recommendations for practical implementation of the DES. These mainly focused on information availability – business case information for building owners, technical information/standards for architects and engineers, and technical support for city council planners. In addition, more general information would need to be given to those organisations playing an advocacy role.

The economic case for the DES appears to be strong, but depends on many unknowns such as the energy efficiency of buildings, the risk of the ‘rebound effect’ (increased consumption due to lower prices), whether the DES is publicly or privately-owned, and others. The three main economic incentives for building owners are given as:

- Lower energy costs
- Lower capital expenditure (connection to DES is 25% the cost of a boiler system and 13% of a heat pump system)
- Flexibility of fuel source (and therefore protection from price fluctuations in one source)

Other, smaller economic incentives include more usable building space (due to a lack of boiler) and potentially reduced building costs (e.g. for strengthening where a rooftop boiler is used). In addition there is the intangible economic benefit of having an extremely reliable heating system, which is very important to, for example, hotels. On a more general level, having the image of a “green” city may bring economic benefits with it too.

From the social point of view, no significant adverse effects were predicted to be caused by the DES, and the most significant positive effect is the encouragement of higher-density living in the central city, thus increasing the vibrancy, safety and vitality of the area. For environmental effects, the only negative effects to be found were those related to potential dust (from straw and wood fuels) and from transport. These effects could be minimised with good planning, and potentially making use of rail links instead of roads. Relevant to this thesis is the point that for the DES to be granted an air discharge permit from Environment Canterbury (ECan), the fuel sources (e.g. wood and straw) would need comprehensive analysis, to estimate availability and reliability. This would need to include an economic analysis of, for example, transport costs.

Ownership and Investment Feasibility Study

The ownership and investment feasibility study was completed in December 2011 by KPMG (Newton et al., 2011). Most of the contents of this report are not directly relevant to this thesis, however some points should be noted.

Firstly it is important to note that the project is economically feasible using KPMG's assumptions. The base case funding gap chart is shown in Figure 5, and shows that profits are expected from year seven onwards.

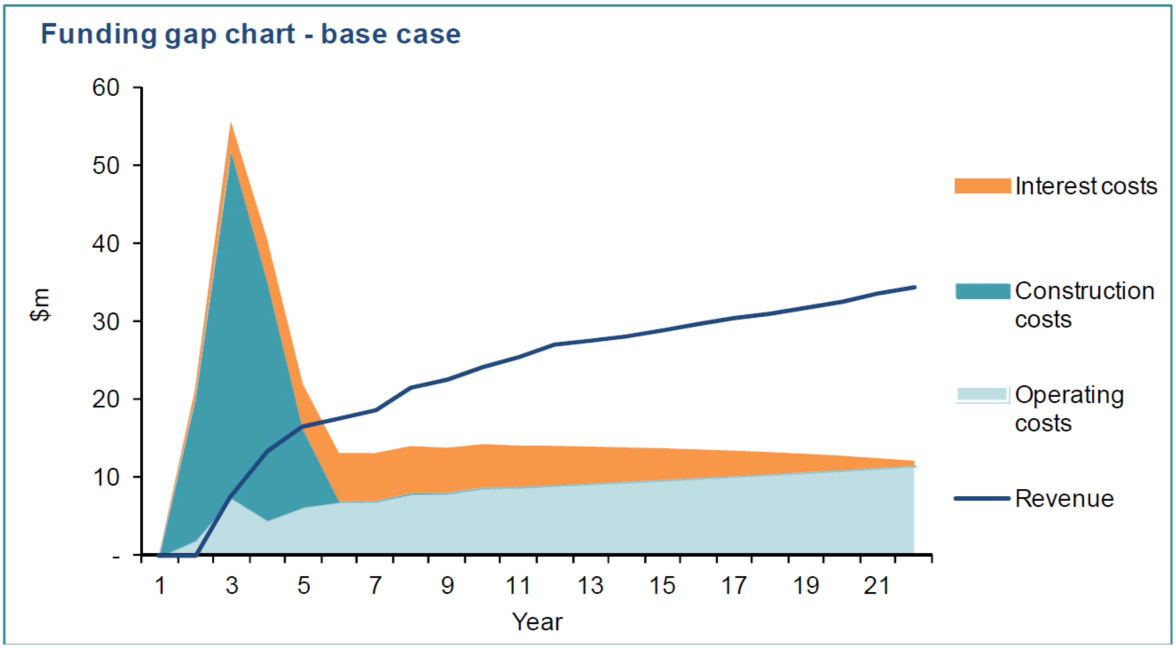

Figure 5: Financials of the base case (Newton et al., 2011)

One of the fuels assumed for the DES in this report was demolition waste wood. In the ownership and investment report, untreated waste demolition wood is accounted for separately from municipal wood waste. The assumed price for demolition wood waste is $20/MWh, and for municipal wood waste $30.60/MWh. This discrepancy is not explained further in the report. There is a high level of uncertainty over prices of demolition wood, and acknowledgement that the buyer will need to pay market prices for this resource.

Four groups of buildings were identified for the DES demand. 'Significant buildings' are those buildings in the CBD with significant demand such as the hospital, central police station, museum, educational facilities and civic buildings. 'Central city' buildings are those planned to be rebuilt, or existing buildings with water-reticulated heating systems. 'University significant buildings' are the buildings requiring heat on the University of Canterbury campus. 'Extension buildings' include schools, private hospitals and a central city swimming pool complex.

The base case in the report (i.e. the case shown in Figure 5) assumed 75% uptake in selected 'significant buildings' and 20% uptake in all other categories. In this scenario, CHP would not be required due to low demand. The idea of the scenario is to convert a hospital boiler to biodiesel for the first year, then adding a waste wood boiler, and finally switching to the main site straw boiler as the primary heat source for the next 20 years. This base case highlights the need for further analysis of straw as a fuel. The internal rate of return (IRR) in this case is 14.33%, which makes the project easily financially viable. Figure 6 highlights how important accurate costing of straw as a fuel is, in relation to the base case.

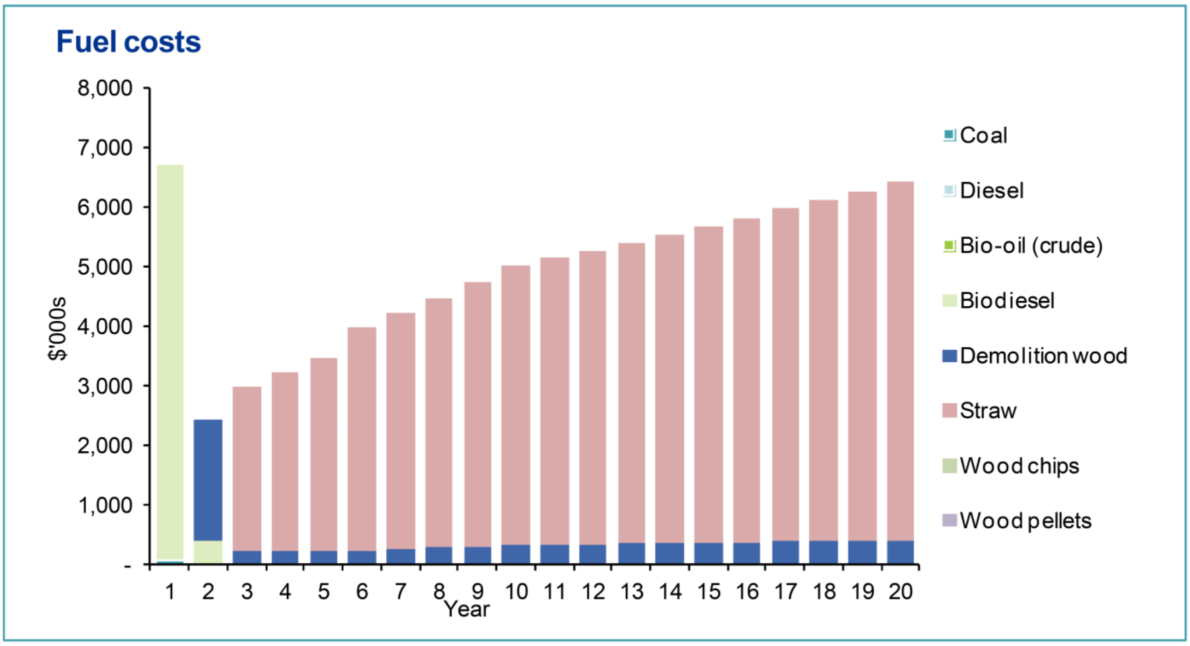

Figure 6: Fuel use (NZ$) for the base case showing high use of straw (Newton et al., 2011)

Two other cases were considered. The first assumes uptake in 75% of significant buildings and no uptake in any other categories, which results in low demand and therefore much lower capital expenditure. It assumed that the heat demand is met with biodiesel and waste wood, and that the IRR is 19.31%, which is also very much financially viable. The final case assumed 90% uptake in significant buildings and university significant buildings, and 51% uptake in the central city and extension buildings. This case has an IRR of 15.28%, meaning it is feasible, but it does rely on the assumption of a relatively constant price for straw and wood chip fuel. CHP is included in this scenario. The relative proportions of fuels can be seen for this scenario in Figure 7, and it can be seen that a much stronger reliance on wood chip fuel is assumed.

Sensitivity analyses for the base case were included in the study, and increases of fuel costs of up to 100% showed that even in this case, the DES was still feasible (though only just). The report also suggests that if costs for wood chips rise, straw could be used in its place[1].

[1] Boilers are in commercial use which can utilise both straw and wood, through usually with a maximum percentage of one or the other, as the two fuels have different combustion characteristics (personal communication, Klaus Winther, 30 May 2013). It is not clear if the higher costs for these flexible-fuel boilers are taken into account in the report.

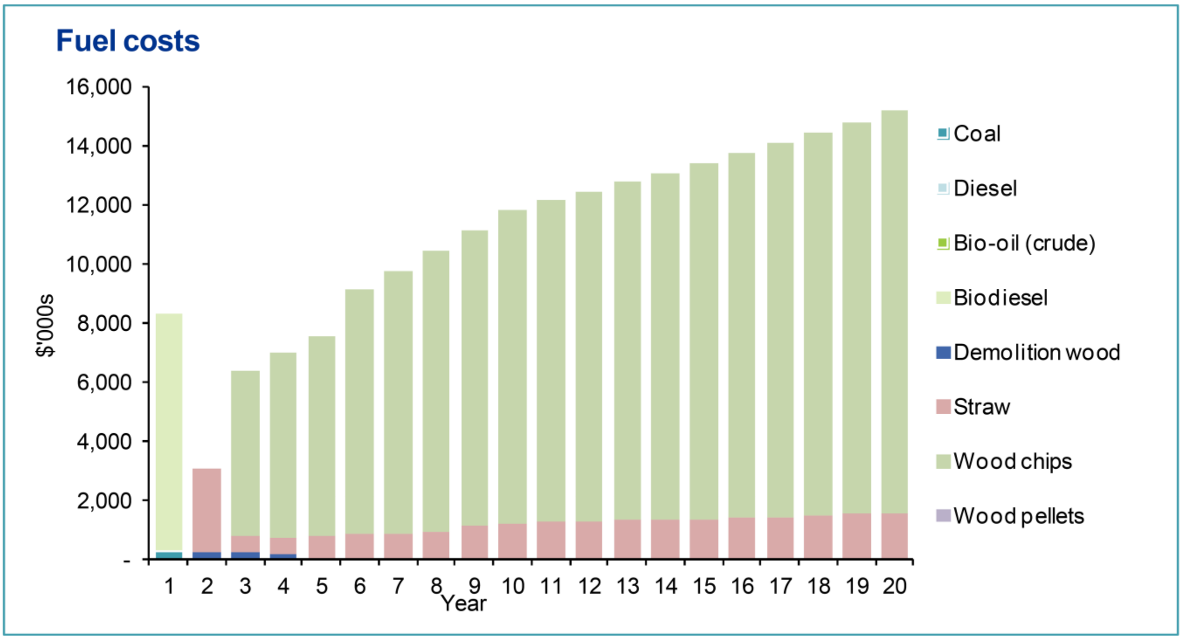

Figure 7: Fuel costs in scenario for DES with enough uptake for a CHP plant (Newton et al., 2011)

Accuracy of Feasibility Study Results

The accuracy of the results in the feasibility studies, especially the technical feasibility study, should be considered in the context of available data, the very short time allocated to complete the reports, and differences to Europe.

In the technical feasibility study, the assumed hours that the main plant of a DES would be operating were between 3,500 and 4,000 hours. This is highly dependent on the type of customer – for example, office buildings and universities may not require heating at night and in weekends, compared to residential buildings. This also depends on how heating is used (for example, preferred indoor temperatures), and characteristics such as the insulation level and the thermal mass of buildings. It has been suggested that hours of operation may be significantly lower than this (personal communication, Peter Houghton, 11 April 2013). Fewer operation hours would have a significant impact on the economics of a project.

The other aspect to the feasibility reports that comes into question is the choice of fuels. The availability and supply chain for wood in Christchurch is partially demonstrated, and indeed has been studied previously for the Christchurch Hospital boilers (Enercon, 2009). However, data on the reliability and security of supply for wood, and to a greater extent for straw, is limited. There seems to be a 'chicken and egg' problem where there is hesitation to commission a wood or straw-fuelled heating plant without established supply chains, and there is hesitation to set up large-scale supply chains without a solid centre of demand such as a DES. Therefore there is some apprehension over the ambitious wood and straw targets laid out in the feasibility studies. Accurate estimation of the price of these fuels is also a difficult problem, and the authors of the feasibility reports explicitly state that more research on pricing and supply of these fuels must be completed. This thesis aims to contribute to this information, although true prices can only be totally accurately given after creation of a functioning market for the fuels in question.

2.1 Summary of Hospital Boiler Reports

In 2009, a report was published looking at wood fuel supply options for the Christchurch Hospital, for the Christchurch District Health Board (CDHB) (Enercon, 2009). It was found that in 2009, the capacity for supply of wood chips to Christchurch from the larger producers was estimated to be 75,000 – 100,000 tonnes for the year. Key points raised in this report included that most wood chips are made from purpose-grown wood (as opposed to forest residues or demolition wood), that many forests in the region are being converted to dairy farms, and that transport of wood over a distance of more than 90 km becomes uneconomical.

In August 2012, a second report was published, which looked at the options for the Christchurch Hospital boilers in the context of a DES (Watson, 2012). This report notes that the hospital currently has a capacity (excluding backup boilers) of 14 MW, yet uses only 9 MW, leaving a spare capacity of 5 MW. There is also space in the boilerhouse for another 7 MW boiler, if required. The boilers currently run on coal, but could also accept wood chips, and for this to happen a new loading system would be needed, along with some minor modifications to the boilers themselves. The hospital does have enough space for this, and wood chips are seen as an essential factor for connection to a DES, for the public image of the system. A conversion to wood chips would also lower the cost of upgrading the boilerhouse to current structural standards, which have been modified since the earthquakes, due to different loading systems and the lower-density fuel. Alternatively, the entire boilerhouse may be moved and/or expanded, as the future of surrounding earthquake-damaged buildings is uncertain.

The other main issue to connect the hospital boilers to a DES is the conversion from the current steam system to a lower-temperature hot water system, which would reduce energy costs. Another suggestion was that it is possible to allow on-site cogeneration at the hospital of up to 3 MW, which would be run at peak times to coincide with peak electricity demands. Low transmission distances also improve the economics of this choice.

If connected to a DES, the hospital would be on its own loop from the boiler. This reduces the effect that other heat consumers could have on the supply to the hospital, which is important in ensuring security of supply to the hospital. In addition, the hospital must be able to increase its share of the heat over time, as it is expected that the full 14 MW will be required at some stage in the future. This would allow the DES to begin operating using existing boilers, and switch to its own boilers over time. Finally, if the hospital installs a 6 MW backup diesel boiler (currently being considered), an agreement between the hospital and the DES could be created in which the DES can access some of the heat (up to 3 MW) from the older backup boiler, at peak times. The entire possible future vision for the boiler system connected to the DES is given in the report, and is shown in Figure 8.

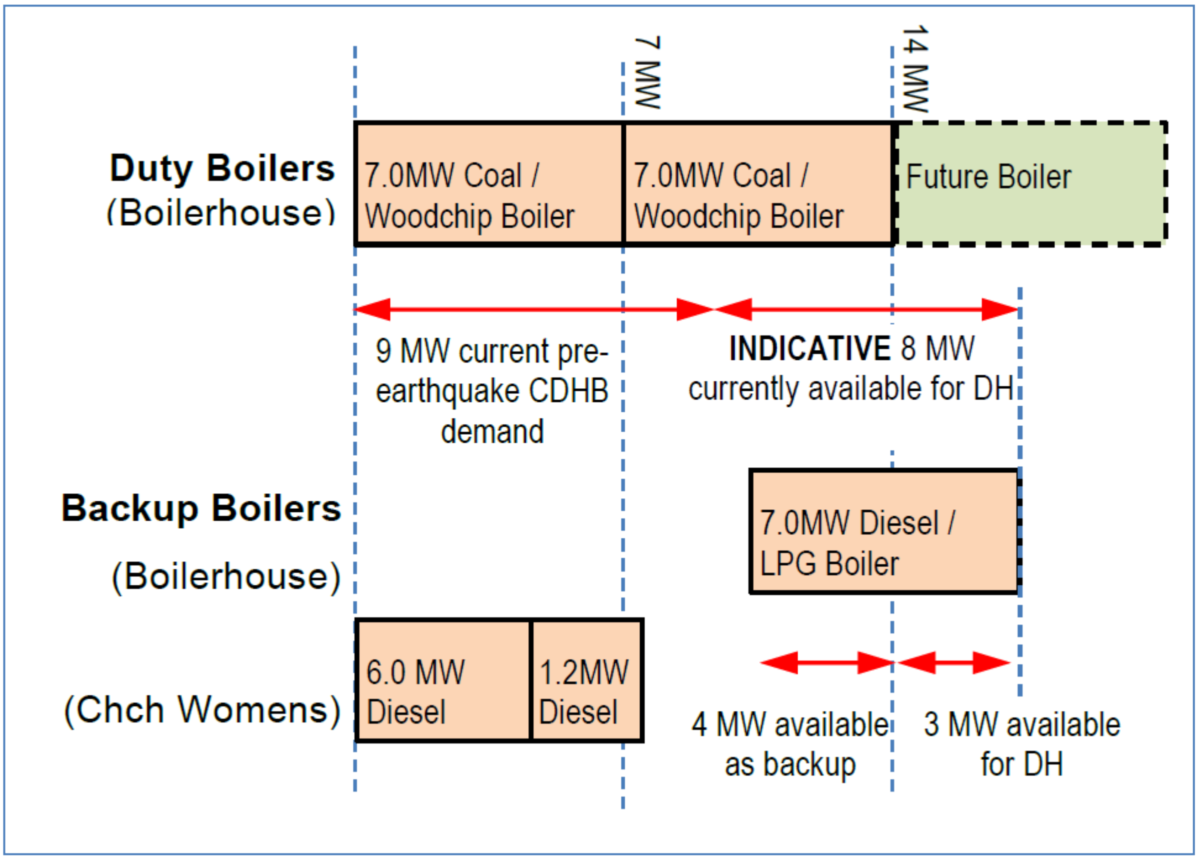

Figure 8: The possible future Christchurch Hospital boiler system, showing the existing (14 MW coal, 7 MW diesel or LPG and 1.2 MW diesel) boilers, the proposed (6 MW diesel) backup boiler, and the potential (7 MW coal or wood chip) future boiler. The image shows that 8 MW would be available for the DES before the future boiler is considered. Image from Watson (2012)

2.3 Previous Studies on Biofuels and Renewable Energy in New Zealand

Bioenergy Pathways Reports

In 2007 and 2008, two reports were published by Scion, one of New Zealand's Crown Research Institutes (CRIs), in collaboration with other CRIs and researchers. The first of these was a situation analysis, which analysed the quantities of bioenergy resources available in New Zealand, and the conversion technologies available, in order to identify the most promising research areas for New Zealand (Hall and Gifford, 2007). This report formed a basis for some of the bioenergy sources investigated in this report.

The follow-up report to the situation analysis was the pathways analysis, which looked for the most feasible pathways for bioenergy sources to be utilised, and analysed them in more detail (Hall and Jack, 2008). This report found that straw to CHP had a favourable energy balance, and could have a significant contribution to heat demand in Canterbury, but that current prices were not competitive. The report also found that the carbon price would have a strong bearing on the economics, and that for straw to become competitive it would need to be used at a large industrial boiler with a constant heat demand.

The other significant pathways for this report were energy conversion of forest residues, and anaerobic digestion of farm effluent. Forest residues were analysed with a number of conversion technologies, from combustion for heat to CHP, to conversion to ethanol and also gasification for heat, CHP or biodiesel production. Combustion was found to be the most economically feasible pathway, and this pathway was shown to be the most economically viable of all pathways in the report. Forest residues were found to be a cost-effective energy source, but costs rose with scale, due to logistics and transport costs. Improved collection mechanisms were mentioned as a way to improve the economics.

Anaerobic digestion of farm effluent was found to be economical and environmentally friendly, though was analysed on the farm-scale, as opposed to combining of effluent for a larger plant. In terms of technologies, gasification (at large scale) of any bioenergy source was assumed to be too costly to be viable, and was described as an unproven technology at this scale. In general, combustion and CHP were found to be the best uses for bioenergy sources in New Zealand.

New Zealand's EnergyScape Reports

A series of research reports were published in 2009 as a collaborative effort between five of New Zealand's CRIs, led by the National Institute of Water and Atmospheric Research (NIWA). These reports covered seven core areas of energy in New Zealand: energy end-use, renewable resources, bioenergy resources, earth resources, distribution infrastructure, secondary conversion, and hydrogen options. These reports cover such topics as available resources, current state of technology, risks of each technology and other relevant topics.

For this report, chapter 3 'Bioenergy Resources' was the most relevant resource, although much of the information in the chapter was taken from the previous Bioenergy Pathways reports (de Vos et al., 2009a). Also relevant for context and non-bioenergy resources were the other reports in the EnergyScape project, mainly the 'Renewable Resources' report which gives an overview of New Zealand's solar, wind, hydro and marine energy resources (de Vos et al., 2009b).

Life Cycle Assessment of Straw to Industrial Energy

One of the reports which fed into the Bioenergy Pathways reports was a life cycle assessment (LCA) of using straw to produce industrial energy in New Zealand (Forgie and Andrew, 2008). This report assumed a location for a 33 MWh CHP (or heat-only) straw-fired plant, based in Timaru, a city approximately 150 km south of Christchurch. The study looked at energy, costs and CO_2 emissions from the construction of the plant, growing and transport of straw and ongoing use of the plant.

The study found that a heat-only straw plant could produce energy at NZ$9 to NZ$13 per GJ, and a CHP plant could produce energy at NZ$15 to NZ$19 per GJ. These costs are significantly higher than coal costs, and the authors note that viability is dependent on the pricing of emissions from fossil-based plants. The study was completed before the introduction of the NZ emissions trading scheme (ETS), and so could not take this fully into account. The straw was assumed to come from an average distance of 44 km, which is likely to be lower than the average distance from the Christchurch city centre, yet comparable to a boiler outside of the Christchurch city area. Some information from the study has been used for calculations in this report; this will be explained in further sections.

Wood Residues, Purpose-Grown Wood, and Construction & Demolition Waste

Wood energy has been described as a cost-effective option for Christchurch, as well as having benefits such as creation of jobs, lowering air pollution and lowering fossil carbon emissions (Bowler, 2009). The Bioenergy Options and EnergyScape reports cover in detail the possibilities for wood residues to energy and also purpose-grown forest to energy.

Construction and demolition wood waste was analysed in a study at Canterbury University prior to the earthquakes (Keene and Smythe, 2009). At this point, more than 26,000 tonnes of timber was being deposited in Christchurch's landfill annually. The report noted crucially that construction waste was decreasing, most untreated timber was being utilised, and that in the future untreated timber would be almost totally recycled or used for energy. Treated wood waste was the main problem, with no current solutions to incinerate it due to emissions. The possibilities for using treated wood waste from earthquake demolition waste is currently being investigated, with results expected during 2013 and 2014 (TNC, 2013).

2.4 Biogas from Animal Waste

A report by the Ministry for Agriculture and Forestry in 2008 examined the energy potentials of animal wastes in New Zealand (MAF, 2008). This study found that in New Zealand, most biogas systems from animal manure were not feasible, with the exception of some systems for pig and chicken manure. The extensive dairy and beef farming style commonly used in New Zealand did not allow for collection of significant amounts of manure from cattle, and thus the systems were not economically possible.

A feasibility study was published in 2010, which analysed in detail the possibility of a biogas plant at Christchurch Men's Prison, using nearby piggery waste and some industrial processing waste (grease, food production by-products) as fuel (Thiele, 2010). This study found that the system was feasible, and offered a good chance for the prison to replace its current heating system, as well as offering the opportunity to produce vehicle fuel in months with low heating demand. Figures from the study have been used for calculations and costings in this report, and are described in detail in further chapters.

3. Theoretical Basis – Renewable Energy Technologies and Fuels Literature Review

3.1 Which Bioenergy Conversion Technologies Exist?

Energy from agricultural sources can have many benefits, including increased security of energy supply, decreased GHG emissions, rural diversification and development, environmental improvement, job creation and strengthening of the agricultural sector (Voytenko and Peck, 2012). Conversion technologies exist at many different scales, and the technologies are also at different stages of development.

This section will outline those conversion technologies that are at minimum at the demonstration scale, and focuses on those technologies suitable for district heating schemes or medium to large stationary heat demands. Thus, technologies for liquid transportation fuels are excluded, and the focus is on direct utilisation of fuels for heat and electricity. Combustion is the most developed of these and will be described in most detail, followed by gasification and anaerobic digestion, and the respective technologies within these categories. Summary boxes indicating fuel sources, the size ranges of the technologies and environmental concerns are included; it should be noted that the environmental concerns list relate only to the conversion technology, not to production of the respective fuels.

3.2 Combustion

Biomass combustion has existed in some form for thousands of years. Today, the three main technologies for biomass boilers are fixed-bed, fluidised bed or pulverised fuel combustion; all of these have their own advantages and disadvantages (Obernberger, 2010). Generally fixed-bed combustion systems are cheaper but less efficient, and suitable for a large range of sizes, from 100 kW to 50 MW. Fluidised bed combustion systems are more efficient, but sensitive to slagging (molten ash formation) and have high capital costs; they are suited to plants greater than 20 MW. Finally, pulverised fuel combustion systems are ideal for co-firing biomass with other fuels such as coal, and can range in size from 500 kW to several hundred MW.

Biomass combustion has traditionally suffered from problems such as high ash contents, aerosol formation, slag formation, and corrosion due to high concentrations of elements such as chlorine. With modern boiler design, filtration systems such as bag filters and electrostatic precipitators, and specific additives, these problems have been minimised or totally resolved (Obernberger, 2010). Even straw, a problematic fuel for many years, is now routinely used in highly efficient CHP plants in Denmark.

Combustion for Electricity

Combustion of fossil fuels for electricity is a technology that has been used around the world for many decades. However, in these plants, which typically have electrical efficiencies of less than 50%, heat is always produced. This heat is sent to cooling towers, where the heat is released to the atmosphere. This is a waste of a valuable resource, and thus electricity-only combustion plants are not considered further in this thesis.

Combustion for Heat

Combustion of biomass for heat is a commonly-used technology worldwide. Alongside household wood and pellet burners, larger plants provide heat for industrial applications and district heating. Biomass (mainly wood) is commonly used for larger-scale heat production in Austria, Bulgaria, Finland, Germany, Italy, Slovenia and Sweden, usually for industrial process and district heating (Vagonyte, 2009). Generally speaking, heat-only combustion plants range from very small systems for household heating up to 20 MW; above this size, it is often economically favourable to begin generating electricity in addition to the heat (Obernberger, 2010).

Combined Heat and Power

Electricity can be generated from biomass alongside heat, and this is done in different ways depending on the scale of the system. For small scale systems, under 100 kW_{el} a Stirling engine is the only feasible choice(Obernberger and Thek, 2008). For medium scales (100 kW_{el} to 2,000 kW_{el}), conventional or organic Rankine cycle engines are possible (Obernberger and Thek, 2008, Salomón et al., 2011). For large scale plants above 2,000 kW_{el}, conventional steam turbine systems (as used in most large-scale thermal power plants) are possible. There are a wide variety of other technologies being developed, many of which are designed to use gas from gasification processes, and these are described in the gasification section below.

Electrical efficiencies are possible of up to around 40%, with total efficiencies ranging from 80% to 95%. An example of the scale possible is the biomass CHP plant in Simmering, close to Vienna, which has a thermal capacity of 66 MW and an electricity generation capacity of over 24 MW (PEI, 2006). This plant can be run at maximum efficiency in winter when both heat and electricity are required, and in summer can increase its electricity output to maximum while sacrificing heat production. Many CHP plants also use heat accumulators (short-term hot water storage tanks) to allow flexibility – when electricity prices are high the plant can focus on electricity generation and feed heat from the accumulator to the grid, and when electricity prices are low the plant can prioritise heat production (Petersen and Aagaard, 2004).

Electricity generation costs from biomass combustion in Europe have been found to range between NZ$0.20 and NZ$0.35 per kWh_{el}, depending on size, fuel price and annual load (Obernberger and Thek, 2008).Therefore economic viability of CHP depends on the location-specific prices of heat and electricity, as well as subsidies, feed-in tariffs, mandated minimum quantities of biomass, and other policies to drive uptake of biomass CHP.

Co-firing of Biomass with Coal

Co-firing of biomass with fossil fuels such as coal is a proven technology, with over 150 examples existing worldwide (Al-Mansour and Zuwala, 2010). At present, co-firing of biomass in coal-fired power plants is possible in percentages of 10-20% of the energy output; however to increase that fraction, fuel upgrading such as pelletising, torrefaction or gasification would need to take place (Kiel, 2008). The biomass source is dried and either pulverised with the coal, or pulverised on a separate line, then injected with the coal into the boiler at the correct ratio.

The three main methods for co-firing of biomass are direct co-firing, indirect co-firing and gasification co-firing (Basu et al., 2011). Direct co-firing involves the burning of pulverised biomass in the same boiler as the pulverised coal, which results in minimal capital costs for boiler modifications, but has risks of fouling and corrosion in the main boiler, especially when using straw. However, the coal ash beneficially reduces the corrosion effects from burning straw, and the fly ash from the process can be used in cement and concrete production (Skøtt, 2011). Indirect co-firing involves a separate biomass boiler which produces low-grade steam to be upgraded in the coal boiler, which involves high capital costs yet totally avoids the risks of fouling or corrosion in the main boiler. Gasification co-firing involves a separate biomass gasification unit which produces heat and sends biogas into the main boiler for combustion, again with high capital costs yet avoidance of corrosion and slagging.

Fuels

Different fuels, or even combinations of fuels can be used for combustion plants, and these are outlined in this section.

Wood

Wood is a common renewable fuel in both small-scale residential boilers and in larger-scale applications such as industrial boilers, CHP plants and district heating plants. For example, in 2010, wood and wood waste provided a high proportion of the inland energy consumption in Latvia (27%), Finland (21%) and Sweden (19%) (Šturc, 2012). Wood is commonly used for district heating plants in Austria, and currently over 1,500 of these plants are in operation in the country (Jauschnegg, 2013).

The technology for utilisation of wood (for heating or CHP) has developed to a relatively mature stage where district energy plants with efficiencies of 70-90% are possible (EU, 2011). Wood-based DESs provide a significant amount of the heating requirements in Sweden and Austria. The trend into the future is towards combining biomass systems with solar systems and heat pumps, and to combine CHP systems with district cooling to improve load factor and economic viability (EU, 2011).

While the technology is relatively mature, the economics still depend on a multitude of factors, including heat load and energy density (demand-side), fuel quality, transport distances, emissions regulations, dust and noise, and the specific technology used . Also critical for success are social and political factors such as good relationships between wood suppliers and the DES owner, a critical mass of actors, and inclusion of all parties during the planning process (Madlener and Bachhiesl, 2007).

Wood can also be pelletised in order to increase density, and provide a fuel source with a regular quality. Pellets can be used on a large scale – they will be the fuel source for three of the six boilers at Drax power station, Europe's second-largest coal-fired power station, once their conversion from coal to biomass is completed in 2015 (Lovell, 2013). This will result in the consumption of 7.5 million metric tons of wood per year at the plant.

Straw

Straw as a fuel for district heating and CHP plants is currently only utilised to a high extent in Denmark, where the technology is most mature. A 2011 report summarised the state of the art in Denmark, for straw-to-energy at a range of scales (Skøtt, 2011). In the period 2004-2008, average annual straw production was 5.5 million tonnes, of which almost two million tonnes was used for energy. There are currently around 55 operating district heating plants using straw in Denmark, ranging from 0.5 to 12 MW (Skøtt, 2011). Straw is also used in the UK, and the Elean power station in Ely, Cambridgeshire, is the largest straw-burning power station in the world, producing 38 MW of electricity from straw (EPR, 2013). This power station consumes 200,000 tonnes of straw per year, and is also capable of handling other biofuels and up to 10% natural gas. The design of the plant is a vibrating grate combustion plant using a conventional steam cycle. An important point to note is that the heat from this power plant is not currently used, which implies that straw-to-energy is feasible even at lower efficiencies.

Before mentioning combustion-specific issues, straw has issues such as nutrient removal and transport problems that must be mentioned. The amount of straw that can be removed from fields without significant negative impacts on soil carbon and nutrients depends very much on each individual site – characteristics such as soil type, drainage, slope, tillage and cropping systems, application of fertilisers/organic amendments and climate all have an impact (Voytenko and Peck, 2012). It is estimated that a safe amount of straw to be removed would be 22% - 50%, (Lemke et al., 2010, Voytenko and Peck, 2012, Blanco-Canqui, 2013). Soil carbon can, in addition, be replenished in other ways such as with the use of cover crops, 'biochar', manure or compost (Blanco-Canqui, 2013). Nutrient losses can be minimised using the straw ash, which can be processed and returned to farmers as fertiliser. This can depend on local regulations, for example governing carbon content and contaminants in ashes (personal communication, Thomas Brunner, 17 April 2013).

Another lesson learned after years of experience is that it is much cheaper for the straw consumer to buy straw on the free market – long-term contracts in the past ended in the failure of straw projects and their subsequent conversion to wood chips which had become more competitive (Skøtt, 2011). Today in Denmark straw is traded on the market, which has improved its competitiveness.

Transport and dust issues with straw can all be minimised with careful planning or with pelletising of straw (Sander and Skøtt, 2007). The most common way of handling straw internationally is baling, yet within this category are different bale shapes and sizes. For energy, in Denmark and the UK it is most common (and most cost-effective) to bale the straw into 'big bales', also called Hesston Bales (Sander and Skøtt, 2007). These bales measure 120 x 130 cm, with a length of 230-270 cm, and weigh up to 600 kg. With modern systems designed for these bales, the process is highly automated; a standard truck can carry 24 of these bales, which are removed 12-at-a-time by automated grabbers at the power plant.

The other way of densifying straw is producing either pellets or briquettes. This option involves significant upfront capital costs. The economics of pelletising straw can be challenging, and previous analysis has shown bales to be more economically feasible for transport distances under 250 km (Mupondwa et al., 2012). Pellets can be crushed and dust-fired, as previously mentioned. A way of densifying straw further, as well as improving its storage, handling, transport and milling properties, could be torrefaction (a form of pyrolysis which creates a uniform, coal-like product), however this is currently in the experimental phase (Kiel, 2008).

In practical terms, issues with combustion of straw include the low ash melting point (resulting in slagging problems in boilers), and the corrosive compounds produced when combusted; both of these issues can be minimised with good boiler design (personal communication, Thomas Brunner, 17 April 2013). Vibrating grate boilers make use of cooled walls to avoid slag deposition, and molten slag instead collects on a designated superheater, and then drops through the grate to be removed. Bag filters, injection of calcium hydroxide, and using straw that has been exposed to rain can all minimise boiler corrosion and emissions.

Gases from Renewable Sources

Combustion of gases produced from anaerobic digestion or gasification is possible either alone, or in combination with conventional fuels such as coal or natural gas. This option will be explained further in the gasification and biogas production sections.

Short Rotation Crops and Miscanthus
Fast-growing forests, short-rotation coppice (SRC) and miscanthus (a fast-growing C4 grass) can all be used as fuel sources for combustion, and are currently utilised on a small scale in Europe and the USA (Aebiom, 2009). While these fuels hold much potential for the future, they are currently available in very small quantities in Canterbury, so are not a focus area for this thesis. The potential role of these fuels in future situations will be discussed further in the results sections.

Sewage Biosolids
Sewage biosolids can be used as a source of energy, although there are many issues with this complex fuel. For example, dewatering and drying consumes a large amount of energy due to the energy requirement for drying the biosolids prior to combustion, and the capital costs for a biosolids-only boiler can be very high (Wang et al., 2008). This material can however be co-fired with coal in existing plants, without high investment costs (Wang et al., 2008). Dried sewage biosolids are available in Canterbury, and specific details will be discussed in the results sections.

Bio-oil and Biodiesel
Bio-oils are renewable fuel oils derived from biomass, while biodiesel is a replacement for diesel that is derived from biomass. These fuels are both designed to be 'drop-in' options that can be used in conventional engines and boilers that would normally use fuel oil or diesel. In general, these fuels are produced on a relatively small scale, so would be considered mainly for peak load and backup boilers in a DES, as previously mentioned in the technical feasibility study for the Christchurch DES (Bizcat Aurecon & FVB, 2012).

Summary
Table 5: Summary of biomass combustion for heat, electricity or combined heat and power

Biomass Combustion	
Primary Energy Source	Solid biomass (wood, straw, short-rotation crops, miscanthus, others)
Size Range	<100 kW – 500 MW
Maturity of Technology	High
Possible Outputs	Heat, electricity or CHP
Efficiency	80 - 95%
Environmental Concerns	Transportation of fuels, dust, noise, localised emissions

3.3 Gasification

Gasification is the reaction of a fuel source with oxygen and/or steam, at high temperatures. The main difference to combustion is that the oxygen input flow is limited, which results in a different reaction process, resulting in production of syngas, a mixture of hydrogen, carbon dioxide, carbon monoxide and other organic molecules. This gas can be further processed into gaseous or liquid fuels, and used in conventional combustion plants, internal combustion engines or even fuel cells (Ahrenfeldt et al., 2013).

Types of Gasifiers
Gasifiers can take many forms; they can be run using air, oxygen or steam, and can be run at atmospheric pressure or and higher pressures. Process possibilities include updraft, downdraft or other flow arrangements, as well as fixed bed, fluidised bed or entrained flow systems, and

slagging or non-slagging ash depending on the temperature in the gasifier. Fixed-bed updraft gasifiers are insensitive to fuel particle size and moisture yet produce an output gas with high tar; conversely, fixed-bed downdraft gasifiers require dry and uniform fuels but are limited in size (<5 MW) and produce a low-tar gas, requiring only a simple cleaning process before use in internal combustion engines (Obernberger and Thek, 2008). In fluidised bed gasifiers, the fuel is mixed with air, oxygen or steam, and mixed into a bed of hot solid material such as sand. These systems can have a high throughput but have a complex design, and at present are only at the demonstration stage (Obernberger and Thek, 2008).

Gasification for Combined Heat and Power

The main advantage of gasification of biomass over combustion of raw biomass is the ability to maximise the electrical output in a CHP plant; the main disadvantage is the capital costs of a gasification CHP plant, which are usually 20-30% higher than combustion plants (personal communication, Christian Aichernig, 15 April 2013). Gasification followed by CHP has been applied to large plants in Europe such as the Amercentrale power plant in Geertruidenberg, Netherlands, where a wood gasification plant converts 150,000 t of building timber and salvaged wood per year to gas, which after cleaning replaces roughly 70,000 t of coal per year (Andrews et al., 2012). The largest biomass gasification plant in the world is in Vaasa, Finland, where a 140 MW gasifier dries and gasifies biomass, and the resultant gas is fed into a coal-fired boiler which provides district heating and electricity (Breitholtz, 2011). Gasification with CHP is an attractive alternative to biomass combustion, and is also very appropriate for systems smaller than 10 MW (Ahrenfeldt et al., 2013).

Other Outputs

One benefit of gasification is that the gasification process itself produces heat, even before the gas is utilised. Therefore it is possible to have a gasification plant which could provide district heating as well as clean gas for the grid (personal communication, Markus Kleinhappl, 21 March 2013). An example of this is currently being initiated in Gothenburg, Sweden, where a 20 MW gasification plant has been built to turn forest residues into syngas, and then upgrade this to synthetic natural gas (SNG) (Göteborg Energi, 2013). The SNG is of similar quality to natural gas, and so can be used in the existing gas grid, and also as a vehicle fuel. It is theoretically possible to use the output of gasifiers to produce liquid fuel products such as methanol, or other hydrocarbons using Fischer-Tropsch processes (personal communication, Markus Kleinhappl, 21 March 2013). Low-temperature gasification of biomass can result in usable ash with a high nutrient content, and this output could be mixed with some char from the process to produce a high-carbon, high-nutrient 'biochar' for soil amendment (Ahrenfeldt et al., 2013).

Fuels

Gasification plants can largely use the same fuels as combustion plants, although specific fuel requirements often differ in terms of particle size and moisture content. Gasification of wood is a proven technology, while straw is at the demonstration stage only (personal communication, Christian Aichernig, 15 April 2013). Gasification systems using wood and straw can be more efficient than combustion plants, because the gas can be used in an internal combustion engine, however at present there can be problems with reliability (personal communication, Thomas Brunner, 17 April 2013). Gasification of straw occurs currently in Kalundborg, Denmark, where a 6

MW low-temperature gasification plant operates as a demonstration of the technology (DONG Energy, 2013). The low temperature means that the corrosive alkali elements in the fuel remain in the solid state, and the energy-containing gas can be sent to the boiler, where it is co-fired with coal, with no corrosion problems. This process can also be used with miscanthus, willow, chicken litter, manure fibre, and other industrial wastes. An example of this latter fuel source is a large CHP plant in Finland which runs on cleaned gas produced from gasification of high-energy waste materials such as plastic wrapping that cannot be recycled (Andrews et al., 2012, Energia, 2013). This shows that in principle many fuels can be used for a gasification process, but much of the technology is still at the experimental and demonstration stage.

Summary

Table 6: Summary of biomass gasification

Biomass Gasification	
Primary Energy Source	Solid biomass (e.g. wood, straw, short-rotation crops, miscanthus), animal wastes, industrial wastes
Size Range	<140 MW
Maturity of Technology	Low (at the pilot/demonstration stage for most fuels)
Possible Outputs	Heat, electricity, combined heat and power, biogas, liquid fuels
Efficiency	up to 95%
Environmental Concerns	Transportation of fuels, dust, noise, localised emissions

3.4 Biogas Production

Biogas refers to gas produced from the anaerobic decomposition of biological feedstocks such as animal manure, sewage sludge or plant waste. This gas can be burned much like natural gas, and is a potential source of heat for smaller district heating systems.

3.5 Generation Technologies

Anaerobic digestion

Organic materials such as manure, sewage sludge, organic waste, and other sources of wet and dry biomass can produce methane under anaerobic (oxygen-free) conditions. This process can happen with relatively simple technology, and is already widely implemented in Europe (Thiele, 2008). The process is ideal for wet fuels that are unsuitable for combustion. Dry fuels such as straw can also be used in combination with other materials. For example, when straw is digested the energy profit is only around 60% of that compared with direct combustion, however this option allows the possibility of returning the nutrients back to the soil, and provides a flexible gas (Skøtt, 2011).

Landfills

Landfill gas (LFG) is a form of biogas that is created as organic waste decomposes in a landfill. Landfill gas is already used around the world (predominantly in the USA), yet its extraction from landfills in Europe is decreasing due to the EU Waste Directive which effectively prevents untreated organic material from entering landfills in Europe (EU, 1999). In New Zealand, landfill gas is currently captured and used for heat or energy in many sites around the country (BANZ, 2013). This resource is easily used for heat or CHP, and could be considered as an option for a district energy scheme. The gas can be used with mature existing technology, but requires cleaning to remove corrosive substances. Drawbacks of LFG include fluctuating supply, and the fact that that once landfills are closed, the gas output begins to decline over a period of years.

Utilisation Technologies

While many examples exist of small-scale biogas combustion, few examples exist on scales appropriate for DESs. Generally for larger-scale use the gas must be thoroughly cleaned; an example of this is the Gasendal plant in Gothenburg, Sweden, which upgrades biogas from a wastewater treatment plant to high quality SNG, which is predominantly used as a vehicle fuel. The system uses a chemical scrubber, and the output of this plant is 216,000 GJ of SNG annually (Biogasmax, 2010). Other similar examples exist in France and Switzerland. The cleaned gas is of a high enough quality to substitute natural gas, which opens up many possibilities for utilisation, as covered previously in the gasification section.

Summary

Table 7: Summary of biogas production

Biogas Production	
Primary Energy Source	Animal effluent, silage, organic waste, landfills
Size Range	0 – 20 MW
Maturity of Technology	High
Possible Outputs	Biogas for heat, electricity, CHP, biomethane, bioCNG, gaseous and liquid fuels
Efficiency	<45% electrical, <85% heat, <95% CHP
Environmental Concerns	Odour, transportation of feedstocks

3.6 Non-Biofuel Renewable Technologies

Solar Thermal

Solar district heating (SDH) plants are gaining in popularity in Europe, and at present there are 86 plants of 700 kW capacity or larger, up to a maximum of 23.3 MW at Marstal in Denmark (SDH, 2013). As of February 2013, in Denmark alone, 280,000 m^3 of panels for SDH were already installed, with another 120,000 m^3 planned (Nielsen, 2013). Usually these systems utilise flat plat collectors, which can generate heat from diffuse radiation, as opposed to for example parabolic collectors which require direct sunlight for efficient use(personal communication, Johannes Luttenberger, 6 May 2013). Other examples exist in the USA, however Europe is the region with by far the most solar district heating systems. The bulk of these systems use flat plate collectors, and most are based in Denmark, Sweden, Germany, the Netherlands and Austria.

Solar thermal district systems can compete with other technologies (at a similar scale), yet have the problem of high capital costs – typically 5 – 12 years of energy costs in one lump sum (Larsen, 2010). There is also a need for backup systems when demand is high in periods of low solar radiation. The business case for these systems depends on the solar radiation available and on fuel prices of competitive technologies. If oil and gas prices are expected to stagnate, then the technology is difficult to make competitive; if oil and gas prices rise year on year then solar thermal begins to become very competitive. Capital costs for such systems range from NZ$300 for large systems to NZ$1500 per m^2 for individual systems for houses (Dalenbäck, 2010). Solar district heating systems have provided in Europe overall heat prices from NZ$0.05 – NZ$0.13 per kWh (Dalenbäck, 2010, Nielsen, 2013). Elsewhere, costs of heat have been estimated based on plant size, and similar results were found, as shown in Table 8.

Table 8: Size of solar array versus heat costs, excluding transport of heat to customer. Prices modified to New Zealand dollars and rounded (1 GPB = 1.85 NZD) (Oliver and Simmonds, 2012)

Size of Solar Collector Array		Annual Heat Production	Cost of Heat
m^2	MW	kWh	NZ$/kWh
500	0.25	250,000	0.13
1,000	0.5	500,000	0.11
5,000	2.5	2,500,000	0.07
10,000	5	5,000,000	0.05
20,000	10	10,000,000	0.03

Solar Thermal and Biofuel Combination

Generally SDH systems will not use only solar heat – they will use a solar collector field combined with a conventional boiler, to ensure a regular and secure supply of heat. Solar collector installations can contribute heat to a DES in one of three ways: 1) they can pre-heat the return line of the system before it enters the main heat plant (this option is not suitable for CHP plants which require a large ΔT), 2) they can take water from the return line, heat it, and directly feed it to the supply line, or 3) they can boost the temperature of the supply line, at a point some distance from the main heat plant (personal communication with Johannes Luttenberger, 6 May 2013). The two former options are employed in Graz, Austria. An example of these is shown in Figure 9 – a solar system heats the return line of the district heating system, before the water is further heated in a gas plant (SOLID, 2008). This system covers 5,000 m^2 of roof space on a council-owned waste processing plant, has a peak output of 3.5 MW, and provides 2,200 MWh/yr of heat to the system. Such a system would easily be constructed in other parts of the world.

Figure 9: The solar thermal pre-heating system for the nearby AEVG gas thermal plant (beyond the left border of the photo) in Graz, Austria. Source: S.O.L.I.D. Gesellschaft für Solarinstallation und Design mbH

Finally, also existing is the potential to combine distributed solar thermal systems on individual buildings with a DES, thus removing the need for short-term in-building heat storage – the DES acts as the storage in this case (Bizcat Aurecon & FVB, 2012). This can save building owners on capital costs of heat storage tanks, and can allow the individual systems to shed excess heat when not required, and import excess heat when required.

Summary

Table 9: Summary of solar thermal technology

Solar Thermal	
Primary Energy Source	Solar radiation
Size Range	0 – 24 MW
Maturity of Technology	Medium (some commercial plants in operation)
Possible Outputs	Heat (up to 98 °C)
Efficiency	<85%
Environmental Concerns	Land use

Heat Pumps

Heat pumps make use of ambient or waste heat, and use electricity to upgrade this heat to usable temperatures. These systems can use heat from the air, ground or water (aquifers, lakes or seawater) as well as from industrial waste heat and solar sources. Heat pumps currently contribute to a number of district energy systems, and also have the benefit of being able to provide cooling in summer and heating in winter. Ground source heat pumps for district heating have been found to have a coefficient of performance (CoP) of around 4 (Rezaie and Rosen, 2012). This means that for every kWh of electricity fed into the system, 4 kWh of heating (or cooling) are produced. This is higher than for small heat pumps for individual buildings; central heat pumps are also cheaper and can produce higher temperatures (Andrews et al., 2012). The main advantage of heat pump systems are that they use low-value or ambient heat; the main disadvantages are that the investment costs can be high, and that the system uses electricity, a high-value energy medium.

In Sweden in 2007, approximately 12% of the heat fed to district heating schemes came from heat pumps using either seawater or sewage sludge as initial heat sources (Eriksson and Vamling, 2007). Other examples include the use of aquifer water for heating and cooling, which can include thermal seasonal storage in the aquifer itself. Two examples of this technology in Sweden are at Stockholm Arlanda airport and the Western Harbour district in Malmö (Geopower, 2013, Swedavia, 2013). Very large heat pumps have been constructed to contribute to district heating systems, such as a 180 MW example in Stockholm (Andrews et al., 2012).

Summary

Table 10: Summary of heat pump technology

Heat Pumps (Air, water or ground-source)	
Primary Energy Source	Ambient or waste heat
Size Range	<180 MW (per system)
Maturity of Technology	Mature
Possible Outputs	Heating and cooling
Coefficient of Performance (CoP)	3.5 – 4 (overall)
Environmental Concerns	Dependent on source of electricity

Waste Heat

Many industrial processes result in excess heat streams, which must cooled using one of many methods such as fan coil units, heat exchangers or cooling towers. This heat may be too low a temperature to be used in processes on-site, but may be warm enough to be used for space heating. While industrial heat users generally try to recover as much heat as possible, this becomes more and more difficult until a point is reached where it is more cost-effective to use the heat for space heating than to try to recover the heat into the industrial process (Andrews et al., 2012). If a high enough temperature, the waste heat can be used directly in the system, or can be upgraded using heat pumps, as described above. In Sweden, political discussion is occurring over allowing third-party access to district heating systems, to allow companies to add their waste heat into these systems (Broberg et al., 2012). A large example exists in Luleå, Sweden, where an 80 MW CHP plant at a steel mill produces 95 °C steam and 80 °C water, which are used via a heat exchanger to heat the return line of the district heating grid, before delivering the heat to customers (Elfgren et al., 2011). Another good example is in Graz, Austria, where the local Marienhütte steel mill feeds into the district heating via a buffer system and heat exchanger, providing up to 60 GWh/yr (216,000 GJ/yr) (Energie Graz, 2011).

Summary

Table 11: Summary of waste heat

Waste Heat	
Primary Energy Source	Waste heat streams from existing industry
Size Range	<80 MW
Maturity of Technology	Mature (heat exchangers/heat pumps)
Possible Outputs	30 ° - 95 ° water/steam
Efficiency	up to 100% (i.e. direct use of excess hot water)
Environmental Concerns	Dependent on source of heat, such as steel mills fired with coal. (Note: This is still an improvement in efficient use of resources.)

Electricity from Wind and Hydroelectric Sources

In Scandinavia, district CHP plants with heat storage are seen as fundamental for increasing the use of renewable energy, because excess energy from wind turbines can be fed into the system, and stored there during peak times of wind (EU, 2011). In addition to combination with CHP plants and short-term storage, excess electricity could heat interseasonal heat storage systems, which are described further in the district heating systems section below. These would use a heat pump to provide district heating in winter, and potentially district cooling in summer.

At present, this system is rare, and the majority of excess wind (and solar) energy in Europe is stored as pumped hydro storage (i.e. excess electricity is used to pump water into a raised storage lake, for later use in a hydroelectric plant); it should be noted that heat storage systems could be much cheaper than this type of storage (Andrews et al., 2012). While short- and long-term heat storage is based on simple concepts, and is used in Denmark and a few other places in the world, this technology is not widely implemented and cannot be considered a mature technology. Electric resistance boilers are also possible with excess electricity, however these systems are usually small (<2 MW). Larger electrode boilers can be installed up to 25 MW, which can be connected at 10 kV and have lower installation costs, yes these are also uncommon (Garcia et al., 2012).

Summary

Table 12: Summary of heat from surplus wind or hydro electricity

Wind and Hydro Electricity to Heat Storage	
Primary Energy Source	Wind or Gravity
Size Range	<25 MW (electrode boiler), <2 MW (resistance boiler)
Maturity of Technology	Low (as direct electrical use in DESs)
Possible Outputs	Low temperature heat, upgradable with heat pumps
Efficiency	99% for electric boilers, CoP of 4 for heat pumps (= 400% efficiency per unit of electricity used)
Environmental Concerns	Wind: visual impact, noise. Hydro: biodiversity effects from damming of rivers and flooding of valleys.

3.7 District Energy Systems – Distribution and Storage of Heat

The focus of this thesis is on technology upstream from DES heat and electricity distribution, such as the harvesting, logistics and energy conversion of biomass and other energy sources. Therefore DESs will not be described in great detail, but this section is intended to give an introduction to the concepts that exist, in order to provide context to the main research focus.

District heating has existed since the 14th century, and is today most common in Europe, but also exists in many other countries such as the USA, Canada and Russia (Rezaie and Rosen, 2012). The general principle is to use a central, large-scale heat source to supply heat to all or part of a district through underground supply and return pipes carrying steam or hot water. District heating has evolved from so called 1st generation district heating systems based on steam, to 2nd generation systems using 120 °C water, to 3rd generation systems using 90 °C water, and finally the very modern 4th generation systems using low-temperature 55 °C water (Wiltshire, 2012). These latter systems can use low-value heat, freeing up higher value heat for electricity generation and industrial processes.

District heating in some countries is extremely widespread, such as Austria where over 1,500 individual boilers connected to distribution grids exist (Figure 10). In Latvia and Lithuania, around 65% of homes are heated with district heating (Rezaie and Rosen, 2012).

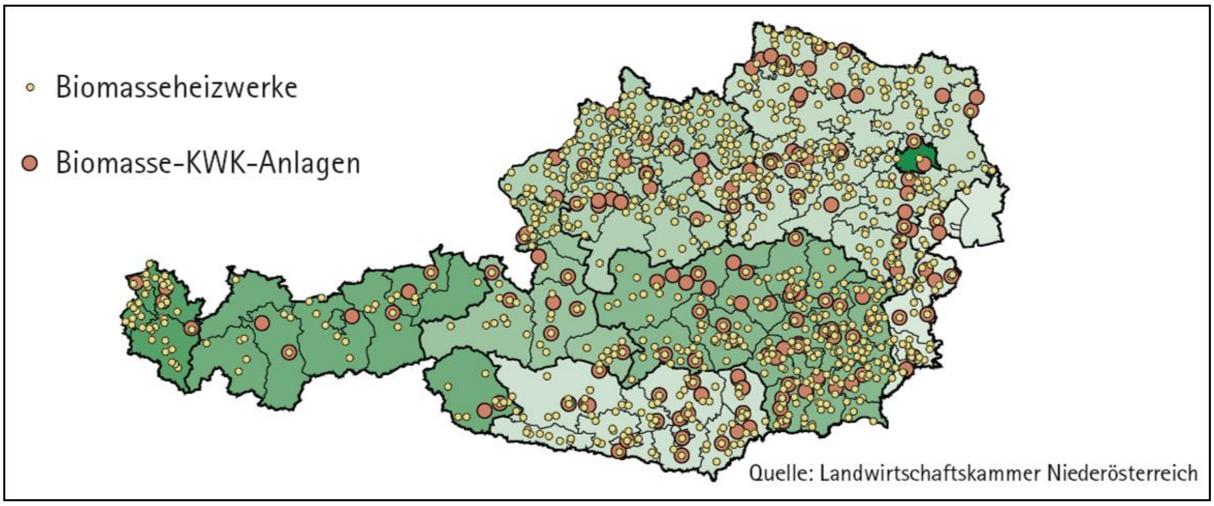

Figure 10: District heating plants in Austria, showing heat-only plants (yellow dots, over 1,500 plants) and biomass CHP plants (red dots, 115 plants). Original source – Lower Austria Chamber of Agriculture. From Jauschnegg (2013)

Barriers to district heating include the local climate (and therefore the annual hours of usage), energy efficiency of buildings, and the high installation costs for the grid. The pipeline costs are in the vicinity of NZ$1,200 per linear metre (Ulloa, 2007). In addition to these costs are the connection systems to each building, and the main connection to the heat source. Due to these pipeline costs, it is desirable to have the source of heat as close as possible to the users of the heat, although large distances exist such as in Prague, where the pipeline for a 200 MW heat plant is supplying customers 40-60 km away (EU, 2011).

District heating systems can also make use of heat storage. This can be in the form of short-term storage (also called heat accumulators), providing a buffer of hours to days, or can be seasonal storage into which heat is added in summer, and withdrawn in winter, using a heat pump to upgrade the heat. Heat accumulators are commonly used in conjunction with CHP plants, and a large example of this type of system exists in Copenhagen, where two 22,000 m^3 heat accumulators hold pressurised water at 130 °C (Figure 11). Inter-seasonal storage systems become more cost-effective with larger systems, and can utilise tanks, aquifers, underground boreholes, or even a simple lined pit filled with water and topped with insulation material, as shown in Figure 12 (Nielsen, 2013).

Figure 11: Two pressurised 22,000 m^3 heat accumulators at Avedøre Power Station in Copenhagen, capable of storing 8000 GJ of heat (Petersen and Aagaard, 2004)

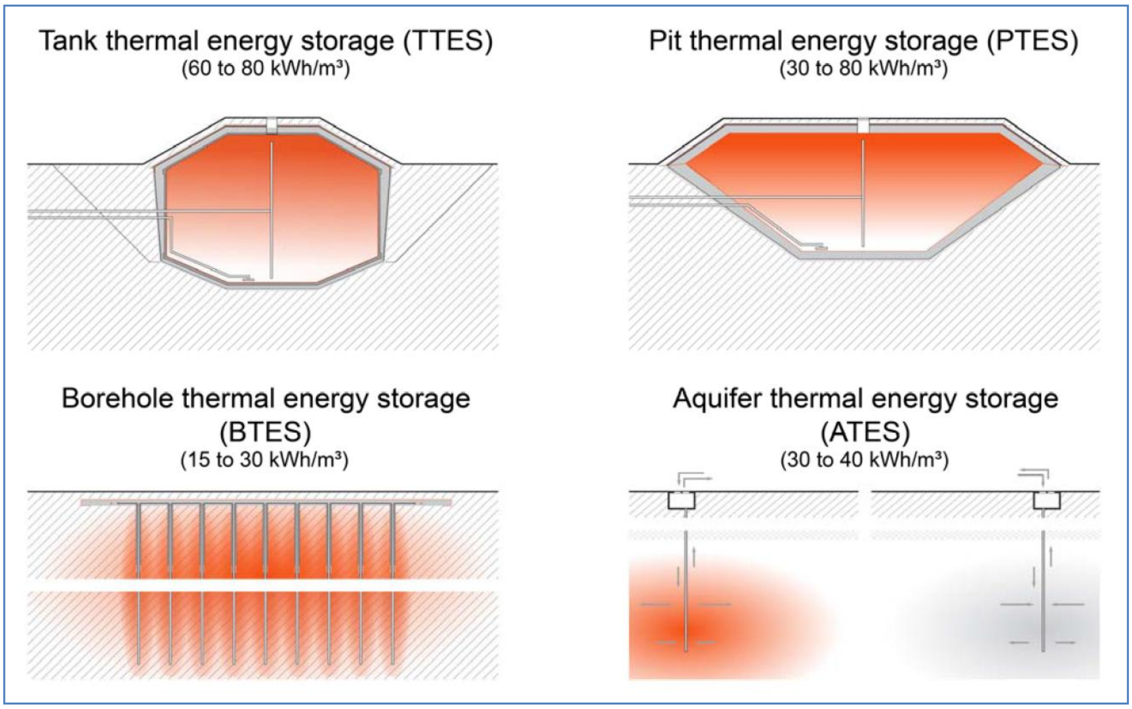

Figure 12: The four types of seasonal storage available for heat produced in summer (AGFW and Solites, 2012)

Some drawbacks of district energy systems have been found, such as lack of know-how and technical skills hindering implementation, the substantial front-end investment required, and finding appropriate sites to have the source of heat close to the users (Rezaie and Rosen, 2012). There can also be the problem of heat losses, which increase with the length of piping in the system. However if the heat demand is great enough and losses are minimised, district energy can be a very efficient way of providing heat and electricity to a district.

The final possibility with district energy systems is district cooling. This is a system where cold water is distributed in a similar grid to the district heating grid, to provide cooling to buildings in summer. The source of cold water can be conventional chillers, absorption chillers (which use heat as an energy source), or natural 'free' sources of cold water such as aquifers, lakes, rivers or seawater. In general district cooling is used by commercial customers such as shopping centres, hotels and office buildings, which have a much greater need for district cooling than residential customers (Andrews et al., 2012). Cooling costs for absorption and compression chillers range from around NZ$36/GJ for systems running 4,730 hours per year, up to NZ$130/GJ for systems running only 700 hours per year (Andrews et al., 2012). Utilising cooling from natural sources can help to lower these costs.

4. Research Method

The research method for this study involved interviews with experts in New Zealand and Europe, as well as data collection and collation. Data was sourced from these interviews and other direct contact with experts, as well as from peer-reviewed scientific studies, commercial information, and publicly-available databases.

Research began in January 2013, refining the research question and beginning literature research, as well as email and phone contact with New Zealand experts. During a trip to New Zealand in February 2013, face-to-face and phone interviews were carried out in Christchurch with persons involved in bioenergy, biofuel feedstock supply, and renewable energy in the area. This information allowed an overview to be gained of the bioenergy potential, current energy issues, and factors surrounding the potential DES in Christchurch. This information provided the background for interviews in March – May with European energy experts, as well as phone interviews with further contacts in New Zealand. During the entire research period, scientific literature and commercial information was gathered.

In May and June, the information was brought together and cost calculations as well as recommendations were completed. The following section outlines the interviewees in the different locations, as well as the reason they were selected for an interview. Also mentioned are those contacts that provided valuable information through brief email contact.

4.1 Interviewed New Zealand Experts

Below is the full list, divided by area of expertise and in alphabetical order, of the New Zealand-based interviewees that provided information used in this thesis.

Governmental and Crown Research Institutes

Shaun Bowler - Programme Manager - Renewable Supply, EECA Business. Shaun is involved with renewable energy in businesses, and has been strongly involved with wood energy in the past.

Stephan Heubeck – Researcher at the National Institute for Weather and Atmospheric Research (NIWA) and member of Bioenergy Association of New Zealand (BANZ) Biogas Interest Group. Stephan has practical experience with on-farm biogas systems, and has completed research into other biogas and bioenergy sources.

Peter Houghton – Contractor - Business Case Development and Investment for Christchurch City Holdings Limited (CCHL). Peter is responsible for assessing economic viability of DES options, and thus is an important decision-maker with regards to which technologies will be implemented in Christchurch.

Leonid Itskovich – former Energy Manager for Christchurch City Council (CCC). Leonid is familiar with current infrastructure in Christchurch, and also with potential opportunities due to his time working as energy manager for CCC.

Tim Taylor - Senior Advisor, Christchurch Recovery Partnerships, Energy Efficiency and Conservation Authority (EECA). Tim was approached due to his involvement with earthquake recovery efforts at EECA, and was able to provide an overview of the current situation as well as a list of useful contacts for further research. Tim has been instrumental in the formation and completion of this thesis.

Umbrella Associations, Research & Non-Governmental Organisations

Merv Altments – Christchurch Agency for Energy (CAfE). The initial ideas for district energy, and commissioning of DES feasibility studies came from CAfE, and Merv has knowledge of the timeline of progress in this area. Merv was able to explain the history of the feasibility studies and current activities.

Brian Cox – Executive Officer, Bioenergy Association of New Zealand (BANZ). Brian has a comprehensive overview of bioenergy activities in New Zealand, and knowledge of important contacts in the area. He was able to provide information about promising bioenergy options for Christchurch, as well as on initiatives from BANZ such as wood fuel quality guidelines.

Nick Hanson – Advisor – Grain & Seed, Bees Industry Groups, Federated Farmers of New Zealand. Nick has knowledge of the grain and seed market in Canterbury, and has daily contact with farmers and others in the grain industry. Nick was able to provide first-hand knowledge of what happens to straw in Canterbury currently, and factors that need to be considered if a functioning market is to be created.

Nick Pyke – Chief Executive, Foundation for Arable Research (FAR). Nick has a good knowledge of local grain farming practices, as well as access to statistics regarding total wheat, barley and ryegrass production in Canterbury. He was able to provide insights from contact with farmers, as well as accurate statistics for straw quantities.

Private Company Employees/Consultants

Markus Benter-Lynch – New Zealand Energy & Industry Business Development & Strategy Manager, MWH Global. Markus has worked in energy-related engineering projects in the South Island, as well as looking into straw supply chains in the past. He was able to provide insights into his previous findings, as well as contacts in this area.

Murray Cowan – Wood Energy New Zealand (WENZ), part of Energy for Industry (EFI). Murray has hands-on experience with wood fuel systems and supply chains, and was able to provide information about supply chains, practical issues with wood supply and use in Christchurch, and information about the wood fuel used at the Bromley biosolids drying facility.

Zeb Etheridge – Senior Water Management Engineer, Golder Associates (NZ) Limited. Zeb has experience with ground source heat pumps, including those using aquifers, and was able to provide information about the suitability of these systems in Christchurch, what is yet to be done in terms of research, and general issues surrounding aquifer and ground source heat usage.

John Gifford – Consultant, Gifford Consulting and contractor for BANZ. John has experience in the area of forestry and wood, and is currently completing work for BANZ in relation to market development for the wood fuels sector. He was able to provide information about the main challenges faced in the development of a wood fuel market in New Zealand, and suggestions for how these issues may be overcome.

Keith Grant –Technical Manager, Acid Plant, Ravensdown Hornby. Keith manages the sulphuric acid production plant at the Ravensdown fertiliser facility in Hornby, Christchurch – one of the larger industrial sites close to the city centre. He was able to provide detailed information about the quantity and temperature of waste heat available at the facility.

Christian Jirkowsky – General Manager, Polytechnik Biomass Energy Ltd, New Zealand. Polytechnik is a company based in Austria, specialising in biomass combustion boilers and CHP systems up to 30 MW in size. Christian represents Polytechnik in New Zealand and has technical knowledge and practical experience with biomass boiler systems. He was able to provide European contacts as well as up-to-date information about conversion technologies.

David Reid – Managing Director, P2P Energy Management. David is a consultant with experience working for EFI, in the field of energy supply chains (including biomass) and industrial energy systems. He has looked briefly into straw as a fuel in the past, and was able to offer insights into practical elements of straw, wood and landfill gas usage in Canterbury.

Mike Suggate – Director, East Harbour Energy. Mike has experience as general manager for EFI and has completed feasibility studies on the commercialisation of fuel crop growing, and digestion of agricultural wastes to produce energy and fertiliser. He recently completed a feasibility study for Fonterra looking at the potential to replace coal with wood chips in their large processing facility in Canterbury. Results from this study were confidential, however Mike was able to offer expert insights into the different technologies which may be suitable in Christchurch.

Josh Thorpe – Senior Project Engineer, Winstone Wallboards Ltd. Josh is familiar with the energy system for the wallboard production facility in Christchurch, and was approached about the potential of using waste heat on-site. He was able to provide waste heat figures for the plant, as well as suggest technical suggestions for how this heat could be used.

Peter Watson - Principal Mechanical Engineer, MWH New Zealand Ltd. Peter has worked on the Christchurch Hospital boiler upgrade projects, and has investigated conversion of the boilers to run on wood chip. The hospital boilers are crucial to the success of a DES in Christchurch. Peter was able to provide insights into the hospital boiler system as well as how this could be integrated into a DES, and how a shared-heat system in Dunedin functions.

4.2 Further New Zealand Contributors

This section contains those contributors who were not interviewed at length, yet still provided valuable information for the completion of this study.

Miranda Brown - Viticulturist, Muddy Water Vineyard, Waipara. Miranda was able to offer insight into the practices associated with vine prunings in Waipara.

Trevor Bunting – Owner, Dallington Downs Vineyard, Waipara. Trevor was able to offer information about the use of vine prunings for energy in New Zealand, and practices in Waipara.

Nick Gill - Viticulturist, Greystone Wines, Waipara. Nick was able to provide information about how vine prunings and residual grape matter are currently processed at vineyards in Waipara.

Peter Hall - Senior Scientist, and Project Leader (Renewable Energy), Scion. Peter has practical experience in forest management, and has been at the forefront of much of the research into energy from forest resources in New Zealand. He was a lead researcher in the Bioenergy Options for New Zealand project, and recently completed a wood resource analysis for EECA regarding the DES. Alongside this analysis, Peter was able to offer insights into the changing land use in the Canterbury region, and resources to assess transport distances in wood supply chains.

Gareth James - General Manager, Transpacific Waste Management South Island. Gareth is familiar with waste flows in Christchurch, due to Transpacific's involvement in the landfills in the area, and the Burwood Resource Recovery Park. He was able to provide information about the nature of demolition waste being processed currently, and the material being sent to the park. Unfortunately, specific details of reuse possibilities were confidential due to the commercial nature of the discussions with other parties.

Warren Mercer – Engineering Manager, Goodman Fielder (owner of Meadow Fresh dairy processing plant in Christchurch). Warren is familiar with the energy requirements of the Meadow Fresh plant in Christchurch and was able to offer information about waste heat streams and unused boiler capacity.

Fraser Scott – Managing Director, True North Consulting. Fraser is managing the current government-funded waste minimisation project looking at end of life options for treated timber waste. He was able to provide information around quantities of waste timber in Christchurch.

Alister Fisher - Asset Manager, Christchurch Biosolids Energy Centre, Energy for Industry Ltd. Alister is involved with the day-to-day running of the boilers at the Christchurch biosolids drying facility at the Bromley WWTP. He was able to provide information about utilisation rates of the boilers, current uses for dried biosolids, and the potential of using dried biosolids as a fuel.

Dr. Shannon Page – Lecturer, Department of Environmental Management, Lincoln University. Shannon was able to suggest background information for farming and land use data, as well as current coal-fired boilers in the Canterbury region, and previous studies.

4.3 Interviewed European Experts

Below is the full list, divided by area of expertise and in alphabetical order, of the European-based interviewees that provided information used in this thesis.

Biomass Supply Chain

Jennifer Hacking – Energy Power Resources (EPR) Ely. Straw for the 38 MW straw-fired Ely power plant in the UK is procured by EPR. Jennifer works in the field office which organises contracting and logistics of straw supply to the power plant. She was able to give an overview of how the supply chains were set up, how contracting works, and how the power plant ensures security of supply.

Dr. Horst Jauschnegg – President, Austrian Biomass Association (Österreichischer Biomasseverband) and Head of Energy and Biomass Unit, Forestry Department, Styrian Chamber of Agriculture (Landwirtschaftskammer Steiermark). Dr. Jauschnegg leads the Austrian Biomass Association, which is primarily a lobby group for the biomass sector. He was able to give a comprehensive overview of biomass to energy in Austria, including supply chains for wood and straw, technologies used, ongoing issues, and economic aspects.

Conversion Technologies

DI Christian Aichernig – Managing Director, Repotec GmbH. Repotec has been involved in the design and construction of the biomass gasifier at Güssing in Austria, as well as the large-scale forest residue gasifier central to the GoBiGas project in Gothenburg, Sweden. Christian was able to provide factors which dictate the choice between gasification and combustion of biomass, as well as differences in capital costs, and funding sources in Europe.

Dr. Thomas Brunner – BIOS GmbH, Bioenergy 2020+, TU Graz. Dr. Brunner is an expert in biomass combustion and CHP systems, and has experience in the design and implementation of both. He was able to explain in detail the technical aspects of combustion of straw and wood, and how the challenges are overcome in modern boilers. He was also able to make recommendations for combustion or CHP based on resource size.

Johannes Luttenberger – Project development / R&D, SOLID GmbH. The Graz-based SOLID is a world-leading company in the design and production of solar thermal collectors, including integrating these systems with district heating. Johannes was able to give an overview of what is possible with solar thermal, how it can be integrated with conventional DESs, and estimate the potential of the technology in Christchurch.

Research

DI Markus Kleinhappl – Bioenergy 2020+ GmbH. Markus is a researcher for the private company Bioenergy 2020+, which aims to research, develop and demonstrate energetic use of biomass. He is knowledgeable about biomass fuel processing and logistics, as well as conversion technologies such as gasification. Markus was able to describe European experiences with biomass, current research areas and their potential, and practical elements of biomass logistics.

Prof. Michael Narodoslawsky – Institute for Process and Particle Engineering, TU Graz. Prof. Narodoslawsky has extensive knowledge of sustainability indicators and sustainable regional development, and offered advice on optimisation of regional energy sources, as well as invaluable guidance for this thesis.

4.4 Further European Contributors

Manfred Wörgetter – Key Researcher, Bioenergy 2020+. Manfred is knowledgeable about many facets of renewable energy in Europe, and was able to provide links and contacts in this area.

Klaus Winther – Power station manager, Vattenfall A/S. The CHP plant in Odense, Denmark is part of the large Fyn power station. The plant has a standalone straw-fired CHP unit, which can also accept up to 60% wood chips. Klaus was able to provide information about the CHP unit, including fuel quantities and financial information.

5. Characterisation of Christchurch

This chapter aims to provide an overview of Christchurch and the surrounding area in terms of physical, social, cultural and political characteristics, as well as the existing markets for bioenergy in the region. These characteristics are contrasted with examples from Europe, to show how differences in these characteristics could affect the viability of different energy sources and conversion technologies.

5.1 Physical Characteristics

Climate and Geography

The temperate climate of Christchurch and surrounding areas is affected by the Southern Alps to the west, and the Pacific Ocean to the east. Summers are warm and dry, with average daytime maximum temperatures between 18 and 26 °C; winters are cool with frequent frost, with average daytime maximum temperatures between 7 and 14 °C, and average minimum temperatures between 1 and 5 °C (NIWA, 2013). This results in a summer climate that is moderated by sea breezes, and thus little cooling is needed. Heating is required in winter, yet temperatures are not as cold as central and northern Europe. This is not a direct reflection of heat required however, as the insulation level of buildings makes a difference to required heat loads. For example the UK, which has a warmer climate than Sweden, has a much higher heat demand per m^2 (Andrews et al., 2012).

Another point to be made about Christchurch is the air quality issues that occur in winter. Due to the geography of the area (bordered on the south by the Port Hills and further away on the west by the Southern Alps) and the prevalence of calm, cold winter days, temperature inversions occur, trapping particulates at ground level. These issues, which are mainly caused by residential wood-burners, have resulted in the introduction of regulations limiting where wood-burners can be used, and a list of wood-burners approved for use in the area (Environment Canterbury, 2013). These air quality concerns may affect the use of larger-scale bioenergy in Christchurch – especially when it comes to public opinion.

Energy Mix

New Zealand's energy mix is covered in detail every year in the Ministry of Economic Development's Energy Data File, the latest of which is the 2012 report (MED, 2012). New Zealand's primary energy supply is made up of approximately 39% renewable sources, and the electricity supply is made up of 77% renewable energy, mainly in the form of hydro, geothermal and wind. This electricity mix will affect the uptake of different renewable energy technologies, as for example heat pumps running on electricity in New Zealand will have a high proportion of renewable energy use compared to those in countries with a high proportion of fossil fuels in the electricity mix.

In 2011, an estimated 7.2 million litres of liquid biofuels were produced, made up of 4.8 million litres of bioethanol and 2.4 million litres of biodiesel. Woody biomass made up most of the direct use (i.e. heat generation) of renewable energy, and was used mainly by industry, and partially in residential applications. Solar energy remains a high potential source of energy but with very limited uptake. New Zealand has large coal reserves (over 15 billion tonnes), and also has oil and gas reserves. Natural gas is produced, and mainly used in the North Island, as there is no gas grid in the South Island (including Christchurch).

Agriculture, Horticulture and Forestry

New Zealand's economy is largely based on agriculture, horticulture and forestry, and this can be summarised, as is also applicable to Christchurch, from the New Zealand Yearbook (Statistics New Zealand, 2010). New Zealand's livestock farming is pastoral, with sheep and cattle grazing on grassland for the full 12 months of the year. In winter, and in very dry periods, the animals' feed is supplemented with hay, or with grass or maize silage. The Canterbury region contained the following numbers of livestock as of 30 June 2008:

Table 13: Livestock in the Canterbury region at 30 June 2008 (Statistics New Zealand, 2010)

Animal Type	**Number**
Dairy Cattle	831,666
Beef Cattle	533,665
Sheep	6,603,300
Deer	340,882
Pigs	177,306

Dairy farming has increased in recent years on the Canterbury Plains, which surround Christchurch, and the average dairy farm carries 2.8 cows per hectare at peak production. This style of farming has consequences for biogas potential from manure – much of the manure falls on the pasture and is unable to be collected, and stocking densities affect the amount of manure available in one area. The assessment of these effects will be discussed in more detail in the results section. One final point about farming in New Zealand is that it is completely free of government subsidies, which is very different from most other developed countries. This may present barriers to policy tools such as price regulation for agricultural residues, which could be seen as unfair competition by the Commerce Commission, New Zealand's competition enforcement agency (personal communication, Nick Hanson, 22 April 2013).

The main horticultural crops around Christchurch are grains such as wheat, barley and ryegrass. Wheat is primarily grown for human consumption, while barley is primarily grown for stock feed and for malting in beer production. There is substantial production of straw from these crops, and this is a resource that will be analysed in this report.

Plantation forestry covers 1.7 million hectares in New Zealand, 90% of which is the pine species *Pinus radiata* (MPI, 2012). Indigenous forests cover a much larger area but are not harvested. In the entire Canterbury region there are 110,055 hectares of forest, which represents only 6.4% of the nation's forest resource. This highlights the fact that Canterbury is a flat region more suitable to agriculture and arable crop production than forestry.

5.2 Social and Cultural Characteristics

Housing Stock and Heating Habits

The New Zealand housing stock is mainly composed of lightweight, timber-framed houses, and only 5% of these use central heating (French et al., 2006). New Zealanders also tend to heat their homes to a lower level than elsewhere in the world, with most people heating only in mornings and evenings. In Canterbury, the mean indoor living room temperature in winter is around 16 °C (French et al., 2006). This combination of lightweight housing stock and restrained heating habits makes the prospect of district heating very challenging for the existing residential building stock, due to the potential for large heat losses from the system, and the lack of existing central heating components (radiators, pipes) in houses.

Therefore the target for the proposed DES for Christchurch is the central city, which will have new, energy-efficient buildings and a denser heat demand, compared with residential and older commercial areas. One important factor to consider is that in the rebuild of Christchurch, new buildings will be subject to height limits of 28 m (seven storeys) in the central city, and 17 m (four storeys) in the mixed-use areas surrounding the core (CERA, 2012a). This is important as it can affect the energy density of the city centre and therefore the economic viability of a district heating system.

5.3 Political Context for Renewable Energy

Due in part to the lack of physical borders with other countries, there is no over-arching political body above that of the national government (such as the EU in Europe). In terms of international commitments, New Zealand took part in the Kyoto Protocol until 2012, at which point the first phase ended and the second phase began. At this point New Zealand declined to sign up to the second commitment period, instead making a pledge under the Convention Framework of reducing emissions by 10-20% by 2020 (MfE, 2013). Some subsidies for renewable energy have been provided in the past, such as the Biodiesel Grants Scheme which provided up to NZ$0.425 per litre of biodiesel, however this scheme finished in June 2012 (MED, 2012). Feasibility study grants are also available for businesses looking to incorporate renewable energy into their operations (EECA, 2013).

Emissions Trading Scheme

New Zealand has an emissions trading scheme (ETS), though this gives a 50% discount for stationary energy producers using fossil fuels, and has a total exemption for agriculture (New Zealand Government, 2013). The price of one New Zealand Unit (NZU), which represents one tonne of carbon dioxide, has collapsed and is currently (April 2013) around NZ$2, as shown in

Figure 13. This low price, plus the current 50% discount for stationary energy producers, results in little to no incentive for stationary energy producers to choose renewable sources over fossil sources. A similar bottoming-out of the carbon price has happened in Europe, where for example in Austria the price per tonne of CO_2 is €4 -€5 (personal communication, Horst Jauschnegg, 16 April 2013).

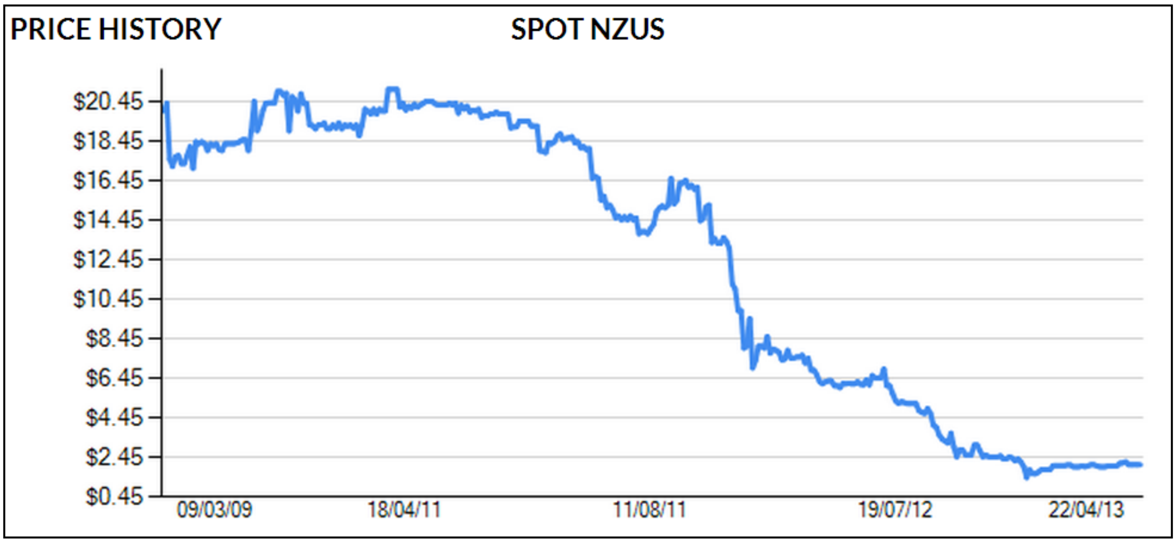

Figure 13: Spot price of New Zealand Units (NZUs) for the New Zealand Emissions Trading Scheme, representing one tonne of carbon dioxide, in New Zealand dollars (CommTrade, 2013)

Carbon Tax and Subsidies

Apart from the ETS, there are no carbon taxes in New Zealand. Coal is subject to a mining tax of NZ$1.50 - $2 per tonne, and natural gas to taxes and levies totalling NZ$0.02 per GJ. This low taxation rate makes a significant difference in economic viability of bioenergy fuel sources in comparison with, for example, Sweden, where non-commercial users of fossil energy sources must pay high energy and carbon taxes (raised in 2011 to around NZ$180 per tonne of CO_2) (Åkerfeldt, 2013). Often in European countries, the government provides a 'feed-in tariff' for electricity from renewable sources, which results in the producer receiving effectively a subsidy for each unit of electricity they provide to the grid. In Sweden and Norway, the system instead involves 'certificates' for each MWh of electricity provided from renewable sources, and generators who use fossil sources must purchase these certificates on the open market to reach a quota, which is set by the government (Swedish Energy Agency, 2012).

Currently, government subsidies for the construction of bioenergy projects, and feed-in tariffs for renewable electricity are not available in New Zealand. This is a very different situation from, for example, Austria, where biomass district heating plants are subsidised at 25% of the investment costs, with an extra 5% given if at least 80% of the wood chips come from local sources (Loibnegger, 2010). This funding comes from the EU (50%), the Austrian national government (30%), and from the regional government (20%) (personal communication, Dr. Horst Jauschnegg, 16 April 2013).

Denmark uses a significant amount of straw for energy, and this was driven initially by subsidy schemes for biomass in the 1980s, and later mandated government targets to increase the use of straw for energy (Voytenko and Peck, 2012). The transition was aided by subsidies for straw-fired

CHP plants, exemptions from fuel taxes for heat from biomass, and feed-in tariffs guaranteeing a minimum price for electricity from biomass (Voytenko and Peck, 2012).

While a combination of many factors make most of the large-scale subsidies, feed-in tariffs and mandates difficult and/or unsuitable to implement in New Zealand, the overseas examples can offer guidance as to which policy tools could be most successful in helping the transition to renewable energy.

Biofuel Standards

Standards for biofuels can also affect the uptake of biofuels through consumer confidence in high quality fuels and supply chains. Austria for example has official standards for solid biofuels (wood pellets: Austrian Standard (ÖNORM) M 1735, wood chips: M 7133, etc.). Standards set out specific limit values for a variety of parameters such as water content, bulk density and ash content (Loibnegger, 2010).

While there are no mandatory New Zealand standards governing solid biofuels in New Zealand, the Bioenergy Association of New Zealand (BANZ) has produced the 'Wood Fuel Classification Guidelines' (BANZ, 2010). This document outlines methods of quality assurance based on European standards, which have been simplified and adapted to the New Zealand situation. The standards which form the basis of the document are European standards relating to fuel specifications, quality assurance, sampling methods and testing methods (CEN, 2013). The New Zealand standards, offer a comprehensive guide to bioenergy quality in line with other standards worldwide.

Other Laws and Regulations

Building codes related to energy efficiency will affect the energy use in buildings. New Zealand has energy efficiency standards in the building code, though these are generally less stringent than the requirements in Europe and the USA (Laustsen, 2008). This is perhaps not surprising due to the relatively mild climate in many parts of New Zealand.

New Zealand has a resource consent system which involves approval from the applicable regional or district council (MfE, 1991). In larger projects, the Environmental Protection Authority (EPA) or the Environment Court may be involved. For new energy systems, these regulations affect land use, pollutant discharges and water use. This will differ for every technology, but must be considered when analysing each option.

Air emissions are subjected to the resource consent process, although there are no set limits for emissions; rather the air in the surrounding areas must fall below certain concentrations of pollutants (personal communication, Christian Jirkowsky, 28 January 2013). This can result in less-stringent standards for boilers than in other parts of the world. In addition, some practices (such as burning of agricultural residues in the fields) that are banned in more densely-populated parts of the world are allowed in New Zealand (personal communication, Nick Pyke, 26 February 2013). These factors are important to consider in assessments of different uses for biomass.

Summary of Policy Incentives

Strong policy incentives for bioenergy and other renewable energy sources do not exist in New Zealand, and may be difficult to introduce in New Zealand which has a very different political context and agricultural system to European countries. Therefore renewable technologies cannot rely on policy incentives for economic viability and must be profitable without subsidies.

5.4 Maturity of Bioenergy Industry

At present, the bioenergy industry in New Zealand is deregulated and is very much in a developing state. Little literature is available on the subject, and much of the evidence around how the industry works is based on personal experiences and anecdotal information. Therefore, personal conversations with Brian Cox, Nick Hanson, John Gifford and Nick Pyke are the main sources for the information contained in this section.

Supply-Side

The use of forest residues has been investigated in the past, and many times was found not to be economically feasible. This may in part be due to a lack of knowledge of modern international residue collection and logistics methods, which could make the process cheaper. Currently log prices are relatively high, resulting in little incentive to collect residues. Logging contractors are paid by the amount of merchantable timber taken from the forest, resulting in little incentive to pile the residues, which would make later collection faster and cheaper (personal communication, John Gifford, 7 May 2013).

Due to an undeveloped trading market for straw (aside from ryegrass straw for cattle feed), straw supply is strongly dependent on demand. In times of high demand, many farmers bale their straw, resulting in an oversupply and subsequent price crash. Currently, farmers generally leave the sale of straw to baling contractors who are more familiar with the market and are more able to find buyers. A more stable demand source (such as a DES or large boilers) could potentially stabilise the price and supply quantity of straw (personal communication, Nick Hanson, 22 April 2013).

Supply of biogas and landfill gas is dependent on market prices of alternative fuels, capital costs, and on regulations (such as the requirements to flare or use LFG). At present the economics of biogas from farms are not strong enough to compete with other energy sources, and so supply is very limited (MAF, 2008). Landfill gas is used in Auckland via 15 MW of generation capacity, and options are being considered for Kate Valley landfill in Christchurch (personal communication, Gareth James, 8 May 2013).

In general, the risk profile of bioenergy supply at present is high – this risk needs to somehow be reduced in order to stimulate investment in the area. This is already beginning with the Bioenergy Association of New Zealand (BANZ) creating of wood fuel specifications and supply contract examples. International trends towards costing of externalities and energy independence may also assist market formation.

Demand-Side

Demand for bioenergy is limited, due to fluctuating prices, concerns over security of supply, and a lack of government incentives to switch to biofuels. Currently, wood fuel sourcing in Canterbury is through a few small to medium-sized suppliers, and through informal sourcing between industrial consumers and suppliers. Demand for wood fuel may increase in rural communities as security of energy supply becomes an issue and fuel prices rise, however fossil fuel prices are likely to be the main influence on bioenergy uptake in the coming years.

Demand for wheat straw is relatively low as it is not a good animal feed, the bedding market is very limited, and boilers need to be specially designed to take straw. The main source of demand for wheat straw is from the farmers themselves as a soil improver or as pest and disease control through burning of stubble. Even in times of drought (such as the previous summer of 2012-13) there is plenty of wheat and barley straw available in the Canterbury region (personal communication, Nick Hanson, 22 April 2013).

5.5 Summary

Many factors combine in New Zealand to make bioenergy a relatively under-used resource. These include the presence of cheap alternatives such as coal, a lack of policy incentives to drive bioenergy uptake, the low energy density of biomass, the extensive farming style of the country, and immature markets for wood and agricultural residues. Extra barriers are present for DESs, such as a lack of knowledge and experience with DESs, lightweight and lightly-insulated houses, low energy density of residential areas, different heating habits, lack of central heating systems in houses and a relatively warm climate.

On the positive side, the potential resource is large, especially when looking at wood and straw resources. With this market at an early stage in its development, there is the chance to learn from European and other international experience, and develop the market in a smart way, with the latest technology. Opportunities such as the Christchurch rebuild are rare, and so currently there is an opportunity to overcome the 'chicken and egg' problem for bioenergy in Canterbury, where the sudden creation of a high demand could initiate the rapid development of supply chains. Many organisations exist that should be stakeholders in this process, such as EECA, BANZ, the New Zealand Forest Owners Association, Federated Farmers, and others, along with local and central governments – collectively there may be a better chance to organise supply chains.

6. Results: Quantification and Assessment of Fuel Resources for Canterbury

In this section all gathered data is combined with literature results to assess, as accurately as possible, the resources available to Canterbury, and the costs of these resources both in their raw fuel state and after conversion to energy. For the final results, quantities are converted to GJ/yr, and costs are given in New Zealand dollars. At the time of writing, exchange rates were fluctuating, and thus a 12-month rolling average was used, from the Inland Revenue Department of New Zealand (IRD, 2013). Exchange rates of €1 = NZ$0.6375, and US$1 = NZ$0.8226 have been used.

6.1 Part 1: Biofuels

Wood

Availability

Canterbury has available wood resources, yet it is a more challenging area than many other areas in New Zealand. The reasons for this are:

- Canterbury does not contain a large amount of plantation forestry (especially around Christchurch city)
- Sections of the current forest land are being converted to dairy farms, and forest area in Canterbury has decreased by around 10,000 ha since 2007 (personal communication, Peter Hall, 14 March 2013)
- There is already strong demand for wood chip fuel, much of it from the Daiken wood processing plant in Rangiora which is an established wood chip buyer (Hall, 2012)

Studies have been completed examining the amount of wood resources available to Christchurch city. The most recent source is a December 2012 report for EECA by Peter Hall, which estimates amounts and prices of wood resources in the region, if a 20 MW combustion plant for the DES were to be built and to run for 3,500 h/hr – i.e. a total energy quantity of 252,000 GJ/yr (Hall, 2012). The figures in the report include municipal wood waste, wood processing residues, pulp logs, low quality saw logs, forest residues, and woody agricultural and horticultural wastes. The report found that at 25, 50 and 75 km distances from Christchurch city, there were approximately 6,000, 20,000 and 15,000 hectares of plantation forest, respectively. There are also 12 wood processing plants within 100 km of Christchurch, processing over 900,000 m^3 of timber annually.

The availability from the Hall report is shown in Table 14.

Table 14: Green tonnes per year of wood available in the Canterbury region. Adapted from Hall (2012)

Transport Distance from Christchurch (km)	Cumulative Wood Availability (green tonnes)	Cumulative Energy (GJ)
30	49,783	324,157
65	70,580	459,476
105	88,980	579,260

Note: The energy figures above correspond to the calorific value of the fuel of 6.51 GJ/t.

Estimates are given in the Hall report for recoverable municipal wood waste, however these must be used with strong caution. Practical experiences with wood waste from the city council have found that the manual sorting required and the low quality of much of the wood makes it very challenging to use (personal communication, Murray Cowan, 27 February 2013). In addition, green waste, which may include some wood, is currently sent to the council-owned composting plant (CCC, 2011).

Estimates in the DES technical feasibility report include 20,000 – 30,000 tonnes of low grade wood material available and an estimate of 100,000 m^3/year of wood residues available within 75 km of Christchurch (Bizcat Aurecon & FVB, 2012). This estimate is higher than the estimate of Hall (2012) above. Finally, it is estimated in the technical report that there will be 50,000 – 100,000 tonnes of untreated demolition waste wood over the coming 4-5 years, yet as described below, the quantity, quality and eventual usability of this wood is unknown.

Most of the demolition waste from the city is currently being stockpiled at the Burwood Resource Recovery Park (BRRP), where a state-of-the-art recycling plant is scheduled to come into operation in 2013 (BRRP, 2012). The material currently going to the BRRP is predominantly timber by volume, but is mixed with other materials as it is not economic for demolition operators to separate this material at the demolition site (personal communication, Gareth James, 24 April 2013). Accurate estimates of the amount of wooden material at the BRRP are difficult; the best estimate so far is 400,000 tonnes, of which 24,000 tonnes are treated timber(Scott, 2013). How much of this timber is recoverable into an energy resource is, as yet, unknown.

There is at present no acceptable solution for the treated component of the timber waste. In New Zealand, timber treated with copper chromium arsenic (CCA) treatment and other types of treatment is common, and this wood is not suitable for burning in normal boilers. Therefore a project is underway to find a use for at least 20% (5,000 tonnes) of this timber, which is expected to have pilot operations in place in December 2013 (TNC, 2013). In the meantime this resource cannot be considered for energy usage.

In terms of current usage of wood resources, the largest single user is a Daiken medium-density fibreboard (MDF) mill near Rangiora (approximately 30 km from Christchurch) which runs an 18 MW wood boiler, and therefore has a strong demand for sawmill chips and pulp log chips.

In summary, the best estimate of wood resources in Canterbury is likely to come from the Hall report. However, the inclusion of municipal waste wood in these figures is of high uncertainty, as practical experience shows that this fuel stream is difficult and unpredictable. As is also noted in the report, the numbers are intended to be indicative only, and the municipal wood waste figures were calculated from general per-capita data from New Zealand. The Hall figures have been used for further calculations, though these are expected to be at the high end of what is available.

Costs

The conservative fuel requirement estimate for a DES of 20 MW is 52,000 tonnes of wood fuel per annum, which resulted in a weighted average price of $15 to $23 per green tonne, or $2 to $4 per GJ (Hall, 2012). This price is an aggregate of the costs of collection and processing of different wood types, and does not represent the market price that sellers of the chips would charge. Because of this, combined with the fact that much of the wood accounted for is waste or residues, the figures are much lower than the current market prices for sawmill chips and pulp log chips, which are around $65 and $55 per green tonne, respectively. This price is also much lower than the assumed price of $7.60 per GJ (approximately NZ$50/t) chosen in the technical feasibility study (Bizcat Aurecon & FVB, 2012). The highest estimates were the prices in the feasibility study for the Christchurch Hospital boilers in 2009, which priced wood chips at $90 - $110 per tonne, including delivery to the hospital site (Enercon, 2009).

Due to the low amount of forestry in Canterbury, combined with the existing demand for wood resources by commercial customers, it cannot be assumed that a DES or large source of demand could purchase wood chips for below the market price of approximately $55 per tonne. Both in the Hall report and the DES technical feasibility study, it was assumed that over 20,000 tonnes of municipal wood waste would be available as a fuel source for very low prices $1/tonne. While this wood is available, conversations with those involved with waste wood in Christchurch have revealed that the wood would require specialised sorting and chipping equipment, and thus is likely to be difficult and/or expensive to use. Wood residues are also assumed to cost $32 - $48 per tonne, excluding transport and further processing, which would bring prices to the vicinity of chips from pulp logs. Therefore wood chip prices are expected to average $45 - $65 per green tonne, which is in line with the $50 estimate in the technical DES study. This cost equates to $4.84 - $6.99 per GJ, assuming 9.3 GJ/tonne (*pinus radiata* at 45% moisture content)[2]. The average of these prices has been used for further calculations - $5.92/GJ, which corresponds to $55/t.

Wood Pellets

Supply of local wood pellets in the Christchurch area has decreased recently, as the largest producer in New Zealand (Nature's Flame) has closed its Rolleston plant, due to the diminishing wood product industry in Canterbury and the predicted reduction of plantation forestry land in the region (Nature's Flame, 2012). Difficulty of supply of raw product (wood chips) was also noted by the company.

Wood pellets are more expensive than wood chips due to drying and pelletising costs, yet have the benefits of consistent moisture content, easy loading and a regular calorific value of around 19 MJ/kg. Different wood price estimates from New Zealand from the previous 5 years put wood pellets at $340 - $375/t (Wilton et al., 2007, EECA, 2009a, Ecomax, 2013). At 8% moisture content and 17.17 GJ/tonne, this price equates to $19.80 - $21.84/GJ. This price is significantly higher than previous estimates, and does not align with calculations from Europe.

In Europe, pelletising costs were estimated to be around $123/t wood (Eder, 2007). This, combined with a wood chip purchase price of $55/t, would bring total costs in New Zealand to $178/t. This price is much lower than the retail price for wood pellets, and may indicate that if a DES were to incorporate pellets, then pelletising the wood in-house could be much more economical. Therefore using an assumption that if a large-scale user were to use wood pellets, they would pelletise the wood themselves, resulting in a final fuel cost of $178/t or $10.36/GJ.

Capital, Operation and Management Costs

The other prices that need to be taken into account are operation and maintenance (O&M) costs, and capital costs. These differ for CHP and heat-only boilers, and so are addressed separately. For this study, O&M costs include all costs associated with the operation and maintenance of the plant, wages, and disposal/removal of ash. Fuel costs are not included, nor are interest payments or margins on heat/electricity sales. Two scenarios are chosen in terms of operational hours per year – 4,000 h/yr and 8,000 h/yr, to show the effect of differing heat and electricity demands on costs. The payback time for capital is assumed to be 10 years.

Capital costs for wood boilers and CHP plants have been taken from the DES feasibility studies. These costs came to $122 million for a CHP plant providing 23 MW of electricity and 50 MW of

[2] EECA Wood Knowledge centre – hog fuel used for calorific basis. http://www.eecabusiness.govt.nz/wood-energy-resources/biomass-calorific

heat, $31.7 million for a 30 MW wood boiler (heat-only), and $5.4 million for a 10 MW wood pellet boiler (heat-only). Wood pellet CHP costs were estimated by using the difference in costs of wood chip and wood pellet heat-only boilers, and using this as an assumption for lower-cost loading and handling systems. The O&M costs are fixed to the value of the plant, which means they are fixed yearly costs, and therefore are inversely related to operational hours. Gasification costs are of high uncertainty and have been estimated from 2012 Danish estimates, with capital costs scaled down by 50% in line with assumptions in New Zealand studies, which note that construction costs in Europe appear to be significantly higher than in New Zealand (Bizcat Aurecon & FVB, 2012, Forgie and Andrew, 2008, Energinet DK and Energi Styrelsen, 2012).

Total Costs

The total costs for energy from wood chips and wood pellets are shown below in Table 15 and Table 16 respectively. For wood chips, the heat-only plant offers the lowest cost at $10.69/GJ for a plant running the whole year, and gasification shows the highest costs, with $27.17/GJ for a plant in regular use. Wood pellet energy costs are higher than those of wood chips, but not by a large margin – the pelletising costs are offset by the ease of storage, handling and loading. Delivered energy costs as low as $12.80/GJ were found for a regularly-running heat-only plant.

Table 15: Estimated total costs for energy from wood chips

	Wood Chip Energy Costs ($/GJ)				
	Wood Chip CHP 4,000 h/yr	Wood Chip CHP 8,000 h/yr	Wood Chip Heat-Only 4,000 h/yr	Wood Chip Heat-Only 8,000 h/yr	Wood Gasifier 8,000 h/yr
Capital Costs	11.60	5.80	7.34	3.67	9.65
O&M	3.42	1.71	2.20	1.10	11.60
Fuel Costs	5.92	5.92	5.92	5.92	5.92
Total	**20.94**	**13.43**	**15.46**	**10.69**	**27.17**

Table 16: Estimated total costs for energy from wood pellets

	Wood Pellet Energy Costs ($/GJ)			
	Wood Pellet CHP 4,000 h/yr	Wood Pellet CHP 8,000 h/yr	Wood Pellet Heat-Only 4,000 h/yr	Wood Pellet Heat-Only 8,000 h/yr
Capital Costs	8.00	4.01	3.74	1.88
O&M	2.35	1.17	1.13	0.56
Fuel Costs	10.36	10.36	10.36	10.36
Total	**20.71**	**15.54**	**15.23**	**12.80**

Other Opportunities

One extra possibility is to truck chipped wood from Marlborough (an area with abundant plantation forests) to Christchurch, a distance of 350 km. The author saw evidence of this happening in the form of wood chips arriving at the Bromley WWTP on 27 February 2013. This is made more cost-effective by “back-filling” trucks that would normally return to Christchurch empty (personal communication, Murray Cowan, 27 February 2013).

There are other opportunities for large-scale usage of wood resources aside from the DES. A large milk processing facility run by Fonterra operates in Darfield (approximately 45 km from Christchurch) and uses two coal-fired boilers of the sizes 30 MW and 45 MW. In 2011, research was completed looking at biomass options for the larger of the two boilers, however the uncertainty and immaturity of supply chains, uncertainties in prices due to the required purchase of export logs, and the higher overall cost of fuel resulted in coal being chosen as the fuel (Chapman Tripp, 2011). The Fonterra boilers currently use coal and have most demand in summer. The DES would have demand in winter, so there could be an opportunity for collaboration in some way (Bizcat Aurecon & FVB, 2012). Finally there is another milk processing factory 45 km West-Southwest of Christchurch owned by Synlait, which has 20 MW and 15 MW coal boilers. Both Fonterra and Synlait could potentially incorporate a percentage of wood into their coal boilers with relatively minor modifications.

The location of forest resources around Christchurch are shown in Figure 14, along with the location of the Fonterra and Synlait boilers.

Figure 14: Location of Fonterra and Synlait boilers, both approximately 45 km from Christchurch, and areas of forestry in green (Source of forest area data: New Zealand Land Cover Database v3)

Straw & Arable Crop Residues

Availability

Christchurch sits surrounded by the Canterbury Plains, a flat area of approximately 17,000 km^2, with much of the land used for arable crop growth. Statistics from the Foundation for Arable Research (FAR) for straw yields in the Canterbury region are shown below in Table 14 (personal communication, Nick Pyke, 26 February 2013). A satellite image showing arable crop growth areas is given in Figure 15.

Table 17: Straw yields in Canterbury for the 2011 season (personal communication, Nick Pyke, 12 February 2013)

Crop Residue	Regional Planting (hectares)	Total Straw (tonnes)	Typical Moisture Content (%)	Assumed Surplus (tonnes)
Ryegrass	10,000 (approx.)	158,000	8%	0
Wheat	46,100	356,700	11-18%	178,350
Barley	42,300	279,500		139,750

Most ryegrass straw is baled and fed to stock, and due to its value as animal feed, is assumed to be unsuitable for energy use, due to competition with food. This leaves the wheat and barley straws for energy uses. Not all of the straw resource is currently used; Nick Pyke estimated that around 20% of the straw is incorporated back into the land, and 10-15% is burned each year. Based on literature assumptions, a maximum available resource (i.e. the amount able to be removed without negative impacts on nutrients and soil quality) of 50% of the total resource is assumed, which results in approximately 320,000 tonnes of straw. At 14.5 GJ/tonne this presents a resource of over 4.5 million GJ/yr (Caslin and Finnan, 2010, Bizcat Aurecon & FVB, 2012).

Also noteworthy is the fact that dairy farming is becoming more common in New Zealand, while arable crop land use is slightly decreasing (Statistics New Zealand, 2009). One indicator of this in Canterbury is the large Fonterra milk plant in Darfield – this could signify the commitment that Fonterra has to increasing dairying in the region (personal communication, Peter Watson, 27 Feb 2013).A move towards dairy farming could affect the amount of straw available for fuel in two ways – the supply decreases due to land conversion, and the demand for straw as feed (on dairy farms) increases. In this study, ryegrass straw - the most common used for animal feed - is excluded, it is noted that wheat straw has limited nutritional value for cows, and previous research has noted that "Despite the growth in dairying in the Canterbury region, supplementary feed would not use large volumes of straw compared to what is produced" (Forgie and Andrew, 2008).

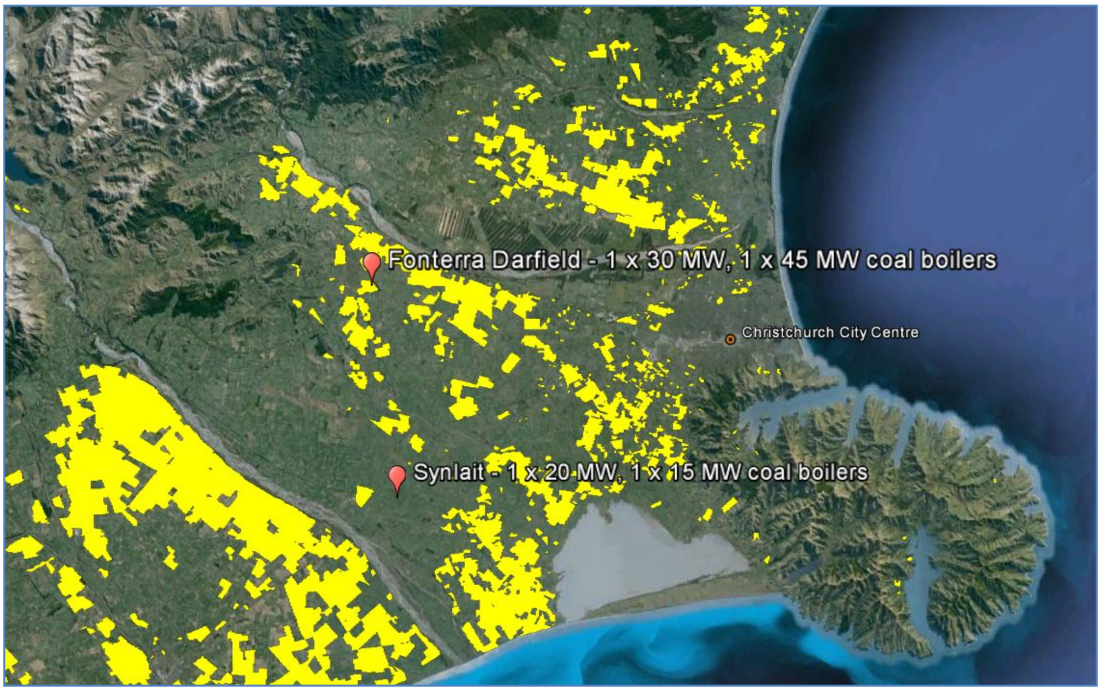

Figure 15: Arable cropland surrounding Christchurch, showing the location of Fonterra and Synlait boilers. (Source of crop area data: New Zealand Land Cover Database v3)

Fuel Costs

The straw market in New Zealand is underdeveloped, with farmers either selling directly to other farmers, or relying on baling contractors to find buyers (personal communication, Nick Hanson, 22 April 2013). With these transactions there is also a quality risk, as the product is often bought sight-unseen; this should not matter as much for energy as it does for feed, indeed older grey straw which has been exposed to rain is actually less corrosive to boilers (Skøtt, 2011). Moisture content however, is important. The market is also susceptible to large swings in price, as described previously.

Straw is not considered by farmers to be a waste product. It contains nutrients and carbon, and improves soil quality when ploughed back into the soil, and can also provide a relatively reliable supplementary income. Previous studies in New Zealand have assumed straw to be a valueless by-product, available for only the processing costs (Forgie and Andrew, 2008, Hall and Gifford, 2007). This thesis assumes that straw has a value to the farmers either as a soil improver, for disease control, as feed or bedding to animals, or potentially as an energy source in the future, so the value of these alternative uses must be considered.

Farmers currently burn straw for pest and disease control, which also returns some nutrients to the soil, so if this straw is removed from the land, the farmers would need to be compensated to allow them to control pests and return nutrients in other ways (personal communication, Nick Pyke, 26 February 2013). This burning process does not happen every year, instead it happens once every few years, often when a different crop is to be planted (personal communication, Nick Hanson, 22 April 2013). If straw is not burned, it may be incorporated into the soil, also returning carbon and nutrients, and having positive effects such as improving drainage. Costs associated with replacing nutrients that are removed with straw can be estimated using a freely available calculator from FAR. The results of these cost calculations based on current prices are summarised in Table 18, showing that for every tonne of wheat or barley straw removed from the land, $37 - $41 of nutrients are also removed. These costs can be offset somewhat in a bioenergy system by returning of ashes to the soil, or by production of fertiliser from the ashes, as is done elsewhere in the world (Skøtt, 2011).

Table 18: Nutrients in wheat and barley straw, and estimated costs of nutrient replacement through conventional fertilisers (FAR, 2013)

	Wheat Straw		**Barley Straw**	
	Nutrient Content (kg/tonne)	**Value ($NZ/tonne)**	**Nutrient Content (kg/tonne)**	**Value ($NZ/tonne)**
Nitrogen	6.9	11.18	4.6	7.45
Phosphorus	0.8	3.16	0.4	1.58
Potassium	13.5	23.30	14.3	24.68
Sulphur	1.3	2.43	1.4	2.62
Magnesium	0.8	0.98	0.8	0.98
Total		**41.04**		**37.30**

Baling costs were estimated in a previous study at $22 per tonne of straw, and this is assumed not to have changed, although costs elsewhere in the world such as in Canada were much lower – NZ$7.83/t for baling (Mupondwa et al., 2012, Forgie and Andrew, 2008). Other costs for the baling system include on-farm storage of baled straw, which is an important part of the logistical system as power plants typically only keep enough supply on-site for a few days. In the Ely plant in England, farmers keep stacks of straw on their farms for an average of eight months (Forgie and Andrew, 2008). The cost of this storage, as well as collection costs, must be taken into account. In Canada, straw was assumed to be kept under plastic, and the cost of the plastic itself was the main assumed storage cost (Mupondwa et al., 2012). Conversely in England, the straw had no specific requirements for storage, and if a large stack of bales was properly constructed, minimal weather damage occurred (personal communication, Jennifer Hacking, 16 May 2013).

As mentioned in the literature review, pelletising straw has been found to be less economically feasible than baling for transport distances under 250 km; still, both options will be analysed for this project. A pelletising plant able to process 2 t/h (10,000 t/yr) of pellets, including drying of the straw, was estimated in a European analysis in 2007 to cost $2.77 million (Eder, 2007). The cost of producing the pellets from straw was estimated to be between $120-130/t of pellets. Estimates from Canada had similar results, with total costs (including capital costs) of $104/t for a 2 t/h plant flattening out to around $65/t when production was above 10 t/h or 50,000 t/yr (Mupondwa et al., 2012).

Transportation of pellets is more economical than transportation of straw bales due to a doubling of the amount that can be transported on one truck, however this is unlikely to outweigh the expensive pelletising process (Mupondwa et al., 2012). Transport costs for one tonne of straw bales in Europe ranged from $1.45 per km for short (10km) distances, to $0.43 per km for 50km and $0.31 per km for 100km (Eder, 2007). The assumed cost in Canada for all distances was $0.37 per km, and the assumed cost in the previous New Zealand study for a return trip of 88 km was NZ$0.15, much lower than the others. This study has taken a conservative estimate of NZ$0.40 per km. Pellet transportation costs are assumed to be roughly half of those for straw, due to a doubling of density, so are estimated to be NZ$0.20 per km.

All of the costs have been entered into Table 19, along with the relevant assumptions and references used.

Table 19: Straw feedstock costs ($/t) for baled and pelletised straw, at small and large scales

	Straw Feedstock Costs ($/t)		
	Small Scale (10,000 t/yr straw)	Large Scale (50,000 t/yr straw)	Reference
Nutrient Value in Straw	41	41	(FAR, 2013)
Baling Costs	22	22	(Forgie and Andrew, 2008)
Storage (Plastic Cover)	7	7	(Forgie and Andrew, 2008)
Total, Baled Straw at Farm	**70**	**70**	
Transport (average 50km)	20	20	(Eder, 2007, Mupondwa et al., 2012, Forgie and Andrew, 2008)
Total, Baled Straw at Plant	**90**	**90**	
Transport from farm to Pellet Plant (average 15 km)	12	12	(Eder, 2007, Mupondwa et al., 2012, Forgie and Andrew, 2008)
Pelletising Costs	130	65	(Mupondwa et al., 2012, Eder, 2007)
Transport to Power Plant (35km)	7	7	(Mupondwa et al., 2012, Eder, 2007, Forgie and Andrew, 2008)
Total, Pellets at Plant	**219**	**154**	

Prices can fluctuate – in recent drought conditions, bales of 400 kg of ryegrass straw were selling for $65, which equates to around $160/t, although this will be lower for wheat straw, as it is not a nutritious feed for cattle (personal communication, Nick Hanson, 8 April 2013). Because of the undeveloped nature of the market however, these prices have a large element of uncertainty and do not necessarily reflect the likely prices when there is a large and steady source of demand.

Assuming a large-scale demand of 50,000 t/yr, the straw prices are estimated at $70 - $90 per tonne, depending on transport distance. At a moisture content of 15%, and a calorific value of 14.5 MJ/kg, this would result in fuel prices (including transport) of $4.80 to $6.20/GJ, with the average being $5.50/GJ. For pellets, a calorific value of 19 MJ/kg is possible, bringing the resultant average fuel price for to $9.82.

Capital, Operation and Management Costs

The main information used for this section comes from four studies: the DES technical feasibility study, Danish figures from 2012, Irish figures for a straw-fired CHP plant from 2010 and New Zealand estimates from 2008 which were based on older Danish numbers and adjusted for New Zealand conditions (Forgie and Andrew, 2008, Energinet DK and Energi Styrelsen, 2012, Erm21c, 2010, Bizcat Aurecon & FVB, 2012).

The Danish figures from 2012 indicate fixed O&M costs for a straw CHP plant of $63,000/MW/yr which makes a total of $2.19/GJ for a plant running at 8,000 hours, or $4.38 for a plant running at 4,000 hours. Variable costs (for additives, water, ash disposal, etc) were given as $2.79/GJ. This brings a total O&M cost (excluding fuel) of $4.98/GJ for the high-usage plant, or $7.17 for the low-usage plant. Cost estimates for a 54 MW Irish CHP plant put O&M costs at $6.13/GJ. Previous New Zealand research put O&M costs at $3.70/GJ which appears to be much lower than other international examples. Therefore a conservative estimate of O&M costs would be $5.00/GJ for a plant running at 8,000 h/yr, and $7.17 for a plant running at 4,000 h/yr.

Capital costs for a CHP plant were estimated in the previous New Zealand research to reach $5.73 per GJ, based on a cost of $1.65 million per MW ($54.45 million for a 33 MW CHP plant producing 10 MW electricity and 23 MW heat from 40,000 tonnes of straw per year) and a plant running at 8000 h/yr. These capital costs were much lower than those assumed in Denmark, though on par with those in England and Spain. Capital costs in the Irish project were $1.43 million per MW of capacity for a larger plant, which is in the vicinity of the New Zealand estimate. Therefore the previous New Zealand estimate (including 10 year payback time) has been retained for this study. A final point to note about CHP is that for the Christchurch DES, a CHP plant would operate the electricity-generating turbine with reduced hours, and this would need to be taken into account with cost calculations.

For heat-only plants, both O&M costs and capital costs will be lower than those for CHP, due to lower levels of technical complexity. For this cost calculation, the straw input remained as 40,000 t/yr, as was done in the previous New Zealand study. The O&M costs remained at $3.70/GJ in the previous New Zealand study. Danish figures gave estimates for heat-only boilers for DESs, and gave total O&M costs of $1.75/GJ. For small boilers (<4 MW) this was given as $2.72/GJ, though economies of scale should apply for larger plants (Evald, 2009). For this study conservative figures were used, with the 4,000 h/yr plant using the costs from the previous New Zealand study

($3.70/GJ), and the 8,000 h/yr plant using a figure based on the large-scale Danish figures, of $2.00/GJ.

Capital costs depend strongly on the size of the plant, and for 40,000 tonnes of straw running at 4,000 h/yr this would mean a 33 MW plant. The same size plant was kept for the 8,000 hour scenario, for consistency. The previous New Zealand study estimated a capital cost of $31.5 million, or $3.17/GJ. The Danish figures for straw-fired DESs put capital costs at $1.25 million/MW, which is identical to the Christchurch DES technical feasibility study and is 30% higher than the assumed capital costs in the previous New Zealand study. This latter figure has therefore been used in this study, resulting in $4.34/GJ and $8.68/GJ for 8,000 h/yr and 4,000 h/yr plants respectively.

Gasification has been added as a final scenario, using the same estimations for the wood gasification plant in the previous section. Capital costs and O&M costs are very high in this scenario, bringing the total cost per GJ to over $20. While these cost estimates are rough estimations, gasification is not seen as a realistic option for Christchurch, due to limited external funding and the immaturity of the technology on this scale.

Total Costs

Table 20: Estimated total costs for energy generation from straw bales

	Straw Bale Energy Costs ($/GJ)				
	Straw CHP 4,000 h/yr	Straw CHP 8,000 h/yr	Straw Heat-Only 4,000 h/yr	Straw Heat-Only 8,000 h/yr	Straw Gasifier 8,000 h/yr
Capital Costs	11.46	5.73	8.68	4.34	9.65
O&M	7.17	5.00	3.70	2.00	11.60
Fuel Costs	5.50	5.50	5.50	5.50	5.50
Total	**24.13**	**16.23**	**17.88**	**11.84**	**26.75**

Combined heat and power from straw pellets has been included. Capital and O&M costs are unknown, as CHP from straw pellets is an undeveloped technology, but are assumed to lie in between wood pellet boilers and straw bale boilers. Straw pellets have a higher density and are easier to handle, yet have the same difficulties as straw bales with regards to corrosion and slagging. Estimations of 75% of the straw bale Capital and O&M costs were used, to give a rough estimation of costs.

Table 21: Estimated total costs for energy generation from straw pellets

	Straw Pellet Energy Costs ($/GJ)			
	Straw Pellet CHP 4,000 h/yr	Straw Pellet CHP 8,000 h/yr	Straw Pellet Heat-Only 4,000 h/yr	Straw Pellet Heat-Only 8,000 h/yr
Capital Costs	8.60	4.30	6.51	3.26
O&M	5.38	3.75	2.78	1.50
Fuel Costs	9.82	9.82	9.82	9.82
Total	**23.80**	**17.87**	**19.11**	**14.58**

Estimates in the DES technical feasibility study put straw at $6-$8/GJ for energy from a CHP plant (Bizcat Aurecon & FVB, 2012). The current study estimates the prices as being much higher for CHP

– with the most cost effective option being a heat-only plant using straw, running for 8,000 hours per year. To achieve these running hours, a use for the heat in summer (for example absorption cooling or industrial heat) would need to be found.

Biogas from Manure and Agricultural By-products

Direct data for quantification of manure was not available, however a study conducted in 2010 for the Energy Efficiency and Conservation Authority (EECA), the New Zealand Pork Industry Board and the New Zealand Department of Corrections assessed the biogas fuel resource from piggery manure and other nearby animal processing facilities around Christchurch (Thiele, 2010). This report was a feasibility report for the digestion facility to be placed at Christchurch Men's Prison, and found a resource of 23,500 GJ/yr (minimum waste scenario) to about 52,000 GJ/yr (maximum waste scenario) in Canterbury. These figures represent real amounts for Canterbury and are assumed to be the best available assessment of the resource in the area.

This amount of fuel could result a plant up to 1.8 MW in size, which could be a CHP plant producing heat and electricity. The fuel feedstock would be transported by truck from sites within 8 – 40 km of the proposed digester facility. The report found that this was enough to heat the prison and have surplus biogas of 1,440– 3,240 GJ/month for 10 months of the year, enough to produce about 1,000 – 2,300 L/day of diesel vehicle fuel grade compressed bioCNG, if that was the pathway chosen. The cost of this upgrading process was assumed to be $8.33/GJ bioCNG produced.

Costs

Two scenarios have been chosen for costs. The minimum and maximum waste scenarios from Thiele (2010) have been used and, to allow comparison with other fuels, it is assumed that the minimum waste scenario results in a 1.8 MW CHP plant running for 4,000 h/yr, while the maximum waste scenario utilised a 1.8 MW CHP plant running for 8,000 h/yr.

Fuel costs in this scenario represent the cost of biogas production, so include capital and O&M costs of the digester system. Capital costs for the digester system itself were given as $5.1 million (Thiele, 2010). High O&M costs for the digester system are then offset by the fact that the producers of the piggery manure and industrial waste are willing to pay to dispose of the waste (income from gate fees, sale of residues for fertiliser and transport fees are included in O&M costs). The combination of these costs results in a relatively low cost for biogas ($5.07/GJ in the maximum scenario, $11.38/GJ in the minimum scenario).

The capital and O&M costs in

Table 22 represent those costs for energy conversion (i.e. the CHP plant, excluding upstream biogas production). These cost estimates were not included in the Thiele study, and therefore European cost estimates for a 2 MW CHP unit were used. The cost of this unit was around $2 million, and so this figure for a slightly larger unit has been used as a conservative estimate. (Streckiene and Andersen, 2008). The same report detailed O&M costs as approximately $13.30 per MWh, or $3.69 per GJ, which is tied to operational hours, keeping the O&M costs the same in both scenarios. The total costs, using fuel costs from the Thiele report, are outlined in

Table 22.

Table 22: Total energy costs from piggery and industrial waste to biogas

	Piggery and Industrial Waste Biogas Energy Costs ($/GJ)	
	Biogas from Pig Manure 1.8 MW CHP 4,000 h/yr	Biogas from Pig Manure 1.8 MW CHP 8,000 h/yr
Capital Costs	7.71	3.86
O&M	3.69	3.69
Fuel Costs	11.38	4.88
Total	**22.78**	**12.43**

Another potential fuel source in the Canterbury region is manure from dairy farms. North Canterbury is the region of New Zealand with the second-largest population of dairy cows - in 2011-12 there were over 550,000 cows in North Canterbury alone, with an average herd size of 773 cows (LIC and DairyNZ, 2012). These herds are spread over an area of 163,106 hectares. The numbers of dairy cows in the districts surrounding Christchurch city can be seen in Figure 16.

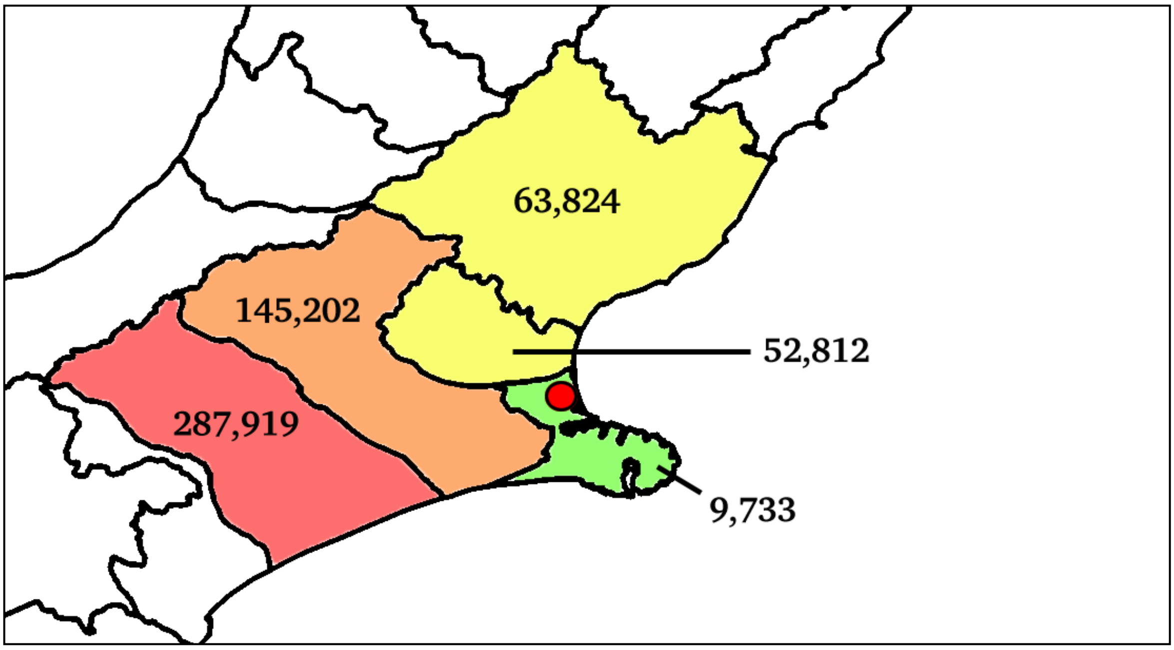

Figure 16: Dairy cow numbers in the North Canterbury territories around Christchurch city, from green (fewest) to red (most). Christchurch city is shown as a red dot. Data from LIC and DairyNZ (2012)

Dairy farms in New Zealand do not normally keep the animals inside, and therefore the only time when manure can be easily collected is from the milking sheds. This would constitute only 10-20% of the available manure resource (personal communication, Stephan Heubeck, 30 January 2013; MAF, 2008). In addition, the resource availability depends on local circumstances such as how the cattle are fed and housed, what is done about manure storage, the seasonality of the NZ dairy operations, local climate and other aspects (personal communication, Jurgen Thiele, 29 April 2013). The seasonality of operations could be a big factor, as milk production is very low in May, June and July the Southern Hemisphere winter), and very high in October, November and December (Scott, 2008). In fact most cows are not milked at all in the period of May until July (Te Ara, 2013).

Based on a 10% collection rate, the amount of methane able to be produced from the effluent from each dairy cow in New Zealand is 12.8 kg/yr (MAF, 2008). Extrapolating this to include the dairy farms in Figure 16 results in around 7,000,000 kg of methane per year, with an energy content of 400,000 GJ. This quantity is enough for around 13 MW of capacity, yet due to the distributed nature of the resource, it is a challenging source of energy and requires further research for quantification and costing. Work is underway to assess some of this resource in more detail; at the time of writing this research is unfortunately still confidential (personal communication, Jurgen Thiele, 29 April 2013).

Finally, there is a small resource of chicken manure in Canterbury with a potential 8,400 GJ/yr from gas (de Vos et al., 2009a). This resource is not considered as a significant source of energy in this thesis, and it is likely to be suited to be used in on-farm applications.

Industrial Effluent from Meat and Dairy Processing

A 2009 estimate of the energy available within Canterbury from dairy effluent was 70,000 GJ/year, and for meat processing 126,000 GJ/year (de Vos et al., 2009a). This same report notes that the biogas production in both of these industries is highest at times of high energy demand in the processing plants themselves, and therefore the resource is best utilised within the sector. This resource has not been considered further for other energy uses.

Landfill Gas and Wastewater Treatment Plant Gas

Landfill gas (LFG) is currently produced at two sites – the now-closed Burwood Landfill (10 km from the city centre) and the Kate Valley Landfill (approximately 60 km from the city centre). In addition, the wastewater treatment plant (WWTP) located at Bromley produces biogas from biosolids digestion.

The Christchurch City Council currently extracts 1,000 m^3/h (around 5.75 MW) of LFG from the Burwood landfill (Itskovich, 2012). This gas was being used for a 1.6 MW (plus another 1 MW at peak times) tri-generation plant at the City Council buildings, to dry biosolids at the Bromley wastewater treatment plant (up to 5.3 MW), and to heat the QEII swimming pool complex (0.23 MW). Since the February 2011 earthquake, the swimming complex has been closed, and the gas has been used only at the other two sites. The Burwood landfill site is expected to provide over 5 MW of LFG until 2019, and so the conservative estimate of a 5 MW flow of gas (158,000 GJ/yr) is assumed for the next 10 years in this study. Another point to note is that the WWTP has two boilers to dry biosolids – one which uses LFG and one which uses wood chips. Due to the existing infrastructure, it would be possible to use predominantly wood chips at the WWTP and pipe the LFG to the central city to be used, thus avoiding the noise and dust associated with wood chip transport in the city. Importantly, the two 4.5 MW boilers are not used at the same time, meaning there is always at least 4.5 MW of spare generation capacity at Bromley (personal communication, Leonid Itskovich, 28 February 2013).

The Kate Valley landfill currently produces approximately 2000 m^3/h (11.5 MW) of LFG, all of which is flared, i.e. not used for energy (Itskovich, 2012). This is an interesting resource when considering a cost-effective and reliable energy source for Christchurch. Currently, the flaring of the gas costs the landfill operator, and so selling the gas for any price would be an economic improvement. Currently, Transpacific Industries, the parent company of the private sector joint owner of the landfill, generate electricity and are trialling conversion of LFG to vehicle fuels at their Redvale Landfill in Auckland (personal communication, Gareth James, 8 May 2013). The company is currently further analysing the gas quality and quantity at Kate Valley, which will be followed by an analysis of the options for using the gas – an ideal time to discuss options with the city council.

Finally, the gas produced at the WWTP digesters in Christchurch amounts to approximately 5 MW. All of this gas is currently used in a cogeneration plant to run the digesters and provide heat and electricity to the on-site buildings. There is the possibility to increase the gas output of the digesters by around 1 MW, which could be used elsewhere, for example in a DES. The total amount of LFG available from both landfills plus the WWTP is therefore at least 17.5 MW, or 550,000 GJ/yr.

Costs

An estimate of a pricing scenario put the gas from Kate Valley landfill at 2 c/kWh, and transmission costs of 2.7 c/kWh resulting in a total cost of 4.7 c/kWh or (Itskovich, 2012). This price corresponds to $13.06/GJ, which matches well with the estimate ($13-$15/GJ) in appendix B of the latest DES technical feasibility report (Bizcat Aurecon & FVB, 2012). This would provide the Kate Valley landfill $2 million in revenue per year and provide a cost-effective fuel for the city council. Burwood landfill has a decreasing quantity of LFG, but has existing infrastructure, some of which has been paid off. Itskovich (2012) estimates that approximately 14 km of pipelines in Christchurch and the compression station at the WWTP have 80% remaining capital costs to repay, and that the compression plant at Burwood landfill has 20% left to repay. Based on Itskovich's assumption of a $16 million cost for 60 km of pipeline, the existing 14 km pipeline network would have approximately $3 million left to repay.

A cost estimate for the compression and treatment equipment has been made using US Environmental Protection Agency (EPA) data, as the USA has many LFG to energy projects. The estimate for capital costs is approximately $700,000 for a landfill the size of Burwood, and double this for Kate Valley (U.S. EPA, 2009b). Included in the fuel costs from Burwood landfill is $3.7 million for gas treatment, compression and delivery, based also on US EPA estimates. Included in the fuel cost from all sources combined is over $21 million for treatment, compression and delivery, $16m of which is a pipeline to the city. The final result is a delivered, cleaned LFG price of $8.37/GJ from Burwood landfill, and $10.19/GJ from Burwood, Kate Valley and the WWTP combined.

Capital and O&M costs for CHP have been estimated using data from the EPA (U.S. EPA, 2009b). Assuming a gas turbine engine for production of electricity and heat, capital costs of around $1,800,000/MW of installed capacity can be expected. The O&M costs are given as $130,000/MW/yr. Pipeline O&M costs follow EPA assumptions and are assumed to be negligible.

The US EPA data did not contain costs for heat-only boilers, and LFG boilers are rare in Europe. Therefore a Danish estimate of capital costs for a natural gas-fired district heating plant (heat only) was modified to approximate costs. The Danish capital costs were approximately $160,000 per MW installed (Energinet DK and Energi Styrelsen, 2012). Operation and maintenance costs of the boiler unit were given as $6,000/MW/yr. Costs for a similar boiler based on LFG will be somewhat higher, due to modified flow systems, the need for corrosion-resistant materials such as stainless steel, and more regular cleaning (U.S. EPA, 2009a). These costs are difficult to estimate, and a conservative estimate of 50% higher than a standard natural gas boiler has been used.

Two scenarios have been calculated below – firstly usage of only Burwood LFG, for which the council already has existing treatment, compression and piping infrastructure, and currently totals around 5.5 MW (though this would decrease slowly over time). The second scenario is a cost estimate for usage of Burwood and Kate Valley LFG, along with extra biogas from the Bromley WWTP, which would result in a maximum of approximately 17.5 MW of LFG. This would involve construction of the $16 million pipeline, a treatment and compression plant at Kate Valley, and CHP units or boilers in the city.

In Table 23 it is seen that for Burwood landfill alone, the costs for heat could be as low as $9.73/GJ, while CHP costs are made significantly higher by the capital costs of a much more complex system. For all sources of LFG/biogas combined, the costs are higher, due to the higher costs of fuel supply. These higher costs stem from the long pipeline from Kate Valley to the city, and the new compression and treatment facility that would need to be constructed on-site. The costs still remain reasonable - as low as $11.33/GJ for heat from this gas source (Table 24).

Table 23: Total energy costs from Burwood Landfill LFG

	Burwood Landfill Energy Costs ($/GJ)			
	LFG CHP 4,000 h/yr	LFG CHP 8,000 h/yr	LFG Heat-Only 4,000 h/yr	LFG Heat-Only 8,000 h/yr
Capital Costs	12.50	6.25	1.67	0.83
O&M	9.03	4.51	0.63	0.31
Fuel Costs	8.59	8.59	8.59	8.59
Total	**30.12**	**19.35**	**10.89**	**9.73**

Table 24: Total energy costs from all LFG and WWTP gas in available to Christchurch

	Combined Landfill Gas (Kate Valley and Burwood Landfills) and Wastewater Treatment Plant Gas Energy Costs ($/GJ)			
	LFG & WWTP CHP 4,000 h/yr	LFG & WWTP CHP 8,000 h/yr	LFG & WWTP Heat-Only 4,000 h/yr	LFG & WWTP Heat-Only 8,000 h/yr
Capital Costs	12.50	6.25	1.67	0.83
O&M	9.03	4.51	0.63	0.31
Fuel Costs	10.19	10.19	10.19	10.19
Total	**31.72**	**20.95**	**12.49**	**11.33**

Bio-Oil and Biodiesel

Bio-oil and biodiesel were considered in the feasibility study, though available quantities have not been found. Approximately 2,500 hectares of rapeseed are grown in the Canterbury region (personal communication, Nick Pyke, 26 February 2013), which, if used entirely for biodiesel, would result in over 100,000 GJ/yr of supply[3]. This figure has been used as a rough estimate of supply in this study. These fuels were estimated to provide energy at $32/GJ (bio-oil) to $45.50/GJ

[3] Assumption of 1,300 l/Ha and 35 MJ/l. Biodiesel quantities from used cooking oil and tallow are unknown and therefore not included.

(biodiesel) (Bizcat Aurecon & FVB, 2012). Recycled lube oils could also be used and are priced at $18-$28/GJ. These fuels may be useful for peak load boilers in which the fuels are costly yet are used in boilers with low capital costs, and are only required for parts of the year. Combined heat and power has not been considered for these fuels as the scale and fuel costs would not allow this use. Capital costs have been taken from the DES technical feasibility studies and are assumed as $2 million for a 10 MW boiler or $200,000/MW installed. Operation and maintenance costs are assumed to be 2% of the capital costs, at $4,000/MW installed/yr. The costs are totalled in Table 25, and range from $33/GJ to $47/GJ for heat-only boilers, effectively restricting these fuels only to peak-load boilers.

Table 25: Total energy costs for bio-oil and biodiesel

	Bio-oil and Biodiesel Energy Costs ($/GJ)			
	Bio-oil Heat-only 4,000 h/yr	Bio-oil Heat-only 8,000 h/yr	Biodiesel Heat-Only 4,000 h/yr	Biodiesel Heat-Only 8,000 h/yr
Capital Costs	1.39	0.69	1.39	0.69
O&M	0.28	0.14	0.28	0.14
Fuel Costs	32.00	32.00	45.50	45.50
Total	**33.67**	**32.83**	**47.17**	**46.33**

Sewage Biosolids

One potential fuel source is the dried sewage biosolids at the Bromley WWTP. These biosolids have a lower calorific value than other fuels but are available to the council at low cost. Currently some of these biosolids are used to remediate former coal mining area on the West Coast of the South Island, though in the future this usage may change (personal communication, Alister Fisher, 27 February 2013).From 2006 until 2012, the amount used for soil remediation was 4,600 t, equalling approximately 650-750 t/yr (Weber et al., 2012). The pre-earthquake amount of dry biosolids (90% solids) available in Christchurch was in the range of 6,100 tonnes per year, so the amount used for soil remediation represents only about 10-12% of the resource (Sinclair Knight Merz, 2006).

It is possible that existing wood or coal boilers (such as the existing wood chip boiler at the wastewater treatment plant where the biosolids are dried) could accept chips mixed with dried biosolids pellets, up to a maximum of 20% pellets and 80% wood (Sinclair Knight Merz, 2006). The net calorific value of the dried biosolids is approximately half of the calorific value of wood, which would be approximately 10 MJ/kg (personal communication, Murray Cowan, 27 February 2013). This would result in a total energy input from biosolids of around 61,000 GJ/yr. The city council is actively investigating ways of utilising this resource in the existing solid fuel boiler without compromising its life cycle (personal communication, Alister Fisher, 21 April 2013). It is possible that the boiler could be more heavily utilised if connected to a DES, with the biosolids replacing a percentage of the wood chips that would normally be used.

Costs for dried biosolids are very difficult to estimate, and depend on factors such as whether the existing boiler can be used, if new filtration equipment is needed, emission requirements, fuel storage and loading, and others. Costs would also depend on if the biosolids are used by the council, or sold to another user. While it was not possible to estimate costs in this study, these biosolids do offer a promising opportunity, and the outcome of the current testing will determine whether this sort of use is possible.

Farm Forestry and Windbreaks

Other potential sources of woody material could include woody residues from small farm forestry blocks, as well as prunings from windbreaks and hedges on farms. Quantifying this resource is a real challenge, as it has not been explored on a systemic scale in the past. Nick Hanson from Federated Farmers suggested that, if feasible to collect, this resource is a true (valueless) byproduct, as opposed to a valuable co-product (such as straw), and therefore is more likely to be available for a nominal fee or no fee at all (personal communication, Nick Hanson, 22 April 2013). This material is usually burned on-farm, with some possibly being mulched.

The market for this product is also very immature, and it is possible that it is more apt to be used locally, instead of being collected and used or sold at a centralised facility (personal communication, John Gifford, 7 May 2013). The reason for this is that rural communities are looking towards improving local energy security by using local resources, and windbreak residues could contribute to this. This resource was unable to be quantified or assessed for costs, due to a real lack of information available.

Vineyard Prunings

Waipara, a wine-producing area 60 km north of Christchurch city, has a yearly supply of vine prunings, which were investigated for this project. A previous case study from New Zealand found that 1.5 t – 2 t of burnable woody biomass was produced per hectare, per year in New Zealand vineyards (EECA, 2009b). Vineyard plantings in Waipara and surrounding areas total around 1800 Hectares, meaning that up to 3600 tonnes of vineyard prunings could be available (New Zealand Winegrower, 2013).

After discussions with viticulturists in the Waipara region, the most common practice for vine prunings currently is to mulch them and leave them in the vineyard to return carbon and nutrients to the soil (personal communication, Miranda Brown, 18 March 2013; personal communication, Nick Gill, 19 March 2013). The practice of burning prunings was formerly implemented to control disease, however the improvement of disease management and a knowledge of the importance of organic carbon content in soil has largely put an end to this. The pomace (the remains of grapes and seeds after pressing) is also utilised for nutrients, through composting and returning to the soil.

Due to the current beneficial uses of these resources, concerns expressed over removal of soil carbon and nutrients, size of the resource and the distance from Christchurch, this resource is not considered as a viable fuel source for use in Christchurch.

Tallow

Tallow is a rendered fat product, which is produced in large quantities at meat processing facilities. It can be used to produce biodiesel, in food products and for making soap (Hall and Gifford, 2007). Tallow can also be used directly in combustion boilers, provided it is filtered to a high enough quality; already an example exists in Christchurch of a boiler using this process (EECA, 2007).

In the first quarter of 2013, 45,000 tonnes of tallow was exported from New Zealand, which would indicate a full-year flow of approximately 180,000 tonnes (Statistics New Zealand, 2013). Most of this is used in countries such as China for soap production (EECA, 2007). Prices for tallow from 2007 were in the range of $0.00 to $0.09 per kg (Barber et al., 2007, Hall and Gifford, 2007).

Some tallow is also used in New Zealand for biodiesel, although exact numbers were not found, due to many recent changes in the industry. Tallow in its raw form was not considered in this report to be a viable option for a DES or large industrial boiler due to the already-strong price competition from exports. The tallow that is used for local biodiesel production is included through the inclusion of biodiesel above.

Other Purpose-Grown Energy Crops

Finally, there are opportunities for purpose-grown energy crops such as miscanthus and willow in the Canterbury region, however currently this is a small-scale niche activity, and thus these energy sources cannot be considered as part of the current or near-term available fuel resource. This topic is instead discussed in part 3 of this section below.

Summary of Bioenergy Resources and Costs

The total available resources and fuel costs described in this section have been compiled and are shown in Table 26. Straw, wood and LFG are all resources of a significant size, with straw being by far the largest resource. Fuel costs for straw are also on average the lowest of all energy sources analysed, though this is offset somewhat by higher energy conversion costs. Therefore in total, LFG offers the lowest costs for a high-usage heat plant, followed by wood and straw. For CHP, biogas from piggery and industrial waste offers the lowest energy costs, followed by wood, straw, and LFG respectively. Further discussion of these results can be found in the following chapter.

Biofuel Resource Summary

Table 26: Estimates for amounts and costs of fuel resources, and energy generation including capital, O&M and fuel costs. Numbers in brackets indicate negative costs.

	Cumulative Size of Resource (GJ/yr) and Cost of Energy					
Fuel	**Estimate of Available Resource (GJ/yr)**	**Fuel Costs only - including transport ($/GJ)**	**Energy Cost (CHP) 4000 h/yr ($/GJ)**	**Energy Cost (CHP) 8000 h/yr ($/GJ)**	**Energy Cost (Heat) 4000 h/yr ($/GJ)**	**Energy Cost (Heat) 8000 h/yr ($/GJ)**
Wood Chips	>500,000	5.92	20.94	13.43	15.46	10.69
Wood Pellets		10.36	20.17	15.54	15.23	12.80
Straw	>4,500,000	5.50	24.13	16.23	17.88	11.84
Straw Pellets		9.82	23.82	17.87	19.11	14.58
Biogas:						
Dairy	400,000	unknown	-	-	-	-
Piggery & Industrial	52,000	5.07 – 11.93	22.78	12.43	-	-
Poultry	8,400	unknown	-	-	-	-
Landfill Gas						
Burwood only	158,000	8.59	30.12	19.35	10.89	9.73
All LFG and WWPT gas	550,000	10.19	31.72	20.95	12.49	11.33
Bio-Oil	unknown	32.00	-	-	33.67	32.83
Biodiesel	>113,750	45.50	-	-	47.17	46.33
Dried WWTP Biosolids	61,000	unknown	-	-	-	-

6.2 Part 2: Other Energy Sources

Waste Heat

Currently, there is no existing database of waste heat sources in the Canterbury region. Some central-city sources may be large enough to contribute to a DES, or to smaller, localised heating projects. Leonid Itskovich, the former CCC energy manager, noted that even supermarket chillers could provide waste heat to such a system, and computer servers housed by Telecom in the central city could release up to 1 MW of waste heat (personal communication, Leonid Itskovich, 27 February 2013).

Two significant sources of waste heat close to the central city were identified from boiler records and aerial maps. These are the Ravensdown fertiliser plant in Hornby (approximately 7 km from the city centre) and the Winstone Wallboards plasterboard factory in Hillsborough (approximately 4 km from the city centre). Contact was made with these two sources to estimate the available heat loads.

Ravensdown is the larger of these two heat sources. The sulphuric acid plant on-site runs 24 hours a day, seven days per week for 46 weeks of the year, with one annual maintenance pause. It has a flow of up to 6.5 MW of heat in the form of a 50 L/s flow of 40 – 50 °C water exiting the acid plant, which is currently cooled in two cooling towers (personal communication, Keith Grant, 29 April 2013). The output flow from the acid plant is mixed with part of the cooled output flow from the cooling towers, to bring the total flow entering the cooling towers to 100 - 130 L/s at 37 – 40 °C. A diagram of this system can be seen in Figure 17. The temperature of the water from the acid plant is lower than is used in most district heating systems, so would need to either be upgraded using a heat pump, or used in a very modern fourth-generation (4G) low temperature system (Wiltshire, 2012). There is another cooling flow at the fertiliser plant from condensers, oil coolers and alternators. This is in the form of water at 29 °C, flowing at 140 L/s, which is a much lower temperature and likely to be too low to utilise. The somewhat long distance to the city centre provides an additional challenge, and so large users of heat nearby should be investigated first, such as the neighbouring Mitre 10 Mega (a large hardware store) or the nearby Hornby Shopping Mall.

Winstone Wallboards produces plasterboard at its factory in Hillborough, to the southeast of the city centre. The production process includes a stage where plasterboard sheets are dried using a 6 MW drier, and the output from this drier is hot, humid air. This air flow is 31,000 kg/hr of air at 98 °C, with a humidity ratio of 0.23 kg H_2O/kg dry air (personal communication, Josh Thorpe, 29 April 2013). This should result in at least 1 MW of heat available from this flow, and this flow could, for example, be used to heat water from 55 to 70 °C. Josh Thorpe, the senior project engineer for the plant, suggested that this heat could be captured using a packed column dehumidifier and a heat exchanger, or directly through a shell and tube heat exchanger. Again the distance to the city centre may result in a heat load such as this being better utilised on-site or by a nearby customer.

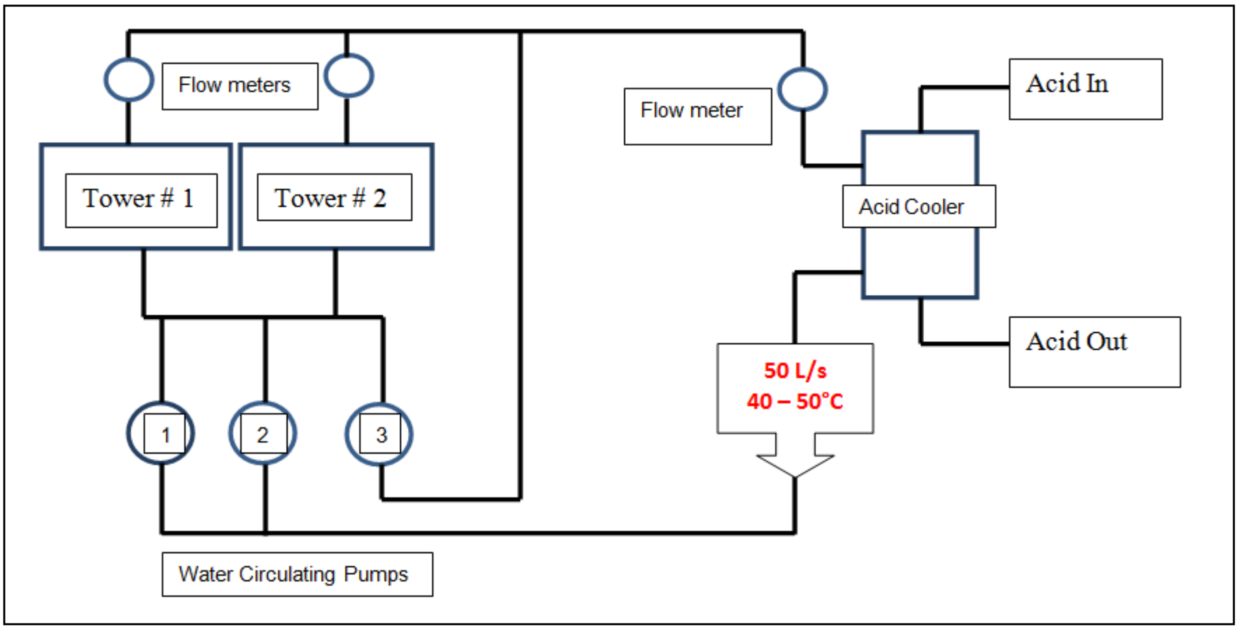

Figure 17: The cooling system at the Ravensdown acid plant in Hornby, showing the point at which the warm flow could be utilised. Source: Personal communication, Keith Grant, 30 April 2013

A final potential source of waste heat was investigated – Meadow Fresh, a producer of milk and yoghurt products. The factory on Blenheim Road lies approximately 5 km from the city centre and hospital. The streams of waste heat from this factory are combined into a single flow of warm water of approximately 1800 m^3 per day, which is low temperature, around 30 °C. This is too low to use as waste heat, however since this is a mixture of flows, some of the upstream flows of heat may be usable. More significant is the fact that as of April 2013, the factory no longer needs one of its two boilers. The total heat demand on site is 4 – 5 MW, and the boiler capacity is 14 MW, made up of a 6 MW and an 8 MW boiler, both fired with liquefied petroleum gas (LPG). The unused 8 MW boiler may be interesting as a backup boiler or peak load boiler for a DES, especially if it can be later converted to use a renewable fuel.

Solar

The National Institute of Water and Atmospheric Research (NIWA) collects data relating to solar radiation in New Zealand. In their solar radiation map (Figure 18), the entire Canterbury Region falls in the region of 13-14 MJ/m^2/day, which equates to 1320 – 1420 kWh/m^2/year. This figure is higher than many parts of Western Europe, and similar to the solar radiation received by southern France.

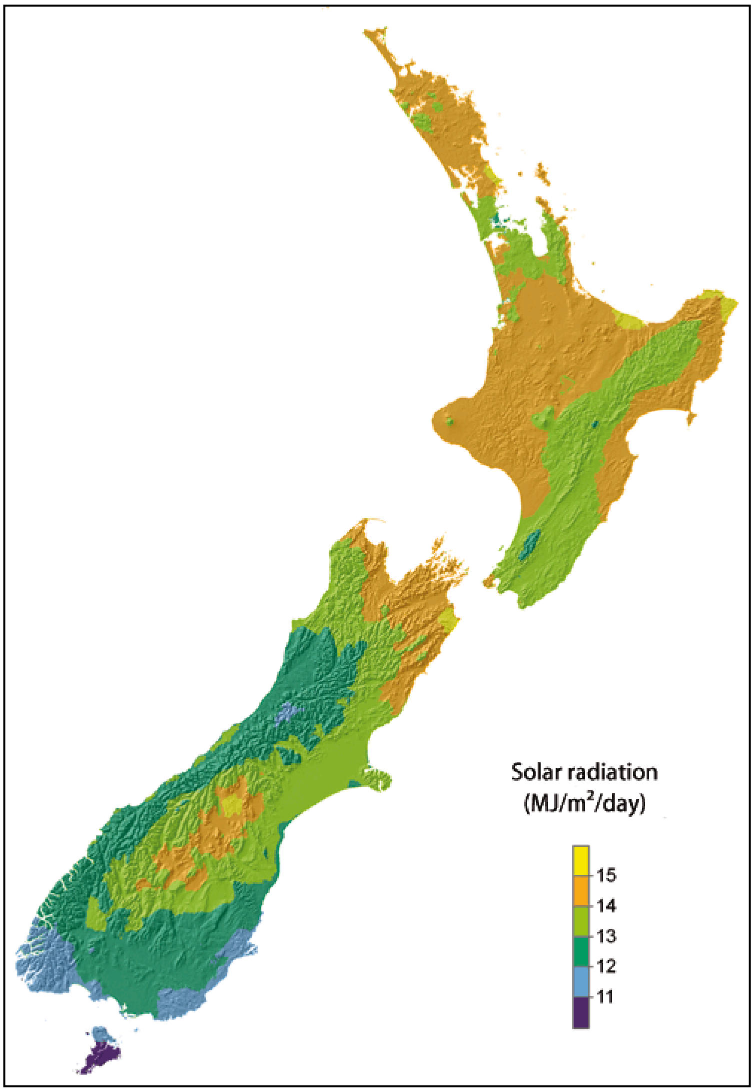

Figure 18: Solar radiation in New Zealand. The Canterbury region falls into the 13-14 MJ/m^2/day range. (Source: niwa.co.nz)

Solar Input from Buildings

Solar collectors could feed into the DES. There are many benefits to a building with a solar hot water system to be connected to the grid – it removes the need for in-building storage, and allows the buildings to export excess heat in times of oversupply and import heat in times of need (personal communication, Leonid Itskovich, 27 February 2013). This in turn can reduce the payback period of hot water collectors.

Solar District Heating

Costs of thermal solar systems for district heating in Europe are around \$300-\$400/m^2 of collector area, and a total installed system including pipes is around \$690/m^2, or \$750/m^2 including short-term heat storage (Garcia et al., 2012, Nielsen, 2013). The measured cost of generating heat in Denmark ranged from \$50 - \$100/MWh, or \$14 to \$28/GJ (Nielsen, 2013). The capital costs are the main cost component of solar systems, as O&M costs are low – in Europe around \$0.90/MWh or \$0.25/GJ (Energinet DK and Energi Styrelsen, 2012).

Austria is home to SOLID, a company specialising in solar thermal projects for district or process heat. An interview was held with Johannes Luttenberger at SOLID to gauge the suitability of this technology for Christchurch. The specific energy availability per m^2 of collector area in Christchurch using a high temperature collector was then calculated. This type of calculation is based on mean collector temperature – i.e. the average of the input and output temperatures. For example if the output from the collectors is 80 °C, and the return line is 60 °C, then the mean collector temperature is 70 °C. Therefore the amount of energy available for such a system depends on the water temperature chosen for the DES (personal communication, Johannes Luttenberger, 7 May 2013). The results of this calculation is shown in Table 27, showing that solar yields of up to 620 kWh/m^2.yr would be available for low-temperature solar systems.

Table 27: Solar yield based on average climate data for Christchurch and the SOLID high-temperature solar plate collector (personal communication, Johannes Luttenberger, 7 May 2013)

Mean collector temperature [°C]	Solar Yield kWh/m².yr
60	620
65	580
70	545
75	506
80	470
85	433
90	389

Storage systems for heat generated from solar thermal arrays can be expensive, although costs reduce drastically with larger systems; costs range from over \$700/m^3 for small (<1000 m^3) systems, down to around \$80/m^3 for large (>10,000 m^3) systems (Nielsen, 2013). Costs for a solar thermal system in Christchurch are not estimated as this is totally dependent size of the system and the temperature of the DES. This is, however, an option that should be investigated further, due to the suitable solar yields and emission-free operation. Talks have already begun between SOLID's Australian partner and CCHL (personal communication, Marc Sheldon, 28 May 2013).

It is possible to make a rough estimate of the maximum potential of solar energy in the central city. The area of the CBD is approximately four km^2, and once the rebuild is complete, roof area could cover approximately half of that. Two km^2 of solar panels, producing heat at a mean collector temperature of 75 °C, would produce around 3,600,000 GJ/yr. While this figure is an absolute maximum, it shows that a significant amount of solar energy could be harvested in the city.

Surplus Electricity from Wind and Hydroelectric Sources

There are currently no wind farms close to Christchurch, although two wind farms of capacities of up to 78 MW each are planned for the Hurunui region (NZWEA, 2013). One of these projects, at Mount Cass, is adjacent to the Kate Valley landfill, 60 km north of Christchurch, and the other, the Hurunui project, is approximately a further 10 km north of that site. These projects have both been in the consenting process for a number of years.

At the current state of progress, it is difficult to see wind energy having any input to a DES. Once the wind farms are completed, it may be worth revisiting, though likely as a more general issue of storage of electricity surpluses, as opposed to being used for DES heating.

Hydroelectric generation makes up almost 60% of New Zealand's electricity generation (MED, 2012). There would be some potential to make use of the water flows that are wasted at times of high river flow and lower demand. However, due to the irregularity and seasonality of this resource, and the difficulty in assessing the feasibility, it has not been considered in this report.

Aquifer and Ground Source Heat Pumps
Ground source heat is an option that was considered in the DES technical feasibility study, however it was noted that the heat needs to be upgraded in temperature by heat pumps to be integrated into a system. This firstly is in conflict with any potential CHP system, which would use heat to generate electricity (while the heat pumps would use electricity to generate heat). Also mentioned were the risks involved if the system were to be dependent on deep boreholes, in an active earthquake area. Therefore the authors excluded this option (Bizcat Aurecon & FVB, 2012).

Others are considering this option still, in the form of open-loop ground source heat pumps using the aquifers that flow underneath Christchurch (personal communication, Zeb Etheridge, 26 February 2013). Many boreholes in the city exist currently, and are used for drinking water as well as other uses. Research would be required on the temperatures and movement of the aquifers, as well as capital and operational costs, and into the risks of earthquake damage. In principle, however, such a system is possible in Christchurch.

The idea behind this type of system would be to take water from the aquifer at 13-14 °C, and use a heat pump with a coefficient of performance (CoP) of around 5 for heating and 6 for cooling (personal communication, Zeb Etheridge, 26 February 2013). This system could use a well taking 50-100 l/s, which is normal for the city. The change in temperature (ΔT) would be 5-7 °C, and so each well could provide 1.4 – 2.8 MW of heating or cooling. The overall CoP of such a system would be 3-5, due to energy needed for fans, pumps and other equipment.

This type of system would be economically competitive with diesel, LPG, and electricity, yet for heating would not be competitive with coal or wood chip systems. Such a system would however have the advantages of making use of New Zealand's high percentage of renewable electricity, no CO_2 or particulate emissions in the city, can be located very close to the demand source, can provide both heating and cooling, and can be scaled appropriately to the level of demand. Interseasonal heat storage in the aquifer may be possible, though would require prior research and testing. In addition, the system would need to be robust enough to survive further earthquakes, and would need to ensure other nearby users of aquifer water are unaffected.

For such a system to be implemented, building owners would need to be consulted early in the process, as this type of system is compatible with under-floor or other radiant heat systems, due to the low temperatures produced (18 – 21 °C). These systems result in higher building costs and need to be incorporated into the design from the outset.

6.3 Part 3: Possible Future Situation Changes and their Effects

This thesis aims to quantify and assess current resources around Christchurch, and the ways in which they could be brought together and utilised. It is worthwhile, however, mentioning future activities which may have a strong bearing on the feasibility of the different alternatives. This section outlines some potential changes and the effect they may have on Christchurch's energy system.

Fuel Crops on Arable and Marginal Land

The Canterbury Plains are not only suitable for arable crops such as wheat and barley, but may also be suitable for energy crops such as miscanthus, or for short-rotation forestry (SRF) or coppicing for energy. Already, around 2,500 hectares of rapeseed is grown in the area (personal communication, Nick Pyke, 26 February 2013). In addition, a 2009 report summarising New Zealand's bioenergy resources noted that a willow project was under way to assess the bioenergy potential of the species (de Vos et al., 2009a). The report also noted that the use of co-products is required to make SRF competitive as a land use. These co-products could be charcoal, pharmaceutical products, salinity mitigation, sawn timber, waste application, carbon credits, animal fodder, wood by-products and others.

Currently, undeveloped markets and lack of economic viability make these crops unfeasible. If fossil fuel prices rise, markets are developed, and there is a governmental push towards biofuels, then these crops could feature in future energy systems. If this were to happen, flexible-fuel biomass combustion or CHP plants would be an attractive option, as they would be shielded from price fluctuations of individual fuels.

Separation and Use of Organic Waste

Currently, around 55,000 tonnes per year of green waste and putrescibles go to the organics processing plant in Christchurch, where the waste is processed into compost for farm fertiliser use, as well as residential use (CCC, 2011). Based on waste figures from 2008, this would represent approximately 40% of the food and green waste available to the Canterbury region (see Table 28). The remainder is assumed to be transported with other non-recyclable waste to the Kate Valley landfill, 60km north of Christchurch. The table below contains figures from before the biosolids drying plant was built, so the biosolids figure can be ignored.

Table 28: Organic waste amounts in Canterbury in 2008 (Smith, 2009)

Organic Waste Type	Quantity (tonnes)
Putrescibles (food waste)	43,803
Green Waste	88,947
Biosolids (wet)	28,766
Other	44
Total	161,560

This indicates that much of the green waste (mainly food waste) in Christchurch still goes to landfill, despite bins being provided for separation of organics. If this behaviour changes and more green waste is sent to the organics processing plant, then less LFG will be produced at Kate Valley, and more fertiliser will be produced at the organics plant. This needs to be considered when predicting future LFG production at Kate Valley. There is also the possibility that green waste is used for anaerobic digestion as opposed to composting, resulting in a new energy source, with a decrease in compost production. At present, this option is not being considered, however if priorities for the city council change, or if energy prices increase, this could be another way to utilise the significant green waste resource in the city.

7. Results and Recommendations

7.1 Summary of Availability

It is clear from this research that large amounts of wood (500,000 GJ/yr) and straw (4,500,000 GJ/yr) are available in the area around Christchurch. It is, however, also clear that the supply chains and markets for these resources are seriously underdeveloped, and also that the best use of these resources may not be in centrally-located boilers, because of transport, emissions and cost concerns. In the current difficult economic environment, budgets are already stretched in the earthquake rebuild, and little government funding is available for renewable energy. A lack of experience with straw as a fuel in New Zealand is another factor holding back the exploitation of this resource. Wood supply in Canterbury is tight due to limited plantation forestry, a trend towards converting plantation forestry to dairy pasture, existing demand from the Daiken MDF plant, and the difficulty of using municipal waste wood and demolition waste from the earthquake demolition.

Landfill gas is the other energy source that is available in a significant quantity. Unfortunately, the largest source of LFG, Kate Valley, is 60 km from the city. While a pipeline, or even trucking the gas, is economically feasible, a use closer to the source (such as providing fuel for the trucks bringing waste to the landfill) may be a better use of this resource, without the capital expense involved with transporting the gas. Other biofuels are available on smaller scales, such as biogas from piggery and industrial waste, and dried biosolids from the WWTP. All of these fuels are being investigated for energy use, and results from testing should appear in the coming months.

Other (non-bioenergy) sources of renewable energy hold promise, such as solar thermal and ground-source heat pumps. The annual solar radiation in Christchurch is higher than many parts of Europe, and solar thermal systems have the added benefit of zero emissions and the mostly-renewable electricity profile of New Zealand makes heat pumps a clean option. These two options have the additional advantage that they are free from emissions in the central city, and do not require fuel to be delivered.

The resource size of the bioenergy and other renewable energy sources assessed in this research are summarised in Table 29. Straw is the largest available source of energy, though has many challenges to be overcome. The solar resource is also very large, yet has high capital costs and the problem of seasonality, with low heat yields in winter. Wood and Landfill gas have potential, and indeed are already used in the city. Further use of wood depends on residue recovery and costs, and further use of LFG depends on the currently ongoing assessment of the Kate Valley LFG supply. Heat pumps, including those using aquifers, could be employed once more resource assessment is completed, along with assessment of the suitability of this technology in an earthquake-prone city. Waste heat requires further quantification, and biogas from dairy would only be suitable if the farming style moves towards a more intensive system, where the animals spend more time on surfaces that allow collection of manure.

Table 29: Bioenergy and other renewable resource availability in Canterbury, and barriers to utilisation.

Fuel	Estimate of Available Resource (GJ/yr)	Barriers to Utilisation
Wood Chips or Pellets	>500,000	Relatively little plantation forest close to Christchurch, ongoing conversion of forest area to dairy pasture, strong existing wood chip demand in Canterbury, demolition waste timber is difficult to sort and use, forest residues are expensive to collect, market is under-developed
Straw or Straw Pellets	>4,500,000	No existing market, straw combustion has ash and corrosion issues resulting in expensive boilers, low density makes straw transportation difficult, long transportation distances, dust, variation in crop yields, nutrient losses from soil
Biogas:		
Dairy	400,000	Extensive farming system results in only 10-20% of manure able to be collected, distributed nature of farms
Piggery & Industrial	52,000	Requires transport of feedstock, relatively high capital costs, relatively small resource
Poultry	8,400	Resource is small, can be corrosive to boilers
Landfill Gas		
Burwood only	158,000	Output decreases over time, gas must be cleaned and piped, output flow can vary
All LFG and WWPT gas	550,000	Large distance from Kate Valley to Christchurch, gas cleaning and compression equipment required, Kate Valley resource still being assessed, output flow can vary
Bio-Oil	unknown	Quantities unknown, high fuel prices
Biodiesel	>113,750	High fuel prices
Dried WWTP Biosolids	61,000	Low energy density, unproven as a fuel, potential corrosion issues
Waste Heat	>216,000	Resource in Christchurch has not been assessed, low flow temperatures, heat pumps possibly required to upgrade temperature
Solar	up to 3,600,000	High capital costs, most heat produced in summer, buildings may need to be strengthened for rooftop application,
Heat Pumps	unknown	Aquifer testing required if it is to be used, risk of failure in earthquake area, electricity required, not suitable for use in combination with CHP

7.2 Summary of Costs

Costs for delivered biofuels were calculated in this study based on information gathered in interviews combined with New Zealand, European and USA-sourced data. There is still uncertainty surrounding these costs, as the true costs can only be found upon implementation. Costs for pellets in this study are based on the setup of a wood pelletising plant as part of the system, as opposed to purchasing wood pellets at current market prices. Straw prices may also be affected strongly by supply and demand, although this would stabilise if multiple users of straw arise. Landfill gas prices are dependent on the price that the seller demands, as well as who the user of the gas is (due to the landfills being half-owned by the city council). Overall, the fuel costs for renewable fuels in this study were found to be lower than those assumed in the DES technical feasibility study (Table 30).

Delivered energy costs were also calculated (Table 31), based on capital and O&M costs from various international studies. It should be noted that the delivered energy cost in this report do not include profit margins – they are merely the combined cost of capital (with a simple payback time of 10 years assumed), O&M costs, and the delivered fuel costs. These costs are intended to assist key stakeholders in Christchurch to be better able to assess how bioenergy sources could be used in the city, either as part of a DES or in other commercial or industrial applications.

Table 30: Fuel costs in this study compared with the DES technical feasibility study (Bizcat Aurecon & FVB, 2012)

Fuel	$/GJ in DES Technical Feasibility Study	$/GJ in this Study
Wood Chips	7.60	5.92
Wood Pellets	15.80	10.36
Straw	6.10	5.50
Straw Pellets	-	9.82
Biogas from Piggery & Industrial Waste	-	5.07 – 11.93
Landfill Gas (Burwood)	-	8.59
Landfill Gas (Kate Valley)[4]	15.00	10.19
Coal	7.60	-
Diesel	36.10	-
Liquefied Petroleum Gas (LPG)	40.00	-

Table 31: Delivered energy costs for CHP and heat-only plants running at 8,000 h/yr from this study

Fuel	$/GJ Delivered Energy CHP @ 8,000 h/yr	$/GJ Delivered Energy Heat @ 8,000 h/yr
Wood Chips	13.43	10.69
Wood Pellets	15.54	12.80
Straw	16.23	9.56
Straw Pellets	17.27	13.20
Biogas from Piggery & Industrial Waste	15.96	-
Landfill Gas (Burwood)	19.35	9.73
Landfill Gas (Kate Valley)[5]	20.95	11.33

[4] The DES Technical study gives a figure for Kate Valley only, while this report gives a combined figure for Burwood, Kate Valley and the extra gas from the Bromley WWTP.

7.3 Short Term Recommendations

In this section, practical and achievable recommendations are made for short term (within the next two years) activities that could improve bioenergy uptake in Christchurch.

District Energy

If a district energy scheme is to go ahead in Christchurch, decisions need to be made immediately. This is because the fuel source chosen will dictate the scale and temperature of the system, and to maximise the use of a DES, buildings should be designed for connection to such a system. This is especially important with lower-temperature systems suited to under-floor or radiant wall heating. Also if solar thermal is to be incorporated into the buildings, the buildings need to be designed to handle the weight of the panels and pipes on the roof (personal communication, Johannes Luttenberger, 6 May 2013).

These decisions also depend on the priorities of the city council. Is the aim to rebuild as fast as possible, to have the cheapest possible heat, or to begin a transition towards a smart city? Realistically, the only way that a fourth-generation low-temperature DES would be feasible is if this type of system was chosen by the council, and building owners in the CBD were mandated to connect to the system. This is extremely unlikely, and thus already consequences can be predicted – in a higher-temperature system, solar would play a diminished role (such as hot water heating in summer) and waste heat is unlikely to be useful at all unless in very close proximity to the DES.

The decision process is currently not transparent, and few of the experts that were interviewed were aware of the current state of the DES discussions. In talks with members of the public in Christchurch, very few people were aware that a DES was even an option for the city. If building owners, architects and engineers are not aware of the potential of DES connection, then they will not design buildings suited to heat grid connection. Likewise if the public, and those interested in working and living in the central city are not aware of this possibility, they will not demand it. The recommendation is therefore to improve transparency and communication of DES discussions with stakeholders and the general public. This could be through a website with regular newsletter, as well as direct contact with building owners.

From a technical perspective, and as also noted in previous feasibility studies, Christchurch Hospital is ideally placed to be the starting point for a DES. With the current spare boiler capacity, and its central location, Christchurch Hospital is the perfect starting point, even if the constructed system is a small 'proof of concept' system which would introduce the concept of a DES to the people of Christchurch. This could improve the case for future extensions, in Christchurch and in other parts of New Zealand.

At this stage, due to lack of activity in this area since the publication of the feasibility reports, and the fact that construction in the centre is already beginning, it is difficult to see a DES happening at the scale that was imagined in the feasibility studies. It is also difficult to see bioenergy playing a role outside of being used in existing boilers, due to CCHL's concerns with supply chains, emissions, dust and noise. This is unfortunate, as all of these can be minimised with modern

[5] See footnote 4 above

technology and good planning. Based on the current level of development of straw and wood residue supply chains, and the up-front expense of technologically-advanced wood and straw boilers, the recommendation can only be for smaller-scale boilers using these fuels to be employed, as a way of introducing the technology to the city and the country.

Waste Heat and Spare Boiler Capacity

Even before bioenergy resources are considered, efficient use of currently-used resources and capacities should be thoroughly considered. This study has identified many points in the city where uses for waste heat or spare boiler capacity should be investigated: the 1 MW of possible excess heat as well as up to 4.5 MW of spare boiler capacity at the Bromley WWTP, the 6.5 MW of waste heat currently being sent to cooling towers at Ravensdown in Hornby, the 1 MW of waste heat available at Winstone Wallboards in Hillborough, and the 8 MW unused boiler at the Meadow Fresh factory on Blenheim Road. A map of this excess boiler capacity and waste heat is shown in Figure 19. This research was completed in a short time frame, and much of this time was spent outside of New Zealand, yet viable waste heat sources were still found. There are likely to be many more sources of heat (such as computer servers, small industrial sites, supermarkets, tanneries), yet unfortunately knowledge of this resource in Christchurch is lacking. Even if these heat sources are unsuitable for use in a DES, there may be opportunities in close proximity to the sources.

For this reason, it is recommended that a database of waste heat sources in the city be compiled as soon as possible. This database would be a very useful asset for future energy systems that may incorporate multiple sources of heat, especially where low-temperature heat is used, such as in systems making use of solar thermal panels and heat pumps. If waste heat is allocated to low-temperature uses such as residential and commercial heating, then valuable biomass resources can be allocated to high-value uses in industrial processes and CHP.

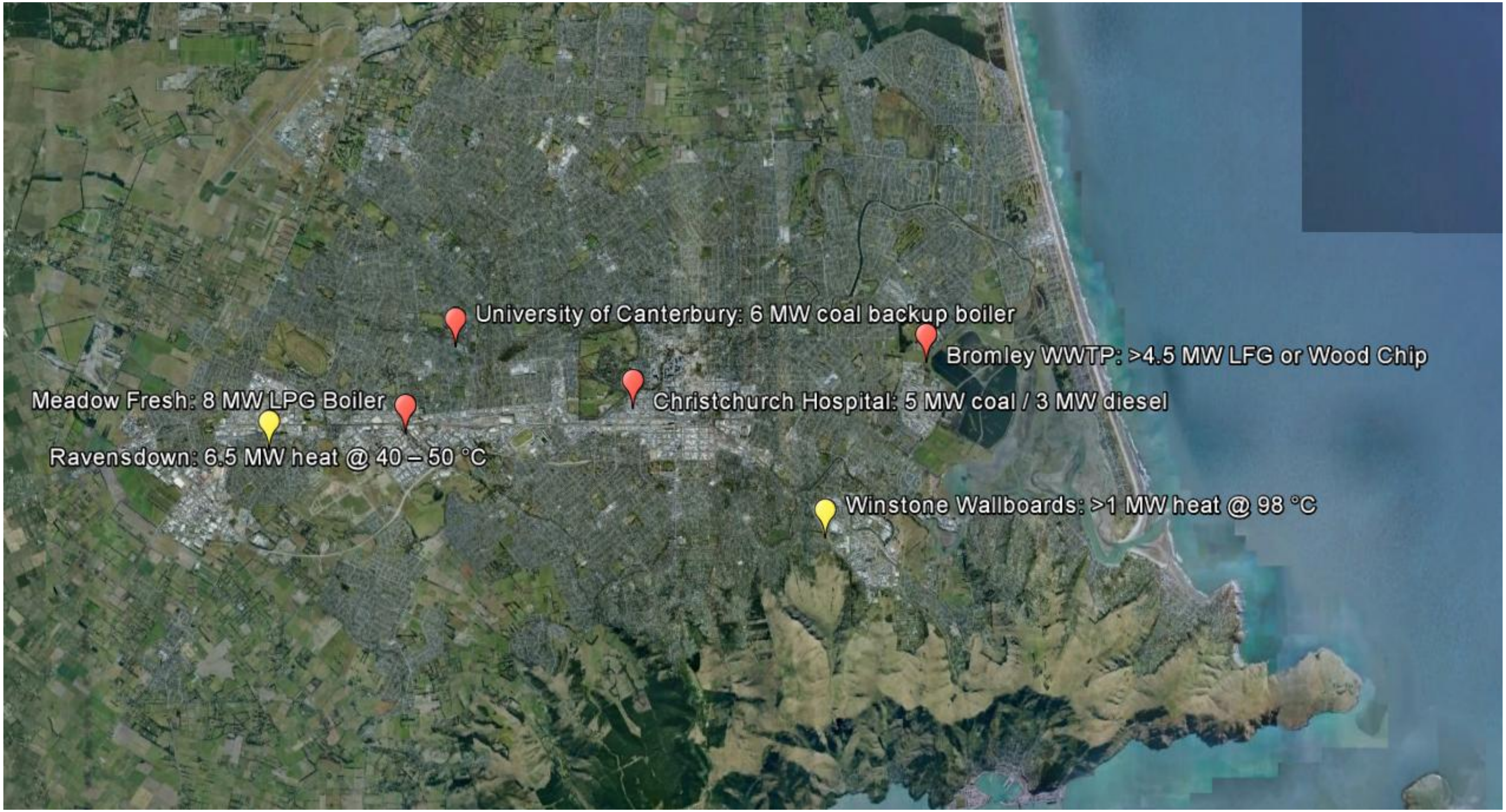

Figure 19: Excess boiler capacity (red labels) and waste heat sources (yellow labels) in Christchurch.

Bioenergy
Another clear finding from this study is that the markets for biofuels, especially from wood and straw, require development before these fuels will be considered as viable, mainstream energy sources alongside conventional fuels. Fortunately, BANZ is working in this area, specifically with regards to wood fuel quality guidelines, however more direct action with growers and fuel suppliers is required. In the short term, for example, a New Zealand version of the AEBIOM 'Wood Fuels Handbook' could guide farmers through the process to sell their wood for smaller projects in Canterbury (Aebiom, 2008).

The best chance for uptake of straw in the short term would be modification of coal boilers to allow co-firing of straw. This would be an excellent chance for formation of a market for straw (i.e. starting small), while requiring minimal start-up capital. The boilers of Fonterra and Synlait are positioned very close to sources of straw, and thus this option also avoids long transport distances, and transport through urban areas. It is recommended that this option be investigated; initial talks could be facilitated between the boiler owners and the farmers by FAR, Federated Farmers, EECA, or the farmers themselves.

Finally, it is recommended that the CCC keep an open dialogue with the other members of Transwaste, the joint owners of Kate Valley landfill, and make sure an option for the LFG is chosen that benefits all stakeholders. While a pipeline for gas is feasible, another promising option is conversion to fuel for trucks - this option has already been trialled in Auckland. It would seem logical, that if trucks are being driven daily from Christchurch to Kate Valley and back, that they be fuelled on the gas that is currently being extracted and flared. The decision-making process around this landfill gas should be transparent, fair, and environmentally driven.

Other Renewable Energy Sources
Solar thermal and heat pump systems are both systems that have potential to contribute to heating in Christchurch with no local air emissions. Christchurch has enough solar radiation to make good use of solar thermal, and discussions have already begun between suppliers of the technology and the city council. No recommendation is necessary as progress has already begun.

Early progress is also underway with ground source heat pumps, using the aquifer under Christchurch. This is a technology which also has potential due to no local emissions, however concerns have been raised about the suitability of such a system in an earthquake zone, as well as the conflict with any potential CHP technology. The recommendation is for those most knowledgeable of the technology (such as Golder Associates) to continue assessing the feasibility of such a system and keep CCHL informed of progress.

7.4 Medium Term Recommendations

The recommendations in this section are those that will take longer to implement than those in the previous section, for example two to ten years.

A Vision for the City

To make the best use of the available energy resources, the city must have a vision. As previously mentioned, this vision will shape any potential energy system and offer guidance for stakeholders. While the Christchurch Central Recovery Plan and the CERA Recovery Strategy describe encouragement of green buildings and energy efficiency, very little is mentioned in terms of energy systems, bioenergy and smart cities. Energy needs to be incorporated into these visions – for example, Christchurch could market itself as a test arena for new technologies, encouraging research and business development in the area.

Biomass Market Development

For biomass fuels to be integrated with mainstream fuels, they must be seen as being of a consistently high quality. For wood, this should involve turning current firewood, wood chip or wood pellet suppliers in Christchurch into 'Biomass Logistic & Trade Centres'. These are centres selling chips, pellets, and other fuels which are graded using the existing wood fuel quality guidelines. The goal of this transformation would be to turn wood fuel from an 'alternative' fuel into a high-quality fuel with stringent quality guidelines and security of supply. Guidelines for these trade centres already exist, and the process can begin immediately (Loibnegger and Metschina, 2010).

Wood residues will also need to be exploited further to develop the use of wood as a fuel. This is a difficult area, as there have been many attempts at improving wood residue collection and use in New Zealand, with limited success. Regardless, supply chains for wood residues, including state-of-the-art methods of collection, should continue to be investigated. A promising development in this area is the upcoming New Zealand forest products levy (which will come into force in 2014), which can fund research to look into new ways of economically gathering residues and also getting advice from European experts (Forest Voice, 2013).

The straw market is even less developed than the wood market, and currently is subject to wild swings in availability and price. The New Zealand government is extremely unlikely to employ European-style policies such as a mandate to use a minimum amount of straw for energy generation, or subsidies for its use. Therefore establishment of supply chains will depend on users who are willing to bear the risk of varying prices. As mentioned in the short-term recommendations, co-firing with coal is one way to develop an initial straw market. Further simple ways to put straw on the agenda could involve, for example, councils requiring a feasibility analysis of straw for a fuel when new boilers above a certain size are commissioned, or if expansions of existing boilers are planned. Farmers could revisit the practice of using straw to fire grain driers, which has died out due to cheap fossil fuels. It is recommended that central and local government look into feasible methods of reducing the risk for early adopters.

Combinations of Technologies – A System View

An important finding from this study is that single technologies alone do not offer the same levels of flexibility and efficiency as combinations of technologies. For example, a system using biomass CHP, heat storage, heat pumps and solar thermal collectors could be implemented in Christchurch, with much flexibility in terms of scale. In winter, and when electricity spot prices are high, the CHP plant could provide heat for space heating (and to top up the heat storage facility) and electricity could be sold to the grid. When electricity prices are low, the heat from the storage could be used, either as-is or upgraded using heat pumps. In summer, solar collectors could provide heat for hot water in the city and also keep the heat storage up to temperature. A heat-only plant could be used in place of the CHP plant, or a different combination of technologies could be found.

The recommendation therefore is for the local and national governments, in combination with CRIs and universities, to lead research into the feasibility of such systems, and the best combinations of components based on the climate, energy prices and geography of New Zealand. This could happen, for example, through formation of a regional or national 'energy agency', who keep a systemic overview of developments, and therefore can inform the council and private sector about potential linkages when new projects are started.

7.5 Long Term Recommendations

Increasing the use of biomass for energy in the Canterbury region will require planning for the future. Many systemic factors will affect this, including fossil fuel prices, energy independence, urban densification, the changing face of agriculture, and global trends.

In terms of agriculture, dairy farming is growing in New Zealand, and is becoming more intensive, with farmers in the South considering indoor housing for cattle in winter. More intensive dairy farming results in further opportunities for manure collection, and therefore opportunities for biogas use. Umbrella groups such as Federated Farmers should keep abreast of international developments, and communicate these developments to farmers, as well as looking for chances to lead the way in this area.

Feasibility studies of energy crops are important to know which energy crops are suited to each region in New Zealand. This is something that can benefit all of New Zealand, and research should be strongly supported by the government, in order to develop a knowledge base and a path towards energy independence. With an economy that is based around use of natural resources, New Zealand should be looking at ways of maximising the opportunities. Some work has already begun, with the Woodscape, EnergyScape and Bioenergy Options reports all highlighting opportunities for modern bioenergy systems. The next step is to make these opportunities a reality; the recommendation is therefore for central government to look at cost-effective ways of reducing the risk for early-adopters of these technologies. Being at the forefront of bioenergy implementation could have many positive environmental and economic effects for the country, as well as offering energy security and independence.

7.6 Institutional and System Changes

Institutional and Other Non-Technical Changes

The bulk of this research has focused on the technical and economic challenges that are faced when looking at bioenergy uptake. However, technology changes can only make large environmental, social and economic gains if they are underpinned by longer-term institutional changes; in fact it has been claimed that it is the non-technical issues that are hindering bioenergy in Europe(McCormick and Kåberger, 2007). Without changes to non-technical aspects, improvements in energy efficiency and usage will be limited. Much of the current discourse in

Europe is focused on shifting aspects at the level of the whole system, such as integration of different energy sources, linking of different actors and increasing know-how and institutional capacity (personal communication, Michael Narodoslawsky, 4 June 2013). The EU is looking at a shift towards a much more sustainable energy system at every level, to meet its ambitious "20-20-20"targets in 2020 (EU, 2012).

In a recent literature review, five dimensions which dictate the success of bioenergy projects were found: project characteristics, policy framework, regional integration, public perception and stakeholders (Blumer et al., 2013). Elsewhere, barriers and drivers for the uptake of bioenergy were discussed; divers included improving energy security, combating climate change, promoting regional development, diversification of energy systems, and creation of new partnerships and synergies (McCormick and Kåberger, 2007). Barriers were identified by the researchers, such as how different energy sources are economically analysed (externalities, both positive and negative, are often not taken into account), lack of institutional capacity and communication between sectors (for example the financial sector and the energy sector), public and political preconceptions, poor supply chain coordination, and tensions between agricultural policy and energy policy.

Another issue to overcome is the sustainability (both real and perceived) of bioenergy systems in general. Concerns have existed for many years around biofuels, particularly with regards to competition with food production and other land uses. A way of overcoming this is through a comprehensive and global sustainability certification system, though at the moment there are many different approaches, and a lack of harmonisation between these approaches (Scarlat and Dallemand, 2011).

These issues easily transfer to New Zealand, where they are likely to be equally valid, or even exacerbated by factors such as New Zealand's relatively immature bioenergy industries, geographical isolation, and economic situation. Unfortunately the solutions suggested in literature are not easy – political measures such as startup grants and feed-in tariffs are often suggested, and for new projects, it is often left up to local champions who are willing to accept the risks involved with new technologies.

Linking of Actors

If New Zealand is to make advances in bioenergy crops and conversion technologies, it must have a way of transferring knowledge from research institutions to private industry. Firstly, connections between New Zealand research institutions to international research institutions must be strengthened. It is wasteful for research funds to be spent on developing technologies which exist already in the USA and Europe. Europe has the experience and available funding to research large-scale projects (such as the GoBiGas project in Gothenburg) and this should be capitalised on through strong networking channels.

To transfer knowledge to the private sector, the crown research institutes (CRIs) and universities must actively pursue connections with private companies who can use bioenergy technologies. Setting up these connections should not be left to the private sector as current research topics within CRIs and universities cannot be known by private companies. On a more local scale, knowledge transfer between farmers, energy experts, the city council and the public of Christchurch and surrounding areas should be encouraged, led by both environmental and economic development specialists in the city council. For example a bioenergy cluster (of research institutions, private companies and academic institutions) in the region could push Christchurch towards being a world-leading centre of bioenergy.

Christchurch city itself should also seek to be members of networks which can aid in information and recommendations for making the best use of the available resources. Already, through CAfE, Christchurch is a member of the Energy Cities network, which focuses strongly on common city issues such as energy efficiency and funding opportunities, though has a strong European focus. Other research networks should be explored, focusing on upstream activities such as market creation, fuel production and distribution, and conversion technologies.

Planning Instruments

On a final note, the planning of the rebuilding of Christchurch needs to also consider long-term goals, especially in relation to energy. Spatial planning and energy planning should have common goals, and should be interlinked, as this facilitates sharing of resources and eases distribution of fuels and of energy. The New Zealand Energy Strategy 2011-2021 prioritises "diverse resource development" and "environmental responsibility", and this strategy must be tied in with the CERA Recovery Strategy for Greater Christchurch and the Christchurch Central Recovery Plan (MED, 2011). A strong, unified vision of the city and region should be held by stakeholders at every level, from central government to the public, and planning processes should always be transparent and participatory.

8. Conclusion

The way to bring bioenergy resources together in Canterbury is dictated by the early stage of development of the markets for the two largest sources: straw, and forest residues. It is difficult to see straw and forest residues playing a large energy role in the short term, because before energy conversion technology can be considered, supply chains and markets must be developed. This should be the strongest focus of research and development, and this research suggests following the lead that BANZ have taken, developing fuel quality guidelines and improving the public's perception of wood and straw fuels. Ways of using these resources in existing infrastructure should be investigated, alongside smaller-scale boilers, to create a small but consistent market which can grow over time.

Landfill gas is easily incorporable into a DES, and the gas from Burwood landfill should definitely be used in a DES of any scale, as the infrastructure is already in place. Heat from the under-utilised LFG and wood chip boilers at the Bromley WWTP could play a role in such a system, provided the piping costs to the CBD or to nearby heat users are not prohibitive. Kate Valley landfill has a significant resource of LFG, which is currently being assessed – use in a DES may not be the best use of this resource, however the analysis and decision-making processes for use of this gas should be transparent and shared between all parties involved with Transwaste.

Non-bioenergy sources such as solar thermal and aquifer heat pumps offer interesting possibilities for heat in the central city with no local air emissions. These are currently being investigated and thus suitability can only be assessed once the results of these investigations are complete. Initial calculations show that solar thermal panels would produce useful amounts of heat in Christchurch. Waste heat sources exist in Christchurch – two significant sources were found in this research, which could heat nearby buildings, or perhaps even feed into a DES. A database of other waste heat sources, as well as spare boiler capacity, would be a very useful asset for energy planning in the future.

Long-term recommendations to come from this research involve unification of planning processes, improvements in communication and transparency, risk reduction for early adopters and improvements in linkages between sectors, and with overseas research projects.

The short term, medium term and long term recommendations that have come out of this research are listed below.

In the short term (up to 2 years):

1) Communication to stakeholders (especially building owners and the public) about the potential DES should be improved. Building owners need to take the possibility of a DES into account when designing and building, so need to be informed as soon as possible.
2) Christchurch Hospital should remain the starting point for a DES; even if the end result is a small loop, this could be a good ‘proof-of-concept’ system for New Zealand.
3) A database of waste heat sources and spare boiler capacity in the city should be compiled as soon as possible, to make sure existing infrastructure is well-utilised. Nearby uses for waste heat at Ravensdown and Winstone Wallboards should be pursued.
4) Talks should be facilitated between grain farmers and Fonterra and/or Synlait, to investigate the feasibility of co-firing of straw in the existing large coal-fired boilers.
5) Member parties of Transwaste (city and regional councils, Transpacific Industries) should be involved in a transparent and fair decision-making process for the use of Kate Valley landfill gas.

In the medium term (2-10 years):

1) Firewood, wood chip or wood pellet suppliers in Christchurch should begin a transition towards becoming ‘Biomass Logistic & Trade Centres’, using the existing New Zealand wood fuel quality guidelines, to improve the consistency and public opinion of wood fuels.
2) The upcoming New Zealand forest products levy should be used to fund research into new ways of economically gathering forest residues and also improving contact with European experts.
3) Central and local government should look into feasible methods of reducing the risk for early adopters of bioenergy sources such as straw.
4) Local and national governments, CRIs and universities should lead research into the feasibility of systems which combine multiple technologies (e.g. biomass CHP, solar and heat pumps), and find the best combinations of components based on the climate, energy prices and geography of New Zealand.

In the long term (10+ years):

1) As dairy farming becomes more intensive, umbrella groups such as Federated Farmers should keep abreast of international developments in biogas from dairying, and communicate these developments to farmers, as well as looking for chances to lead the way in this area.
2) Central government should look at cost-effective ways of reducing the risk for early-adopters of new bioenergy crops such as miscanthus, and of methods such as short-rotation forestry.
3) Connections between New Zealand research institutions and international research institutions must be strengthened, to avoid duplicate research and to accelerate bioenergy technology development.
4) Universities and CRIs must actively pursue private-sector connections to make sure the technologies enter the New Zealand economy.
5) Christchurch City should seek to become a member of more networks (such as the existing Energy Cities membership).
6) Spatial and energy planning in the city must be linked, and a unified, transparent and participatory long-term planning process must be adopted.

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